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Review article

Blockchain for the Circular Economy: Analysis of the Research-Practice Gap

Alexa Böckel, Anne-Katrin Nuzum*, Ilka Weissbrod

Leuphana Universiät, Centre for Sustainability Management (CSM), Universitätsallee 1, 21335 Lüneburg, Germany

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ABSTRACT

Extant research claims that the circular economy concept has enormous potential to overcome downsides of status quo economic activities and to contribute to sustainable development, but that the concept also faces challenges in realizing its potential. Blockchain technology has been suggested as one possible critical solution to overcome the current barriers of implementing the circular economy concept. This article addresses the nascent research field of blockchain for a circular economy and examines current developments, from both research and practice. By developing and conducting a research-practice gap analysis using a systematic literature review, this article identifies patterns of interests and opportunities for research and practice and uncovers mutual blind spots that need to be addressed in either sphere. A systematic literature review and qualitative analysis covering 57 diverse documents (journal articles, contents linked from twitter, and google results) revealed three key findings: 1) a clear terminology of blockchain types, their technical properties and benefits are lacking in research, 2) trust and verification are major potential benefits but a challenge to create, and 3) a closer examination of possible benefits and challenges of blockchain technologies for the circular economy with its links to sustainable development is crucial.

1. Introduction

The prevailing economic model in the Global North is based on a linear approach, also called a “take-make-dispose” economy (Blomsma and Brennan, 2017, p. 603). This economic system has provided substantial growth in the gross domestic product, as well as human well-being, while simultaneously leading to considerable damage to the natural world (EMF, 2015; WWF, 2018; IPBES, 2019). At this point in time, humankind runs an ecological deficit, using the resources of about 1.75 earths per year (Global Footprint Network, 2020) and living beyond the planetary boundaries (Rockström et al., 2009). This building of wealth while damaging the environment has led to calls for alternative economic models, such as the circular economy. This alternative model has experienced growing interest in the past few years (Petit-Boix and Leipold, 2018). While the idea that resources are used perpetually is common in nature, the concept of circularity emerged in economy and policy discussions in the 1970s, followed by the Cradle-to-Cradle (McDonough and Braungart, 2013) design principles in the 1990 (PwC, 2019a; Pearce and Turner, 1989). (McDonough and Braungart, 2013) The need to ensure sustainable production and consumption patterns has also been recognized in the United Nations Sustainable Development Goals, in particular target 12.5, aiming to “substantially reduce waste generation through prevention, reduction, recycling and reuse” (United Nations, 2020).

Yet, the circular economy can be seen as a concept and practice that is still in development, both in research (Geissdoerfer et al., 2017), as well as in its application (EMF, 2013; 2015, 2019). The circular economy shows great potential for sustainable development due to its ability of reducing waste, closing resource circles, and changing business models (Geissdoerfer et al., 2017; Kirchherr et al., 2017; Korhonen et al., 2018) and is expected to fulfill a “catalytic function“ (Blomsma and Brennan, 2017, p. 603). At the same time, technological advances, including the Fourth Industrial Revolution (EMF, 2016), are enabling a circular economy (EMF, 2015). In particular, blockchain technology has been identified as a key enabler to overcome challenges towards a circular economy (Kouhizadeh et al., 2019a). Building digital networks to distribute information about materials and supply chains transparently can lead to more circular resource flows, waste reduction, and an improved data base for decision making towards a circular economy (ibid.). Meanwhile, current blockchain technologies are

* Corresponding author at: Leuphana Universität, Centre for Sustainability Management (CSM), Universitätsallee 1, 21335 Lüneburg, Germany.
E-mail addresses: alexa.boeckel@leuphana.de (A. Böckel), anne-katrin.nuzum@leuphana.de (A.-K. Nuzum), ilka.weissbrod@leuphana.de (I. Weissbrod).

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criticized for a high use of energy and whether the disadvantages outweigh the promised advantages (Zheng et al., 2018).

Using blockchain technology for the circular economy is a topic at the intersection of two megatrends: digitalization and sustainability (WBGU, 2019). The connection of these two megatrends is a nascent field, both in research and practice, with the goal to design and use technology for a sustainability transformation of the linear economic paradigm (WBGU, 2019). To aid the implementation of this vision, understanding early developments and extant gaps of knowledge concerning blockchain technology for a circular economy is of utmost importance. Both aspects are relevant to define the need for future research and to develop further ideas for practical innovation. This research paper, hence, shows the differences in research and practice regarding the use of blockchain for a circular economy. We developed and conducted a research-practice gap analysis using a systematic literature review and identified patterns by analyzing qualitative data as suggested for nascent research fields (Edmondson and McManus, 2007). Extant research in the field of the circular economy (e.g. Lyytimäki, 2018) has already acknowledged the relevance of societal and practice debates for the transition towards a circular economy by including media articles.

Practical solutions using blockchain in the context of a circular economy are being developed (Wu et al., 2019) and academic literature connects these two topics as well (Kouhizadeh et al., 2019a). Differences in practice and academia, however, and in particular how these two topics are discussed, might exist. Kirchherr et al. (2017) asserted that definitions for the circular economy differ between practitioners and researchers. Our research explores how this gap manifests in the application of blockchain to the circular economy and addresses the research question of:

What are the differences in research and practice regarding the use of blockchain for a circular economy?

Our work was motivated by four aspects: first, the pressing need to address resource issues and understanding the role of technological enablers; second, the recent identification of blockchain technology as a key enabler to overcome challenges towards a Circular Economy; third, to understand the research-practice gap we could informally observe when engaging in the practitioner community; and, fourth, to define future research and to develop further ideas for practical innovation.

In this research, we illuminate the nascent research field at the interface of blockchain for a circular economy and examine current developments. Through our analysis, we offer inspiration for research through questions raised in practice but, not yet, in research. We also offer opportunities for practice through challenges identified in research. Finally, and perhaps most importantly, our analysis highlights the blind spots for both research and practice which needs to be explored in order to unleash the potential for sustainable development.

We go on to introduce the concepts of blockchain technology and circular economy and their connection. Chapter two describes the method by defining the research-practice gap as a construct and by deducing a possible methodology to determine such a gap. Findings for both research and practice are presented and discussed and, finally, the conclusions state the implications of our research.

1.1. Fundamentals of blockchain technology

The concept of blockchain technology was developed in a different context than circular resource loops and the connection between these topics emerged only recently. This section describes the development of blockchain technology, its potentials and challenges, as well as the circular economy with its potential contribution to sustainable development, prior to connecting the two topics.

The idea of developing a network that is transparent, uninfluenced by members and non-members of the network, decentral as well as open, and to use it for a financial system was mentioned first in 2008 (Nakamoto, 2008). The attention for blockchain technology peaked when BitCoin, a cryptocurrency, was discussed as one of the most disruptive technologies after the invention of the internet (Swan, 2015). Even though BitCoin is often used as a synonym for cryptocurrencies and is the most popular currency based on a blockchain (Crosby et al., 2016), other digital currencies such as Ethereum or Ripple hold market shares (Makarov and Schoar, 2020). No single definition has been identified in research (Pilkington, 2016). Nonetheless, blockchain can be described as “a distributed database that is organized as a list of ordered blocks, where the committed blocks are immutable” (Casino et al., 2019, p. 55). Different blockchain types exist, differing in access rights of the network participants. Table 1 shows the four blockchain types (i.e. public permissionless, public permissioned, consortium, and private permissioned) and associated reading, writing and committing rights (Hileman and Rauchs, 2017). The type of blockchain is essential for the application and its context because the permission type and the consequential rights to access and change the information on the blockchain determine the grade of centrality and transparency. This means that a public blockchain is not suitable to store sensitive company data or a consortium blockchain does not fit for a matter of public interest (ibid.). Blockchain technology allows for a direct transaction, or exchange of value or information, between two parties without a third party - a process, which secures this transaction. The information in the network is processed and updated in real-time, which speeds up data transfer in diverse contexts (Wang et al., 2019).

Over the years, three different generations of blockchains have evolved, differing in their application fields and technological characteristics (Xu et al., 2019). The focus on the currency application came first, the next generation brought contracts distributed via blockchain, while in the third generation a range of different applications have been developed on the basis of the blockchain technology (Swan, 2015).

In research, blockchain applications have been discussed in diverse contexts such as supply chain management, as well as the healthcare, financial, and agricultural sector (Casino et al., 2019). Scholars concentrated on the economic potential of blockchain on initial coin offering (Venegas, 2017), blockchain as a fintech revolution (Cai, 2018), and the link to the sharing economy (Hawlitschek et al., 2018). The scientific domains covered include engineering, telecommunication, business, and economics (Casino et al., 2019).

1.2. Potentials and challenges of blockchain

Blockchain technology is associated with properties of “decentralisation, persistency, anonymity and auditability” (Zheng et al., 2018, p. 354). It is assessed as an “extremely disruptive technology that would have the capacity for reconfiguring all aspects of society and its operations” (Swan, 2015, p. 82). While these properties benefit diverse use cases (e.g. supply chain management, agriculture), there are some distinctions across different applications. For all contexts, smart contracts, data management and data analytics (Zheng et al., 2018), as well as data storage and sharing (Xu et al., 2019) apply. For supply chain management, the focus is on products and material traceability (ibid.). For the energy sector and the development of smart grids, blockchains can support the negotiation between smart grid actors without an intermediary (Mengelkamp et al., 2018). Likewise, in emissions trading,

Table 1
Blockchain types clustered by permissions (adapted from Hileman & Rauchs, 2017, p. 20).

			Read	Write	Commit	Example
Blockchain types	*Open*	*1. Public permissionless*	Open to anyone	Anyone	Anyone	Bitcoin, Ripple, Ethereum
		2. Public permissioned	Open to anyone	Authorized participants	All or subset of authorized participants	Sovrin
	Closed	*3. Consortium*	Restricted to authorized set of participants	Authorized participants	All or subset of authorized participants	Multiple banks operating a shared ledger
		4. Private permissioned	Fully private or restricted to a limited set	Network operator only	Network operators only	Internal bank ledger shared between parent company and subsidiaries

blockchain technology can secure transparency and prevent fraud in trading management (Khaqqi et al., 2018).

Research and experimentation with the technology since 2016 have, however, exposed challenges. As the technology is new and its integration in different domains is constantly evolving, regulation and government control are pending discussions (Crosby et al., 2016), e.g. in the field of cryptocurrencies (Xu et al., 2019). Similarly, in some cases blockchains are not as secure as expected as a leakage of private information can take place in transactions even though security standards are met (Biryukov et al., 2014). This security flaw is remedied by the centralization of blockchains, hence contradicting the original idea of the technology (Zheng et al., 2018). Some researchers have articulated skepticism towards the abilities of the technology in regards to the timescale of realization of the different potentials (e.g. Swartz, 2017).

Studies connected to sustainability research explored the benefits for managing and fostering biodiversity in indigenous knowledge systems (Bose et al., 2019), increasing accountability in carbon markets (Chen, 2018) and tracing carbon emissions in the fashion industry (Fu et al., 2018). Likewise, gaining transparency and trust in sustainable development programs (Horner and Ryan, 2019) or trading locally produced energy in smart grids (Mengelkamp et al., 2018) were part of the research agenda. A practitioner-led report (WEF, 2018) evaluated the potential of blockchain and discovered 65 use cases. In line with the findings, the (WEF, 2018, p. 4) asserted that the increased implementation of blockchain can lead to “resource-preserving decentralized solutions, unlock natural capital and empower communities”. The trade-off between the diverse possibilities and benefits of application and the prevalent criticism of high energy use (Zheng et al., 2018) remains, however, unresolved.

1.3. The circular economy as a sustainable economic model

Unlike blockchain technology, the circular economy concept originated from the explicit intention of addressing sustainability challenges. Building wealth while damaging the environment has led to calls for alternative economic models and the circular economy has experienced growing interest in the past few years (Petit-Boix and Leipold, 2018). The circular economy can be seen as a concept and practice that is still in development, both in research (Geissdoerfer et al., 2017), as well as in its application (EMF, 2013). So far, there is no consensus on the concept as well as its definition in academia (Kirchherr et al., 2017; Homrich et al., 2018; Korhonen et al., 2018). For example, Homrich et al. (2018) found more than 20 definitions for circular economy in their body of reviewed literature; Kirchherr et al. (2017) identified as many as 114 definitions. Despite different conceptions and definitions, there is agreement on the general principles of closing and extending resource loops, rather than degrading and wasting them (European Commission, 2015; Blomsma and Brennan, 2017). For this research, the following definition serves as the foundation:

The term ‘circular economy’ denotes an industrial economy that is restorative by intention and design. In a circular economy, products are designed for ease of reuse, disassembly and refurbishment, or recycling, with the understanding that it is the reuse of vast amounts of material reclaimed from end-of-life products, rather than the extraction of resources, that is the foundation of economic growth. (EMF, 2013, p. 14)

Specific strategies or actions exist in the discourse. In particular, the three R-strategies - reducing, reusing, and recycling – have been covered widely (Zhu et al., 2010; Reh, 2013; Kirchherr et al., 2017); in some cases, a fourth strategy was added: recovering[1]. Reducing covers activities in the early stage of the development and consumption processes including redesigning, refusing, and rethinking material usage. Reusing addresses activities to close material loops as well as repairing products. Recycling includes reusing of wastes and other materials; recovering includes energy recovery when materials are burned (Kirchherr et al., 2017). Blomsma and Brennan (2017) went a step further and summarized the R-strategies as well as servitization, product longevity approaches, cascading of substances, and waste-to-energy concepts under the framing of “resource life-extending strategies” (p. 606). An additional perspective was provided by Blomsma and Tennant (2020), who introduced a framework for resource states and flows by focusing on products, parts, and particles. Similarly, some argued that the circular economy can be implemented at different levels (Ghisellini et al., 2016). Others also argued for closed value chains (e.g. Homrich et al., 2018) as well as circular business models (Bocken et al., 2018).

The practice debate has been led by the Ellen MacArthur Foundation since 2013 (e.g. EMF, 2019; 2015; 2013), addressing broad questions as well as the specific opportunities for individual sectors or regions. They provided a definition of the circular economy, guidance on principles, the possible social and economic impacts, and collected successful case examples. Consultants, governmental institutions, and non-governmental organizations (e.g. PwC, European Commission, and WEF) have been vocal about the potential for a circular economy as well (PwC, 2019a; European Commission, 2015; WEF, 2018). Furthermore, several industries are highlighted of primary concern, such as plastics, construction, food, critical raw materials, and biomass (European Commission, 2015).

There is an ongoing debate whether implementing a circular economy requires systemic changes rather than smaller, incremental improvements to the existing economic system (Kirchherr et al., 2017). Some argued that the circular economy is contributing to the discourse on alternative economic growth models and that the

[1] Other R-frameworks range from three to nine R-strategies, as mentioned for example in Sihvonen and Ritola (2015) and Van Buren et al. (2016).

circular economy is threatening some aspects of traditional economic growth and ownership assumptions (e.g. Ghisellini et al., 2016; Temesgen et al., 2019). Others argued the circular economy concept "may rather be considered a way to design an economic pattern aimed at increased efficiency of production (and consumption), by means of appropriate use, reuse and exchange of resources, and do more with less" (Ghisellini et al., 2016, p. 18). As such, the circular economy might be an operationalization for achieving a more efficient resource use, independently of whether (limited) growth, degrowth or steady-state economics should be achieved.

The economic and environmental dimensions of sustainability are the main focus areas of a circular economy, while the social dimension, as well as future generations, are barely covered (Kirchherr et al., 2017). Others agree that social and ethical dimensions are absent in the conceptualization of circular economy (Murray et al., 2017) or assert that social and institutional dimensions are widely left out (Merli et al., 2018). This has led to the call to address the linkages between sustainability dimensions and the circular economy more strongly (Blomsma and Brennan, 2017; Geissdoerfer et al., 2017; Kirchherr et al., 2017).

1.4. Circular economy and blockchain technology

Circular economy and blockchain technology have emerged both as new and distinct real-world phenomena as well as corresponding new and separate bodies of (academic) literature (e.g. Casino et al., 2019). Several sources focused on the potential of blockchain technology in circular supply chains. Several conditions need to be met to mainstream the circular economy and to overcome challenges, among them circular product design and production, new business models, capabilities to reverse the cycles to collect materials for reuse or recovery, and underlying system conditions (EMF, 2015; 2013). One of the system conditions is an infrastructure for information sharing and platforms for collaboration. This infrastructure is essential to a circular economy, as shared and transparent information are the foundation for building different resource and material flows (Derigent and Thomas, 2016). Such an information technology infrastructure could be provided by blockchain technology. By building up a shared information infrastructure on a blockchain, the technology can enable circular sourcing of renewable inputs and support resource efficiency. It can also aid in the recovery of the materials, in particular refurbishing and recycling from manufacturers and consumers via tracking of material and resource flows through different supply chains and consumption steps. Nonetheless, blockchain cannot provide a solution for other aspects of the circular economy, most notably in sustainable design or in maximizing product use (PwC, 2019a). For these areas, other technologies are needed.

2. Methodology

We establish how a research-practice gap can be approached methodologically and deduce how to identify one. The systematic literature review approach is described including the data collection and selection steps.

2.1. Defining and examining a research-practice gap

The concept of a gap between research and practice has been known and discussed in a variety of academic domains, including education (Hirschkorn and Geelan, 2008; Belli, 2010; Grima-Farrell et al., 2011), management (Bansal et al., 2012), accounting (Tucker and Schaltegger, 2016; Jansen, 2018), medicine (Munro and Savel, 2016; Leach and Tucker, 2018), psychology (Polkinghorne, 1992), foreign policy (Nye, 2008), and conservation (Esler et al., 2010). Sometimes, the research-practice gap has also been named a theory-practice gap (Belli, 2010). Table 2 illustrates the different understandings of the research-practice gap.

Where the production of knowledge is at fault, jointly conducting research with practice was proposed (Van de Ven and Johnson, 2006), hence moving from mode 1 research, conducted solely in the academic domain (Gibbons, 1994), to mode 2 research, conducted jointly with practice. This is in line with the relationship between research and practice in sustainability science as proposed in action research and transdisciplinary research which often address real-world problems (Lang et al., 2012).

None of the academic papers covering the research-practice gap have defined the terms *research* or *practice*. In particular the term *practice* warrants further consideration. In applied sciences, the related practice is clear - covering a wide range of professional groups, such as nurses, managers, or human resources employees. These practitioners are situated "in particular problems encountered in everyday activities" and have a "deep understanding of the problems and tasks that arise in particular situations and of means-ends activities that make up their solutions" (Van de Ven and Johnson, 2006, p. 806). Transferred to the subject of our study, practitioners at the intersection of circular economy and blockchain technology might be a wide range of people: entrepreneurs, managers, employees at various companies; software developers; members of non-profit organizations; governmental employees, among others. In addition, relevant practitioners for the circular economy were identified as "policy-makers, businesses, business consultants, business associations, business foundations etc." (Korhonen et al., 2018, p. 37).

In the academic discussion, a few papers address how to bridge the gap and whether it should be bridged, brokered, or even closed (e.g. Belli, 2010; Bansal et al., 2012; Neal et al., 2015), or at least analyzed based on diffusion theory and the stages of discovery, translation, dissemination and change (Tucker and Schaltegger, 2016).

This research will not necessarily close the gap at the intersection of circular economy and blockchain technology but, in an effort to bridge it, we identify possible future research areas as well as possible areas for application in practice. This research takes an academic perspective on research and practice items. Yet, this cannot be considered transdisciplinary research as practitioners were not involved in other research aspects (Lang et al., 2012).

2.2. Systematic literature review of research and practice

Different attempts and methodologies aimed to establish a research-practice gap in other domains of research, analyzing research or practice perspectives, though not both (e.g. Hirschkorn and Geelan, 2008; Sitas et al., 2014; Tucker and Parker, 2014; Neal et al., 2015; Homrich et al., 2018; Leach and Tucker, 2018). The research-practice gap does not have an established methodology yet (Sitas et al., 2014), but it is clear that any methodology needs to be based on both research and practice views. Tucker and Parker (2014) argued that a clear framework to analyze the relationship between research and practice is missing. At the same time, a plurality of methods and "multiple frames of references are needed to understand a complex reality" (Van de Ven and Johnson, 2006, p. 813).

We identified three papers with methodological approaches suitable to address the research question of this paper (i.e. Tkachenko et al., 2017; Jansen, 2018; Petit-Boix and Leipold, 2018). All used systematic literature reviews to understand research-practice gaps via comparisons of research and practice literature and this approach provided the foundation for our research design.

A systematic literature review can establish whether a gap exists by identifying different content and discussions

Table 2
Different understandings of the research-practice gap in academic literature.

Understanding of the research-practice gap as..	Sources
..a communication gap between two communities	Neal et al., 2015; Remy and Huang, 2018
..a disconnect between research and actual practice	Leach and Tucker, 2018
..a (lack of) diffusion of research results into practice	Kristensen et al., 2016
..a translation gap	Tucker and Parker, 2014; Kelemen and Bansal, 2002
..a dissemination gap	Kelemen and Bansal 2002; Neal et al., 2015; Tucker and Schaltegger, 2016
..a (lack of) searching for information by practitioners	Neal et al., 2015
..a time lag	Munro and Savel, 2016
..a lack of research's (practical) relevance	Nicolai and Seidl, 2010
..a knowledge transfer problem, a knowledge production problem and distinct kinds of knowledge	Van de Ven and Johnson, 2006

Table 3
Steps of the review process (after Merli et al., 2018).

Step	Description	Section
1	Data Collection: definition and delimitation of data and unit of analysis	2.3
2	Descriptive Analysis: formal aspects of collected material are assessed and analyzed using quantitative methods	3.1
3	Category Selection: first, deductive codes are generated from the theoretical literature of both topics (blockchain and circular economy), then these codes are applied, and the code scheme is extended by inductive codes	3.2
4	Material Evaluation: the material is evaluated according to dimensions and categories previously established. Results are interpreted to define relevant issues	3.3

in academic and practice documents. This approach heeds the call by Kieser et al. (2015) to conduct more systematic analyses to understand research-practice gaps. Furthermore, Tranfield et al. (2003) recommended systematic literature reviews for generating science with practical relevance and for understanding evidence-based practice. The authors envisioned an approach to identify gaps of academic knowledge or to summarize evidence-based approaches to a practical problem within a research domain. Our research, however, extends the systematic literature review into the area of practice, in order to gain insights into the research-practice gap beyond academic perspectives. Such an inclusive approach can enable solutions for real-world problems (Lang et al., 2012). Based on Tranfield et al. (2003) and Merli et al. (2018), we conducted a systematic literature review on blockchain for the circular economy. Subsequent methodological steps are adapted from Merli et al. (2018); with all steps conducted for the review of research articles and for the practice review (Table 3).

2.3. Review process

The review follows the *Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)* guidelines developed by Moher et al. (2009). The process is shown in Fig. 1. The terms records and items are used interchangeably in the following sections.

The first step, record identification, was conducted in both academia and practice databases. To ensure comparability between research and practice, the data collection used the same search terms and time frames in academia and practice databases. The academic systematic literature review included journal articles, books, conference presentations, and proceedings; the practice publications included newspaper articles, blog posts, special interest websites, reports by consultants and governmental organizations, and opinion papers. The items of analysis for the practice review were either directly retrieved from Google results or from tweets that linked web pages.

For the research review Scopus and Google Scholar were used in order to utilize large scale databases, including both peer-reviewed and non-peer reviewed items. The additional terms ledger and bitcoin were included to identify papers that do not necessarily use the term blockchain prominently but would still provide relevant results. Research items were collected until April 2020. Searching the Scopus database with the search term *(blockchain OR ledger OR bitcoin) AND "circular economy"* in either title, abstract, or key words led to 20 results. A sufficiently high quality was assumed since the documents underwent a review process, ranging from conference committee review to peer-reviews. Searching the Google Scholar database with the same search term led to 1,930 initial results.

For the practice review Twitter and Google were selected. Google is the most used search engine (Statista, 2020), while Twitter was selected as a supplement to Google due to four aspects: Twitter functions as a platform of discourse and exchange about relevant topics (Hermida, 2012), serves as a data- and information base for journalists (Parmelee, 2013), is used by businesses for voluntary information disclosure (Grover et al., 2019) and, finally, is a relevant platform for actors outside of the elites in the domains of politics, academia, and economy (Rogstad, 2016). In addition, the analytics of Twitter as social media have already been used to evaluate the diffusion of blockchain technologies (Grover et al., 2019). Tweets on Twitter were used as a source for further links and articles and the *top tweet* and the *advanced search* function by Twitter was used. The research goal was to identify broadly discussed topics and questions; hence hashtags instead of search terms were used. For these, the probability of being retweeted is higher and the self-association to the discourse is higher. As there is no advanced search option, the search term for Twitter was *#blockchain AND #circulareconomy* from all accounts from all years and all locations and was conducted on 4/24/2020. In order to have sufficiently rich data for analysis, the websites and reports linked from tweets were used. Google was searched with the search term *(blockchain or ledger or bitcoin) and "circular economy"* on 4/13/2020. Google identified several hundred thousand initial results.

From the initial results of Twitter, Google, and Google Scholar, the first 50 results sorted by relevance were collected each, following an initial convenience sampling strategy (Moser and Korstjens, 2018). Such a sampling strategy is sufficient for Twitter and Google as users typically only use the first results (Southern, 2020). Whether the sampling approach was also suitable for Google Scholar was determined by analyzing the next 50 results. Since the findings from this additional sample did not change the identified research-practice gap, it was determined that saturation was

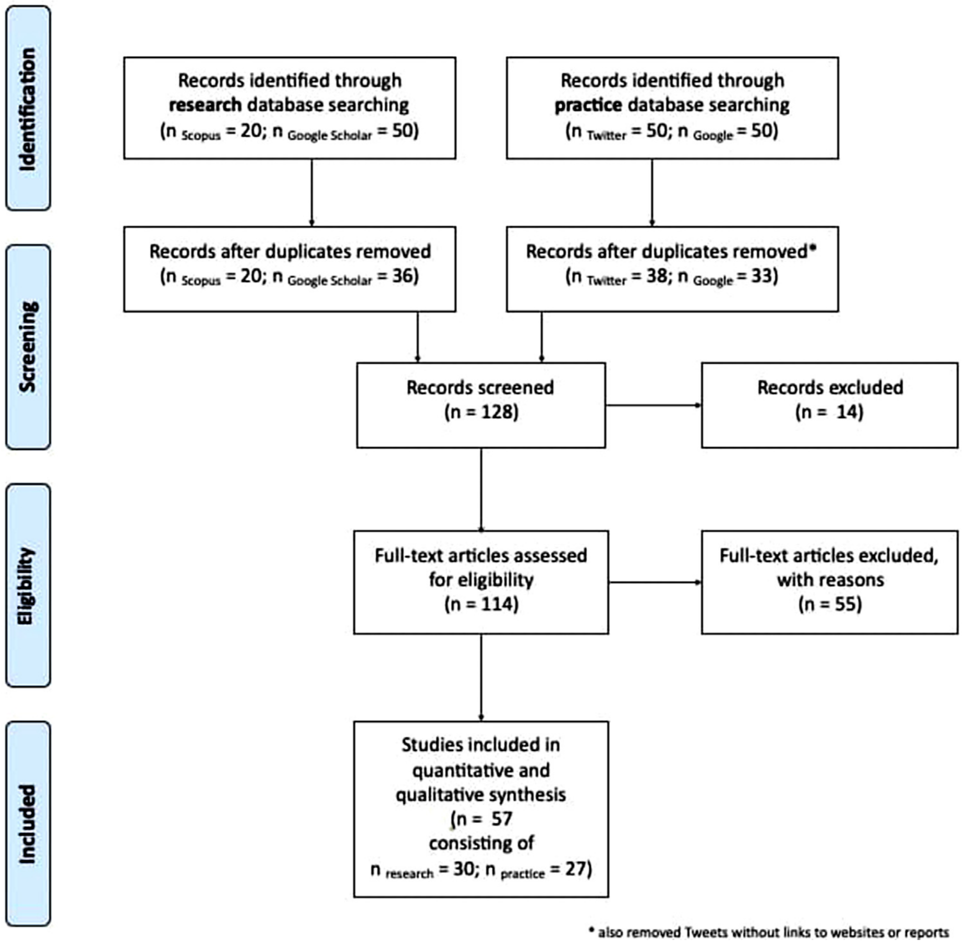

Fig. 1. The review process, according to the PRISMA guidelines (Moher et al., 2009).

achieved and that the initial convenience sample was adequate (Moser and Korstjens, 2018). The data collection process from all four databases resulted in a data set of 57 items for analysis. As an additional reason to consider the overall sample size to be adequate is the fact that other papers covering literature reviews of the circular economy have used similarly sized data sets with 45 documents (Petit-Boix and Leipold, 2018) and 53 documents (Lazarevic and Valve, 2017).

After the initial sample was identified, the screening process removed duplicates, inaccessible records, as well as 11 tweets without links to websites or further reports. In the next step, records were assessed for eligibility criteria. As eligibility criteria, the data needed to have a clear focus on both blockchain and circular economy. All items were scanned by two researchers. Eligibility criteria were applied by two coders on a tenth of the items in order to check their suitability and clarity. The coders disagreed on one item and came to an agreement after an exchange. The intercoder reliability in the form of Krippendorf's Alpha was 0.9. The review process provided a total of 57 items - 30 items from research and 27 items from practice. A descriptive analysis of the sample is included in the next section.

3. Results

This section provides descriptive data results as well as the inductively and deductively identified categories, which are then applied to the data set. The results of the material evaluation are presented for each of the categories.

3.1. Results of descriptive analysis

The analysis of a total of 57 items showed a fragmented and nascent topical field; both in research and practice (see Table 4).

The earliest items were published in 2016 in practice and 2017 in research (see Fig. 2). Since then, the numbers of publications have been increasing continuously in all data sources; albeit at a low level. The highest number of publications for both research and practice was in 2019. The data sample for the year 2020 is the first year with a greater number of practice items than research items (see supplementary materials for a detailed breakdown of the analysis by year (Table A1), by publication type (Table A2), by method type (Table A3), and region (Table A4)).

The range of authors was diverse: with the exception of one main author group with four academic publications in Scopus and Google Scholar [Kouhizadeh, M. (authorship 4 times), Zhu, Q. (3 times), and Sarkis, J. (3 times)], every other author had one publication in the sample. In addition to individual authors, several organizations published documents on blockchain and circular economy, including EMF (2015), OECD (2019), PwC (2019b), Climate KIC (2019), LoopCycle (2019), and Circularise (Poole, 2020). The data sample originated from 16 different countries, based on the affiliation of the first author. No main journals, websites, or newspapers have emerged for the intersection of the research topics. The main publication types across all items were journal articles (25 %), reports (21 %), opinion papers (16 %), conference presentations (16 %), and press releases (14 %). While all journal articles and conference presentations were obtained from academic

Table 4
Overview of items in dataset for analysis.

Research items (30)		Practice items (27)	
Scopus (11)	Google Scholar (19)	Google (15)	Twitter (12)
Alexandris et al. (2018)	Andrews et al. (2017)	Achterberg (2019)	Burnson (2020)
Damianou et al. (2019)	Bolier (2019)	Arup (2019)	Clancy (2020)
Hagan et al. (2019)	Carbone et al. (2018)	Bauwens and Pazaitis (2019)	Folk (2020)
Kamilaris et al. (2019)	Chidepatil et al. (2020)	Climate KIC (2019)	Gennari (2019)
Kouhizadeh et al. (2019b)	Dapp (2019)	Circle Economy (2018)	Iles (2018)
Kouhizadeh et al. (2019a)	Faber and Jonker (2019)	EMF (2016)	LoopCycle (2019)
Narayan and Tidström (2020)	Koscina et al. (2019)	ERCIM (2017)	Marchesoni (2019)
Phung (2019)	Kouhizadeh and Sarkis (2018)	Gillick (2018)	Moore (2019)
Shojaei (2019)	Limata (2019)	Kemp (2020)	Poole (2020)
Wu et al. (2017)	Oude Weernink et al. (2017)	Layton et al. (2018)	Teo (2018)
Wu et al. (2019)	Pardo (2018)	OECD (2019)	Usody (2020)
	Poberezhna (2018)	Patel (2019)	Vorobiova (2020)
	Ramadoss et al. (2018)	PwC (2019b)	
	Rudolphi (2018)	Sandner (2018)	
	Rusinek et al. (2018)	Water Saver (2019)	
	Sankaran (2020)		
	Tate et al. (2019)		
	Volgel et al. (2019)		
	Zhu and Kouhizadeh (2019)		

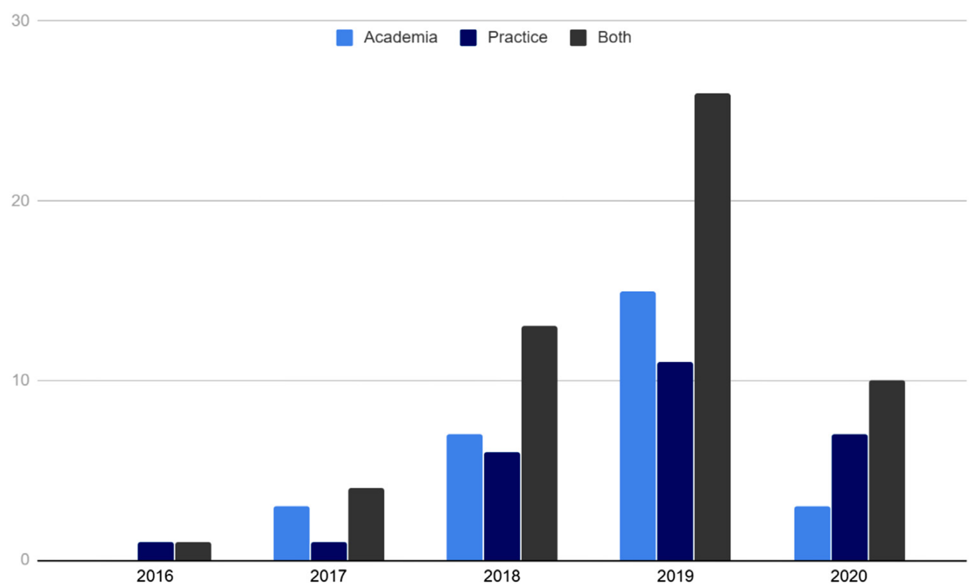

Fig. 2. Research and practice items in the sample over time (N=57) (2020 results were included for the first quarter).

data sources, all opinion papers and press releases stem from practice data sources. Of the academic items, a high share was conference presentations, indicating an early stage of research. The methods employed equally indicate a nascent research domain. Conceptual approaches accounted for 42 % of methods, empirical qualitative approaches (including case studies and interviews) accounted for 23 % of methods, with one paper employing a quantitative survey. A third of all items had no identifiable approach and announced or described developments in practice, or were opinion papers without a clear conceptual framework. All but one of the items following no clear methodology came from practice, while about 80% of items with an empirical and conceptual foundation originated from academic data sources.

In order to understand the diversity of the sources used, the traditional overlap was calculated (Gluck, 1990; see Table 5). The overlap between research and practice data stem from the integration of academic papers on the search engine Google or academics sharing academic articles via Twitter. Likewise, some reports that stem from practice were also listed on Google Scholar. In the table, a higher value indicates a higher level of similarity.

The results indicated that there was a medium or low overlap between Scopus and Google Scholar (18.6 %), while the overlap within Google and Twitter is minimal (3.4 %). Only 6.9 % of items overlapped between research and practice, indicating different discussion foci.

3.2. Category selection

The process of category selection and material evaluation followed the suggested steps by Merli et al. (2018) in order to be able to answer the research question by starting with a selection of six structural dimensions based on the reviewed literature: technical properties, contexts, use cases, benefits, challenges, and R-strategies. The structural dimensions of Merli et al. (2018) are not adopted as they do not fit to the interface of blockchain and circular economy. No complete framework could be identified that provided exhaustive and distinct categories for the analysis of blockchain for the circular economy related to research and practice items. Therefore, single categories were identified (see Table 6 and Table A5 in the supplementary material for a complete and

Table 5
Diversity of sources before application of exclusion criteria.

Diversity and overlap scores	Calculations	Results
Traditional overlap within research data sources	(Scopus ∩ Google Scholar)/ (Scopus ∪ Google Scholar) * 100 = (13/70) * 100	18.6 %
Traditional overlap within practice data sources	(Google ∩ Twitter)/ (Google ∪ Twitter) * 100 = (3/89) * 100	3.4 %
Traditional overlap between research and practice data sources	(research ∩ practice)/ (research ∪ practice) * 100) = (11/159) * 100	6.9 %

∪ = number of elements present in either of the sets A or B; ∩ = number of elements present in both the sets A and B; research = Scopus and Google Scholar; practice = Google and Twitter; the denominator is based on the identified results in Fig. 1 minus 11 tweets without links or websites.

Table 6
Overview of structural dimensions and analytical categories.

Structural dimensions	Analytical coding categories ordered by frequency
Technical properties	1) permissions and data rights, 2) technical properties of specific use case, 3) combination with other technologies, 4) data processing, 5) brief information about blockchain type
Contexts	1) supply chain, 2) logistics, 3) plastics, 4) construction, 5) manufacturing, 6) waste management, 7) audit, certificates, 8) various, 9) agriculture, food, 10) smart cities, 11) mining, metals, 12) sharing economy, 13) small, medium companies, 14) electronics, 15) retail, 16) green marketing, 17) accounting, 18) life cycle analysis, 19) government, 20) energy, 21) clothing
Use Case	1) material passports, 2) smart contracts, 3) asset tracking, 4) incentivization, 5) cryptocurrency, 6) product deletion, 7) token, 8) credit rating, 9) trust mechanisms, 10) distributed ledger, 11) leasing, 12) escrow
Benefits	1) traceability, 2) security and privacy, 3) multiple, 4) transparency, 5) immutability, 6) efficiency, 7) cost reduction/ profitability, 8) decentralization, 9) new business models, 10) trust/ verification, 11) streamlining/ automatization, 12) increased sustainability, 12) no intermediary, 13) other
Challenges	1) accessibility/ complexity, 2) energy use, 3) security/ privacy, 4) acceptance of the technology, 5) false initial information, 6) scalability, 7) reluctance of sharing information, 8) inefficiency, 9) lacking regulation, 10) lacking maturity of the technology, 11) high costs, 12) risk of centralization, 13) interoperability/ standardization, 14) other
R-Strategies	1) reduce, 2) reuse, 3) recycle, 4) recover

detailed overview of structural dimensions, coding categories and coding instances). Through the previewed theoretical literature, it was possible to capture the diverse dimensions of the discussion which contribute to answering the research question.

For each of the structural dimensions, analytical coding categories were developed, either deductively or inductively. Deductive categories were developed for the structural dimensions 'R-strategies', since predefined analytical categories exist to evaluate circular economy practices (Kirchherr et al., 2017). The structural dimensions 'benefits' and 'challenges' were discussed in previous studies (e.g. Hughes et al., 2019; Kouhizadeh and Sarkis, 2018), but did not provide complete or consistent analytical categories. Hence, the development of analytical categories for these two structural dimensions was inductive, following the content analysis approach by Mayring and Fenzl (2014) and Seuring and Müller (2008). Similarly, the structural dimensions 'technical properties', 'use cases', and 'contexts of blockchain' were examined in previous literature (e.g. Crosby et al., 2016; Jaoude and George Saade, 2019) without a transferable coding scheme. Hence, the analytical categories for these structural dimensions were identified inductively as well. Coding instances were reviewed in two rounds to cluster them according to similarities in content and summarized under different codes. Coding and pattern identification were performed by two researchers to minimize bias.

3.3. Results of material evaluation

In order to answer the research question – what are differences in research and practice regarding the use of blockchain for a circular economy – the thematic differences between research and practice items were analyzed in-depth for the six structural dimensions in this section.

3.3.1. Technical properties of blockchains

Technical properties were not widely discussed or even mentioned in practice, as only four items refer to specific technical characteristics whether the blockchain is open or closed and who has which permissions. In contrast, 16 research items mentioned 22 aspects concerned with technical properties, however often only briefly. Three exceptions were identified that go beyond superficial descriptions: Damianou et al. (2019), Kamilaris et al. (2019), and Wu et al. (2017) were the only research items that put technical properties in the center of their research. Damianou et al. (2019) focus on the technical architecture of the network and how they transfer the core ideas behind blockchain to an edge-computing concept. Wu et al. (2017) employ public key cryptography to enable a credit rating between business partners in the circular economy. Kamilaris et al. (2019) assess advantages and disadvantages of public and private blockchains for food chains. While Kouhizadeh et al. (2019a) do not address technical details; they give a detailed overview of how different applications are connected to their technical characteristics. Additionally, no clear distinction between the different levels of technology was executed in some items from research as well as practice, e.g. distributed ledger, blockchain, and smart contracts were mentioned interchangeably (e.g. Crosby et al., 2016; Casino et al., 2019).

3.3.2. Contexts

Nearly all of the items (52 of 57) discussed a specific context in which blockchain for a circular economy is applied. The analysis revealed 21 different contexts, of which half are mentioned in both research and practice items. These contexts range from manufacturing to supply chain management, from certification schemes to the sharing economy, from specific industries (plastics, electronics, food, energy, logistics, and mining) to the governmental sector. Of the 95 coding instances, nearly two thirds of codes were applied in research. Ten of the coding instances originated from one academic paper discussing different application contexts (i.e. Kouhizadeh and Sarkis, 2018).

The most frequently mentioned context in both research (12 coding instances) and practice (8 coding instances) was *supply chain management*, in particular tracking sustainable supply chains and supplier development (Kouhizadeh and Sarkis, 2018). Tracking materials via blockchain was a core theme here (e.g. Circle Economy, 2018), but the complex information sharing needs to address complex supply networks are addressed in more detail in research (Kouhizadeh et al., 2019b). The *plastics sector* was mentioned frequently in both research and practice. In practice, pilot projects and startups were announced (PwC, 2019b; Clancy, 2020) while in academia, a recycled plastics economy and collection systems as well as implications for job skills were discussed (Kamilaris et al., 2019; Koscina et al., 2019; Phung, 2019). Eight of the contexts only appeared in research, for example, tracking and rewarding sustainable driving behavior of truckers (Kouhizadeh and Sarkis, 2018) and port logistics (Oude Weernink et al., 2017). There were also two master theses that specifically focus on the construction industry (Rudolphi, 2018; Bolier, 2019). Ensuring valid environmental audits and certification schemes is addressed in two academic papers (Alexandris et al., 2018; Kouhizadeh and Sarkis, 2018). Three of the contexts solely appeared in practice items: energy, government, and clothing sector.

3.3.3. Use cases

The majority of items (40 of 57) discussed a specific use case for which blockchain for a circular economy has been applied. In many of the analyzed items, both context and use case were jointly discussed, e.g. the use of smart contracts (use case) in supply chains (context). The analysis revealed 12 different use cases, of which seven are mentioned in both research and practice items. These use cases covered material passports, asset tracking, tokens, behavioral incentives, smart contracts, and trust mechanisms, among others. Of the 98 coding instances, nearly 70 % of codes were applied in research and less than one third in practice. 28 of the coding instances stemmed from three academic papers from one group of authors where different use cases (and contexts) were discussed (Kouhizadeh et al., 2019a; Kouhizadeh et al., 2019b; Kouhizadeh and Sarkis, 2018).

The most frequently mentioned use case in both research (20 coding instances) and practice (10 coding instances) were *material passports*, in particular how blockchain technology can enable tracking product-related information throughout the lifecycle and thus enabling later reuse and recycling (e.g. Rudolphi, 2018; Tate et al., 2019). In research, it was discussed how this information does not need to be exclusively related to physical characteristics of materials but can also relate to non-physical ones, such as the integrity and safety of foods (e.g. Kouhizadeh et al., 2019a), the value of waste (e.g. Kouhizadeh et al., 2019b), and the related soil conditions of agricultural products (e.g. Kamilaris et al., 2019). The use cases mentioned with second frequency are *smart contracts*, with 17 coding instances in research and 5 in practice. The practice items in the majority included brief mentions and explanations of smart contracts (e.g. Sandner, 2018; Water Saver, 2019). In parallel, academic items provided specific use cases for smart contracts, including credit rating mechanisms (Wu et al., 2019), audit systems (Alexandris et al., 2018), building information models (Shojaei, 2019), and supply chains (Zhu and Kouhizadeh, 2019). Furthermore, the role of smart contracts in increasing efficiency and traceability of information was discussed (Kouhizadeh et al., 2019b; Rusinek et al., 2018). The use of *tokens* was the sole use case discussed more strongly in practice (6 coding instances) than in research (3 coding instances). In research, one journal article highlighted the role of tokens for addressing coopetition (Narayan and Tidström, 2020), as well as several papers using tokens for *incentivization* (e.g. Kouhizadeh et al., 2019a; 2019b; Kouhizadeh and Sarkis, 2018). In practice, several pilot projects have already put in place using tokens for incentivization, in particular for collecting plastic waste (PwC, 2019b; Climate KIC, 2019).

3.3.4. Benefits

The benefits of blockchain technology for the circular economy were dominant in research as well as in practice (91 coding instances in practice and 130 in research). The most mentioned benefits both in research and practice were traceability and transparency. Especially the ability of storing and providing access to certain information along a process seems to be helpful for supply chain management in a circular economy (e.g. Kouhizadeh et al., 2019a; Shojaei, 2019). Likewise, transparency can increase the communication with actors of the supply chain and with the consumer (e.g. Carbone et al., 2018; Poole, 2020). Security and privacy were not equally dominant in both fields since they were mentioned in 60 % of the research items, while only 11 % of the practice sources covered these subjects. Through the immutability of the data stored on the blockchain the members of the network can be sure that the information is still the same to when it was verified from the network with the proof of work protocol (e.g. Kouhizadeh et al., 2019a; Wu et al., 2019). Trust and verification were far more frequently mentioned in practice (11 from 27 items debated this benefit), whereas in research five out of 30 sources discussed it.

Concerning the potential of blockchain for sustainability, different benefits were mentioned in research but not in practice. These are the changing awareness of the consumer for the environmental and social impact of a product (Volgel et al., 2019), increasing use of recycled plastic (Sankaran, 2020), waste reduction (Carbone et al., 2018), or the incentivization of sustainable behavior via cryptocurrencies (Dapp, 2019). The opportunities for new and sustainable business models through blockchain in the circular economy were reflected upon solely in practice (Sandner, 2018).

3.3.5. Challenges

More challenges were mentioned in research (72 coding instances) than in practice (39). In research, the most addressed challenge in one third of all items was how users and companies lack a technical understanding of blockchain in order to make it exploitable for the circular economy (e.g. Dapp, 2019; Kamilaris et al., 2019). Accessibility and complexity were both the least named challenges in practice. Similarly, security and privacy issues connected to blockchain use in circular economy contexts were highly debated in research (27 % of the research items named them), whereas only one practice item each covered risks as cyber-attacks (Kouhizadeh et al., 2019a), user privacy (Kamilaris et al., 2019), or theft or private keys (Achterberg, 2019). Also, 30 % of the research items evaluated the needed amount of energy for running a blockchain application, whereby four of 27 practice items (15 %) argued that “blockchains are inefficient in terms of energy consumption” (Bauwens and Pazaitis, 2019, p. 57). The only challenge that was debated more in practice than in research, and was also the most addressed challenge in practice, was the problem of false information being entered in the blockchain and, thus, the necessity for a validation and certification process outside of the blockchain (e.g. Circle Economy, 2018; Climate KIC, 2019).

3.3.6. R-strategies for a circular economy

Overall, nearly all data sample items (50 of 57) addressed specific R-strategies to achieve a circular economy. Of the overall 107 coding instances, 65 % occurred in research items and 35 % occurred in practice items. Nearly half of the codes were applied for reuse strategies, followed by a third for recycling strategies, and a fifth for reducing strategies. Less than 5 % of coding instances address recovering strategies. While some items focus on one of the R-strategies, in particular on reusing or recycling, many items cover multiple R-strategies. While recovering and recycling strategies were equally frequently addressed in research and practice items, there was a stronger focus on reusing and reduction strategies in research compared to practice.

Within the *reuse strategies*, practice items covered the increased use of materials through multiple life cycles as well as tracking these materials (e.g. Arup, 2019; Clancy, 2020). In contrast to the discussion in practice, the discussion in research was more nuanced. Several items mentioned repair and remanufacturing strategies (e.g. Andrews et al., 2017), as well as leasing precious metals as raw materials (Hagan et al., 2019). Three items also discuss the RESOLVE framework as an alternative framework (e.g. Kouhizadeh et al., 2019b; Alexandris et al., 2018). Furthermore, the academic discussion debated the requirements for new value chains and second hand markets (e.g. Kouhizadeh et al., 2019b; Wu et al., 2017) and mentioned a need for reverse logistics and other return processes. Only within this last context – reverse logistics – blockchain technologies were directly mentioned. Kamilaris et al. (2019) described examples of plastic collection with blockchain-based incentives. Kouhizadeh et al. (2019b) mentioned the information needs to be addressed via blockchain for secondary materials. Within *reduction strategies*, the practical discussion was very limited and covered avoiding waste (e.g. Kemp, 2020), in particular food waste and saving water. While avoiding food waste was also discussed in research, there were several items that mention sharing as a possible reduction strategy (e.g. Kouhizadeh et al., 2019b; Wu et al., 2019). In this context, blockchain technology was referred to as an important mechanism to establish trust (Wu et al., 2019). The practice discussion on *recycling* was held in the context of waste management strategies, but also mentioned a need for markets for recycled materials (Moore, 2019) and deposit systems (Usody, 2020). Two sources named tracking and information requirements (Circle Economy, 2018; Arup, 2019). The latter ones were also included in the academic discussion (Bolier, 2019). However, the academic discussion covered the values of waste (e.g. Carbone et al., 2018) and three publications specifically focused on plastic recycling (e.g. Chidepatil et al., 2020). *Recovering* strategies were mentioned in passing in research and practice items. The most insight was found in Kouhizadeh et al. (2019b), where recovering was described as the least preferable option.

3.3.7. Additional findings

Some articles stood out in regard to depth of analysis or concerning conceptualization: putting the focus on the intersection of blockchain and circular economy and not only mentioning the possible connection. Questions explored in-depth were how a platform called Circularise might support the circular economy in the built environment (Bolier, 2019) and how a material passport based on a blockchain can lead to a transition towards the circular economy (Rudolphi, 2018). More recently, Achterberg (2019) examined a circular service platform based on a blockchain and Kouhizadeh and Sarkis (2018) provided an extensive list of examples how blockchain can be applied in sustainable supply chain management. Kouhizadeh et al. (2019a) developed a framework on how to conceptualize the connection between the technology and economic and resource systems. Bauwens and Pazaitis (2019) published a joint report by several foundations on post-blockchain applications, challenging the current economic rules by focusing on blockchain for the common good. Several perspectives from Twitter users were included in a web page of the Circle Economy (2018), where a discussion about advantages and disadvantages of blockchain for the circular economy was presented.

With regards to addressing sustainability related questions, none of the publications had an exclusive focus on sustainability. Research items, however, provided more details on the connection between blockchain technology, circular economy, and sustainability than practice items. In particular, three publications addressed sustainability in detail: for social sustainability in precious metal mining and circularity (Hagan et al., 2019), tensions and critique of practice (Kouhizadeh et al., 2019a), and implications of circularity on jobs in the plastics sector (Phung, 2019).

4. Discussion

The previous section highlighted where the academic and the practice debates regarding blockchain technology and circular economy differ for structural dimensions. The differences between research and practice items were indicated by the variety of publication types and (research) methods used, as well as the only minor overlap between research and practice databases. While the sample was dominated by research items in earlier years, from 2020 there were more practice items in the sample. While the number of items from research versus practice databases was comparable, the number of coding instances in academic items was higher. This indicates a more detailed and nuanced discussion, in particular for technical properties, context, and use cases. Table 7 provides an overview of the identified research-practice gaps.

The aspects that were both covered in research and practice (field 1 in Table 7) were the contexts of supply chain management and plastics, the common use cases of smart contracts and material passports, and the benefits of traceability and transparency to overcome information asymmetries (PwC, 2019a). This is not surprising as these aspects were the starting point of the debate (e.g. EMF, 2015). A possible goal for research and practice could be to scale up the use cases in these contexts and, therefore, enable the streamlining of implementation processes.

Open questions in research (field 2) center on trust. The question of how to provide the data that is entered into a material passport or a smart contract was asked in practice and, particularly, how correctness of entered information could be guaranteed. As soon as a certification process depends on humans, the advantage of automatized information processing is nullified. Further, there is no extensive research in the context of energy, or on how governments may implement blockchain to steer a circular economy, e.g. by setting up a mandatory material passport for solar panel production.

In practice (field 3), a clear distinction between nested concepts, i.e. distributed ledger, blockchain, or smart contracts, and their associated benefits is missing. This distinction is, however, essential to enhance the understanding of blockchain technology in practice - a challenge that is visible already (e.g. Kouhizadeh and Sarkis, 2018; Hughes et al., 2019) but, not yet, discussed in the academic literature. Nevertheless, this lack of distinction might limit applications of blockchain technologies. Furthermore, experimentation with blockchain technology might be possible in additional contexts, for example logistics, construction, and certification schemes; however, this was not yet observable in practice. The discussion of reusing and reduction strategies has a much stronger focus in research compared to practice, which might lead to additional areas for exploration in practice. Most importantly, a critical self-evaluation of the possible drawbacks and unintended consequences of a wider application of blockchain technology, i.e. high energy use, is currently lacking. In order for blockchain developers and supporters to maintain their license to operate and social legitimacy (e.g. Gunningham et al., 2004; Powell and DiMaggio, 2008), we argue that critical dialogue led by industry is essential. In particular, the questions of security and privacy, both as a benefit and a challenge, are in need of further discussion.

In both research and practice (field 4), the technical properties of the blockchains discussed were not clearly indicated. Especially in research, one might assume that the technical characteristics are essential to assess challenges, potentials and use cases, e.g. a private blockchain is not suitable for contexts in which accessibility for the public is required. The types of blockchain examined, however, were not clearly described. For example, different use cases were presented without clarifying what types of blockchains are required for each of the use cases (e.g. Volgel et al., 2019). Likewise, low-tech approaches, such as simpler databases, are sparsely considered and the environmental downsides (e.g. high energy use, low accessibility) are not discussed. Consequently, solely general statements regarding the potential of blockchain for a circular and sustainable economy are currently made and more

Table 7
Overview of research-practice gaps.

	Addressed in research	Not addressed in research
Addressed in practice	**1. Focus in research and practice** ➔ Supply chain management and plastics as context ➔ Smart contracts and material passports as use cases ➔ Traceability and transparency as main benefits	**2. Inspiration for research** ➔ How can trust and verification benefits be achieved? Can a technology as blockchain enable trust if there is none in the social system? ➔ To what degree is false data entry a challenge? How can it be overcome? ➔ Blockchain applications in the context of the energy, government, and clothing sector
Not addressed in practice	**3. Opportunities for practice** ➔ Clear distinction between nested concepts needs to be made (distributed ledger, blockchain, smart contracts) ➔ Experimentation with blockchain in the contexts of logistics, construction, and certification schemes, among others ➔ Critical self-evaluation of blockchain developers and supporters with possible downsides, e.g. high energy use ➔ Security and privacy as a benefit and challenge	**4. Blind spots** ➔ Specification of blockchain typology in the discussion (e.g. public, private, decentralized, centralized) ➔ Systematic assessment of technical properties, use cases and contexts and the resulting benefits ➔ Challenge of understandability and accessibility is underexplored ➔ Implications of blockchain applications in the circular economy regarding sustainability, in particular social sustainability ➔ Disruptive potential of blockchain technology

systematic approaches (e.g. life-cycle-assessments or environmental impact assessments) are absent. This echoes Kouhizadeh and Sarkis (2018) who assert that "moving beyond the hype and hope is necessary for rational determination of effectiveness" (p. 14).

Further, a systematic assessment of advantages and disadvantages of blockchain for a circular economy is lacking for different use cases and contexts. The techno-positive perspective on blockchain as proposed by Swan (2015) was found in a majority of both research and practice items and the potential was often stated without weighing up negative aspects. Researchers as Swartz (2017) even call the promises of blockchain for a better future "dreams" (p. 83) and criticize the techno-fix approach. The impression of blockchain as a simple solution to a lot of problems is, thus, supported by the focus on the solution rather than the problem. Phrases such as "this practice is quite suitable for blockchain technology" (Kouhizadeh and Sarkis, 2018, p. 3661) illustrate that, not necessarily, the solution to a problem is placed at the center of an inquiry. Rather, the focus is on the range of possibilities in which the blockchain could be applied. Critiquing the lack of problem focus, O'Dwyer (2015) argues that "there is real potential in the blockchain if we appreciate it not as some ultimate techno-fix but as a platform that, when combined with social and political institutions, has real possibilities for the future of organisation" (p. 1).

Finally, meaningful discussion of the possible contribution from blockchain to the circular economy with regards to the three dimensions (i.e. social, environmental, economic) of sustainable development is lacking. The focus on economic prosperity in the circular economy and blockchain literature mirrors previous results from reviews of circular economy literature (e.g. Kirchherr et al., 2017). The missing focus on social potential, as well as justice and equality perspectives can lead to reproducing existing inequalities (Stahel, 2016; Murray et al., 2017). Furthermore, such an absence of social dimensions, also including institutions, legislation, and culture, can be seen as a major challenge for achieving a circular economy (Homrich et al., 2018).

The research methodology entails some limitations. Including research and practice sources leads to a data set from two distinct spheres of communication, each with its own rules and incentives. For example, in science, self-referencing tendencies are known (e.g. Nicolai and Seidl, 2010). Khelfaoui et al. (2020) found strong patterns in referencing papers from the same country as the authors themselves, leading to possible skews in the data set. This phenomenon has not been discussed for practice sources; however, other factors might skew the practice items. For example, commercial interests might be stronger forces for publications in practice. There might be differences in terminology between research and practice items as well, leading to differences in data selection and analysis. Kelemen and Bansal (2002) described how academic knowledge is not always translated to a practitioner-oriented language, indicating differences between the two spheres. Beyond differences in the data production and the language, practitioners and scientists might have different interpretations of the same concepts (Kirchherr et al., 2017). Hence, while research and practice items might use the same terminology, they might invoke different meanings to them. For instance, the excluded item by Mougayar (2016) spoke of a circular economy as one where work and pay flows stay within a single community and did not address circular material flows.

While the data set allowed for a detailed and sufficient analysis to address the research question, the data set is limited in scope and quantity. This is to be expected since the topical field is still emerging. Similarly, Homrich et al. (2018) found that the circular economy literature is still in an exploratory phase. Despite such an early stage, this research was able to use a systematic literature review to identify patterns in the data as suggested for nascent research fields (Edmondson and McManus, 2007). Furthermore, additional categories, such as the resource states as suggested by Blomsma and Tennant (2020), could have provided additional insight.

Finally, the methodological approach is scientific and was performed by scientists. Practitioners could have been integrated into the research process. Methods for such integration exist and range from conducting expert interviews or participatory observation, holding a review panel of academic literature with practitioners (proposed by Jansen, 2018), or transdisciplinary approaches (e.g. Lang et al., 2012). Further participatory or transdisciplinary research could address this limitation.

5. Conclusions

Blockchain for the circular economy is nascent in both research and practice. By identifying research-practice gaps via a systematic literature analysis, several areas for further research and application in practice have been identified. In particular, a closer linking of possible benefits and challenges of blockchain technologies for the circular economy to sustainable development will be crucial.

The 'Inspiration for research' and 'Blind Spots' were identified. With regards to learnings from practice as inspiration for research, future research will benefit from in-depth qualitative studies, e.g. how certification processes of information that are to be entered in a blockchain are handled. The promise of gained trust between the network participants will profit from questioning from sociological, cultural, and psychological perspectives: the question remains how a technology might be able to create trust, if there is a lack of trust in the first place. To address the blind spots, transparent and clear information about the used or analyzed types of blockchain must be provided. This could, for example, mean developing a framework for a status-quo analysis of all contexts and existing use cases with regards to the specific blockchain types and technical properties. Moreover, the challenge of how to set up a blockchain as a business and lowering the use barrier of the technology has to be explored.

Our analysis revealed a range of aspects that are essential in the context of sustainable development. The question remains, how and how far blockchain can accelerate the change towards a circular economy and how sustainable a blockchain-based circular economy might be. Blockchain can only overcome parts of the challenges that the circular economy faces, in particular addressing information asymmetries by providing uniform information to all participants of a given network. Other technological advances, such as the Internet of Things, sensors, and artificial intelligence can play a role in a transition to a circular economy and must be considered as context. Likewise, behavioral and systematic changes are required, e.g. rethinking consumption behaviors and business model development.

The disruptive nature of blockchain has not been proven, yet theoretical and conceptual discussions argue for the disruptive potential of the technology. Projections and scenarios, whether blockchain will be broadly adapted in the context of the circular economy, remain questionable and, consequently, so does the disruptive potential for a sustainability transition. Moreover, in order to increase the positive contribution of blockchain for sustainable development, a determination of effectiveness should go beyond the application suitability in a given context and evaluate the contribution to sustainable development. Future research will, therefore, benefit from going beyond addressing isolated aspects of sustainable development questions and apply a systematic and holistic approach.

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Supplementary materials

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