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The future of the circular economy and its effect on supply chain dependencies: Empirical evidence from a Delphi study

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ABSTRACT

This paper conducts a Delphi study to empirically explore the future roadmap of the circular economy (CE). Moreover, we build on the resource dependence theory to explore the CE's potential to reduce dependencies in supply chain (SC) networks. Based on current literature, the CE practices of the 4R framework (reduce, reuse, recycle, recover), and a series of workshops, we formulated 11 future-oriented projections. In two subsequent Delphi rounds, 78 international CE and SC management experts quantitatively assessed the projections regarding their probability of occurrence in 2030, their potential to reduce SC dependencies, and their desirability. A fuzzy c-means algorithm was applied to cluster the projections based on the expert assessments. We found that the implementation likelihood of CE practices in 2030 is not congruent with the value retention hierarchy advocated by the 4R framework. Qualitative analyses of the panelists' written statements revealed that regulation, financial attractiveness, customer demand, technological innovation, and product design are the most prominent influencing factors for the future implementation of various CE practices. Moreover, different practices revealed a varying capacity to reduce SC dependencies. More precisely, we found that diversifying a company's supply base through recycled materials and components has the highest potential. Our qualitative data further provides evidence that CE practices' capacity to lift dependencies can become an enabler for SC resilience.

1. Introduction

Supply chain (SC) managers are currently living through challenging times. The COVID-19 pandemic propagated disruptions across SCs and negatively affected organizations' performance (Ivanov, 2020; Chowdhury et al., 2021). The crisis exposed vulnerabilities of ever-more-complex SCs, particularly for firms that heavily depend on (often unknown) networks of overseas suppliers (Ellen MacArthur Foundation, 2020; Gölgeci et al., 2020; Ivanov, 2020). Moreover, the climate crisis poses increasingly salient risks to operations globally (Ghadge et al., 2020).

Researchers and practitioners pointed out that the current economic model exacerbates those risks and their implication on SC performance (Ivanov and Dolgui, 2020). In this context, Wieland and Durach (2021) argued that an economic model relying on eternal material growth and non-renewable resources will likely lack the capabilities to cope with future disruptions. Calls have been made to rethink the current economic model and 'build back better' after the COVID-19 pandemic (Ivanov and Dolgui, 2020; Sarkis et al., 2020; Ibn-Mohammed et al., 2021).

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In this context, the transition from the current ‘take-make-dispose’ model towards a circular economy (CE) is increasingly considered as a promising system change towards environmental sustainability as well as shorter, more local, and more robust SCs (Ellen MacArthur Foundation, 2020; Ivanov and Dolgui, 2020; Sarkis et al., 2020; Wuyts et al., 2020; Ibn-Mohammed et al., 2021). The CE is restorative and regenerative by design, puts end-of-life products to new uses across different value streams, and ultimately aims to design waste-free SCs (Geissdoerfer et al., 2017; Farooque et al., 2019). Efforts to transform towards a CE are gaining considerable traction (de Angelis et al., 2018; Prieto-Sandoval et al., 2018; Stewart and Niero, 2018). Some anecdotal examples of the COVID-19 crisis show that CE practices can help to cope with critical SC dependencies. Industrial companies introduced recycling practices to manage continuous material and component shortages from global SCs (Nandi et al., 2020). In the healthcare SC, medical professionals systematically refurbished decommissioned medical equipment to cope with supply shortages and spiking demands (Wuyts et al., 2020). Meanwhile, governments worldwide are positioning the CE as a central paradigm for the aspired transitions of their economies and SCs (Zhu et al., 2019; Mhatre et al., 2021). For instance, the European Union designed part of its EUR 750 billion COVID-19 recovery plan (‘NextGenerationEU’) to support a transformation towards more circularity (European Commission, 2020). It particularly aims at decreasing Europe’s dependence on foreign materials by reducing waste and encouraging the use of secondary raw materials (European Commission, 2020).

To assess the CE’s future potential to reduce dependencies, several gaps in understanding the concept and its likelihood of adoption remain. Even though the CE’s goals are clear enough, there is still high uncertainty regarding its future roadmap (Stewart and Niero, 2018; de Jesus et al., 2019). The current implementation baseline is low, as only ∼ 9% of the global economy is circular (Circle Economy, 2020). While a Gartner survey at the beginning of 2020 revealed that 70% of SC leaders plan CE investments (Gartner, 2020b), research on CE implementation remains fragmented and there is continued uncertainty whether, how, and when more SCs will transition towards circularity (Korhonen et al., 2018; de Jesus et al., 2019). Investigating which of the many CE practices (Reike et al., 2018) are most likely to be implemented in the future allows closing this gap. To establish this baseline, consistent with the 2030 time horizon of many political CE agendas, we formulated our first research question (RQ):

RQ1: Which circular economy practices are most likely to be adopted by 2030?

Before the increasing dynamics around the CE transition, SCs have gone through other paradigmatic changes. For instance, the rise of information and communication technologies and the globalization of trade have considerably altered dependence structures (Davis and Adam Cobb, 2010). Offering an established perspective to explore such interorganizational relationships, the Resource Dependence Theory (RDT) postulates that firms aim to reduce dependencies to ensure organizational survival (Pfeffer and Salancik, 1978; Davis and Adam Cobb, 2010). High dependencies on resources controlled by exchange partners can considerably lower an SC actor’s ability to respond to extreme supply and demand shifts and negatively impact SC performance (Pfeffer and Salancik, 1978; Wagner and Bode, 2006). As the frequency and magnitude of demand and supply shocks have increased in the last decade, it will be critical that a sustainable SC transformation addresses the rising risks induced through such dependencies (Lechler et al., 2019; Al-Balushi and Durugbo, 2020; Craighead et al., 2020). While many studies point towards the considerable environmental and economic benefits of circularity (Sarkis et al., 2020; Werning and Spinler, 2020), it remains unclear if a CE transition can mitigate the perils of highly interdependent SCs.

It is obvious that moving from linear to circular supply chains (CSCs) will fundamentally change SC relationships and the different CE practices will have varying effects on SC setups and interdependencies (de Angelis et al., 2018). Several previous studies theorize that CE models can decrease dependence on customers and suppliers through diversification and integration (Bauer et al., 2017; Gaustad et al., 2018; Bag et al., 2019). However, some scholars argued that CSC structures can also introduce new dependencies on partners for recollection systems or product end-of-life treatment (de Angelis et al., 2018). None of those studies empirically explored nor validated those claims. Hence, it has not been conclusively examined whether a transition towards a CSC can effectively reduce resource dependencies for various stakeholders in an SC. Therefore, we formulate our second RQ:

RQ2: To what extend can CE practices reduce supply chain dependencies?

Since the CE’s future development is highly uncertain and existing empirical data is scarce, we applied the Delphi method for addressing the RQs (Webler et al., 1991; Korhonen et al., 2018; Finn et al., 2020). The Delphi technique has already been leveraged in the CE literature (e.g., de Jesus et al. (2019), Finn et al. (2020)). Chowdhury et al. (2021) advocated it as an appropriate method to study the considerable SC reconfigurations expected in the aftermath of the COVID-19 pandemic. We developed 11 future projections on the transition towards the CE, subsequently evaluated by a diverse panel of 78 CE and supply chain management (SCM) experts. To address RQ1, the panelists assessed the projections’ likelihood of occurrence in 2030. To address RQ2, each projection’s potential to decrease dependence on suppliers and customers was assessed. Lastly, through a desirability rating, we examined whether the participants generally concur with the hierarchy of CE practices advocated in literature (Reike et al., 2018).

The remainder of this paper is structured as follows: First, we review related research on the CE, SC dependencies, and the RDT and derive the Delphi projections. Second, we describe the research methodology. Third, we present our quantitative and qualitative results, discuss them to answer our RQs, and derive implications for theory, practice, and policy-making. Lastly, we conclude our paper by pointing out limitations and proposing future research directions.

2. Theoretical background and projection development

2.1. The circular supply chain

The CE has traditionally been discussed as a means to achieve environmental sustainability by decoupling economic growth from the arbitrary consumption of resources (Lieder and Rashid, 2016; Geissdoerfer et al., 2017). Despite the lack of a literature consensus on the CE definition (Kirchherr et al., 2017; Korhonen et al., 2018; de Jesus et al., 2019), several common characteristics can be attributed to the concept. The CE represents a paradigm change towards a more sustainable economic system where resource input, waste, emission, and energy leakage are minimized by closing, narrowing, or slowing energy and material loops (Geissdoerfer et al., 2017; Korhonen et al., 2018). SCs are the basic unit of activity enabling circular flows whereby "circular supply chain management is the integration of circular thinking into the management of the SC and its surrounding industrial and natural ecosystems" (Farooque et al., 2019, p. 8).

The CE's future development remains uncertain and has received only limited attention in literature. Scholars have explored different scenarios and corresponding enablers of CE's potential development (de Jesus et al., 2019), discussed the CE's future implementation scope based on its current adoption in various sectors (Mhatre et al., 2021), or developed CE roadmaps for specific industries (Finn et al., 2020; Burgess et al., 2021). However, no study has taken a concrete foresight perspective and investigated the likelihood of different CE practices' adoption for a specific time horizon.

Practices to operationalize CSCs are commonly conceptualized in 'R' frameworks (Kirchherr et al., 2017; Reike et al., 2018). Different 'R' frameworks have been used in academia and practice, such as 3R (Ghisellini et al., 2016), 4R (Shivonen and Ritola, 2015; Henry et al., 2020), 6R (Yan and Feng, 2014), or even 9R (Potting et al., 2017). They all include a value retention hierarchy, where the 'R's' order reflects the priority in terms of environmental sustainability, aiming at retaining the maximum resource value at all times (Potting et al., 2017; Reike et al., 2018). Kirchherr et al. (2017) conducted a comprehensive literature review of CE definitions and concluded that the 4R framework (reduce, reuse, recycle, recover) best reflects the CE conceptualizations discussed by scholars. The 4Rs also incorporate the 'Rs' of the more nuanced frameworks as sub-dimensions (see Table 1). The 4R framework serves as a conceptual base for this study.

2.2. Resource dependence

Interconnectedness among economic actors has risen in the past (Gölgeci et al., 2020; Ivanov and Dolgui, 2020). To take the increased complexity into account, the perception of SCs has evolved. Christopher (2016, p. 3) defined the SC as "a network of connected and interdependent organizations mutually and co-operatively working together." Ivanov and Dolgui (2020) even suggested extending the concept of single interdependent SC networks towards multiple intertwined and mutually dependent supply networks.

The RDT offers an established frame for studying interorganizational relationships and their implications (Pfeffer, 1989; Gligor et al., 2019). The theory states that an organization's need for scarce, external resources creates dependence on exchange partners and thereby a potential source of adversity (Pfeffer and Salancik, 1978; Bode et al., 2011). The dependence construct draws on the concept of power applied to organizations' resource control (Schnittfeld and Busch, 2016). Thereby, an organization's control is never absolute and characterized by uncertainty, which leads firms to engage in interorganizational relationships with external actors (Pfeffer, 1989). The level of a focal firm's dependence is determined by the importance of the required resource and the substitutability of controlling suppliers or customers (Pfeffer and Salancik, 1978). Dependence is usually mutual, creating interdependence between actors (Davis and Adam Cobb, 2010). Thereby, dependence asymmetry describes how much more (or less) an organization depends on a particular business partner, hence creating power imbalance (Hillman et al., 2009). Increasing dependencies among globally dispersed business activities aggravate vulnerabilities as resource access becomes more uncertain (Gölgeci et al., 2020; Ivanov and Dolgui, 2020). To secure such resources and reduce uncertainty, organizations try to either minimize their dependence on external actors or increase others' dependence on them (Pfeffer and Salancik, 1978). Organizations can do so through governance mechanisms, such as contracts, joint planning, and incentivization, or more structural changes in their SC set up such as the diversification of supplier and customer bases or modifications in their product offering (Pfeffer and Salancik, 1978; Fink, 2006; Bode et al., 2011). Various empirical studies in different industries have shown that dependence-reducing practices can improve companies' risk management as well as innovation capability and ultimately enhance firm performance (Jean et al., 2012; Al-Balushi and Durugbo, 2020).

The shift to CSCs can undoubtedly alter the configuration and dependency structures within SC networks. It transforms buyer–supplier relationships, establishes new interorganizational links within and beyond industrial boundaries, and also partially severs traditionally linear connections (de Angelis et al., 2018; Ellen MacArthur Foundation, 2020). The degree to which focal companies depend on suppliers and customers, for instance for virgin materials, manufacturing capacities, or (recollection) logistics services, changes and thereby alters power balances (Potting et al., 2017; Gaustad et al., 2018). According to the RDT, such essential adaptations considerably affect a firm's risk exposure, vulnerability, and ultimately its performance (Bode et al., 2011; Nandi et al.,

Table 1
4R framework for this study's investigation. Adapted from Kirchherr et al. (2017).

4R practice	Description
Reduce	Refusing, rethinking, redesigning (including prolonging the lifespan of products), minimizing, reducing, preventing of resource use, and/or preserving of natural capital
Reuse	Reusing (excluding waste), closing the loop, cycling, repairing, repurposing, and/or refurbishing of resources
Recycle	Remanufacturing, recycling, closing the loop, cycling, and/or reuse of waste
Recover	Incineration of materials with energy recovery

2020). However, the cited studies address resource dependence in a CE context either as a side topic or they remain conceptual and miss to establish an empirical link between the CE and dependence (Bauer et al., 2017; Potting et al., 2017; Gaustad et al., 2018; Bag et al., 2019). Hence, the RDT offers an interesting perspective to explore the CE transition's effect on SC structures and its potential to address the previously described challenges from increased interconnectedness and complexity in global SCs.

2.3. Projection development along the 4R framework

In the following, we detailed the various 'R' practices along the 4R framework introduced in Section 2.1, discussed their potential to reduce SC dependencies, and introduced 11 future-oriented projections for evaluation in the Delphi study. The second column of Table 2 displays the formulated projections.

2.3.1. Reduce

The 4R framework's hierarchy starts with 'Reduce'. From a product perspective, 'Reduce' aims at waste prevention by simply using less (packaging) material per manufactured unit (Gaustad et al., 2018; Reike et al., 2018). Furthermore, products can be redesigned for longer lifetimes, decreased product exchange rates, and reduced resource consumption (Bakker et al., 2014; Shivonen and Ritola, 2015). From a consumer perspective, 'Reduce' practices aim to intensify resource utilization by designing product-service systems (i.e., sharing or leasing models whereby the producer retains product ownership at the end-of-life) (Beuren et al., 2013; Henry et al., 2020).

'Reduce' practices such as dematerialization approaches (product and packaging) can limit the need to procure raw materials, thereby decreasing dependencies from material suppliers (Gaustad et al., 2018). Prolonging product lifetimes reduces the rate of product exchange and thus reliance on material and component suppliers (Bakker et al., 2014; Kouhizadeh et al., 2019). Sharing or leasing models limit the number of products required to satisfy overall customer needs, further decreasing dependencies on suppliers (Potting et al., 2017; Gaustad et al., 2018). Moreover, such models can diversify the customer base by attracting new, environmentally conscious segments or consumers that cannot afford one-time purchases (Beuren et al., 2013).

Table 2
Delphi projections, underlying rationales, and literature foundation.

4R	Projections (2030)	Abbreviation	Decreasing dependence from	Sources
Reduce	**P.1:** Companies have significantly reduced overall material consumption for product manufacturing	Product materials	• (Raw) material suppliers	Gaustad et al. (2018), Reike et al. (2018)
	P.2: Companies have significantly reduced overall material consumption for product packaging	Packaging materials	• (Raw) material suppliers	Gaustad et al. (2018), Reike et al. (2018)
	P.3: Companies have significantly redesigned products for longer lifetimes	Redesign for lifetime	• (Raw) material/ component suppliers	Bakker et al. (2014), Shivonen and Ritola (2015), Kouhizadeh et al. (2019)
	P.4: Companies have significantly upscaled as-a-service business models (e.g., pooling, sharing, leasing)	Product-as-a-service	• (Raw) material/ component suppliers • Customers (diversification)	Henry et al. (2020), Gaustad et al. (2018), Beuren et al. (2013)
Reuse	**P.5:** Companies have significantly expanded their engagement in reselling/second-hand business for their products	Product resell	• (Raw) material/ component suppliers • Customers (diversification)	Bauer et al. (2017), Shivonen and Ritola (2015), Fernández and Kekäle (2005)
	P.6: Companies have significantly expanded repair operations for longer product lifetimes	Product repair	• (Raw) material/ component suppliers • Customers (lock-in)	Wuyts et al. (2020), Thierry et al. (1995), Fernández and Kekäle (2005)
	P.7: Companies have significantly expanded customers' options to upgrade/downgrade products instead of buying a completely new product	Product up-/ downgrade	• (Raw) material/ component suppliers • Customers (lock-in)	Bauer et al. (2017), Shivonen and Ritola (2015), Oghazi and Mostaghel (2018), Fernández and Kekäle (2005), Thierry et al. (1995)
	P.8: Companies have significantly increased repurposing activities for their products	Product repurposing	• Customers (diversification)	Potting et al. (2017), Bauer et al. (2017), Oghazi and Mostaghel (2018)
Recycle	**P.9:** Companies have significantly increased the share of remanufactured components in their products	Remanu-facturing	• Component suppliers • Customers (diversification)	Reike et al. (2018), Bag et al. (2019), Thierry et al. (1995)
	P.10: Companies have significantly increased the share of recycled materials in their products	Recycled raw materials	• (Raw) material suppliers • Customers (diversification)	Worrell and Reuter (2014), Field and Sroufe (2007), Thierry et al. (1995)
Recover	**P.11:** Companies have significantly increased utilization of by-products/waste for energy production (e.g., capturing energy in waste through incineration)	Energy recovery	• Energy utilities	Kirchherr et al. (2017), Potting et al. (2017), Tomić and Schneider (2018), Halkos and Petrou (2019)

2.3.2. Reuse

The second priority in the 4R framework concerns "checking, cleaning, or repairing recovery operations, by which products […] can be reused" (European Union, 2008, p. 10), whereby the products retain most of their resource value (Henry et al., 2020). This includes directly reusing a product 'as-is' as second-hand for the originally intended purpose (Shivonen and Ritola, 2015; Bauer et al., 2017). In case a product does not fulfill its full functionality any longer, repair activities aim to restore a product to working order (Thierry et al., 1995). Another 'Reuse' practice is to upgrade or downgrade a product (i.e. refurbish), thereby exchanging components

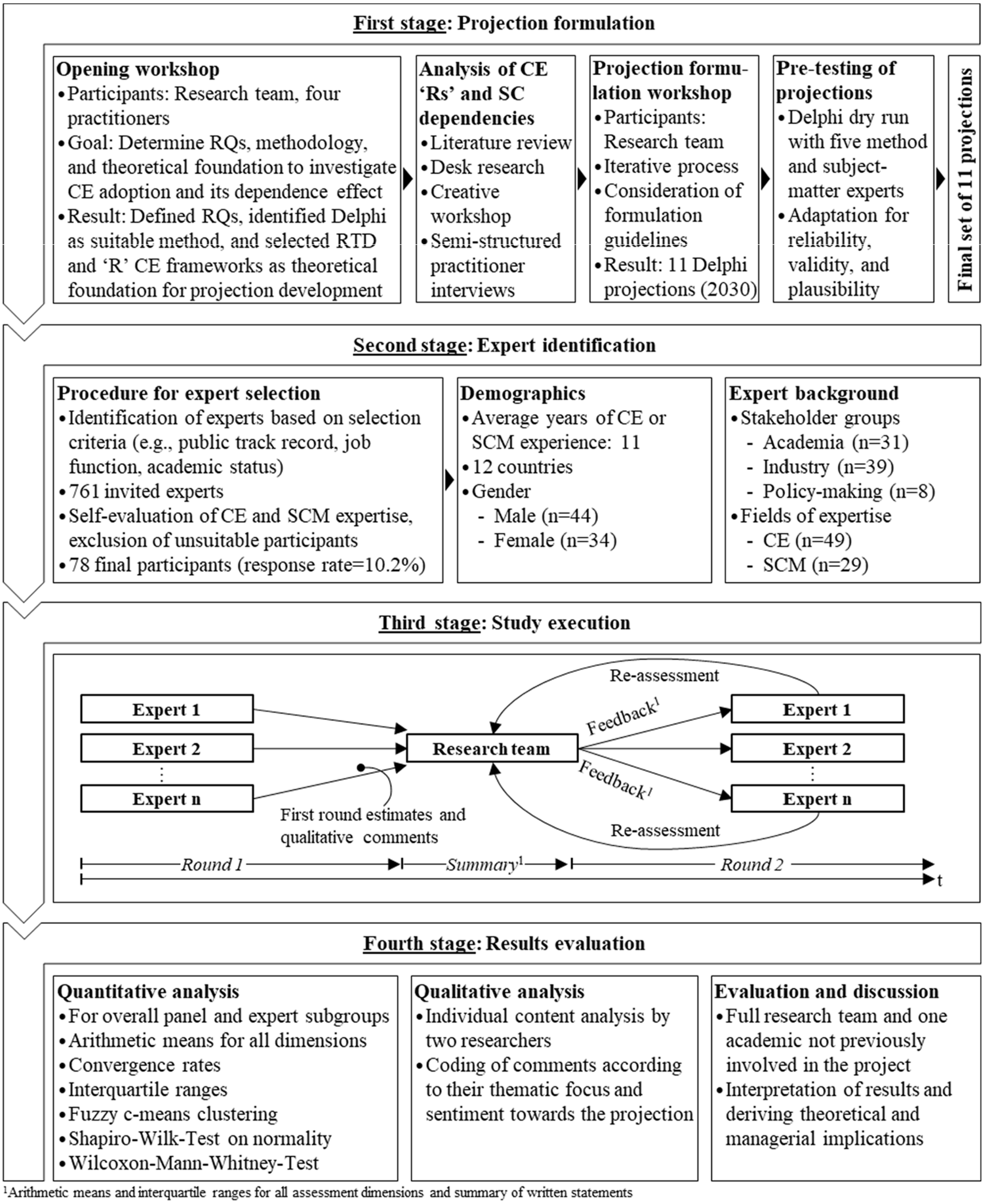

Fig. 1. Four-stage Delphi process, adapted from Gnatzy et al. (2011), Kopyto et al. (2020).

to alter its quality (Thierry et al., 1995; Fernández and Kekäle, 2005) and bring it "up to the state-of-art" (Shivonen and Ritola, 2015, p. 256). Finally, repurposing practices refer to using discarded products or components for a different use case (Potting et al., 2017).

Direct reuse and repair operations can slow down production loops by keeping product lifetime high, thereby reducing the need for production materials (Fernández and Kekäle, 2005; Bauer et al., 2017). Upgrades or downgrades through refurbishment can increase a product's utilization time, reduce exchange rates, and decrease the reliance on material and component suppliers (Thierry et al., 1995). Reparability and upgradability can increase customer dependence, as there is potential for additional monetization and consumer lock-in (Bauer et al., 2017; Oghazi and Mostaghel, 2018). Second-hand operations can address previously unserved segments and diversify the customer base (Fernández and Kekäle, 2005). Lastly, repurposing practices target entirely new markets and decrease dependence on existing customers (Bauer et al., 2017; Oghazi and Mostaghel, 2018).

2.3.3. Recycle

'Recycling' begins with resource streams after product usage and aims to keep components and materials in circulation loops as long as possible (Reike et al., 2018; Henry et al., 2020). Thereby, the structure of the original product is lost (Henry et al., 2020). 'Recycle' practices can be differentiated between recycling of materials and remanufacturing. The latter refers to completely disassembling a product and using some or all of its components to produce a new product with the same functionality (Reike et al., 2018). For material recycling, components of discarded products are further broken down, classified into distinct material categories, and reused to produce new parts (Thierry et al., 1995). Recycled materials have a broad application field and are also termed 'secondary materials' (Worrell and Reuter, 2014; Reike et al., 2018).

Particularly in the light of material shortages, secondary materials can be a promising lever to decrease dependence on virgin raw material providers (Thierry et al., 1995). Field and Sroufe (2007) showed that integrating recycled materials can increase a company's bargaining power towards raw material suppliers. Thierry et al. (1995) found that leveraging remanufactured components can decrease the reliance on component suppliers by reducing the required volume per supplier. On the sales side, recycled materials and remanufacturing can attract additional customer segments (Thierry et al., 1995; Bag et al., 2019).

2.3.4. Recover

The last 'R' practice refers to capturing energy embodied in waste, for instance, through incineration (Kirchherr et al., 2017; Halkos and Petrou, 2019). This practice has the lowest priority among the CE approaches, though it is still considered preferential compared to processing waste into landfills (Potting et al., 2017; Reike et al., 2018).

Tomić and Schneider (2018) and Halkos and Petrou (2019) showed that energy recovery could satisfy a considerable share of an industrial system's energy need, diversify energy supply, and decrease dependence on utilities. They specifically argued for the 'Recover'-practice's potential to reduce import dependence from international oil and gas providers.

3. Methodology

3.1. Delphi study characteristics

Delphi studies enable and structure the exchange of opinions and knowledge in a group of experts through a written, multi-stage survey process (von der Gracht, 2008; Darkow et al., 2015). We selected the Delphi method for three reasons. First, it is well-suited for investigating future scenarios (Linstone and Turoff, 1975). The research approach allows building on expert opinions, which is often the only feasible option for studying topics with limited data and high uncertainty (Webler et al., 1991; Rowe and Wright, 2001; Winkler et al., 2015). This characteristic is particularly important since the future development of CE practices reveals high levels of uncertainty (Finn et al., 2020). Second, this research approach guarantees anonymized group discussions (Rowe and Wright, 1999) and helps to prevent group inefficiencies, such as bandwagon, underdog, and halo effects (von der Gracht, 2008). This is particularly relevant for socially desirable research topics such as sustainability and CE (Roxas and Lindsay, 2012; Geissdoerfer et al., 2017), where panelists might feel pressured to award positive ratings when being identifiable (von der Gracht, 2012; Dodou and de Winter, 2014). Third, the Delphi method allows the inclusion of different parties affected by a future transition (Warth et al., 2013), which is of great importance in a CE setting since this topic has the potential to disrupt the society and the economy holistically (Geissdoerfer et al., 2017; Korhonen et al., 2018). The present Delphi study comprises four research stages (see Fig. 1).

3.2. First stage: Projection formulation

To ensure the value, validity, and reliability of our Delphi study, the future projections resulted from a systematic process (von der Gracht and Darkow, 2010).

The decision to conduct the research project and the determination of the RQs took place during an opening workshop. All participants agreed that an empirical and future-oriented research project at the intersection of the CE and SC dependencies is a promising research endeavor. Furthermore, on this occasion, the RDT and the 'R' CE frameworks were established as suitable theoretical foundations.

The second step comprised collecting and structuring factors influencing the relationship between the CE 'Rs' and resource dependencies in SCs (Gausemeier et al., 1998). We leveraged several data sources and triangulated findings to provide a holistic groundwork for the subsequent projection formulation (von der Gracht and Darkow, 2010). The research team reviewed the collected factors, excluded duplicates, and clustered the remaining factors along the different 'R' practices.

Based on this well-structured foundation, the research team conducted a full-day projection formulation workshop. On an iterative basis, Delphi projections were drafted, discussed, and revised. We carefully considered formulation guidelines (e.g., Salancik et al. (1971), Linstone and Turoff (1975)) since a projection's structure and wording can influence the experts' assessments (Jiang et al., 2017). The time horizon for the projections' occurrence was determined for the year 2030 for three reasons. Firstly, previous Delphi studies in SCM (e.g., Keller and von der Gracht (2014)) proved that a ten-year time horizon promotes essential characteristics of future-oriented research, including creative thinking and novel thoughts (Murphy, 1989). Secondly, the timeline matches many political CE agendas at national and supranational levels (e.g., the EU's '2030 CE Action Plan,' the United States Environmental Protection Agency's '2030 National Recycling Strategy'). Thirdly, practitioners confirmed that the timeline seemed suitable to assess the projections' future progress.

In the last step, we pre-tested the Delphi projections. We conducted a dry run with five experts, all of them academics or practitioners with deep methodological or subject-specific knowledge. As a result, we modified some of the projections to ensure their reliability, validity, and plausibility (von der Gracht and Darkow, 2010).

3.3. Second stage: Expert identification

The Delphi expert panel's composition is one of the most sensitive steps since it directly impacts the quality of findings (Spickermann et al., 2014). Diverse perspectives and deep professional expertise are guiding principles when identifying suitable experts (Rowe and Wright, 2001; Nguyen et al., 2019).

To reduce potential biases by allowing holistic perspectives (von der Gracht, 2012; Winkler and Moser, 2016), we invited topic experts from three distinct stakeholder groups: Industry, academia, and policy-making (Lechler et al., 2019; Kopyto et al., 2020). For assessing innovative topics leading to social and economic change, these three parties possess individual knowledge and interests (Etzkowitz, 2003; Warth et al., 2013). Moreover, opposed to earlier Delphi studies in the area of the CE (e.g., Prieto-Sandoval et al. (2018), de Jesus et al. (2019), Finn et al. (2020)), we did not limit our expert panel to CE professionals. Since "the integration of cross-functional and interdisciplinary subject matter experts increases the information processing capability of the panel as a whole" (Roßmann et al., 2018, p. 140), we also included experts from different SCM functions (e.g., procurement, operations), who experience material flows and SC dependencies in their daily work routines.

To account for participants' specialist knowledge on the CE and SCM, we only relied on experts with a public track record (see Appendix A) or approached further recommended experts (snowball system) (Rowe and Wright, 2011). Moreover, in line with recent Delphi studies (e.g., de Jesus et al. (2019), Kopyto et al. (2020)), we defined additional criteria (e.g., organization type, job function, academic status) to ensure an unbiased selection (von der Gracht, 2008). Apart from the research team's assessment of the experts' fit, we asked for self-evaluation (Rowe and Wright, 1996). Seven participants, who rated either their CE or SCM expertise on two individual 10-point Likert scales (from very low (1) to very high (10)) lower than 6 in the first round, were excluded from the second round. In this way, only panelists with a solid understanding of both disciplines contributed to the interdisciplinary research project.

Overall, 78 suitable experts from 12 countries (Australia, Austria, Belgium, Chile, China, Germany, Netherlands, Spain, Switzerland, UAE, UK, USA) completed both Delphi rounds. This represents a participation rate of 10.2% since 761 potential panelists were initially invited. The panel size and the participation rate exceed the ones of recent comparable web-based Delphi studies (e.g., Roßmann et al. (2018), Lechler et al. (2019)).

3.4. Third stage: Study execution

This research project comprised two consecutive Delphi rounds, which meets the method's requirements and is in line with earlier Delphi studies (Rowe and Wright, 1999; von der Gracht, 2008). Data was collected using a survey tool and analyzed with statistics software.

During the first round, invited panelists quantitatively assessed the 11 projections along three dimensions:

- EP: The expected probability of occurrence in the year 2030, on a percentage scale: 0 to 100%
- P: The potential to reduce supplier and customer dependencies in case of occurrence, on a five-point Likert scale (very low = 1, low = 2, medium = 3, high = 4, and very high = 5)
- D: The desirability of occurrence (macro-perspective, i.e., for production and consumption system (Korhonen et al., 2018)), on the same five-point Likert scale

Furthermore, the participants explained their evaluation of each projection and dimension through qualitative comments (Tapio et al., 2011). In this way, the research design allowed contextualizing the quantitative ratings and reducing uncertainty regarding the experts' assessments (de Jesus et al., 2019; Nguyen et al., 2019).

After the first evaluation round, the experts received monitored feedback on the other participants' assessments (von der Gracht, 2008). The information included boxplots with statistical data and a summary of representative comments (Rowe and Wright, 1999). Based on this additional information, the experts could re-evaluate their ratings and provide more comments in the second round (Warth et al., 2013). The data from both rounds laid the foundation for evaluating, discussing, and interpreting the results.

3.5. Fourth stage: Results evaluation

After the second Delphi round, we calculated the mean values for the EP, P, and D of each projection (Warth et al., 2013; Keller and von der Gracht, 2014). Since survey-based research with a response rate < 20% poses a non-response bias risk (Lambert and Harrington, 1990), this circumstance was tested. To reject a non-response bias, we assumed that late responders show characteristics of non-responders (Wagner and Kemmerling, 2010) and compared the assessments of early responders (first 10) to the ones of late responders (final 10) across both rounds and all assessment dimensions. Since a Shapiro-Wilk-Test on normality ($p < 0.05$) revealed a non-normal distribution of the sample, we used a Wilcoxon-Mann-Whitney-Test to compare both groups. The test did not uncover any significant differences ($p < 0.05$) between early and late responders, allowing us to reject a non-response bias.

Subsequently, we calculated the EP, P, and D averages on a more granular level across stakeholder groups and fields of expertise (Warth et al., 2013; Roßmann et al., 2018). To reveal significant deviations from the overall ratings, Wilcoxon-Mann-Whitney-Tests were performed. Moreover, two additional statistical values were determined for each projection's EP: The convergence rate (CV) and the interquartile range (IQR). The CV informs about changes in the standard deviation between the Delphi rounds, with negative values indicating convergence towards the group opinion (Keller and von der Gracht, 2014; Jiang et al., 2017). The IQR is a generally accepted indicator for measuring group consensus in Delphi research (von der Gracht, 2008; de Jesus et al., 2019). Following previous studies in the SCM field, we set a threshold of IQR ≤ 25 to define consensus (e.g., Lechler et al. (2019), Kopyto et al. (2020)). This threshold implies that at least 50% of all EP ratings fall within a range of 25 percentage points on the 0 to 100% scale. Moreover, consistent with recent Delphi studies (e.g., Roßmann et al. (2018), Fritschy and Spinler (2019)), we employed a fuzzy c-means (FCM) algorithm to assign each projection to a designated cluster, based on their EP, P, and D mean values. With this approach, we ensured a systematic and objective interpretation of the quantitative results (Tapio, 2003).

Furthermore, the experts' qualitative comments were analyzed using a coding procedure inspired by Corbin and Strauss (2015). Each expert statement was categorized across two dimensions: Its topic focus (e.g., enablers, barriers) and its sentiment towards the projection (i.e., positive, balanced, or negative). With these two perspectives, we covered the comments' manifested and latent content (Tapio et al., 2011). Two experienced members of the research team coded all comments individually to reduce investigator bias, and discrepancies between both researchers were discussed until reaching a consensus (Pagell and Krause, 2005). The resulting database of qualitative comments was an important input for interpreting the quantitative clusters (Tapio et al., 2011). A full-day discussion and interpretation workshop with all research team members and an additional academic complemented the research stage.

4. Results

4.1. Quantitative Delphi results

The quantitative results after the second round, including means, CVs, and IQRs, are summarized in Table 3. We identified a broad EP range between 38.9% and 70.9%. The projections' potential to decrease SC dependencies was either determined high (P ≥ 3.5) for two projections or medium (2.5 ≤ P < 3.5) for the remaining nine projections. The desirability of eight statements was rated high (3.5 ≤ D < 4.5), two projections even achieved very high (D ≥ 4.5) assessments. Only P.8 did not reach a high desirability score (D < 3.5). A negative CV across all projections and a total standard deviation decrease of 11.4% between both Delphi rounds indicate that the Delphi study's group-based consensus-building process worked as intended (Rowe and Wright, 1999; Keller and von der Gracht, 2014). In this context, P.4 (product-as-a-service) showed the highest and P.11 (energy recovery) the lowest CV (indicating very confident ratings). In general, the highest CVs were observed among 'Reduce' projections. The fact that experts were most willing to rethink and

Table 3
Overall quantitative results from the Delphi panel.

Projection (2030)	EP [0–100%]	IQR [0–100]	CV [%]	P [1–5]	D [1–5]
P.1 Product materials	54.4	30.0	−16.1	3.4	4.5
P.2 Packaging materials	70.9	*15.8*	−15.8	3.2	4.4
P.3 Redesign for lifetime	46.9	*23.0*	−5.9	3.3	4.6
P.4 Product-as-a-service	69.7	30.0	−20.1	3.4	4.1
P.5 Product resell	48.2	35.0	−11.2	3.1	3.9
P.6 Product repair	63.9	30.0	−13.0	3.3	4.3
P.7 Product up-/downgrade	53.1	31.3	−9.1	3.0	4.1
P.8 Product repurposing	38.9	29.8	−6.2	2.9	3.4
P.9 Remanufacturing	57.3	30.3	−12.2	3.5	4.1
P.10 Recycled raw materials	65.2	30.0	−10.6	3.6	4.4
P.11 Energy recovery	70.9	30.0	−5.3	3.0	3.7
Note:	*EP: Ø Expected probability* *P: Ø Potential to decrease SC dependencies*	*D: Ø Desirability* *CV: Convergence (i.e., change in standard deviation)*		*IQR: Interquartile range (≤ 25 equals consensus, highlighted in italics)*	

adapt their assessments for the most desirable 'R' in the CE hierarchy is remarkable. It unveils that consensus building in this area is far from completed and that research can contribute to this process. Apart from P.11, projections with a comparably low EP rating also had the lowest CVs. The experts' confidence towards their ratings dates from their conviction that many barriers do not allow more optimistic assessments. The application of the IQR ≤ 25 threshold revealed expert consensus for P.2's (packaging materials) and P.3's (redesign for lifetime) probability of occurrence. Moreover, Table 4 summarizes the Wilcoxon-Mann-Whitney-Test results for comparing expert ratings from different stakeholder groups and fields of expertise. The analysis revealed significant deviations for 10 out of 11 projections.

The FCM algorithm allowed to unbiasedly distinguish between three clusters with a varying number of projections (see Fig. 2). Five projections form a high probability cluster, three statements reveal a tendency towards occurrence, and the final three projections only have a low probability of occurrence in 2030.

4.2. Qualitative Delphi results

The experts provided 1,180 comments substantiating their quantitative assessments. An average of 15.1 comments per participant and the fact that 83.3% contributed at least one comment indicate high levels of interaction. The content analysis results based on the coding procedure are displayed in Table 5. Expert sentiments towards our projections were overall supportive. Only P.5 (product resell), P.7 (product up-/ downgrade), and P.8 (product repurposing) received as many or even more rejective than supportive comments. The topics discussed in the expert comments were particularly the projections' triple bottom line effect, enablers and barriers, their dependence effect, and their occurrence until the year 2030. <4% of all comments were not interpretable and therefore not coded. Insights from the content analysis lay the foundation for the quantitative results interpretation in Section 5.

Table 4
Average dimension ratings across expert backgrounds and significant deviations.

			Expert backgrounds				
			Fields of expertise		Stakeholder groups		
Projection (2030)	**Dimension**	**Total (n = 78)**	CE (n = 49)	SCM (n = 29)	Industry (n = 39)	Academia (n = 31)	Policy-making (n = 8)
P.1 Product materials	EP	54.4	53.6	55.8	57.6	53.5	**42.0***
	P	3.4	3.4	3.5	3.6	3.2	3.3
	D	4.5	**4.7*****	**4.3*****	4.5	4.6	4.6
P.2 Packaging materials	EP	70.9	69.9	72.8	71.1	71.8	67.1
	P	3.2	3.2	3.1	3.0	3.3	3.5
	D	4.4	**4.5***	**4.2***	4.4	4.4	**4.9****
P.3 Redesign for lifetime	EP	46.9	44.9	50.3	50.4	44.2	39.8
	P	3.3	**3.5*****	**3.0*****	3.2	3.4	3.4
	D	4.6	**4.8*****	**4.1*****	**4.4***	4.7	4.9
P.4 Product-as-a-service	EP	69.7	69.2	70.7	71.3	66.9	73.3
	P	3.4	3.3	3.4	3.5	3.4	**2.8***
	D	4.1	4.1	4.0	4.0	4.1	4.1
P.5 Product resell	EP	48.2	48.7	47.4	51.4	44.0	49.4
	P	3.1	**3.3*****	**2.7*****	**2.9****	3.3	3.5
	D	3.9	**4.1*****	**3.5*****	**3.5*****	**4.2***	4.4
P.6 Product repair	EP	63.9	61.4	68.3	**69.2****	**57.6****	63.0
	P	3.3	3.3	3.2	3.2	3.4	3.3
	D	4.3	4.4	4.2	4.3	4.3	**4.8****
P.7 Product up-/ downgrade	EP	53.1	51.6	55.7	56.7	51.5	42.1
	P	3.0	3.0	3.0	2.9	3.1	3.0
	D	4.1	**4.3*****	**3.7*****	**3.8*****	4.2	**4.8*****
P.8 Product repurposing	EP	38.9	35.4	44.7	42.3	37.7	27.0
	P	2.9	3.1	2.7	2.7	3.1	3.3
	D	3.4	**3.7****	**3.0****	3.3	3.7	3.3
P.9 Remanufacturing	EP	57.3	54.5	62.0	58.9	52.4	67.9
	P	3.5	3.5	3.5	**3.7***	3.4	3.1
	D	4.1	4.1	4.1	4.1	**4.4****	**3.6****
P.10 Recycled raw materials	EP	65.2	66.2	63.5	67.4	63.3	62.1
	P	3.6	3.6	3.6	3.7	3.5	3.5
	D	4.4	4.4	4.3	4.4	4.3	4.5
P.11 Energy recovery	EP	70.9	70.4	71.8	71.0	73.6	59.9
	P	3.0	3.1	2.9	**2.8***	3.3	3.3
	D	3.7	3.5	3.9	3.6	3.9	3.3
Note:	*EP: Ø Expected probability* *P: Ø Potential to decrease SC dependencies* *D: Ø Desirability*		*Deviations are significant from total panel results based on Wilcoxon-Mann-Whitney-Test at ***p < .01, **p < .05, *p < .10.*				

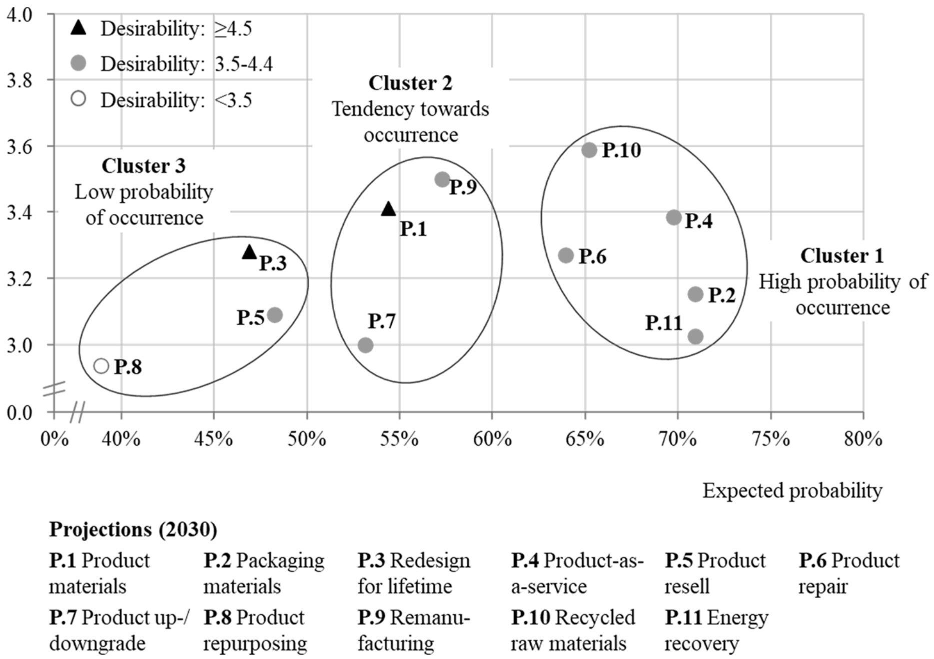

Fig. 2. Projection clusters based on FCM algorithm.

5. Discussion

5.1. Projection clusters

5.1.1. Cluster 1: High probability of occurrence

Cluster 1 comprises the five projections with the highest expected probability scores (EP > 63%), indicating substantial realization potential for the year 2030. P.2's (packaging materials) probability assessment (EP = 70.9%) even achieved consensus (IQR = 15.8). While four out of the five projections received medium ratings for reducing SC dependencies ($3.0 \leq P \leq 3.4$), P.10 (recycled raw materials) achieved the highest score in this dimension (P = 3.6) out of all projections. Moreover, all projections in this cluster show a high desirability rating ($3.7 \leq D \leq 4.4$).

Packaging materials (P.2). In line with the CE 'R' hierarchy, this 'Reduce' projection received the highest probability rating, together with P.11 (energy recovery). The panelists stated that multiple factors enforce its occurrence. Current packaging still reveals much reduction potential. The measure is comparably easy to implement since no major product design changes are required, and companies can save procurement spend. Innovative packaging design will further support this development. Moreover, experts emphasized that the topic is receiving much attention in public, which will result in more pressure to reduce packaging. Panelists also expect legislation backing this trend; however, special packaging regulations in sensitive sectors (e.g., food, pharmaceuticals) may remain and will partially impede reductions. More local manufacturing, making extensive packaging for cross-continental shipping obsolete, was another frequently mentioned lever. With the expected reduction of required material, the experts see considerable potential to decrease packaging supplier dependencies. Nevertheless, they also admitted that dependence reduction opportunities are limited since the packaging is not among a product's key elements and multiple alternative providers exist. Furthermore, new dependencies might result from reducing packaging, for instance, when collaborating with load carriers or even customers to implement reusable packaging systems.

The projection's desirability is overall high but was controversially discussed between the expert groups. While SCM representatives highlighted the environmental and economic potentials, CE representatives pointed out that revising non-reducible packaging with more secondary material will also be decisive to tackle ecological challenges. The high desirability rating in the policy-making group hints at further regulatory intervention in this area.

Recycled raw materials (P.10). This projection received the highest score to reduce SC dependencies. Decreasing dependence on current customers by addressing new environmentally conscious clients was a repeatedly expressed justification. The panelists also stated the opportunity to hedge against geographical risks since they expect recycling operations to be performed more locally. Moreover, the experts emphasized the opportunity to add secondary material providers to the supply base. In this context and considering the experiences during the COVID-19 pandemic, many experts drew comparisons with common SC risk measures such as multiple sourcing and redundancy building. According to them, decreasing dependencies through increased bargaining power could lead to improved supply chain resilience (SCRES). However, the Delphi participants occasionally noted that they expect a consolidation of virgin and secondary material suppliers in the long run, which would revoke the supply alternatives. In this context, potentially becoming autarkic by establishing own recycling operations was negated by the experts since this would require special skills most companies do not possess and will not develop over the following years. This is consistent with Thierry et al. (1995), who already pointed out that integrated recycling operations would require a considerable buildup of inhouse capabilities and realization through third parties would be more likely. The high competence requirements currently concentrated at few firms were one reason for the low occurrence rating compared to the rest of the cluster. Furthermore, the participants raised doubts about whether recycled materials will meet durability, health, and safety requirements at scale until 2030. In this context, complex product design adaptations might become necessary to increase the share of recycled materials.

Nonetheless, the experts also presented several reasons which will push the projection's implementation. With technological advancements resulting in cheaper and more efficient recycling methods and rising virgin material prices, the panelists are convinced that the business case for using secondary materials will become more attractive. Moreover, legislation, particularly in the EU (e.g., 'Battery Directive', 'Single Use Plastics Directive'), will require more recycled materials, making this projection "not a nice to have but a must," as stated by one participant. The high desirability rating reflect the projection's environmental and economic benefits; however, important objections were made. Compared to other 'Rs,' experts confirmed previous research (e.g., Ghisellini et al. (2016), Reike et al. (2018)) by emphasizing the inferiority of 'Recycling' regarding energy requirements. Besides, leveraging completely different materials, for instance, using bio-based instead of recycling fossil-based resources, might be more desirable from an ecological perspective. However, these drawbacks did not impede the projection from reaching high ratings across all dimensions, contradicting other scholars' CE priorities (e.g., Reike et al. (2018)).

Product-as-a-service (P.4). Delphi participants expect the product-as-a-service trend to continue. Overall, product design adaptation requirements are limited as stated by the panelists, making the projection comparably easy to implement. According to the experts, particularly B2B relationships show high potential for expanding this business model since these customers appreciate and increasingly demand flexibility. In B2C, the panelists stated that this might only apply to high-cost, low-utility products since consumers still value ownership for practical and reputational reasons, as previous as-a-service attempts have revealed. Moreover, the COVID-19 pandemic may prevent consumers from sharing products because of new hygienic concerns. A regulatory push for products-as-a-service is not expected.

The projection received the second-highest rating in this cluster for lowering SC dependencies. Higher product utilization in as-a-service business relationships would reduce supply needs for new sales, and a new and recurring revenue stream would lead to more independence at the customer front. Experts stated that companies might not only be able to reduce own dependencies through this projection. They might also achieve consumer lock-ins and increase customer dependence on their products, which would also be favorable based on the RDT. A considerable number of experts noted that lower supply needs and steadier revenue streams have the potential to reduce SC risks and improve SCRES. However, manufacturers will depend on suppliers for spare parts and may also rely on service providers for repairs or telematics. Due to its considerable potential to reduce material consumption, the projection received high desirability scores. However, compared to other projections, it only achieved a mid-position in this dimension. The reasons stated most often are the questionable business benefits for manufacturers in B2C markets and potential 'rebound effects' that might negatively affect the environmental impact, such as consumers using car-sharing instead of bikes.

Product repair (P.6). This projection revealed a high realization probability; however, it is the lowest in Cluster 1. Experts expect a strong regulatory push for more repair activities, including tax incentives (partially already in place, e.g., in Austria and Sweden), product labeling requirements (e.g., 'repairability score'), and mandatory product design for repairability (e.g., 'right to repair'). However, the participants suggest international standards to increase reliability and planning security for companies. Moreover, panelists believe an increasing number of companies will recognize the business potentials of aftersales transactions, making this projection more interesting for manufacturers than other projections focusing on extended product life (e.g., P.5). However, experts were undecided about customers' perceptions regarding the projection. While B2B clients may value extended repairability options and services, a considerable share of consumers will continue to prefer new over repaired products. Panelists also dread the complexity of implementing a holistic repair network, coordinating spare part supplies, and aligning product handovers with customers. These circumstances may only permit big corporates or specialized third-party providers to grow business in the aftersales market. Besides, we identified significant deviations of industry and academia probability ratings, with practitioners recognizing business opportunities and legislative pressure and scholars potentially underestimating the trend.

Panelists see possibilities to decrease SC dependencies with extended repair activities. On the supply side, longer product lifetimes will reduce resource needs, though spare part supplies will gain importance. On the demand side, additional after-sales revenue streams would alleviate dependence on new sales. As for P.4 (product-as-a-service), companies might also achieve higher customer dependence when providing attractive repair services (e.g., by offering extended warranties). However, if manufacturers rely on third-party providers to perform repair services, dependencies at this intersection will likely increase and the business case become less attractive. Due to its potential to reduce material consumption and extend product lifetimes, the projection achieved high desirability ratings. Nevertheless, experts stated that exchanging old products with more environmentally friendly substitutes can sometimes be even more preferable. Moreover, local repair needs to be ensured since additional transports would revise the ecological impact. In the desirability discussion, panelists from the industry and SCM groups admitted that selling new products might generate higher margins than offering repair in some industries, making the projection less desirable in these settings. Finally, it is important to note that the desirability assessment of the policy-making experts unveiled very high ratings, further underlining the expected legislative push.

Energy recovery (P.11). Together with P.2 (packaging materials), using by-products for energy generation reveals the most likely realization until 2030. With the lowest CV overall, the expert ratings for this projection's implementation demonstrate very high confidence. Participants stated that some companies already have successful projects in this area. The projection's economic benefits (e.g., reduced energy and waste disposal costs), its comparably easy implementation not requiring major process or product

Table 5
Coding of qualitative comments.

Projection (2030)	**Sentiments**			**Topic**[1]																															**Unclear**
				Positive (+), negative (-) triple bottom line effect						Enablers (e)/ barriers (b)																		Dependence effect			Time horizon				
	Positive (+), balanced (=), negative (-)			Environ-mental		Economic		Social		Regula-tion		Market demand		(Techn.) Inno-vation		Product design		Company culture		(Logistics) Infra-structure		Collab-oration		Capa-bilities		Supply avail-ability		Decrease	Increase	SCRES	Confir-mation	Faster	Slower	Other[2]	
	(+)	(=)	(-)	(+)	(-)	(+)	(-)	(+)	(-)	(e)	(b)	(e)	(b)	(e)	(b)	(e)	(b)	(e)	(b)	(e)	(b)	(e)	(b)	(e)	(b)	(e)	(b)								
P.1 Product materials	56	62	20	35	0	24	3	2	1	3	6	2	0	2	5	0	8	4	1	0	0	1	1	0	1	3	0	16	3	9	3	0	8	17	7
P.2 Packaging materials	81	33	20	23	0	16	0	0	0	16	6	24	0	8	0	3	2	3	3	0	0	6	1	1	0	0	0	10	2	3	5	1	1	13	8
P.3 Redesign for lifetime	41	47	28	20	5	6	38	2	0	17	1	3	7	2	6	1	3	1	10	0	0	4	0	0	2	0	0	16	7	4	2	0	5	13	4
P.4 Product-as-a-service	49	39	22	10	6	7	5	1	3	3	1	8	7	5	1	4	0	0	2	0	1	0	0	0	2	0	1	15	8	8	2	5	4	17	1
P.5 Product resell	20	34	21	8	2	3	13	4	0	2	1	3	5	0	0	0	1	1	7	0	3	5	2	1	0	0	4	7	6	2	3	5	1	17	2
P.6 Product repair	43	34	15	17	5	8	6	2	0	16	0	8	5	0	1	0	3	0	3	0	7	4	3	0	1	0	0	11	9	1	2	1	0	7	1
P.7 Product up-/ downgrade	32	33	28	9	2	5	7	1	0	3	1	5	6	9	0	0	3	0	1	1	7	0	0	0	2	0	0	13	11	4	4	1	3	7	4
P.8 Product repurposing	19	28	31	5	8	2	9	0	0	3	5	1	2	1	0	0	8	0	2	0	2	2	0	0	3	0	0	3	3	0	2	2	1	23	0
P.9 Remanu-facturing	41	60	18	15	7	12	9	1	0	12	1	3	6	3	4	1	7	0	4	0	8	2	0	2	2	2	8	19	7	11	2	1	4	16	7
P.10 Recycled raw materials	39	47	7	16	9	10	5	1	1	11	2	5	1	5	0	1	4	2	1	0	2	1	1	2	6	3	1	19	6	12	3	2	1	11	8
P.11 Energy recovery	48	21	21	13	17	16	1	2	1	9	0	0	1	1	0	0	2	1	0	4	1	2	0	1	4	3	0	7	3	3	8	5	0	14	0
Subtotal	**469**	**438**	**231**	**171**	**61**	**109**	**96**	**16**	**6**	**95**	**24**	**62**	**40**	**36**	**17**	**10**	**41**	**12**	**34**	**5**	**31**	**27**	**8**	**7**	**23**	**11**	**14**	**136**	**65**	**57**	**36**	**23**	**28**	**155**	**42**
Total	**1,138**			**1,456**																															**42**

Note: 1. Multiple tags per comment possible 2. Several tags with < 15 appearances.

adaptations, and public authorities' support for establishing industrial symbiosis zones made participants call it an "easy win" or a "low hanging fruit." Only lacking capabilities may impede the projection's realization, based on the panelists' comments.

Despite the high occurrence likelihood, the statement achieved the second-lowest desirability rating. While many experts praised the business advantages, the ecological benefits were scrutinized. In line with the CE 'R' hierarchy, panelists claimed that using resources solely for energy generation should be the last resort since incineration ends all possible material loops. Instead, alternative forms of material usage should be evaluated, or waste creation completely avoided. Considering the experts' high confidence in their ratings and the low implementation barriers, considerable efforts will be required to prioritize more desirable CE approaches over this projection. Its potential to decrease SC dependencies has also been assessed comparably low. The panelists saw chances to reduce dependence on waste management companies and energy suppliers relying on fossil fuels. The latter opportunity was repeatedly emphasized since dependence on politically unstable regions and varying commodity prices could be decreased. Nevertheless, particularly experts with an industry background stated that power asymmetries in this area play a minor role and that SCDs usually do not evolve from these dependencies.

Overall, the projections in Cluster 1 have in common that business opportunities, legislative and consumer pressure, or (technological) innovation support their realization and outweigh drawbacks from necessary business model or product design adaptations. All high probability projections also unveil considerable potential to reduce SC dependencies with experts even pointing out SCRES opportunities. P.10 (recycled raw materials) reached the highest score in this dimension and received a substantial number of supportive comments. Remarkably, two out of the five projections in this high probability cluster relate to environmentally low prioritized CE 'Rs'. This indicates that not only industry (Shivonen and Ritola, 2015) but also academia and policy-making representatives expect another realization priority of CE practices than the ecologically preferred hierarchy.

5.1.2. Cluster 2: Tendency towards occurrence

The intermediate cluster includes three projections with a considerable probability of occurrence ($53.1\% \leq EP \leq 57.3\%$), medium to high potential to reduce SC dependencies ($3.0 \leq P \leq 3.5$), and high to very high desirability ratings ($4.1 \leq D \leq 4.5$). Interestingly, all three projections were controversially rated with an occurrence dissent ($IQR > 25$) across the expert panel and significant deviations of desirability ratings across stakeholder groups or fields of expertise.

Remanufacturing (P.9). The second 'Recycling' projection also received a high score in terms of SC dependence reduction potential. The panelists' reasoning was similar to P.10 (recycled raw materials). Particularly the industry experts see an excellent chance to establish alternative and more local supply sources, enabling companies to buffer against potential failures of virgin material suppliers and thereby potentially increase SCRES. Since remanufacturing requires less specialized knowledge than material recycling, some panelists even emphasized that "companies could become more self-sufficient" when implementing this procurement strategy independently. At the same time, new dependencies may arise on the demand side, as customers need to be educated to return end-of-life products to suitable collection points, which is more complex to be realized than just relying on recycled material from any kind of product. Combining this procurement strategy with other projections where manufacturers maintain ownership (e.g., P.4) can be helpful to overcome this dependence, a perspective that has already been pointed out by Thierry et al. (1995). In this context, product returns can generate additional revenue streams through 'new for old' promotions and further reduce customer dependencies, as emphasized by many panelists.

The projection received less support regarding its realization than the one on material recycling (P.10). Although the panelists stated that remanufacturing will receive equal regulatory support, the practice is comparably profitable (particularly for cost-intensive parts), and remanufactured components will offer superior quality and safety (particularly components produced in-house), multiple obstacles remain. Panelists see potential acceptance issues among customers since the public discussion on remanufactured components' suitable quality is less prominent than for recycled materials. Moreover, to enable disassembly and remanufacturing options, far-reaching product design adaptations will be required in many cases. The technological progress with shorter product development cycles and new component requirements may also impede using parts from older product generations. The projection's relative desirability rating is in line with the CE 'R' hierarchy expectations. Potentials to reduce virgin material consumption support desirability; however, the projection received lower scores due to the additional energy and material requirements to perform remanufacturing activities. The significant deviations of the academia and policy-making expert groups arose from the differently perceived collection complexity. While academia panelists do not expect major barriers, policy-making participants unambiguously pointed to the required efforts to ensure reverse product flows.

Product materials (P.1). The likelihood of reducing overall material consumption in product manufacturing only shows a slight tendency towards realization. As for P.2 (packaging materials), experts pointed out the economic benefits of optimizing material usage. However, most panelists stated that the Lean movement already eliminated most resource waste from manufacturing processes and also reduced product material usage over the last decades. Future reductions would need to be achieved through additional product design adaptations, making further improvements difficult and complex to realize within the given time frame. In this context, some participants even stated that the steadily increasing technical complexity of industrial products will require more, not fewer materials. Compared to other groups, policy-making experts even see a significantly lower realization probability, referring to absent regulatory pressure. They stated that legislation rather acts in relative than absolute dimensions (e.g., share of recycled content). For all these reasons, the experts rather expect a shift towards secondary materials than an overall reduction of material consumption, as indicated by P.10's (recycled raw materials) results. This view is consistent with the development of CE literature, where studies on the 'Reduce' practice are underrepresented and recycling practices receive the most scholarly attention (Kirchherr et al., 2017).

Regarding SC dependencies, multiple participants confirmed that less material consumption would undoubtedly lead to reduced supplier dependencies and less SCD possibilities. Further SC risk improvements can be expected, if multiple suppliers for the same material were required and the least reliable ones could be terminated. Nevertheless, the projection does not expand the supply base or increase bargaining power, such as both 'Recycling' statements, leading to a slightly lower rating. Moreover, according to the panelists, it has no impact on dependencies on the demand side. In line with the CE 'R' hierarchy, the projection achieved very high desirability scores, justified through many positive triple bottom line effects expected by the experts. The measure would not only reduce materials usage and thus resource extraction but also offers business opportunities. However, significant desirability deviations of the CE and SCM experts were identified, indicating a disconnect between both groups regarding the projection's implementation difficulties.

Product up-/downgrade (P.7). The 'Reuse' projection on up-/downgrading products received the lowest probability rating in this cluster. Experts stated that many industries recently reduced product customization options and product variants to counter SC complexity, a trend that will not reverse over the following years. Nevertheless, the increasing software foundation of many new products may allow relatively easy up-/downgrading actions while keeping the hardware, making refurbishment more realizable. In this context, many uncertainties remain regarding the projection's business impact. Moreover, the participants do not expect regulatory pressure to enforce the projection's realization. The projection's attractiveness for customers has been controversially discussed without a clear tendency.

However, if customers accept the offering and up-/downgrading would be based mainly on software adaptations, the participants predict possibilities to reduce SC dependencies. On the demand side, recurring revenues would ease the dependence on new clients and potentially bind repeat customers. On the supply side, relying on in-house developed software updates rather than external material supplies could lift supplier dependencies. In contrast, allowing up-/downgrading of hardware would increase SC complexity and dependencies, as the majority of experts emphasized. The desirability ratings of individual panelist groups showed significant discrepancies. While all panelists confirmed the positive environmental effects, only CE and policy-making experts were fully convinced of the business opportunities resulting from this projection. Participants with an industry or SCM background questioned economic advantageousness and repeatedly stressed the threats from SC complexity.

Cluster 2 again unveiled the dissent between the projections' positioning in the CE 'R' hierarchy and their desirability ratings on the one hand and their expected realization potential until 2030 on the other hand. It becomes apparent that, compared to Cluster 1, fewer business benefits, missing customer pressure or regulatory incentives, and technical hurdles hinder highly desirable projections' implementation (i.e., P.1 and P.7). At the same time, with P.9 (remanufacturing), the second out of two 'Recycling' projections also achieved high ratings and supportive comments for its potential to decrease SC dependencies. This circumstance implies that, from an RDT perspective, CE measures mostly relevant for reducing dependencies and potentially building SCRES are not at the CE hierarchy's top but reveal considerable realization potential for 2030.

5.1.3. Cluster 3: Low probability of occurrence

The three projections in Cluster 3 show the lowest expected probability ratings (EP $<$ 49%). Remarkably, this cluster contains the projections with the highest (P.3, redesign for lifetime) and the lowest (P.8, product repurposing) desirability ratings. This circumstance makes a desirability bias in our results unlikely (Winkler and Moser, 2016). According to the panelists, all three projections show a medium potential to decrease SC dependencies ($2.9 \le P \le 3.3$), with P.8 (product repurposing) revealing the lowest score out of all projections.

Redesign for lifetime (P.3). Despite representing a 'Reduce' practice and being awarded the highest desirability score, this projection is part of the low probability cluster. Its low implementation likelihood even reached consensus across the panel (IQR = 23.0) and its low CV indicates high confidence in the expert ratings. Although many panelists stated that the technical implementation of the projection would be easily possible, many barriers were discussed. First and most importantly, the experts see high economic risks for companies if they cannibalize new sales with an extended product lifetime. In this context, most customers will not be willing to accept a price premium for longevity to offset future sales drops. Our findings underline that substantially prolonging product longevity is still "regarded as economical suicide" as Bakker et al. (2014, p. 14) summarized. Therefore, companies will prioritize other CE levers with higher revenue potentials. Second, the panelists emphasized that customers got used to short product lifecycles and expect innovative products in quick succession. Third, a regulatory push would be a breakthrough but cannot be expected since legislation is focusing more on topics discussed in Clusters 1 and 2. Only label requirements (i.e., 'durability scores') can be anticipated soon. Fourth, experts criticized that the current company culture at many firms would impede the projection's flourishing, since sales targets are a predominant steering metric.

The very high desirability rating can be explained by the projection's potential to reduce material consumption considerably, with several experts claiming "probably the biggest possible impact." However, there were also critical voices stating that long product lifetimes are not always desirable when more environmentally friendly alternatives exist. Moreover, materials required to guarantee longer product lifetimes are often environmentally harmful. The desirability scores of industry and SCM representatives were significantly lower, reflecting the projection's economic dilemma. As one industry expert stated, the statement's desirability is "as manager low, as consumer high." Potentials to reduce SC dependencies were also controversially discussed between the expert groups. While CE representatives pointed out the lower resource needs, industry and SCM professionals indicated that the projection's SC dependence effects would only be visible in a couple of years when regular product lifecycles would terminate. Moreover, SCM panelists claimed that longer product lifetimes would make more co-creation with suppliers necessary, leading to additional dependencies, including power shifts.

Product resell (P.5). Experts were pessimistic about companies increasing their product resell efforts. According to them, margins in the second-hand business are comparably low, and companies will hesitate to cannibalize new sales. Participants rather expect manufacturers to expand their business models with more profitable activities generating recurring revenues (e.g., P4, P.6). Moreover, many resell markets are already being developed by other parties, as stated by the panelists. Either third-party providers (e.g., for used vehicles) or online exchange platforms supporting C2C sales (e.g., in fashion second-hand) will dominate the resell market. This indicates that the trend could accelerate until 2030, although not driven by the original manufacturers. In general, the panelists expect a limited resell market potential since many customers will still prefer new products and no regulations are anticipated. This tendency might even increase because of hygiene concerns originating from the COVID-19 pandemic. However, some experts claimed that this trend is socially desirable to support the access of low-income groups to costly products.

Desirability ratings of industry and SCM experts, on the one hand, and academia and CE representatives, on the other hand, showed significant deviations. While the latter emphasized the projection's ecological benefits, the former referred to the economic, cultural, and organizational barriers to implement it at their own companies. Apart from profitability concerns, the complexity of parallel SCs, the mindset and self-image of constantly developing and selling new products, and potential quality issues of second-hand products damaging the brand were mentioned. In general, all experts agreed that a high resell revenue share could lift supplier dependencies. However, the dependence ratings also revealed significant differences. Since industry and SCM experts anticipate third-party providers to assume the market, they do not expect a broader client base for their own companies. They also see the challenge of new dependencies if collaborating with these service providers, which could undermine dependence improvements on the supply side. New dependencies may also arise from customers who need to return products before they can be resold.

Product repurposing (P.8). This final projection received the lowest ratings across all three assessment dimensions, despite being part of the 'Reuse' category. Regarding its probability, experts stated that conceivable use cases are very limited. According to them, only selected cross-industry applications seem reasonable (e.g., car batteries for energy storage). To extend fields of application, repurposing would require more aligned technical standards across industries. However, more regulation for this or any other aspect related to the projection cannot be expected. Furthermore, repurposing would require consideration straight from product design, potentially hampering products' original purpose. Moreover, most panelists doubted an attractive business case since searching for and adapting products to alternative use cases is a complex and time-consuming process. This includes certification requirements since companies are expected to avoid off-label use due to liability concerns. This is particularly due to products' non-transparent composition since most companies refrain from publishing detailed material information. Even representatives from companies that relied on repurposing during the COVID-19 pandemic under scarce supply conditions emphasized that this practice was the last resort and is not recommended as a long-term solution.

The panelists presented several reasons for the only medium desirability rating in the study. From an environmental perspective, considerable energy and material efforts are required for repurposing activities, thereby leading to downcycled instead of upcycled products in most cases. In this context, repurposing may hinder more ecological-desirable solutions. The significantly lower SCM group desirability rating can be traced to severe concerns regarding profitable use cases. In line with the 'Recycling' projections, repurposing would theoretically allow for alternative supply sources. However, the potential to decrease SC dependencies was rated comparatively low because of the limited use cases. Furthermore, a very high level of trust would be required in this context since repurposing might only be a sideline business for sellers but part of the core business for buyers. Significant power asymmetries favoring the sellers would be the consequence.

Overall, Cluster 3 shows that CE initiatives without clear economic incentives, market demand, or regulatory pressure only have a low implementation likelihood. Moreover, companies' current culture is another barrier for the projections in this cluster, as the expert comments revealed. The high desirability of the cluster's 'Reduce' and 'Reuse' projections from an ecological and a CE hierarchy point of view will not be sufficient to overcome implementation barriers and drive these initiatives over the next couple of years. Remarkably, the projections with the highest potential to decrease SC dependencies are part of the first two clusters, indicating that a non-realization of Cluster 3 would not severely impede companies' attempts to reduce SC dependencies through the CE. Only very few SC risk management associations were made by the experts for this cluster.

5.2. Implications for theory, practice, and policy-making

From the results and the cluster discussions, we can derive important implications for theory, practice, and policy-making. Starting with our theoretical contributions, we deducted a future roadmap for implementing CE practices along the 4R framework. This perspective, addressed through RQ1, was lacking in literature so far (Stewart and Niero, 2018; de Jesus et al., 2019). We found that the priority with which CE practices will likely be implemented (see EP ratings) is not congruent with the value retention hierarchy advocated by the various frameworks in literature (Kirchherr et al., 2017; Potting et al., 2017; Reike et al., 2018). While two 'Recycling' and 'Recovery' practices (P.10, P11; third and fourth 4R hierarchy) are among the projections with the highest probability of occurrence in 2030, various 'Reduce' or 'Reuse' practices (first and second 4R hierarchy) reveal a low probability of occurrence. This may become a threat to the transition towards a CE. In recent years, research and industry reports revealed some disillusion with another far-reaching transformational SC topic: digitalization. There is much uncertainty regarding the return of SC digitalization initiatives due to high required investments and a lack of focus, leading to inflated expectations and transformation failure (Issa et al., 2018; Horváth and Szabó, 2019; Gartner, 2020a). Suppose that companies focus their efforts on implementing low CE value retention measures which might not fulfill environmental expectations. In that case, there is a high probability of stakeholders also getting disappointed with the CE in the next years. While most panel groups would generally advocate realizing high-value retention practices (see D ratings), missing use cases and multiple barriers impair future implementation. Research can help to cushion such a 'trough of disillusionment' by analyzing influencing factors and establishing a realistic CE target vision companies and the society can aim for. Investigation on CE enablers and barriers already started (Kirchherr et al., 2018; Bressanelli et al., 2019) and is complemented by this paper. We added the foresight and specific 'R' perspectives to this discussion and presented which of the multiple influencing factors will play a central role for implementing specific CE 'Rs' in the next 10 years. According to our experts' qualitative statements, financial attractiveness, regulation, consumer demand, (technological) innovations, product design, and company culture will be the central pillars for many CE approaches. At the current stage, our findings reveal that broadly accepted roadmaps considering these factors are still missing, threatening CE advancements until 2030.

Second, in response to RQ2, we picked up scholars' calls for an extended understanding of an SC's capacity to transform towards a more desirable system in the face of changing external circumstances (Walker, 2020; Wieland and Durach, 2021). We explored how a paradigmatic shift from a linear 'take-make-dispose' model towards CSCs could alter SC dependencies which were a main reason for recent SCDs (Gölgeci et al., 2020; Ivanov and Dolgui, 2020). In this context, the expert panel provided persuasive evidence that lifting dependencies through CE measures can become an enabler for another topical subject in SCM research: the improvement of SCs' resilience. Particularly diversifying a company's supply base and increasing redundancies through 'Recycling' practices (P.9 and P.10) comprised the greatest capacity for reducing dependencies and motivated many experts to express SCRES opportunities. Similar statements on potential SCRES benefits were made for three 'Reduce' practices (P.1, P3, and P.4) with relatively high P ratings, hinting at a potential synergy between pursuing the environmentally most desirable CE practices and increasing SCRES. The results indicate that a nuanced approach is required to understand SCRES opportunities of different CE approaches. With these findings, we initiate a promising bridging process between the two rapidly evolving research streams of CE and SCRES. In this context, the RDT, which was already applied in other contexts to analyze SCRES opportunities (e.g., Bode et al. (2011), Al-Balushi and Durugbo (2020)), can serve as a possible conceptual linkage between both topics.

This research also offers managerial implications. First, we found that several CE practices face similar implementation barriers. Common challenges include the lack of incentivizing regulation, financial attractiveness, customer demand, or missing use cases. Therefore, managers planning to implement various CE practices within their SC network are advised to design their CE transformation strategy holistically and address common barriers jointly. Second, existing literature has established that the CE can be beneficial both environmentally and economically (Lieder and Rashid, 2016; Korhonen et al., 2018; Werning and Spinler, 2020). We detail these benefits for an SCM context and provide empirical evidence that CE practices can lift SC dependencies and potentially improve SCRES. This represents an important insight for managers interested in simultaneously driving their SCs' ecological and resilient transformation. They can rely on our findings to internally promote CE practices as substantial sustainability and resilience enablers. Third, as our results predict considerable CE implementation, according to the RDT, companies' internal power dynamics are likely to be affected by these subsequently changing SC dependencies (Pfeffer, 1989).

Several policy implications complement our contributions. First, we confirmed the central role policy-making occupies in the transition towards a CE. For many CE practices, for instance, P.3 (redesign for lifetime), P.5 (product resell), and P.8 (product repurposing), current economic value potential seems to be insufficient to drive implementation at scale. Despite the high desirability of these CE practices across expert groups and their promotion through the CE value-retention hierarchy, we identified the need for stronger regulatory intervention if the practices are meant to be established by 2030. The fewer companies and consumers favor specific CE measures for economic or other reasons, the more regulatory intervention will be required to reach implementation. Possible actions are manifold and range from incentives such as tax benefits to legal requirements. Moreover, current regulations impeding the CE transition (e.g., waste classifications, antitrust laws) should be reconsidered. Policy-makers need to understand that a single 'silver bullet' does not exist, a full set of suitable interventions will be required. At best, policy-making initiatives should be coordinated on an international level to create a location-independent perspective for multinational companies considering a transitional shift towards the CE. Second, we uncovered significant projection assessment deviations between experts with policy-making and other backgrounds. This finding confirms previous studies (Kirchherr et al., 2018) and unveils continuing differing perceptions of stakeholder groups involved in the CE discussion. It becomes clear that policy-makers need to understand other stakeholders' current state and future motives better to successfully establish the necessary conditions for a transition towards a CE. Continuing public–private learning, for instance through intensified consultation processes, is thus encouraged. Third, our findings on a connection between CE and SCRES should inspire policy-makers to target the CE and SCRES paradigm jointly, which validates recent legislative efforts in that direction (European Commission, 2020; Mhatre et al., 2021).

6. Conclusion, limitations, and future research

With the COVID-19 pandemic causing SCDs and exposing the vulnerabilities of globally interconnected SCs, the discussion on how to redesign SCs has gained momentum. Particularly opportunities to reduce SC dependencies were promoted as potential fields of action (Al-Balushi and Durugbo, 2020; Craighead et al., 2020). In this context, the unprecedented severity of the crisis triggered a debate on whether the current linear economic model exacerbates SC vulnerability and adverse effects of SCDs. Therefore, many scholars claimed that a transformational shift towards a CE could help establishing future-proof SCs (Ellen MacArthur Foundation, 2020; Sarkis et al., 2020; Wieland and Durach, 2021). However, both the CE's future development and its potential to lift SC dependencies remain unclear in the literature (Stewart and Niero, 2018; de Jesus et al., 2019; Nandi et al., 2020; Ibn-Mohammed et al., 2021).

To investigate this research gap, we conducted a Delphi study with 78 international SCM and CE experts evaluating 11 future-oriented CE projections. The panelists assessed the projections on their probability of occurrence in 2030 and their potential to decrease SC dependencies. Through extensive analyses of the experts' quantitative assessments and their qualitative reasoning, we started to lift the fog on which CE practices will succeed in the near future and whether they will help to reduce SC dependencies.

Our results reveal that some CE practices have a high probability of occurrence until 2030. However, we also found that their realization is not aligned with the CE value retention hierarchy established by the 4R framework. There still exist many barriers that hinder the timely implementation of the most desirable CE practices. This finding is problematic since desired sustainability improvements could be impeded. Moreover, the expert panel reported that particularly ‘Recycle’ and ‘Reduce’ CE practices have a considerable potential to decrease SC dependencies, potentially leading to more resilient SCs. This empirical finding supports previous conceptual papers which advocated the CE as a potential paradigm shift that could solve the resilience problem (Ivanov and Dolgui, 2020; Sarkis et al., 2020).

This study is not exempt from limitations, which, at the same time, offer opportunities for future research. First, while CE barriers and respective enablers have been previously studied on a holistic CE level, analyses on the level of the individual ‘R’-practices remain scarce (Govindan and Hasanagic, 2018; Werning and Spinler, 2020). Our study identified the main implementation barriers for the CE practices but did not investigate their relative level of influence and potential solutions. Future research on this topic is particularly important for projections that revealed relatively high desirability and potential to decrease dependence but a low probability of occurrence (e.g., P.1 and P.3). Second, our research has confirmed a positive link between implementing CE practices and the potential to reduce SC dependencies through a Likert scale assessment and supporting expert comments. However, a more detailed view of how exactly different dependencies are altered and how this effect might differ in varying contexts would be desirable. Therefore, future research studies should investigate which specific customer or supplier dependencies are changed by implementing different CE practices, which new SC dependencies materialize, and how these changes differ in varying industrial, geographical, or cultural contexts. Lastly, while this paper uncovered an existing relationship between the CE and SCRES, our scope was limited to an RDT perspective. Exploring the CE-SCRES relationship through additional theoretical perspectives will be required for a more comprehensive picture, as the RDT does not have the capacity to explain all variations and consequences of intercorporate activity (Pfeffer, 1989). Staying in the RDT context, various panelists pointed out that implementing CE practices might actually increase dependencies in some cases due to the high interconnectedness in a CE system. However, SCRES might be ultimately improved nevertheless, as more interdependent setups might positively affect other SCRES levers (e.g., visibility, collaboration, flexibility). Thus, we call on the scholarly community to conduct additional studies investigating the effect of CE practices on those other levers. The objective must be to construct a holistic, empirically grounded framework that defines the relationship between the CE and SCRES.

CRediT authorship contribution statement

Maximilian Gebhardt: Conceptualization, Methodology, Data curation, Formal analysis, Validation, Writing – original draft, Writing – review & editing, Project administration. **Alexander Spieske:** Conceptualization, Methodology, Data curation, Software, Formal analysis, Validation, Writing – original draft, Writing – review & editing. **Hendrik Birkel:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tre.2021.102570.

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