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Linking circular economy and digitalisation technologies: A systematic literature review of past achievements and future promises

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A R T I C L E I N F O

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A B S T R A C T

The circular economy (CE) has the potential to capitalise upon emerging digital technologies, such as big data, artificial intelligence (AI), blockchain and the Internet of things (IoT), amongst others. These digital technologies combined with business model innovation are deemed to provide solutions to myriad problems in the world, including those related to circular economy transformation. Given the societal and practical importance of CE and digitalisation, last decade has witnessed a significant increase in academic publication on these topics. Therefore, this study aims to capture the essence of the scholarly work at the intersection of the CE and digital technologies. A detailed analysis of the literature based on emerging themes was conducted with a focus on illuminating the path of CE implementation. The results reveal that IoT and AI play a key role in the transition towards the CE. A multitude of studies focus on barriers to digitalisation-led CE transition and highlight policy-related issues, the lack of predictability, psychological issues and information vulnerability as some important barriers. In addition, product-service system (PSS) has been acknowledged as an important business model innovation for achieving the digitalisation enabled CE. Through a detailed assessment of the existing literature, a viable systems-based framework for digitalisation enabled CE has been developed which show the literature linkages amongst the emerging research streams and provide novel insights regarding the realisation of CE benefits.

1. Introduction

The transformation towards circular economy (CE) has increasingly become the strategic priority for organisations across the globe. The CE is seen as an alternative to the linear economy (take–make–waste), and it operates on the principles of regeneration, keeping materials in use while reducing waste, and reducing pollution (Ellen MacArthur Foundation, 2013). The CE system thus replaces the 'end-of-life' approach with the principles of reducing, reusing, recycling and recovering. While organisations must shift from a linear approach to the CE, issues such as data unavailability and integration often impede this firm and ecosystem levels transformation. Consequently, scholars argue that key to CE transformation goes hand-in-hand with digitalisation transformation (Ajwani-Ramchandani et al., 2021; C. Chauhan et al., 2019; Ingemarsdotter et al., 2019), which includes effective utilisation of big data, artificial intelligence (AI), blockchain, the Internet of things (IoT) and cloud computing. Thus, academics agree on that adoption of the CE is clearly linked with digitalization as it can facilitate predictive analytics, tracking and monitoring throughout the product life cycle for organizations (C. Chauhan et al., 2019).

Specifically, several studies in the extant literature have described digitalisation as an impetus of the CE transition for several reasons. For example, these digital technologies can transform theoretical CE principles into feasible and practical activities(Antikainen et al., 2018; Garcia-Muiña et al., 2018a; Kintscher et al., 2020). From the perspective of the CE, in particular, the application of emerging technologies has measurable benefits. For example, technologies can complement labourers' skills and capabilities and better assist their efforts to make

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circularity-based operational decisions (Mboli et al., 2020). Designing for circularity using data-driven insights can also improve products' economic and environmental sustainability through efficient resource utilisation (Garcia-Muiña et al., 2019). Such products, their sub-components and associated processes can be designed and optimised using CE principles by applying the predictive and prescriptive machine learning insights (Bressanelli et al., 2018a). Past and real-time data can predict demand and manage inventory, thereby minimising waste and enhancing sustainable operations. Digital technologies can also eliminate waste by assessing the best practices for remanufacturing and recycling. For example, AI-based image recognition can improve e-waste recycling (Wilts et al., 2021). Thus, scholars suggest that digital technologies, such as AI is associated with models and systems that perform functions related to human intelligence (e.g. reasoning and learning) and can provide firms with the necessary support to implement CE principles (Wilts et al., 2021).

Indeed, the application of diverse digital technologies such as AI and big data can disrupt liner business models because they enable mass personalisation allowing the firms to select sustainable inputs to match customers' requirements. These technologies also support the extension of product life by developing predictive maintenance requirements and thereby further enhancing the customer experience and reducing waste on the consumer end. Firms that are moving towards digitalisation can enhance overall opportunities in production, processing, logistics and waste recovery through improved visibility across all supply chain stages. The unprecedented technology integration involved in this transition has the potential to allow local and global economies and enterprise-level business models to be more productive and sustainable. However, integration between CE and digitalisation is subject to several issues that require attention from researchers. For example, integration is susceptible to challenges, and the progression might not be uniform across sectors. Managers can capitalise upon certain enablers to realise the anticipated changes in circular performance with the help of technologies. Evidently CE adoption would also require firms to undergo a transition in terms of their business models. These transformational complexities have led to a surge in the literature at the intersection of the CE and digitalisation. However, the findings of these studies remain fragmented across various research disciplines. Thus, creating an opportunity and timeliness to conduct a systematic survey of the literature and obtain a holistic view of the key themes addressed in the extant studies. Moreover, the opportunities presented by digitalisation in the context of CE are numerous, and various stakeholders, including managers, policymakers, researchers, practitioners, NGOs and society at large, must devote their attention to them. The domain has already witnessed a proliferation of scientific studies in recent times. A systematic literature review (SLR) can aid the assimilation of these studies and guide stakeholders towards an appreciation of their findings' implications.

Although existing reviews studies on CE are contributing they often have a narrow focus on linkages between CE and digitalisation. For example, Demestichas and Daskalakis (2020) focus on the interaction of the CE with information and communication technology. In their review of literature, Bag and Pretorius (2020) focus mainly on the challenges firms face with respect to the digitalisation required to achieve the CE. Kerin and Pham (2019) direct their attention primarily to the remanufacturing sector. Awan et al. (2021) shed light on the digitalisation tools that can support CE implementation. In light of these limitations, the present review is necessary to delve deeply into the literature at the intersection of the CE and digitalisation technologies and provide a detailed synthesise of the key themes and areas of concern. The present study's research questions are as follows: i) What is the research profile of the prior literature at the intersection of the CE and digitalisation technologies? ii) On what key themes and pressing issues does the extant literature focus? iii) What research questions can guide future investigations in this domain?

To answer the research questions identified above, we conducted an SLR. The review is structured in the following manner. First, the paper presents the scope and methodology for conducting the review. Second, it outlines the profile of the sample of studies in this domain. Third, in an effort to unbundle the literature at the intersection of the CE and digitalisation, the paper identifies the major themes in the literature thus far. Fourth, the study presents future research directions. Fifth, the paper develops a comprehensive framework to provide a holistic view of the digitalisation-led CE transition. Finally, the study concludes by pinpointing its own limitations and implications for managers and researchers.

2. Scope of the review

A crucial initial step in the SLR is understanding the study's scope and periphery. These efforts assist in developing a protocol for the search of publications and subsequently build a comprehensive database of studies at the intersection of the CE and digitalisation technologies. Clearly defining the scope and boundary of the review involves defining the inclusion and exclusion criteria. A time frame from 2010 to 2021 was chosen for the inclusion of peer-reviewed studies in this domain.

Digitalisation methods and technologies are popularly summarised in five main categories: big data and analytics simulation, IoT, cyber-physical systems (CPS), cybersecurity cloud computing, augmented reality, machine-to-machine communication and collaborative robots (Rüßmann et al., 2015). Combining managerial skills with the methods and technologies mentioned above can enable the transformation towards the CE by capitalising on their potential. Several authors recognise Boulding's (1966) work as amongst the first studies to introduce the concept of the CE (Geissdoerfer et al., 2017; Ghisellini et al., 2016). Boulding (1966) conceptualised the CE as a preliminary condition for safeguarding and sustaining life on earth. Another of the earlier works in the CE domain by Pearce and Turner (1990) argued that natural resources drive an economy because they act as inputs for manufacturing and are consumed. In addition, natural resources act as a sink for the outputs of a process. Therefore, the circular system must replace linear and open-ended systems. In recent times, scholars have not only investigated the antecedents of the CE in economics and ecology but have also provided an operational perspective on the CE (e.g. Murray et al., 2017). They have argued that the integration of CE principles and sustainability will drive gains for the environment (Yang et al., 2018). The concepts of the CE, the green economy (GE) and the bioeconomy are understood to be interconnected as a result of economic, environmental and social goals. However, the CE is resource-focused, while the GE acknowledges the supporting role of all ecological processes (D'Amato et al., 2017). The CE significantly enhances sustainable and green performance by stressing the regenerative dimension (Kadar and Kadar, 2020). In this endeavour AI can accelerate the application the CE to every supply-chain stage and process (Kadar and Kadar, 2020).

Scholars have studied concepts such as closed-loop supply chains (CLSC) and reverse logistics in conjunction with the CE (Wilson et al., 2021). The CLSC improves the environment and enhances value recovery by returning materials to the producer (Wilson et al., 2021). However, the extent of value recovery in a CLSC is limited to the focal firm's supply chain and does not include other supply chains or channel members (D'Amato et al., 2017). For this reason, the scope of the present study is restricted to studies that deal strictly with the concept of the CE in conjunction with digitalisation technologies. Studies pertaining to sustainability, green supply chains, CLSCs and reverse logistics have been excluded.

After establishing conceptual boundary conditions (i.e. the concepts of digitalisation and the CE), the authors developed several strings of keywords to be used in an electronic database search. The terminology used varies as does the research conducted on various aspects of digitalisation and the CE. The authors conducted an initial search of studies on *Google Scholar* and then brainstormed collectively to identify important keywords that were helpful in fetching relevant search results at the intersection of the two concepts. To uphold scholarly standards, studies published in recognised, scholarly and peer-reviewed journals were considered. Books, book chapters and studies published in predatory journals were thus excluded. Defining the inclusion and exclusion criteria based on journals is important, and high-quality SLRs follow these criteria (Khan et al., 2021). To address the call for research from an interdisciplinary management perspective, well-recognised and popular electronic databases were searched, and rigorous forward and backward searches were conducted to reduce the risk of excluding important papers.

3. Method

The present study followed the SLR methodology. This approach ensures that future scholars can replicate the SLR's findings. The first step of the SLR methodology involves strategically planning to search the relevant publications (Chetna Chauhan et al., 2021; Hina et al., 2022; Khanra et al., 2020; Talwar et al., 2020). Then SLR authors select the target journals, finalise the inclusion and exclusion criteria and review the selected publications. Finally, they document the study's findings. The present SLR was conducted in four main stages. The first stage involved finalising the keywords and the inclusion and exclusion criteria. Then the authors searched the databases to retrieve relevant documents. Successively, they conducted a strict quality evaluation of these studies by applying the criteria already established. Finally, they documented the outcomes of the SLR (Kushwah et al., 2019).

3.1. Planning the review

This SLR aimed to analyse and understand the existing scholarly work at the intersection of the CE and digitalisation. Based on the suggestions of Chaudhary et al. (2021) and Kushwah et al. (2019) it utilised two main databases—*Scopus* and *Web of Science* (*WoS*)—and complemented the results from these databases with a *Google Scholar* search. The present study focused specifically on the CE and, therefore, excluded similar domains of research, such as CLSCs, reverse logistics and sustainability if they did not focus on circularity aspects. Initially, a few keywords were selected to conduct a preliminary database search and identify the publications relevant to the present SLR. The authors also searched the selected keywords on *Google Scholar* and assessed the first 10 pages of results from these searches to update the keyword list. Subsequently, the authors searched the leading management journals separately to ensure that the list contained all relevant keywords. Noting an overlap of CE studies with bioeconomy studies in the analysis of the initial *Google Scholar* search, the authors added 'bioeconomy' to the list of keywords.

To ensure the rigour of the SLR process and eliminate biases in the review process, a panel of experts was established. This panel included five experts (two professors and three researchers). The authors consulted the panel of experts to reach a final consensus regarding the keyword list (Table 1).

3.2. Specification of the study

Specifying the study involves establishing the inclusion and exclusion criteria (Table 2). These criteria help to refine the list of studies obtained in the keyword search. Because journal and conference publications are more likely to be peer reviewed than other sources, such as book chapters, short surveys, reports, errata and notes, the present SLR included only peer-reviewed journal and conference articles. To limit the number of publications and focus on the outlined objectives, highly technical works on topics such as chemical, biological, metallurgical and biochemical processes were excluded from the review. Research with a highly technical or engineering rather than management perspective was also excluded.

Table 1
Selected keywords.

Digitalisation-related keywords	CE-related keywords	Search string
Artificial intelligence Machine learning Web intelligence Artificial neural network Digitalisation technology Big data Blockchain Cloud computing Virtual or augmented reality Internet of things Cyber-physical systems Cybersecurity Collaborative robots	Circular economy CE principles Bioeconomy	('circular economy*' OR 'CE principle*' OR 'bioeconomy*' OR 'circular design*' OR 'circular business*') AND TOPIC: ('Artificial intelligence*' OR 'Machine learning*' OR 'Machine intelligence*' OR 'Web intelligence*' OR 'Artificial neural network*' OR 'Digitalisation technolog*' OR 'Big data*' OR 'Internet of thing*' OR 'IoT' OR 'Blockchain' OR 'Cloud computing' OR 'Virtual reality' OR 'Augmented reality' OR 'Cyber-physical systems' OR 'CPS' OR 'Cybersecurity' OR 'Collaborative robots')

Table 2
Inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
Articles with a specific focus on the CE and digitalisation technologies	Articles that mention the CE and/or one or more aspects of digitalisation but do not focus specifically on these concepts
English language articles published up to July 2021	Editorials, short surveys, reports, errata, book chapters and notes
Peer-reviewed journal and conference articles	Articles that focus on chemical, metallurgical, biological and bio-chemical processes and biotechnology
Articles that focus on one or more digitalisation technologies and the CE	Studies that focus on technical or engineering aspects of CE

3.3. Data extraction

The keywords ultimately chosen were converted into search strings with the help of Boolean logic—that is, the application of * along with 'OR' and 'AND' connectors. The authors then searched titles, abstracts and keywords in the Scopus and WoS databases. This search was accompanied by a search on Google Scholar using a search string. These searches were undertaken on studies up to July 2021. A total of 305 studies were obtained from the Scopus database while the WoS document search retrieved 292 publications. The duplicate articles across databases were then removed, leaving 597 articles. The authors then further screened the pool by applying the inclusion and exclusion criteria. This reduced the pool of articles to 301.

The authors then invited the review panel to further filter the remaining articles. The experts reviewed and analysed the titles, abstracts and keywords based on the predesignated conceptual boundaries and screening criteria. Each panel member conducted these tasks individually to ensure rigour in the screening protocol. In the next phase, the panel members shared the short-listed articles. This resulted in a pool of 191 articles. Subsequently, the panel members were asked to resolve their differences and arrive at a consensus regarding the short-listed pool of studies. At this stage, the panel members recommended that the authors eliminate studies that failed to align with the scope and conceptual boundaries of the SLR. The authors then assessed the full texts of the remaining 151 articles to ensure their fit with the present SLR. Following this full-text analysis, 110 studies remained. Most of the articles removed in this step dealt with engineering, chemical, biological and biochemical processes. Subsequently, forward and backward citation chaining was completed for each of the selected studies to ensure that no relevant study was excluded. The panel reviewed a total of 17 articles found through citation chaining. Of these, 13 articles were added to the pool based on the advice of the panel members.

In the final stage, the panel examined and recommended including all 123 studies. The authors then developed the research profile for the selected studies. Fig. 1 depicts the SLR process in detail.

3.4. Data execution: Research profiling

This section describes the research profile of the pool of studies in the sample. The results presented in this section assess the extant research on the basis of year-wise publications and the spread of studies according to source titles and types of papers. Organising and summarising the research profile in a particular domain of knowledge illuminates the direction and momentum of research in that field. Fig. 2, which presents the time-wise proliferation of research at the intersection of the CE and digitalisation, reveals that this intersection is a recent phenomenon. However, scholarly attention has burgeoned in the last two years (2019–2020). The observation of increased academic interest in the domain is further accentuated by underlining the range of journals in which such research has been published (Fig. 3). In fact, only four journals have published more than four articles in this domain. Of these four journals, three are related to the domain of sustainability or aspects aligned with sustainability. Fig. 4 shows the types of publications. Finally, Fig. 5 categorises the sample of articles based on the predominant methodologies used. It reveals conceptual studies as the dominant methodology—a fact that is true for any emerging topic of interest.

4. Thematic foci

This section overviews the literature in terms of frequently addressed themes and prominent topics. The authors of this SLR performed a thematic analysis of the content of the selected studies to comprehensively assess the extant literature and synthesise the findings. Scholars have frequently applied content analysis, which relies upon the systematic classification, coding and identification of themes, to facilitate the subjective analysis of texts (Hsieh & Shannon, 2005). To identify primary themes in the extant literature, the first author assigned open codes to each study and categorised similar studies together. In the next step, the authors discussed the open codes to reach a consensus regarding the categorisations. Thereafter, similar open codes were grouped together to create axial codes, and the authors finalised the study themes. Fig. 6 outlines the key themes and sub-themes in the literature.

4.1. Digitalisation technologies and CE

A burgeoning body of literature asserts a positive linkage between digital technologies and the CE (C. Chauhan et al., 2019). The enormous amount of data generated in the organisations combined with various cutting-edge technologies can assist the systematic transition towards the CE (Kristoffersen et al., 2020; Nazareth, 2019). Therefore, a vast stream of studies focuses on understanding the ways in which the adoption of various digitalisation technologies can enable the implementation of the CE by enhancing the capabilities of the firms that adopt such technologies.

Research has widely acknowledged that the adoption of digitalisation technologies can promote the adoption of CE and carbon-free economy concepts (Kokkinos et al., 2020). Furthermore, the adoption of digitalisation technologies is positively linked to development of CE capabilities (Bag et al., 2021; Ma et al., 2020). With the application of

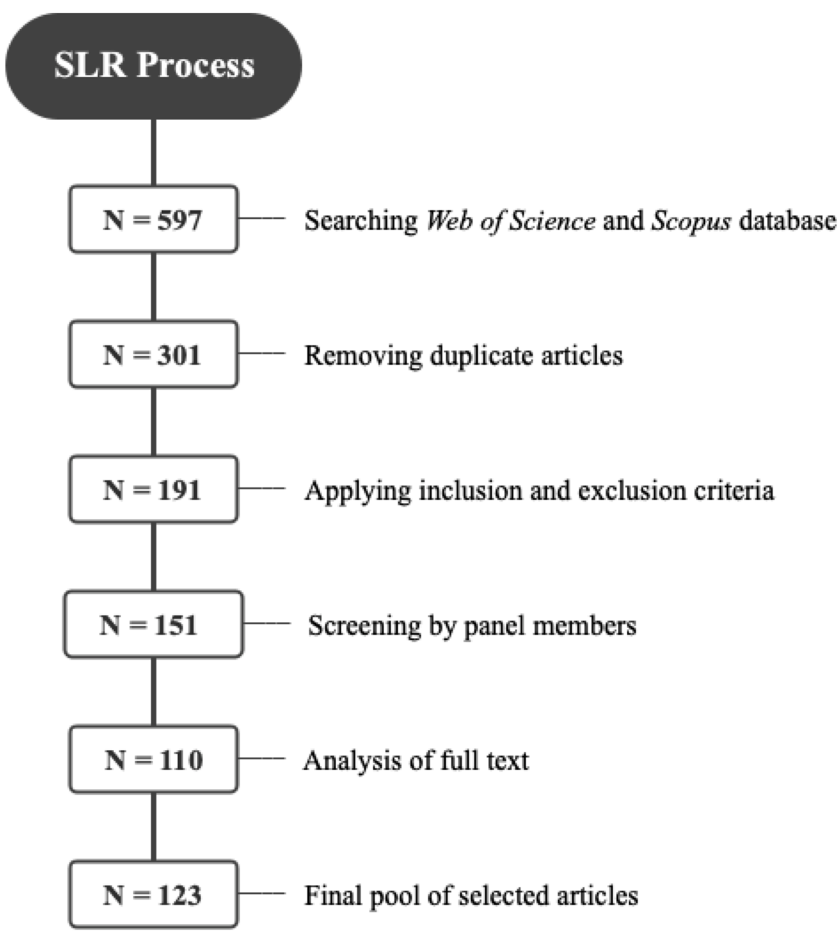

Fig. 1. SLR process and protocols.

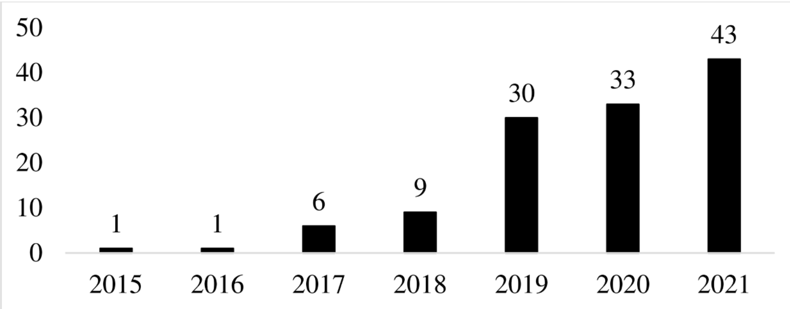

Fig. 2. Year-wise number of publicationsNote: Other journals that published the selected articles include Benchmarking, Computer Communications, Computers in Industry, Economics and Policy of Energy and the Environment, Energies, Engineering Economics, Enterprise Information Systems, IEEE Vehicular Technology Magazine, IFAC-Papers OnLine, Industrial Management and Data Systems, Industrial Marketing Management, Information Systems and e-Business Management, International Journal of Advanced Science and Technology, International Journal of Automation Technology, International Journal of Information Management, International Journal of Logistics Management, Johnson Matthey Technology Review, Journal of Advanced Mechanical Design, Systems and Manufacturing, Journal of Applied Economic Sciences, Journal of Business Research, Journal of Communications, Journal of Fashion Marketing and Management, Materials Today Communications, Resources, Rivista di Studi sulla Sostenibilita, Science of the Total Environment, Science, Technology and Society, Sensors (Switzerland), Urban Geography and Waste Management.

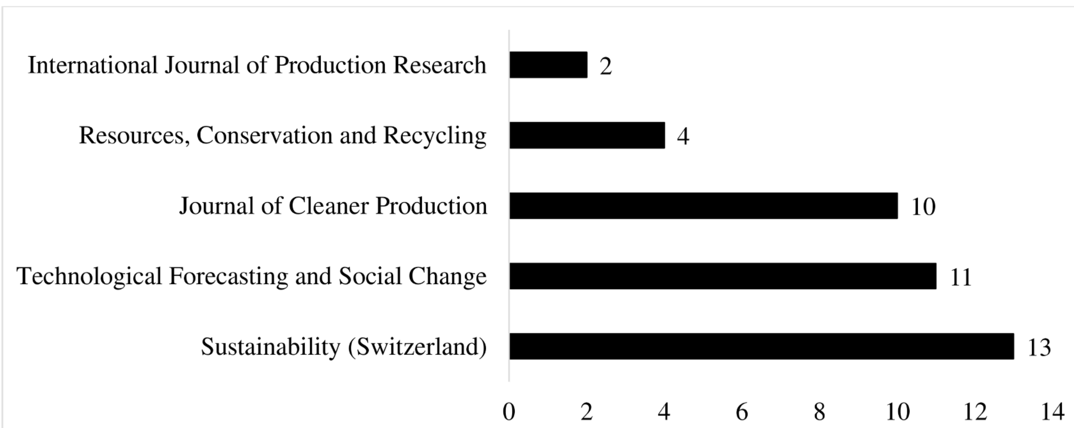

Fig. 3. List of studies across journals.

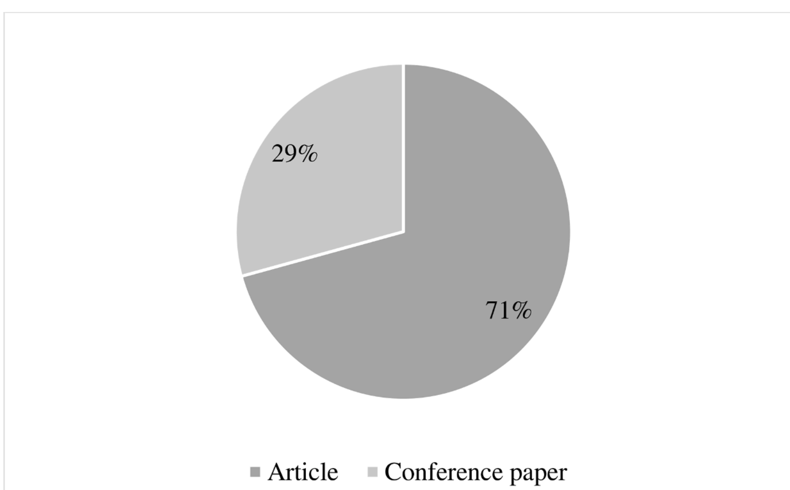

Fig. 4. Classification of articles.

these technologies, products can be coordinated across life cycles and factories (Çetin et al., 2021). Digitalisation technologies are expected to introduce new innovative business models that can generate value and enhance well-being (Manavalan and Jayakrishna, 2019; Uçar et al., 2020). A number of sectors in various countries have implemented these technologies, the CE concept and related tools (Hoosain et al., 2020). Such tools include life-cycle costing, impact assessments and circularity measurements (Hoosain et al., 2020). Blockchain and artificial intelligence can be used to implement incentive schemes for CE adoption (Ajwani-Ramchandani et al., 2021). Without reliable and precise information flows regarding resources, materials and processes, quantifying circular initiatives is difficult (Bianchini et al., 2019). However, institutional pressures generally enable the adoption of digitalisation technologies and CE practices (Bag et al., 2021). This section outlines, in particular, the prominent digitalisation technologies and how they uniquely influence organisational transformation towards CE (see

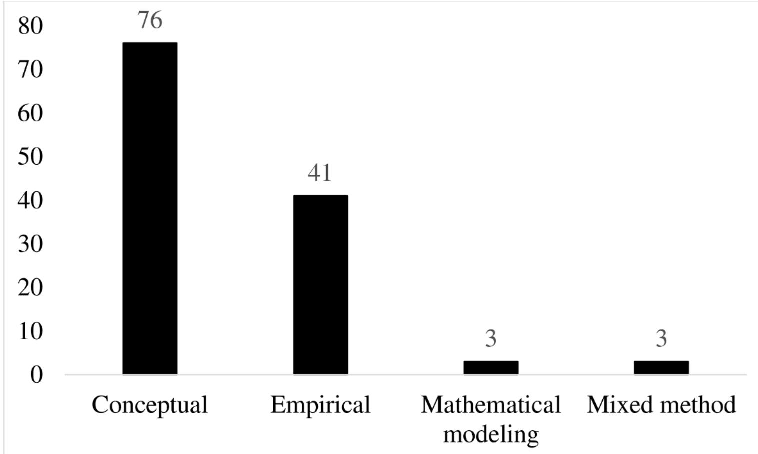

Fig. 5. Nature of studies.

Fig. 7).

IoT is the main enabler of the integration of processes with other technologies, which, in turns, enhances circularity (Hatzivasilis et al., 2019). IoT bolsters CE initiatives by supporting data-driven solutions for optimisation (C. Chauhan et al., 2019). These technologies, combined with proactive decision-making, nurture circular and ethical business practices not only for the focal firm but also for collaborating organisations (Jinil Persis et al., 2021). According to Ingemarsdotter et al. (2019), the implementation of IoT-enabled CE approaches helps to prolong the usage stage of products. Moreover, IoT architecture permits the integration of smart objects into the business ecosystem (Nobre and Tavares, 2020). The circular-by-design IoT architecture drives data harvesting can enable circularity (Askoxylakis, 2018; Miaoudakis et al., 2020). For example, Forlastro et al. (2018) suggest that traditional equipment can be converted into smart objects, making it easier to print parts using recyclable materials. IoT also improves tracking and record keeping, enables monitoring and maintenance, improves estimations of the remaining lifetime of products in use and helps firms to make informed design decisions to improve product durability (Ingemarsdotter et al., 2020). IoT can also enable the assessment of CE measures. For example, Ouyang and Ma (2014) developed an IoT-based platform for monitoring CE performance through the real-time tracking of CE indicators and early warning systems. Digital twins can provide inputs for supply chain actors to increase the potential of CE adoption, especially in the end-of-life (EOL) management of products (Pehlken and Baumann, 2020). Despite the benefits outlined above, IoT-enabled looping strategies, such as remanufacturing, recycling and reuse, have received little attention in practice (Nobre and Tavares, 2020).

4.1.1. Big data and CE

Big data plays an important role in facilitating the acquisition of desired information and effective decision-making through accumulation of diver datasets (Čábelková et al., 2021; Gupta et al., 2019; Kamble et al., 2021; Kazancoglu et al., 2021). Within manufacturing industry firms are taking an active role in create new databases by diverse set of data integration. Previously overlooked data sets such as weather conditions, changing economic conditions are being accessed by third party provider and used to create firm specific decision-making models (Ambruster and Macdonell, 2015). The integration of big data and large-scale group decision-making can promote circularity by addressing diverse linear economy problems as it integrates various aspects of the CE through physical, cyber and stakeholder interactions (Modgil et al., 2021). For example, Big data facilitates the application of techniques such as cluster analysis, and reduces the cumbersomeness of decision-making process. Thus, decision making challenges associated with a large-scale group of decision makers that include– knowledge distribution, cost and behavioural changes, can addressed with the help of big data (Modgil et al., 2021).

Recently, scholars have argued that a big data-driven supply chain affects the relationship between resource management and firm performance for a CE (Del Giudice et al., 2020). For example, Edwin Cheng et al. (2021) identify CE practices as significant mediating variables between big data-related capabilities and supply chain performance. In terms of quality management, the big data extracted from production can be utilised to understand characteristics of product that are critical for quality. These actions would reduce rework and scrap generation and increase reuse and recycling rates while extending the life of components (Lin et al., 2019). Big data also supports newer business models that can drive CE. For example, instead of producing compact discs that lead to e-waste issues, companies now develop online content with the help of big data (Jabbour et al., 2019; Modgil et al., 2021).

4.1.2. Artificial intelligence, machine learning and CE

AI and machine learning provide various benefits such as cutting the costs, identifying hidden patterns, improving quality, and enhancing responsiveness (Bag et al., 2021). Novel data science and AI techniques are helpful in each step of the circular design and optimisation process because they accelerate firms' regenerative approaches (Rajput and Singh, 2019). AI can also accelerate leapfrog innovation in the design of urban facilities and the urban CE transformation (Kadar and Kadar, 2020). Implementing AI enhances productivity via improved optimisation, real-time data analysis and enhanced design, which all help to enable circularity (Ghoreishi and Happonen, 2020a, 2020b). Machine learning algorithms can predict the uncertain performances of various processes, monitor those processes in real time, predict the uncertain performances of various processes and detect flaws in circular systems (Sundui et al., 2021). This is possible because the architecture of AI-based platforms enables them to gather, explore and disseminate knowledge related to the dynamics of circular systems (Mercier-Laurent, 2020).

AI can also effectively aid managerial decision-making through identification of hidden patterns. The decision tree algorithm of AI has been used to design environmental cost control systems for manufacturing companies (M. Chen et al., 2020; Wang and Zhang, 2020). Alavi et al. (2021) propose an AI-based customisable decision support system to select the most suitable suppliers based on circularity criteria. Alonso et al. (2021) developed an application of AI-based systems that learns from a small set of images and then classifies materials with reliability levels as high as 90 per cent. Such systems can be used to segregate materials. Provide an planning-based analysis of failure statistics using an AI-based decision support system can help to minimise

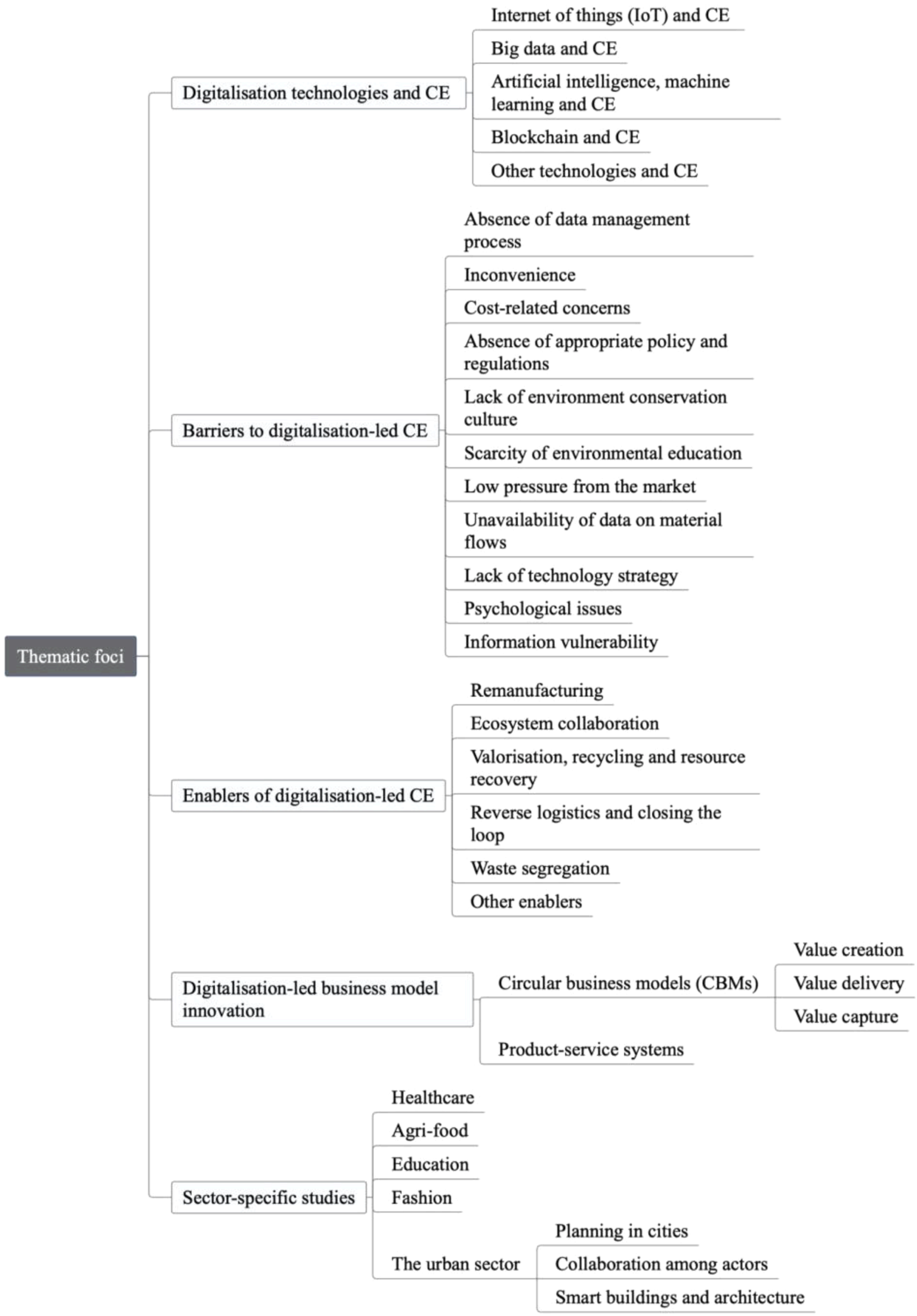

Fig. 6. Key themes and sub-themes in the literature*Internet of things (IoT) and CE.*

resource consumption and enable the CE (Makarova et al., 2018).

Making decisions regarding many CE activities requires the input of several experts from various fields. These cases thus require efficient multi-attribute group decision-making models that can support cooperation on a large scale. Natural language processing techniques based on AI can be adopted to mine important information during group decision-making (Tang and Liao, 2021). These technical developments based on natural language processing are valuable insights for reducing and removing traditional inefficiencies within the system level. For example, carriage optimisation of long-haul truck transportation across different logistical companies through AI algorithms have been founds to be highly valuable to reducing Co2 emissions and providing economical gains for parties involved. In the domain of capability building, Salminen et al. (2017) propose the application of an intelligent

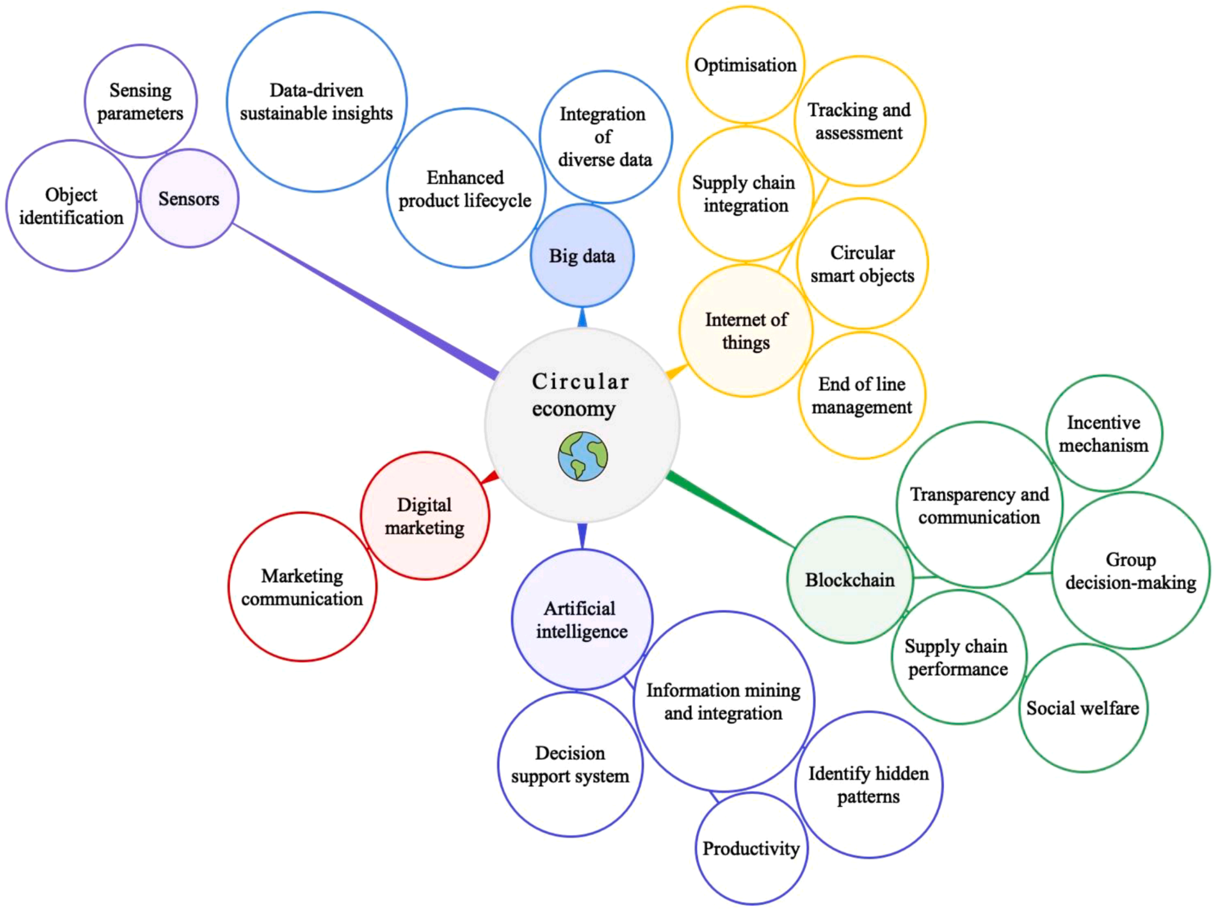

Fig. 7. Capabilities driven by digitalisation technologies to achieve CE.

web-based system to manage expert opinions, experiences and relationships and thereby build responsible business leadership capabilities.

4.1.3. *Blockchain and CE*

Blockchain can facilitate the design of incentive mechanisms to encourage consumer green behaviour, increase visibility, enhance efficiency and support performance monitoring and reporting (Esmaeilian et al., 2020). Achieving the CE is a common goal for many enterprises as well as governments, and it requires group decision-making that includes input from these actors. In particular, blockchain can facilitate this type of large-scale group decision-making (Choi and Chen, 2021). An important part of blockchain is to provide digital identity and proof for transaction between diverse actors. This can provide incentives for facilitating a new system of pricing and trading resources between actors at a lower cost of transactions and with greater transparency (Treiblmaier and Beck, 2018). Blockchain ensures decentralised and reliable data, better transparency, smart contracts, and traceability and thus enhances supply chain performance (Groening et al., 2018). Particularly, with blockchain technology, platforms such as those for shared leasing can be developed and firms can collaborate and redistribute of their excess resources (Nandi et al., 2021). The transparency feature of blockchains would also boost the internal and external communication, (Narayan and Tidström, 2020) and support the development of plans for the CE. Application of blockchains would further eliminate waste and promote environmental benefits through improved product designs, letting customers to use products for longer duration and return them without hassle at their end-of-life (Nandi et al., 2021). Thus, in addition to cost and environment related benefits, blockchains would also promote social welfare.

4.1.4. *Other technologies and CE*

Scholars have argued that sensing capabilities can unlock the potential of CE implementation opportunities (Romero and Noran, 2017). A few studies highlight the role of sensor-based smart tags and barcodes in driving CE implementation. These sensors can identify objects, track a product's life cycle and sense parameters from the environment (Gligoric et al., 2019). Digital marketing can facilitate communication between the firm and the market, driving CE adoption (Tkachuk et al., 2020). Scholars posit that a firm's digital-platform usage is positively linked to CE implementation and competitive performance (Kristoffersen et al., 2021). Information and communication technology (ICT), in particular, can support the management and optimisation of EOL operations and enable circularity (Garrido-Hidalgo et al., 2020; Mboli et al., 2020).

4.2. *Barriers to digitalisation-led CE*

Several studies have identified and examined the barriers to the implementation of digitalisation technologies. The literature has also devoted much attention to policy-specific issues and international platforms that require the attention of local governments.

A few studies have identified and explored the barriers that firms encounter while adopting business models at the intersection of the CE and digitalisation. For example, Ingemarsdotter et al. (2020) pinpoint the absence of structured data management processes and the inconvenience of developing IoT-enabled products as significant barriers. Indeed, the cost associated with the adoption of big data technology has a significant effect on commodities (Xiong, 2020). The absence of appropriate regulations, the scarcity of environmental education, the lack of an environmental conservation culture and the low pressure from market demand are amongst the other challenges facing the digitalisation-led CE transition (Zhang et al., 2019). Antikainen et al. (2018) contend that technological and strategic barriers are the most significant economic barriers to adopting a big data-drive CE supply chain (Kazancoglu et al., 2021). Similarly, Sineviciene et al. (2021) emphasise that the negative consequences of disruptive technologies, such as the lack of predictability, psychological issues and information vulnerability, impede the adoption of digitalisation technologies that enable the CE. Moreover, poor data quality and higher variability in the data formats significantly worsen the performance of predictive models of waste management for the CE (Rosecký et al., 2021).

Policy concerns Kazancoglu et al. (2021) argue that the absence of a governmental push impedes the implementation of big data applications. However, it should be noted that the lack of data regarding material flows and data related to other phases of the operations, such as collection and treatment, hinder policymakers' efforts to devise the appropriate policies necessary to initiate feasible solutions to environmental issues (Ranta et al., 2021). For example, the European Union's (EU) CE policy covers several aspects of CE, including the treatment, recycling and reduction of waste (Umeda et al., 2020). It promotes remanufacturing and servitisation and seeks to enhance the EU's competitiveness via the CE. On the other hand, firms in Japan find it difficult to differentiate between the traditional 3Rs (reduce, reuse and recycle) and CE policy due to the failure of regulators and policymakers to devote adequate attention to the issue (Umeda et al., 2020).

4.3. Enablers of digitalisation-led CE

A sizeable number of studies highlight opportunities to enable the CE transition in linear economy-based models. The prior literature has highlighted a multitude of enablers that derive from resources efficiency and sustainability gains. In addition, the presence of specific enablers can accelerate the transition from a linear economy to a CE.

4.3.1. Remanufacturing

A few studies demonstrate how modern technologies can encourage the implementation of CE principles via remanufacturing. Remanufacturing is seen as a challenge, mainly due to the unavailability of product usage data (Okorie et al., 2018); such data, if available, could be utilised to understand the parameters involved in implementing remanufacturing (Okorie et al., 2018). Charnley et al. (2019) apply discrete event simulation to a remanufacturing process to assist decision-makers in a remanufacturing facility. Under their model, decisions are made by optimising time, effort and cost. Mao et al. (2021) designed a stochastic optimisation algorithm and combined it with AI technology to disassemble used car parts. Their model incorporates the decision-maker's perspective with respect to remanufacturing.

4.3.2. Ecosystem collaboration

According to Antikainen et al. (2018), ecosystem collaboration provides the most significant opportunity to system level adopt CE-based business models in the wake of digitalisation. An concreate example can be that product data is shared with recyclers globally, thus connecting suppliers and disassembly part selectors with the help of IoT to make recycling more efficient (Irie and Yamada, 2020). In the context of food waste streams, Jiménez-Zaragoza et al. (2021) argue that food-sharing practices based on digital food-sharing apps contribute to food waste prevention. Thus, studies increasingly recognise the importance of ecosystem collaboration, however, existing studies provides limited insights on how to effectively coordinate and orchestrate ecosystem relationships for realizing sustainable benefits (Parida et al., 2019).

4.3.3. Valorisation, recycling and resource recovery

Researchers argue that data-driven models may facilitate and improve the application of CE principles, especially resource waste valorisation, within manufacturing systems (Fisher et al., 2020)(Fisher et al., 2020). Deng et al. (2020) assert that the economic feasibility of product recycling can be identified by integrating machine learning techniques. In the case of an electric vehicle battery, Garrido-Hidalgo et al. (2020) suggest that information infrastructure requirements for the recovery of materials can be developed with the help of digitalisation technologies. Similarly, Kintscher et al. (2020) advance a model for recycling traction batteries by developing a marketplace where the appropriate technologies facilitate the ready exchange of information. Poschmann et al. (2021) develop an AI-based multi-criteria assessment to uncover optimal EOL options for particular components.

4.3.4. Reverse logistics and closing the loop

Scholars have suggested utilising digitalisation technologies to achieve the CE with the help of reverse logistics (Rajput and Singh, 2021; Xun et al., 2021). The application of technologies in reverse logistics is important for gathering, treating and transporting waste for remanufacturing (Akkad and Bányai, 2021). Wilson et al. (2021) stress the importance of AI as a key enabler of optimal reverse logistics operations. AI can enhance the identification, inspection and segregation of materials for reverse logistics (Schlüter et al., 2021). At the EoL stage, reverse logistics can be employed to manage operations, which are dependant on the flow of information. Digitalisation technologies, such as IoT and ICT, can support the management and optimisation of end-of-life operations for circularity (Garrido-Hidalgo et al., 2020; Mboli et al., 2020). The closure of the loop in the supply chain can be confirmed with the help of blockchain technology. Blockchain technology supports tracking and tracing operations after a new asset is created. Thus, whether the waste has been converted into energy (closing the loop) can be verified with blockchain (Mastos et al., 2021).

4.3.5. Waste segregation

Alonso et al. (2021) suggest that AI-based systems can be employed to classify and segregate materials. The application of an appropriate arrangement of IoT and blockchain can help manufacturers to maintain control over products until their EOL stage; it can also promote CE strategies and support the decision-making process (Magrini et al., 2021). Fatimah et al. (2020) advocate that waste management systems should incorporate IoT at the waste segregation stage to identify the appropriate waste treatment technology based on waste characteristics. An AI-powered robot could be utilised to test, evaluate and improve municipal waste-sorting plants by augmenting or replacing manual sorting with digitalised sorting (Wilts et al., 2021).

4.3.6. Other enablers

Scholars suggest that social awareness and technology approval are the most important factors driving the digitalisation-led CE transition (Čábelková et al., 2021). Kazancoglu et al. (2021) identify government incentives as the fundamental enabler in implementing big data applications in food supply chains. Operational efficiency, supply chain integration and the commitment of top management are other relevant enablers.

4.4. Digitalisation led business model innovation

Flexible business models must enable the transformation of technology, the economy and the environment. The literature on business models at the intersection of the CE and digitalisation can be categorised into two streams. The first stream focuses on the ways in which digitalisation enables and accentuates introduction of circular business models (CBMs) and the second stream of literature explores transformation to product service systems (PSS).

4.4.1. Circular business models (CBMs)

Because firms often face resource scarcity, the choice of profitable business models is essential for their growth (Bressanelli et al., 2018b).

In particular, incorporating circularity principles into business models requires that manufacturing processes be reconfigured. To enable this reconfiguration, CBMs receive crucial support from ICT, traceability and online data mining (Su et al., 2019). CBMs have been characterised to influences all dimensions of how the business model creates, captures and delivers value by expanding products' useful lives through the remanufacture, repair or design of long-life products and the closing of material loops (Nußholz, 2017; Oghazi & Mostaghel, 2018). The extant literature has frequently deployed 'CBM' terminology. However, we still lack agreement on a definition. According to Frishammar & Parida (2019) CBM is defined as a focal company, together with partners, uses innovation to create, capture, and deliver value to improve resource efficiency by extending the lifespan of products and parts, thereby realizing environmental, social, and economic benefits. They also argue that CBM are not only about closing loop or sharing models but can be interpreted by industries in different ways. In essence business models must integrate the practices and principles that enhance such models' alignment with the CE vision (Pieroni et al., 2019). The interplay between CBM and digitalisation suggests novel ways through which products, services and associated ecosystems can be altered to achieve circularity (Miaoudakis et al., 2020; Ranta et al., 2021). The following sections review the literature relating to digitalisation and the CBM; these efforts aim to address the ways in which digitalisation impacts the elements of value creation, value delivery and value capture to drive existing CBMs.

4.4.2. Value creation

The value creation component of the business model is employed in the context of products or services offered to customers. Ranta et al. (2021) argue that implementing digitalisation is a key driver of value creation from CBMs. Digitalisation helps firms manage value chains in a way that narrows, slows and closes their resource flows while helping to create value for actors involved (Ranta et al., 2021). Digitalisation can create sustainable value in several ways. Technologies such as big data, IoT, additive manufacturing and blockchain can optimise value creation by increasing efficiency and improving performance (Ignacio et al., 2018). For example, Turner et al. (2019) propose that introducing a 3-D manufacturing facility enhances the creation of robust products and services for customers and delivers value creation benefits for CBMs. In essence, as traditional manufacturing firms adopt digitalisation and CE, they tend to move towards servitization, that is transformation towards service portfolio development, such as extended service contractions, performance contacts, etc. IoT and big data create unique opportunities for firms to improve and broaden their services portfolios and deliver value to their customers. IoT helps firms to monitor operational flows and performance in real-time, improving managerial decisions aimed at servitization value creation (Garcia-Muiña et al., 2018). Garcia-Muiña et al. (2019) suggest that information and knowledge systems create value for a new set of consumers because such consumers seek detailed information regarding the environmental impacts of the advanced services offered to them.

4.4.3. Value delivery

The value delivery component of the business model aims to deploy activities and processes capable of delivering the promised value. Thus, value delivery encompasses the specific resources and capabilities required (e.g. technical support systems, digital infrastructure; Parida et al., 2019). Very few studies have attended to the value delivery component of the CBM. Cutting-edge technologies help firms to deliver greater value to their customers in several ways, including amalgamating external demand information with the firm's internal processes (e.g. through vertical and horizontal integration of systems; D.L.M. Nascimento et al., 2019) and stakeholder cooperation (Iacovidou et al., 2021). Garcia-Muiña et al. (2019) suggest that the application of technologies should strengthen information and knowledge systems based on a collaborative network of stakeholders.

4.4.4. Value capture

Value capture is concerned with a firm's revenue streams and the cost structure (Linde et al., 2021). To capture value for the CBM, firms can utilise digitalisation to improve profits via a variety of actions; these include efficiently utilising resources, managing product life cycles, tracking residual value and reducing transportation (Linde et al., 2021). An important consideration also relates to moving from transactional based revenue model to relational revenue model, where flow of revenue occurs over time. Moreover, firms also need to reconsider the risk mitigation strategy in light of CBM under discussion, such sharing risks and seeking premiums for higher risk taking are common industrial practices. Firms can also capture value by developing new revenue streams—for example, by attracting demand from a new set of customers.

Table 3 shows the value creation, value delivery and value capture benefits that firms can accrue from digitalisation. The success of the CBM over time can be ascertained only if profits far exceed any negative consequences, such as expenditures for product design. Though conversations regarding profitability comprise a central element of the CE and digitalisation, the present literature survey reveals a dearth of studies focused on the value capture component of the CBM in the context of digitalisation. Digitalisation involving IoT can improve firms' tracking and monitoring of products' residual value and thereby improve cost efficiency, which creates a positive effect on competitiveness (Ingemarsdotter et al., 2020; Mboli et al., 2020); meanwhile, digitalisation that involves the application of blockchain can enhance firms' control over products. In addition, technologies such as distributed manufacturing have the potential to limit the unnecessary movement of materials and improve firms' price margins (D.L.M. Nascimento et al., 2019; Turner et al., 2019). Digitalisation also translates into cost savings and increased cashflows by overcoming barriers to the adoption of the CBM (Pizzi et al., 2021).

4.4.5. Product-service systems

Business model innovation can reduce the impact on the natural environment, promote the development of sustainable products and drive the redesign of supply chains (Garcia-Muiña et al., 2018; Miaoudakis et al., 2020). Digitalisation not only enables CBMs but also acts as a trigger for novel business models that promote CE (Uçar et al., 2020). PSS is seen as a novel business model, which focuses on cost, convenience, the CE and the environment (Han et al., 2020) and has ability to improve value creation through improvements in circularity (Ranta et al., 2021). The vast majority of literature on business models in the context of digitalisation and the CE focuses specifically on the PSS. In a PSS business model, products are either offered entirely as a service, or services, such as customisable maintenance contracts, are provided in addition to the product; this combination of products and services enhances the value creation aspect of the business model (Tukker, 2015). The support services also enhance the product life cycle and improve reuse, recycling and remanufacturing operations of products (Ingemarsdotter et al., 2020). PSS ecosystems consist of intelligent systems that form the infrastructural base to enable interconnectedness and smartness (the technical aspect) along with servitisation, which provides the value proposition to increase revenue (the business aspect; Zheng et al., 2019b).

Big data, IoT and cloud computing have emerged as influential enablers of PSS business models (Bressanelli et al., 2020). Technologies, particularly IoT, drive PSS business models by improving the tracking of products during and after use. PSS is seen as effective in the modern context, given the rise in smart products and digitalisation technologies. PSS-based waste management platforms can provide detailed information on waste streams that were previously limited by the lack of data (Casazza et al., 2019). Nevertheless, developing, assessing and verifying the feasibility of the PSS requires understanding consumer behaviour and certain intervening factors (Jiménez-Zaragoza et al., 2021). The PSS focuses on service innovation because services are viewed as an avenue

Table 3
Mapping the impacts of digital technologies on elements of CBM.

Digitalisation aspect	CBM—Value creation	CBM—Value delivery	CBM—Value capture	Key references
IoT adoption	-Durable products -Meeting the demand of 'green-segment' customers	NA	-Easy tracking and monitoring -Reduction in costs	(Mboli et al., 2020; Ingemarsdotter et al., 2020; Garcia-Muiña et al., 2018)
Distributed manufacturing	-Robust products and services	-Customer centricity and involvement	-Reduced transportation -Reuse and recycle	(Turner et al., 2019; D.L.M. Nascimento et al., 2019)
Knowledge generation from technology	-Slowing, narrowing and closing resource flows	NA	-Attracting additional customers	(Ranta et al., 2021)
Information and communication technology	-Sustainable and efficient products	-Cooperation between stakeholders	-Robust decision-making at the design stage	(Iacovidou et al., 2021)
Digital technologies combined together	-Improved product design -Preventive and predictive maintenance	- Technical support	-Increased efficiency -Attracting target customers	(Bressanelli et al., 2018a; D.L.M. Nascimento et al., 2019; Dahmani et al., 2021)
Digitalisation enabled eco-design tools	-Improved quality functionality	-Industrial symbiosis with key suppliers	- Enhanced competitiveness	(Garcia-Muiña et al., 2019)
Blockchain adoption	-Robust CE products	NA	-Increased control on products and systems until the end of life - Decision support	(Magrini et al., 2021)
Fintech innovations	-Financial inclusion and economic growth -Societal welfare	-Infrastructure for a digital economy	- Evade barriers to adoption of CBM -Cost savings and cashflows	(Pizzi et al., 2021)

of value creation and circularity improvement (Hansen & Alcayaga, 2017). Sinclair et al. (2018) suggest that consumer intervention mapping can be conducted to describe existing product service systems that are adapted to the CE paradigm. Furthermore, Spring and Araujo (2017) and Zheng et al. (2019a) advance the idea that managerial and institutional efforts and intelligent systems are vital to increase the stability of products via service value creation.

4.5. *Sector-specific studies*

In some sectors, the adoption of digitalisation and the transition to the CE have been highly successful. Consequently, these sectors are at the focal point of linear-circular transformation studies. Studies have also demonstrated that collaboration with universities and the educational sector can facilitate this transition. The following section discusses studies that focus primarily on the findings from some of these sectors.

4.5.1. *Healthcare*

A. Chauhan et al. (2021) endorse digitally connected healthcare facilities, centres for waste disposal and a feedback app for stakeholders to drive the CE in the healthcare sector through digitalisation. Daú et al. (2019) argue that corporate social responsibility plays an important social role in healthcare institutions and can facilitate the adoption of digitalisation technologies. The adoption of these technologies, in turn, adds value to ecological practices in the healthcare sector.

4.5.2. *Agri-food*

Food supply chain actors have advocated for digitally-enabled food sharing platforms to promote a CE-orientated future (Andreopoulou, 2017; Jiménez-Zaragoza et al., 2021). Decision-making tools that utilise analytics and optimisation algorithms can guide authorities and decision-makers to reduce the carbon footprint of circular agriculture (Kokkinos et al., 2020). Beliatis et al. (2019) propose an amalgamation of IoT technologies with alternative methodologies for managing disposable food containers. Data mining technology can be used to construct a path analysis system for sustainable development in agriculture and to depict interactions between renewable resources and agricultural output (Zhenjian et al., 2021). Big data-based smart agricultural waste-discharge systems can improve system performance and agricultural sustainability (Yuzhen, 2021).

4.5.3. *Education*

The education sector, including colleges, universities and technical institutes, can act as a laboratory for investigating the use of breakthrough technologies in prompting a global shift towards the CE (Ramakrishna et al., 2020).

4.5.4. *Fashion*

Sandvik and Stubbs (2019) suggest that digitalisation technologies can enhance sorting and recycling in the fashion sector by creating transparency, traceability and automation. Indeed, the new business models and digital innovations in the pull demand-driven model are vital to the CE transition in the fashion industry (Huynh, 2021).

4.5.5. *The urban sector*

4.5.5.1. Planning in cities. The utilisation of innovative digitalisation technologies in the domain of urban planning offers a fresh outlook on the optimisation of existing facilities. For example, Damianou et al. (2019) propose an IoT-based architecture that decreases resource requirements and increases the overall performance of cities. New facilities can be developed by applying IoT, big data, ICT and smart applications to drive the processes of reducing, recycling and reusing waste (Schmeleva and Bezdelov, 2020). The big-data approach can provide potential industrial symbioses within the boundaries of a city (Song et al., 2017).

4.5.5.2. Collaboration amongst actors. Advancements such as social digital platforms and apps have increasingly connected social actors and empowered citizens to implement various CE practices in cities (Hatzivasilis et al., 2018; Lekan and Rogers, 2020). The finite smart resources of cities and their citizens are considered a pool of assets that can contribute to greater resource utilisation via crowdsourcing and real-time decision-making (Angelopoulos et al., 2019). These technological solutions have the potential to improve the city by increasing public participation in municipal and solid waste management via reduce, recycle, reuse, recovery and repair programmes (Kurniawan et al., 2021).

4.5.5.3. Smart buildings and architecture. Smart buildings represent an asset for sustainability. During construction, intelligent components can be used to facilitate the required data flows over all stages of a smart building's life cycle (Turner et al., 2021). Two key approaches to the CE in urban housing are the development of smart houses and the use of smart demolition technology (Schmeleva and Bezdelov, 2020). Płoszaj-Mazurek et al. (2020) suggest that a machine learning model can be trained and applied to predict the optimal features of a smart building. Furthermore, an urban layout analysis can be conducted, and the carbon footprint of a building design can be managed with the help of neural networks (Płoszaj-Mazurek et al., 2020).

5. Framework development

The present study employs the viable system model (VSM) as a theoretical lens to develop a framework to guide firms or entities in making the transition to the CE. The developed framework presents a holistic perspective on the aspects of the CE transition that require attention. The framework is anchored on themes found in the current literature review, and it highlights the interconnectedness of these themes. Thus, the framework facilitates a comprehensive investigation by conceptualising the viability of the system.

The VSM is based on systems thinking, which emerged in the middle of the twentieth century. Since then, scholars have drawn inspiration from systems thinking to develop several models to represent practical and dynamic reality (Elphick and Beer, 1981). The VSM posits that the features of a system should remain viable even in a turbulent environment. Furthermore, it draws upon the functionalist paradigm and aims to ensure that the system functions effectively (Barile et al., 2018). In the VSM, the boundaries of the system are blurred, which means that the system is partially open (Barile et al., 2018). Such systems include several components, and the interactions of these components are dynamic. The VSM centres its approach on the systemic functioning of entities and players. It provides a reference framework that specifies the clear positioning of the theoretical contributions (key themes; Dominici and Palumbo, 2013). A firm's primary activities, which are responsible for the products or services offerings and imply the firm's identity, are at the core of the VSM.

In the present framework, these activities encompass the ways in which an organisation creates, delivers and captures value with the help of digitalisation (input). The VSM assumes that the components of the system interact with one another. In this way, the VSM characterises the relationship between firms and technology (input), barriers, enablers and benefits accrued (output). The realised benefits in terms of CE (output) that accompany digitalisation are due to three major reasons. First, digitalisation augments the effect of CE enablers such as remanufacturing, ecosystem collaboration, and waste segregation. As digital platforms support the integration between collaborating partners, they act as the ideal forum for systematically driving CE – particularly, by managing the resources are not directly under the ownership or control. Second, the barriers to CE such as low pressure from market, unavailability of data and cost related concerns are very well handled by the cutting-edge technologies. Specifically, these technologies favour customer centricity, improve the data management within firms and lower the operational cost through higher resource utilisation and extending the lifecycle of products. Thus, digitalisation helps the firms to achieve *economic* and *environmental benefits*.

Third, manufacturing firms can create, deliver and capture the value, by addressing all the components of so-called CBM. For example, technologies such as IoT and big data create unique opportunities for firms to improve and broaden their services portfolios and deliver value to their customers. In this manner, the digital technologies also lead to social benefits. In addition, *social benefits* also encompass better workplace safety, and the elimination of job hazards with automation.

The viable system also faces industry orientation variations, which affect the kind and level of digitalisation, the nature of business model innovation, the barriers and enablers of digitalisation and the level of the realised benefits. Digitalisation drives business model innovation in the presence of multifaceted barriers and enablers. This investigation for system viability is conducted by coupling the associated realisation of CE benefits (output) and a feedback loop in terms of CE indicators. The complex system behaviour that is manifested in the presence of industry orientation variations is assessed and fine-tuned with the help of feedback loops, which ensure that any change will inevitably affect all of the system's components (Everard, 2004). However, the key parameters that affect the system are extracted from the literature (barriers and enablers) by conducting the present SLR study. Scholars have explained the concept of the business model as an approach through which firms create value (Kallio et al., 2006). The management literature asserts that business model innovation works by accentuating the systems through which firms, in collaboration with other actors, create value for their customers (Osterwalder and Euchner, 2019). Circular business model innovation is propelled system-wide by value creation, value capture and value delivery, which are facilitated by digitalisation. Sustaining a viable CE system is achieved with help of the appropriate technologies and enablers, which feedback loops help to strengthen.

These feedback loops guide actors to make changes to improve the system. A multi-sectoral system is considered viable if it maintains a balance in feedback cycles, can adjust to these changes and correct adverse performance. The VSM approach emphasises collaborative actions that take into consideration the perspectives of stakeholders, such as policymakers and managers, through the feedback loop. Policymakers work to achieve the appropriate policy mix (an enabler), while managers, with the help of CE performance indicators, utilise feedback from the output (the CE) to adjust their CBM or their choice of digitalisation technology. Consistent with the VSM, the system learns, adjusts and progresses over time (Barile et al., 2014). It is established that involving stakeholders for CE makes considerable sense with respect to value and opportunities for new CBMs (Chiappetta Jabbour et al., 2020). In line with the same, in the present model, the feedback loop focuses on the decision-making (policies) and actions (digitalisation and business model innovation) that stakeholders must pursue to achieve the CE.

The framework developed with the VSM illuminates the dynamics of multi-sectoral systems. These dynamics illuminates the importance of alterations and streamlining that are required in response to the changing environment, which is affected by dynamic barriers and enablers that make the decision-making process complex. The VSM framework enables a reasonable dialogue regarding feasible policy interventions and expected strategic outcomes. Fig. 8 presents the VSM-based framework for the CE transition.

6. Research gaps and avenues for future research

Via its rigorous analysis of the studies selected, the present SLR identifies the gaps in the extant literature. Table 4 presents the gaps in the literature and the potential research questions.

7. Conclusion

The paradigm shift from the linear economy to the CE requires the contribution and commitment of stakeholders and the redesigning of systems to align with business model innovation principles. The present analysis reveals that research in this domain is fragmented across interdisciplinary fields. Publications are scattered across a multitude of journals, methodologies and themes. The key themes are as follows: (a) digitalisation technologies and CE; (b) barriers to digitalisation-led CE; (c) enablers of digitalisation-led CE; (d) Digitalisation-led business model innovation and (e) sector-specific studies. In recent years, rising concerns about the CE, digitalisation and the attendant challenges have spurred increasing scholarly interest in the specific measures that are necessary to tackle such challenges. A comprehensive assessment of the literature emphasises the prominence of the theme that aims to assess the enabling role of digitalisation in the CE transition. Additionally, a few studies examine challenges firms face regarding the adoption of business models at the intersection of the CE and digitalisation. According to Ingemarsdotter et al. (2020), for example, the key challenges include the absence of structured data management processes and the

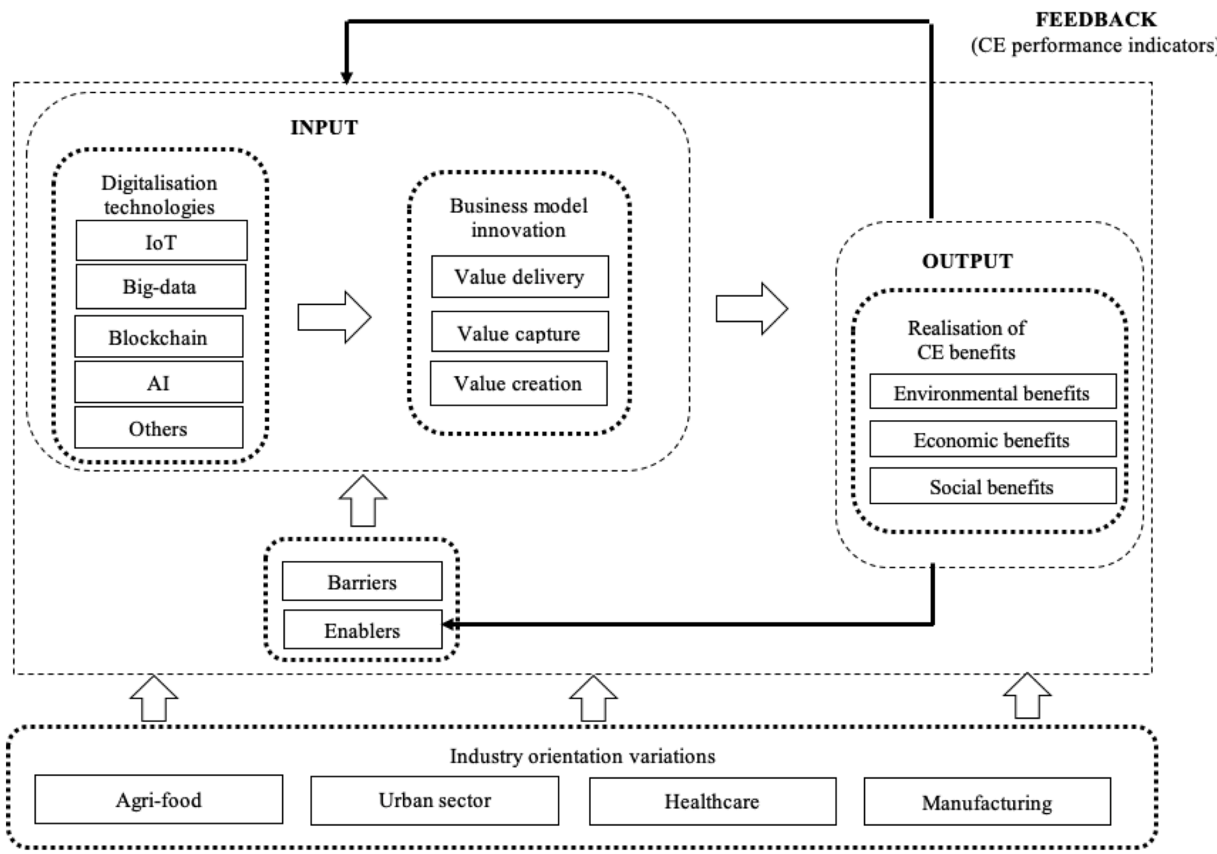

Fig. 8. VSM-based framework for transition towards the CE.

inconvenience of developing IoT-enabled products. The absence of appropriate regulations, the scarcity of environmental education, the lack of an environmental conservation culture and the low pressure from market demand are other relevant challenges (Zhang et al., 2019). The present analysis reveals that PSS is an important business model innovation that drives the CE with the help of digitalisation. The collaboration of local, national and international governments, people and NGOs, universities and businesses can facilitate and ensure the integration of circularity into businesses. The present study concludes by highlighting the avenues for future research and the development of a VSM framework to facilitate the CE transition.

7.1. Implications for research

The present study holds numerous implications for CE and digitalisation literature streams.

First, CE literature has long recognised the importance of digitalisation as the key enablers (C. Chauhan et al., 2019; Kristoffersen et al., 2020; Nazareth, 2019). However, we have been lacking insights into the specific application of digital technologies for CE adaption. Ourstudy highlights, numerous technologies to be relevant for current conversation. For example, AI (Ghoreishi Happonen, 2020a, 2020b; Mercier--Laurent, 2020), blockchain (Esmaeilian et al., 2020), big data (Modgil et al., 2021) are the important technologies that would help to draw insights from previously overlooked data, improve transparency and help to create a CE-conducive ecosystem. Also, it is found the AI and IoT to be two prominent technologies in CE literature. AI can effectively aid managerial decision-making AI-based customisable decision support systems (M. Chen et al., 2020; Wang and Zhang, 2020). In addition, circular-by-design IoT architecture drives data harvesting and has a proven record of enabling circularity (Askoxylakis, 2018; Miaoudakis et al., 2020). Future studies are encouraged to take an more distinctive view on the relationship between CE and digital technologies.

Second, aligned with dominant discussion within the CE research stream, we find a bulk of studies focusing on CBM (e.g., Miaoudakis et al., 2020; Ranta et al., 2021; Ignacio et al., 2018). Business model innovation represents a key step towards organisation's adoption and implementation of CE principles (Pieroni et al., 2019). We find that CE studies have just begun to look more deeply into the CBM and PSS concepts when considering business model innovation. Specifically, we find that all elements of business models, that is how firms create, capture and deliver value need to be changed as they transform towards CE adoption through use of diverse technologies. A key challenge faced by traditional firms related to business model innovation is that they need to shift from product centric models to service centric models, which changes the organizational DNA (Jiménez-Zaragoza et al., 2021). From review of CBM literature, it is also evident that value capture dimension of business model element has received least academic attention, while remaining practically the most critical component for enabling adoption of digitalisation-led CE implementation.

Finally, we find that digitalisation-led CE are largely industry dependent. Studies on CE have been clearly targeting agricultural (Andreopoulou, 2017; Jiménez-Zaragoza et al., 2021) to manufacturing (Bressanelli et al., 2018a) to urban industrial practices (Hatzivasilis et al., 2018; Lekan and Rogers, 2020). Industry specific conditions play an important role in understanding how the adoption process for CE unfolds. It is also evident that most learnings from one industry to another are not easily transferable. For example, healthcare tends to be highly regulated as compared to supply chain heavy manufacturing industry (Daú et al., 2019). Thus, we continue to encourage CE scholars to focus on advancing academic dialogue on how diverse industries view application of digitalisation technologies for business model innovation, which leads to realization of CE benefits.

Table 4
Theme-based gaps and research questions.

Theme	Gaps	Potential research questions (RQs)
Digitalisation and CE linkage	1 Empirically examining the role of institutional pressure 2 Pace of digitalisation 3 Understanding the sector-wise application of technologies 4 Developing a comprehensive framework for achieving the CE using digitalisation tools 5 Understanding the role of consumers 6 Some technologies (e.g. virtual reality) receive less attention in the literature and require further exploration 7 An integrated CE system with knowledge sharing using digitalisation technologies 8 Link of digitalisation and CE with process capability 9 Performance measurement system for digitalisation-based CE implementation 10 The role of different stakeholders in the implementation of digitalisation technologies 11 IoT-enabled looping strategies	RQ1. What is the role of institutional pressure in the link between digitalisation and the CE? RQ2. Why is the pace of digitalisation slow despite its role as a driver of CE? RQ3. How does the role of digitalisation in achieving the CE vary across sectors? RQ4. How is the role and effectiveness of each technology in achieving CE assessed? RQ5. How can consumers be part of CE vis-à-vis interconnected technologies? How should such participation be encouraged? RQ6. How can technologies such as virtual reality drive digitalisation? RQ7. How does digitalisation impact knowledge management to achieve CE principles? RQ8. How can process capability be improved via digitalisation, and what effect does it have on the CE? RQ9. How should the performance of CE systems be measured using digitalisation technologies? RQ10. What digitalisation tools can managers employ to integrate all stakeholders into the CE system? RQ11. Why have IoT-enabled looping strategies, such as remanufacturing, recycling and reuse, not received much attention in practice?
Barriers to digitalisation-led CE	1 Understanding ways to mitigate the challenges to digitalisation 2 Understanding the specific technologies that can mitigate the barriers to CE 3 Challenges faced by specific industries 4 The geographical scope of policy advocacy on digitalisation and the CE 5 Policy criteria to eliminate cybersecurity and privacy risks for various technologies and industries 6 Assessing existing policies	RQ1. How can the challenges in adopting technologies that contribute to CE goals be mitigated? RQ2. What specific innovative solutions can managers adopt to reduce barriers to the achievement of the CE? RQ3. What interdisciplinary research can inform us about digitalisation challenges that are specific to particular industries? RQ4. What policy challenges do countries face as they work to promote digitalisation and achieve CE goals in emerging markets? RQ5. What policy initiatives will help countries to improve digitalisation technology adoption and achieve CE goals in their specific contexts? RQ6. How are the long-term costs and benefits of specific policies explored?
Enablers of digitalisation-led CE	1 Empirically examining the impact of incorporating digitalisation for waste management to attain the CE 2 Comprehensive assessment of the aspects of waste management can be addressed using digitalisation 3 The utilisation of digitalisation technologies for remanufacturing and reverse logistics to attain the CE 4 The role of stakeholders	RQ1. What impact does incorporating digitalisation for waste management have on efforts to attain the CE? RQ2. How can digitalisation technologies facilitate target analysis of the node of the waste management supply chain? RQ3. How can various digitalisation technologies can be utilised for remanufacturing and reverse logistics to attain the CE? RQ4. What role do stakeholders play in implementing the CE in waste management systems using digitalisation?
Digitalisation-led business model innovation	1 Limited number of detailed studies on the CBM 2 Choosing the appropriate technologies and criteria for assessing the performance of the CBM vis-à-vis digitalisation 3 Industry and firm-specific research on business model innovation implementation 4 Ensuring alignment between value creation, value delivery and value capture for profitable CBM 5 Advancing understanding towards value capture element of CBM 6 Cybersecurity and data privacy challenges between actors hinder CBM and PSS 7 Role of robotics in the CBM 8 Limited focus on the components of business model innovation, particularly the value delivery aspect	RQ1. What array of performance evaluations are best suited to investigating waste reduction? RQ2. How can different industries choose the appropriate technology for boosting the CBM, and how can the performance of such adoption be assessed? RQ3. How to develop a process model for alignment between CBM elements for successful implementation? RQ4. How to choose appropriate revenue model based on assessment of diverse CBM opportunities? RQ5. How can the cybersecurity and data privacy challenges of PSS be mitigated? RQ6. How do intelligent robotics affect the CBM? In what prominent areas can robotics application can be utilised? RQ7. How is CBM value delivery affected upon adoption of various digital technologies?
Sector-specific studies	1 Certain sectors receive less attention in the literature 2 Inter-sectoral partnerships	RQ1. Which sectors have benefitted the most from the digitalisation-led CE? RQ2. How can partnerships with universities and institutes help to achieve the CE?

7.2. Implications for practitioners

The present study entails some important implications for practitioners. To play a pivotal role in the transition from a traditional to a CE-based setup, managers and policymakers must develop a detailed understanding of the role of digitalisation in CE adoption. The knowledge derived from and presented in this SLR will help practitioners to adopt a more holistic view of digitalisation technologies and manage them to better harness their key benefits.

Digitalisation would ensure that policymakers' efforts to devise the appropriate policies necessary to initiate feasible solutions to environmental issues are not hindered due to absence of relevant data – such as data on material flows. Therefore, the first implication of the present study is that it highlights the importance of policy interventions needed to enhance digitalisation, which would further trigger CE related benefits.

Second, managers can refer to the analysis of the present study as they work to identify potential digital technology applications for boosting CE. For example, the study highlights that better decision making for CE could be achieved with seamless data flow between the actors. Also, the present study points out that firms should not take an internal perspective when thinking about CE and CBM. Technologies such as IoT and blockchains will enhance ecosystem partnerships and enable profitable CE implementation.

Third, a VSM-based framework provides a structured approach to ensure CE benefits. Firms can start with adoption of a technology, introduce CBM related changes, assess company and ecosystem specific barriers as well as enablers. Further, industry variations should also be considered to ensure CE benefits. The framework developed in the present study would act as a blueprint of the steps involved in realisation of CE benefits.

7.3. Limitations of the study and areas for future SLRs

The first limitation of this study is its exclusive focus on English language articles found in WoS and Scopus databases and Google Scholar searches. The authors acknowledge the likelihood that they missed some relevant studies as a result of these strict inclusion criteria. The review also excluded book chapters and reports. Therefore, future studies could include book chapters and studies in other languages and examine other academic databases. Second, the SLR's strict inclusion and exclusion criteria also may have led the authors to omit studies that focused on the technical aspects of digitalisation or the biological or chemical aspects of the CE. Third, research on themes related to the pandemic situation remains nascent. However, the authors anticipate that new insights and research gaps will emerge as research on the COVID-19 pandemic matures. Finally, the present paper focused on explicating key themes. To complement these efforts, future researchers could pursue a dedicated bibliometric analysis of this domain.

Despite the limitations outlined above, the present SLR provides a detailed account of the emerging themes and research gaps in this domain, and it is expected to act as a cornerstone for future scholarly explorations in the area.

Author statement

We confirm that the paper entitled- Circular Economy and Digitalization. A systematic literature review of past achievements and future promises- is an original work and is not currently under consideration at another journal.

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