**A systematic literature review exploring uncertainty management and sustainability outcomes in circular supply chains**

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## Abstract

The circular economy (CE) has inspired the emergence of circular supply chains (CSCs) to reduce the environmental impacts of linear production systems. However, the transition to CSCs faces numerous challenges and uncertainties, which in turn impact the sustainability performance of CSCs. Following a systematic review process, this paper aims to identify the uncertainties that CSCs entail and the uncertainty management strategies which can be used to mitigate them to enhance their sustainability performance. A conceptual framework is proposed under which the current literature on CSCs, including 106 peer-reviewed English journal articles, is analysed and discussed based on CE practices, uncertainty management, and sustainability performance indicators. This framework offers guidance to CE and CSC scholars and supports practitioners and policymakers in being aware of the uncertainties related to the operationalisation and implementation of the CE in order to offer CE-inspired solutions. This paper also proposes a research agenda to investigate the integration of CE practices with supply chain management; the ways in which organisations manage different uncertainties simultaneously; and the effect of multiple uncertainty management strategies on firms' sustainability performance.



**Keywords:** circular economy; circular supply chain; closed loops; uncertainty; sustainability; systematic literature review


## 1. Introduction

The circular economy (CE) is concerned with a thorough rethink of production systems, in which materials, components, and products (MCPs) are designed to continuously add, recreate, and preserve value at all times (Esposito, Tse, and Soufani 2018; Genovese et al. 2017). The CE constitutes a paradigm shift, going from a 'take, make, use, dispose' model to a circular one (Govindan and Hasanagic 2018). Bocken et al. (2016) categorised design and business model strategies according to the mechanisms by which resources flow through a system in the move from a linear economy to a circular one. The terminology of slowing, closing, and narrowing is used to describe these strategies. Slowing loops can be achieved through durable design (service loops to extend the life cycle of MCPs, e.g. through repair, remanufacturing), whereas closing loops occurs through recycling. Narrowing loops is aimed at using fewer resources per product. However, CE-inspired solutions 'change supply chains substantially by introducing new entities and material flows, and more uncertainty' (Turken et al. 2020, 4690). Consequently, the complexity of transitioning from linear to circular supply chains (CSCs) challenges many manufacturers, whose knowledge of the implications tends to be poor (Van Loon and Van Wassenhove 2020). This indicates that companies require knowledge in addition to that inherent in the business-as-usual model due to complex product design and manufacturing operations, technological changes, and political, cultural, and economic structures (Bressanelli, Perona, and Saccani 2019a; Genovese et al. 2017).

However, previous studies addressing the topic of uncertainty are focused on either reverse logistics or closed-loop supply chains (CLSCs) (e.g. He 2017; Kazemi, Modak, and Govindan 2019), while missing the opportunity to understand SCs in CE terms (Batista et al. 2018). In order to comprehend and explore uncertainty in CSCs, it is imperative to define it. Uncertainty is usually used interchangeably with risk in practice, so it is also essential to delineate how these two concepts differ (Simangunsong, Hendry, and Stevenson 2012). Rodrigues et al. (2008) explain the difference, pointing out that risk is a function of outcome and probability and hence it can be estimated. If the probability of an event occurring is low but the outcome of that event can have a highly detrimental impact on the SC, the occurrence of that event represents a considerable risk for the SC. Uncertainty occurs when decision-makers cannot estimate the outcome of an event or the probability of its occurrence. In other words, decision-makers can list the events that may happen in the future yet have no idea which one will happen or their relative likelihoods (Waters 2011). The key reason for distinguishing the concepts of risk and uncertainty is that risk can lead exclusively to negative effects, while uncertainty may result in positive outcomes as well—for example, the risks of a natural disaster are likely to disrupt SCs and hence yield negative effects, whereas an uncertainty related to customer demand can lead to demand being either better or worse than expected (Simangunsong, Hendry, and Stevenson 2012). Analysing uncertainties in terms of the CE has the potential to ensure a smooth transition to CSCs or reveal related opportunities. This could be achieved by systematically reviewing the management of CSCs under uncertainty and investigating uncertainty arising from different CE practices adopted in CSCs. In addition, the linkages between uncertainty and uncertainty management strategies have been unexplored in the CE context while offering relevant insights regarding their outcomes in terms of sustainability performance. This would provide further evidence about the possible effects of strategies on an organisation's competitive position (Simangunsong, Hendry, and Stevenson 2012, 2016).

The CE has received significant consideration because of its focus on sustainability, covering the triple bottom line (TBL) approach, i.e. economic, social, and environmental sustainability dimensions (Agrawal and Singh 2019). The main beneficiaries of the CE appear to be the economic actors that implement the system. The environment is also seen to benefit through less resource depletion and pollution, and society benefits from environmental improvements and opportunities, such as increased manual labour and fair taxation (Geissdoerfer et al. 2017). From an SC perspective, Beske-Janssen, Johnson, and Schaltegger (2015) argue for the need to include the TBL approach to measure all three sustainability dimensions in SCs, as conventional systems have solely prioritised financial and operational performance, such as quality, speed, dependability, flexibility, and cost. Simangunsong, Hendry, and Stevenson (2016) stress that within the context of SC uncertainty management, it is necessary to consider appropriate SC performance measurement and management as well as the specific links of certain facets of performance with specific uncertainty management strategies.

Despite its evident relevance for theory and practice, the management of CSCs under uncertainty remains unexplored, and the effects of uncertainty on the sustainability of CSCs require careful scrutiny. Against this backdrop, this paper asks:

1. *What are the uncertainties found in CSCs?*
2. *Which uncertainty management strategies can be used to mitigate them?*
3. *How are uncertainties and uncertainty management strategies related to the sustainability performance of CSCs?*

To address these research questions and the evident lacunae, a systematic review of the literature was performed to take stock of existing scientific approaches and evidence at the intersection of CE and supply chain management (SCM). The systematic review is an evidence-based approach that advances existing knowledge (Tranfield, Denyer, and Smart 2003) and adopts rigorous and transparent steps to retrieve, select, and synthesise pertinent literature (Durach, Kembro, and Wieland 2017). Moreover, by interlinking a systematic inquiry with a 'contingency analysis' to excavate relations between the conceptual frameworks herein adopted (Bressanelli, Perona, and Saccani 2019a, 7417), a combined analysis of uncertainty management and sustainability outcomes in CSCs is offered.

The remainder of this paper presents the research background and develops the theoretical framework for the analysis in Section 2. Section 3 outlines the review process. Section 4 presents the review findings with content-, frequency-, and contingency-related results, offers unique research directions, and is followed by a discussion of the findings in Section 5. Section 6 presents the concluding remarks, the managerial implications, the paper's limitations, and a future research agenda.

## 2. Research background and framework development

This section contextualises SC operations for the CE and problematises their inherent uncertainties and potential impacts on sustainability performance. Therefore, a brief background of three key building blocks of this paper is necessary, i.e. CSCs, uncertainty management, and sustainability performance.

### *2.1. The CE emergence and its operationalisation in CSCs*

The CE concept traces back to different schools of thought (Ghisellini, Cialani, and Ulgiati 2016) and its origins can be found in economics (Boulding 1966; Pearce and Turner 1990), industrial ecology (Frosch and Gallopoulos 1989; Graedel 1996), and industrial symbiosis (Chertow 2000). Furthermore, according to Geissdoerfer et al. (2017), the contemporary understanding of the CE and its practical applications to economic systems and industrial processes has evolved to incorporate different features and contributions from various concepts sharing the idea of closed loops. Ghisellini, Cialani, and Ulgiati (2016) state that the CE has the potential to implement radically new patterns and help society reach increased sustainability and wellbeing at low or no material, energy, and environmental costs.

Although CE thinking is not new, it is only recently that it has gained momentum among practitioners and academics; this may be explained not just in light of the worsening environmental impacts but also because of changing socio-economic and regulatory landscapes (De Angelis, Howard, and Miemczyk 2018). SCM research is at a nascent stage when it comes to conceptualising how to advance SC theories and practices to realise the CE's vision and potential (Farooque et al. 2019). In this regard, CSCs are a relatively novel approach that allows managers to implement circularity into SC operations to optimise resource usage, bolster circular loops, and maximise sustainability (Lahane, Kant, and Shankar 2020; Mishra, Hopkinson, and Tidridge 2018; Sehnem et al. 2019). Batista et al. (2018) provide a systematic literature research of CSCs to identify overlapping between four sustainability narratives: reverse logistics, green SCs, sustainable SCM (SSCM), and CLSCs. Reverse logistics is a crucial activity in the collection of end-of-life and end-of-use returns, which are reintroduced into the SC for value recovery (Govindan and Soleimani 2017; Kazemi, Modak, and Govindan 2019). Green SCs involve the integration of environmental concerns into organisations and SC operations to reduce the negative impacts of production and consumption processes (Sarkis, Zhu, and Lai 2011). SSCM theoretically extends traditional SCM by including the TBL perspective (Beske and Seuring 2014). CLSCs are concerned with the design, control, and operation of product returns and value recovery (Guide and Van Wassenhove 2009; Souza 2013). CLSCs are regarded as an important 'backbone' of the CE and a subset of operations management and SSCM; they can be a tool for making business activities more sustainable by ensuring slow and closed resource loops (Lüdeke-Freund, Gold, and Bocken 2019). In order to close the loop of MCPs, companies need to design large-scale industrial systems that have the capability to return all MCPs back into the system. Besides, companies need to encourage and facilitate a set of CE activities (e.g. repairing, refurbishing, remanufacturing, and recycling) and develop infrastructure and SCs capable of handling such reverse-cycle initiatives (Agrawal, Atasu, and Van Wassenhove 2019). Yet, other supply systems can also close the loop of MCPs (Miemczyk, Howard, and Johnsen 2016). This configuration refers to an open-loop SC, where MCPs are recovered by parties other than the original producers who are capable of using these MCPs (Genovese et al. 2017). At the enterprise level, the implementation of CE practices would push for the design of CSCs, thereby enabling products at the end of their life cycle to re-enter the SC as a production input via reusing, remanufacturing, or recycling (Nasir et al. 2017). Batista et al. (2018) pinpoint a need for comprehensive analysis to apprehend the full range of contributions and different perspectives in CSC research.

The CE inspires multiple approaches and practices, varying according to the definitions and contexts being considered, yet a baseline level of understanding can be reached via the existing literature (Esposito, Tse, and Soufani 2018). Campbell-Johnston et al. (2020) affirm that the CE implementation is being pursued by utilising the R-imperatives, whose number and sequence are inconsistent and have evolved across time. The R-imperatives—or Rs—are prioritised based on a varying number of circularity levels (Blomsma and Brennan 2017; Kirchherr, Reike, and Hekkert 2017). A recent and nuanced framework regarding R-imperatives is that of Reike, Vermeulen, and Witjes (2018). The authors synthesise the most common perspectives on R-imperatives into a single systemic typology of 10 resource value retention options. Accordingly, the retention of resource value means conservation of resources closest to their original state, and in the case of finished goods retaining their state or reusing them with a minimum of entropy as to be able to give them consecutive lives. The R-imperatives are categorised into short loops (where the product remains close to its user and function), medium loops (where products are upgraded and producers are again involved), and long loops (where products lose their original function). They include two preventive design practices, which consist of refusing and reducing hazardous substances, and eight recovery activities, which are reselling/reusing, repairing, refurbishing, remanufacturing, repurposing, recycling, recovering (energy), and re-mining MCPs. Reike, Vermeulen, and Witjes (2018) claim that while the 3R-imperatives (reduce, reuse, and recycle) form an accepted notion of CE in theory and practice, there has recently been an emphasis on more nuanced hierarchies with shorter loop options as enabling the highest possible value retention of resources over multiple product life cycles. Therefore, the 10R framework by Reike, Vermeulen, and Witjes (2018) is adopted in this review to analyse CSCs.

Table 1 presents the R-imperatives. The description, frequency, and examples in the reviewed literature of each R-imperative are given in Appendix 1 as supplementary material due to space restrictions.

Table 1. Coding framework adapted from Reike, Vermeulen, and Witjes (2018).

| **Short loops** | **Medium loops** | **Long loops** |
|---|---|---|
| R0/Refuse | R4/Refurbish | R7/Recycle |
| R1/Reduce | R5/Remanufacture | R8/Recover energy |
| R2/Resell, reuse | R6/Repurpose | R9/Re-mine |
| R3/Repair | | |

The aforementioned CE practices indicate that the shift from linear to CSCs is far from straightforward because CSCs would require substantial changes in the business structure and SC operations (Van Loon and Van Wassenhove 2020). Turken et al. (2020) point out that manufacturers might deal with increased complexity and more uncertainty while managing materials and information flows, new actors included, and their relationships to each other. Galvão et al. (2020) state that companies should expect long-term system changes, whereby the SC goes beyond the delivery of a product to a consumer and spans complex product design, take-back operations, and recovery activities. Suzanne, Absi, and Borodin (2020) argue that decision-making under uncertainty is one of the main issues of most recovery operations. For example, in upstream operations, the product returns and undesirable production outputs are qualitatively and quantitatively subject to high variability, usually conditioned by factors that are difficult to be explained, controlled, or anticipated. The ambiguity surrounding the exact meaning of CE practices (e.g. repairing, reconditioning, refurbishing) and uncertainty in managing intellectual property in many industries inhibit organisations from adopting a remanufacturing strategy (Hartwell and Marco 2016). Cao and Zhang (2020) claim that manufacturers need to align incentive mechanisms with convincing the other members in the SC to perform responsible operational and marketing activities. However, there is still reluctance on the part of commercial SCs to implement CE, mainly because a proactive assessment of uncertainties is lacking (Linder and Williander 2017). This evidences that organisations and SCs can be prone to CE-related uncertainties, associated with different challenges stemming from complex operations to data privacy and security concerns (Bressanelli, Perona, and Saccani 2019a; Gonzalez, Koh, and Leung 2019). Therefore, it becomes paramount to investigate the augmented uncertainties that CSCs entail by adopting an uncertainty management perspective, which is presented in the next subsection.

### *2.2. Managing uncertainty in CSCs: from uncertainty identification to sustainability outcomes*

Van der Vorst and Beulens (2002, 413) define SC uncertainty as 'decision-making situations in the supply chain in which the decision-maker does not know definitely what to decide as he [or she] is indistinct about the objectives; lacks information about (or understanding of) the supply chain or its environment; lacks information processing capacities; is unable to accurately predict the impact of possible control actions on supply chain behaviour; or, lacks effective control actions (non-controllability).' A comprehensive review in this area is that of Simangunsong, Hendry, and Stevenson (2012), who provide a list of 14 uncertainties and 21 uncertainty management strategies. As shown in Table 2, the sources of uncertainty are categorised into (U1–U6) uncertainties which come from the focal company, (U7–U12) uncertainties which originate from the organisation's SC, and (U13–U14) external uncertainties from factors outside the realm of the company or SC. Uncertainty management can be defined as (RU1–RU10) reducing uncertainty strategies that enable organisations to reduce uncertainty at its source, and (C1–C11) coping with uncertainty strategies, which do not try to influence or alter the source of uncertainty but try to find ways to adapt and hence minimise the impact of uncertainty. The framework by Simangunsong, Hendry, and Stevenson (2012) is employed herein as a theoretical lens because of its acknowledged comprehensiveness in the SCM field (Fadaki, Rahman, and Chan 2020; Kazemi, Modak, and

Govindan 2019; Sauer and Seuring 2018). Appendix 2 describes each uncertainty construct and its frequency and examples in the reviewed literature.

Table 2. Coding framework adapted from Simangunsong, Hendry, and Stevenson (2012).

| **Internal organisation uncertainties** | **Internal SC uncertainties** | **External uncertainties** |
|---|---|---|
| U1/Product characteristics | U7/End-customer demand | U13/Environment |
| U2/Process/manufacturing | U8/Demand amplification | U14/Disruption/natural uncertainties |
| U3/Control/chaos uncertainty | U9/Supplier | |
| U4/Decision complexity | U9.1/Customer as a supplier | |
| U5/Organisation structure and human behaviour | U10/Parallel interaction | |
| U6/Information technology/systems (IT/IS) complexity | U11/Order forecast horizon/lead-time gap | |
| | U12/Chain configuration, infrastructure, and facilities | |

| **Reducing uncertainty strategies** | **Coping with uncertainty strategies** |
|---|---|
| RU1/Lean operations | C1/Postponement |
| RU2/Product design | C2/Volume/delivery flexibility |
| RU3/Process performance measurement | C3/Process flexibility |
| RU4/Good decision support system (DSS) | C4/Customer flexibility |
| RU5/Collaboration | C5/Multiple suppliers |
| RU6/Shorter planning period | C6/Strategic stocks |
| RU7/Decision policy and procedures | C7/Collaboration |
| RU8/Information and communication technology (ICT) system | C8/ICT system |
| RU9/Pricing strategy | C9/Lead-time management |
| RU10/Redesign of chain configuration or infrastructure | C10/Financial risk management |
| | C11/Quantitative techniques |

Note: U9.1/Customer as a supplier was added to the coding framework because customers' returns pose quality, timing, and quantity uncertainties to the operation of CSCs.

By adopting an uncertainty management approach, it is necessary to consider its links with sustainability performance (Simangunsong, Hendry, and Stevenson 2016). The rationale underlying this observation is that an organisation's sustainability performance is strongly related to the alignment between uncertainties and managerial perceptions of them, and the choice of uncertainty management strategies (Simangunsong, Hendry, and Stevenson 2012). This offers to be an insightful lens to analyse CSCs, as cyclic flows of MCPs entail new uncertainties which alter their normal performance. For example, the uncertain quantity and quality of returns and related recovery processes that have to be implemented to restore the returns increase the complexity of managing modern SCs. Consequently, these issues may generate inefficiencies that increase operational costs, resource consumption, and environmental pollution (Dominguez, Cannella, and Framinan 2021). Goltsos et al. (2019) underline the need to understand how the uncertain quality and quantity of returns affects the remanufacturing process, and what strategies there are to alleviate its effects as a source of uncertainty on the sustainability performance of the closed-loop system.

In order to analyse sustainability performance in CSC research, the TBL approach is adopted. Achieving the TBL dimensions of sustainability becomes an important issue for organisations and related SCs (Agrawal and Singh 2019; Saeed and Kersten 2020). Murray, Skene, and Haynes (2017) argue that the re-knitting together of the three pillars of sustainability must happen if society is to rediscover a balanced existence with the biosphere. Howard, Hopkinson, and Miemczyk (2019) point out that although indicators and performance measurement are well developed in the sustainability literature, there is relatively little research into indicators that explicitly support CE objectives. This is due to the ambiguity surrounding terms such as sustainable and circular in the current literature. Besides, executives might benefit from indicating the long-term advantages of CE practices and the concept of CSCs in terms of resource utilisation, greenhouse gas emissions, and energy consumption (Atabaki, Mohammadi, and Naderi 2020) which are beyond traditional SC measures, such as quality, service responsiveness, and costs.

Based on an extensive literature review, Saeed and Kersten (2017) categorise the three sustainability dimensions of the TBL into 18 attribute categories. According to Saeed and Kersten (2020), attribute categories are sustainability issues an organisation should address to measure its sustainability performance. Each attribute category has goals associated with it. For example, the goals regarding the energy efficiency attribute category are to increase renewable energy use and decrease the use of total energy. As shown in Table 3, the environmental sustainability dimension consists of eight attribute categories (EV1–EV8), the social sustainability dimension of six (S1–S6), and the economic sustainability dimension of four attribute categories (E1–E4). Each attribute category consists of sustainability performance indicators. Organisations assess their sustainability performance for each sustainability performance indicator, which leads to the sustainability performance at the attribute category level. This framework comprehensively covers the interplay of social, environmental, and economic sustainability, thereby justifying its relevance for organisations and related SCs in the CE context. Table 3 shows the sustainability performance indicators based on Saeed and Kersten (2017). The description, frequency, and examples in the reviewed literature of each sustainability performance indicator can be found in Appendix 3.

Table 3. Coding framework adapted from Saeed and Kersten (2017).

| Economic indicators | Social indicators | Environmental indicators |
|---|---|---|
| E1/Stability and profitability | S1/Human rights and anti-corruption | EV1/Energy efficiency |
| E2/Income distribution | S2/Human resources | EV2/Material efficiency |
| E3/Market competitiveness | S3/Health and safety | EV3/Water management |
| E4/Sustainability expenditures | S4/Training and education | EV4/Waste management |
| | S5/Consumer issues | EV5/Emissions |
| | S6/Social compliance | EV6/Land use |
| | | EV7/Environmental compliance |
| | | EV8/Supplier assessment |

Following the prior conceptualisation, Figure 1 proposes a conceptual framework for analysing the management of CSCs under uncertainty.

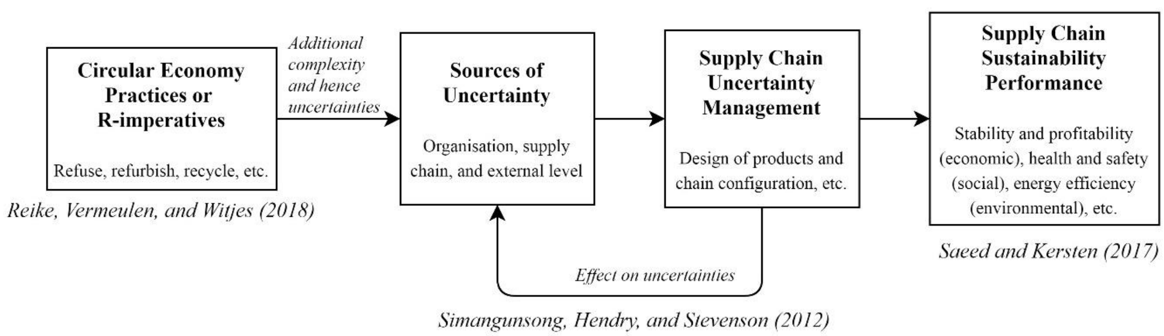


Figure 1. A conceptual framework for analysing the management of CSCs under uncertainty.

At first, the literature will be analysed in terms of whether CE practices add increased complexity to CSCs by following Reike, Vermeulen, and Witjes (2018). The uncertainties and uncertainty management strategies will be identified primarily by considering Simangunsong, Hendry, and Stevenson (2012). Then, the literature will be classified by considering the linkage between uncertainty management and SC sustainability performance whose framework is of Saeed and Kersten (2017). The combined CE practices, uncertainty management, and sustainability performance indicators will be used for the upcoming analysis.

## 3. Methodology

### *3.1. Conducting the review*

Systematic reviews can be used to refine and advance theory (Seuring et al. 2021) by mapping and consolidating a specific research field, thereby facilitating subsequent scholarly work to build onto this ground (Seuring and Gold 2012). As this technique is labour-intensive and time-consuming, Huff's (2009) recommendation became useful in the sense that before commencing the review process, the research boundaries and gaps were first outlined. This was validated by presenting an initial problematisation of the management of CSCs under uncertainty at international conferences in mid-September and early December 2019. Thereafter, Tranfield, Denyer, and Smart's (2003) systematic approach was adapted in three stages (Figure 2).

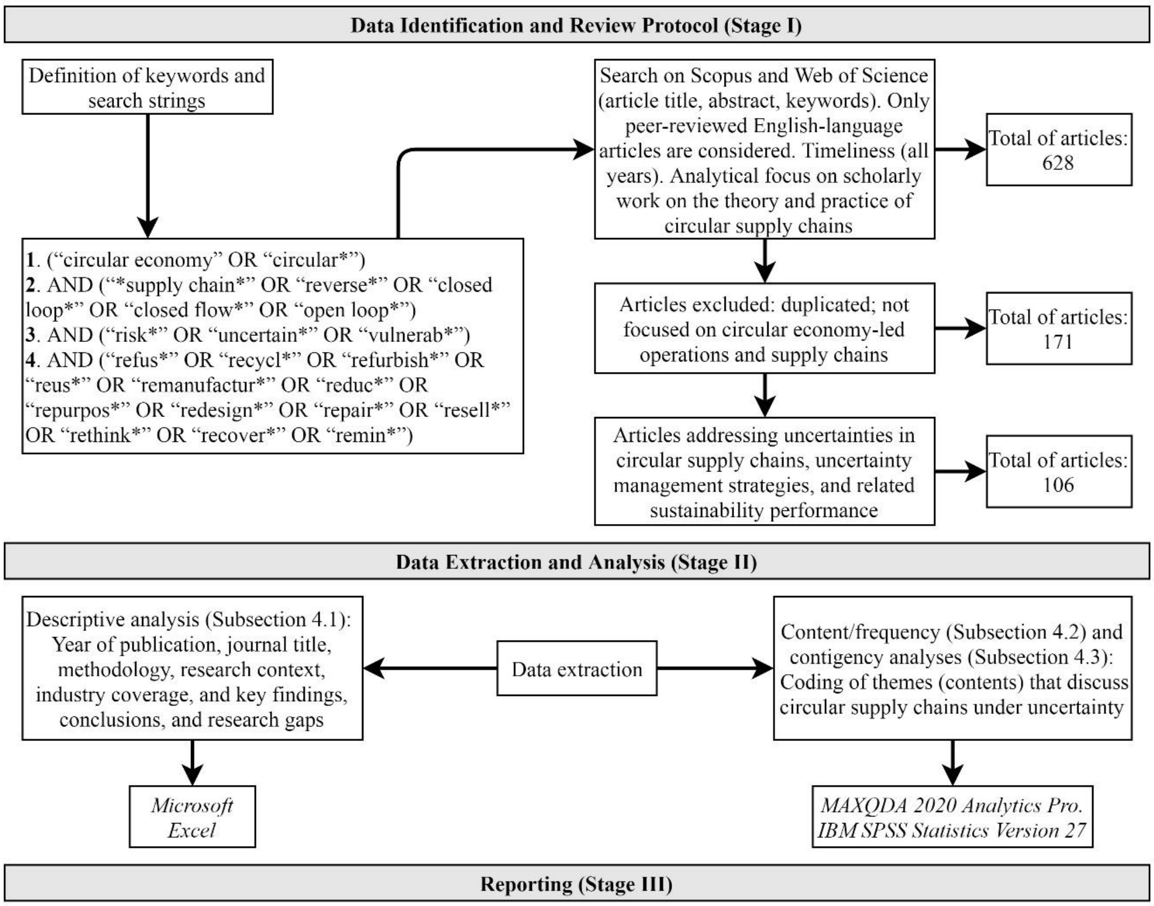


Figure 2. The review process, adapted from Tranfield, Denyer, and Smart (2003).

In Stage I, the keywords and search strings were defined. Hart (1998) affirms that a literature search can address the major issues and debates on a given topic. The literature search was conducted by the authors with the support of two independent researchers to minimise bias and errors. Following Thürer et al. (2020, 2438), the literature search was not carried out in 'a full-text database (such as EBSCO, Elsevier, ProQuest, Sage, Springer, Taylor & Francis, or Wilson) in a bid to avoid excluding any particular publisher from the search.' Rather, an abstract and citation database was used because this provides broad coverage across the different full-text databases. There are three major abstract and citation databases: Google Scholar, Scopus, and Web of Science. In this study, Google Scholar was not used for the search process given concerns about its suitability for research evaluation (Mongeon and Paul-Hus 2016). Therefore, Scopus and Web of Science were used because they are the main sources for abstract and citation data (Mongeon and Paul-Hus 2016). Scopus indexes over 23,452 peer-reviewed journals, and its key indexed publishers include, e.g. Elsevier, Springer, Wiley Blackwell, and Taylor & Francis (Elsevier 2020). In its core collection, Web of Science indexes articles and their references from over 21,100 peer-reviewed journals (Clarivate Analytics 2021). In keeping with Sauer and Seuring (2017), the search was operationalised using Boolean operators with combinations of search strings in Scopus and Web of Science databases, in which only peer-reviewed English language articles were considered. In Scopus, the search was applied to 'Title, Author Keywords, Abstract,' while in Web of Science 'Topic' (Title, Author Keywords, Abstract, Keyword Plus®) was used. The timelines encompassed all years, including all of 2020, as discussions on CE started before the 2000s (Ghisellini, Cialani, and Ulgiati 2016). Six hundred and twenty-eight articles were gathered during the initial search and abstract screening. As an intermediate result, duplicated articles and those not focused on CE-led operations and SCs were excluded, yielding 171 publications. Finally, the 171 full-text articles were thoroughly checked, and 106 were selected for further analysis, as they were considered relevant for answering the research questions of this review since they addressed at least one part of the theoretical framework presented in Figure 1. The articles selected for review are marked in the References with an asterisk symbol (*).

### *3.2. Data extraction and analysis*

In Stage II, descriptive information was retrieved from the selected papers ($N = 106$) and organised in Microsoft Excel to facilitate the identification of the formal characteristics and evolving trends in the reviewed literature (Durach, Kembro, and Wieland 2017; Seuring and Gold 2012). Then, the first author performed a content analysis on the papers against the deductively derived constructs shown in Tables 1, 2, and 3. The adopted deductive approach enabled a structured analysis and theory refinement via the use of comprehensive and validated frameworks (Seuring et al. 2021). The first author requested clarification from the research team in ambiguous cases to avoid biased interpretations of the analysed papers, which were coded with the original description and interpretation of the constructs to ensure construct validity (Saldaña 2009). The content analysis was conducted with one framework at a time to guarantee a consistent interpretation based on reflection and interaction with the material (Weber 1990). During this process, MAXQDA 2020 Analytics Pro was used to methodically classify and assign the contents to the constructs. Consequently, the precise organisation of constructs along with the totality of all categories in the shape of a coherent category system was of vital importance to the reliability of the analysis and reporting process (Kuckartz and Rädiker 2019). Following Seuring and Gold (2012) and Durach, Kembro, and Wieland (2017), the final coded material was intensely discussed among the authors and two independent researchers to reach an interrater agreement through a 'discursive alignment of interpretations.' If a different judgment emerged regarding the content-analysed material, it was individually assessed and resolved by gradually unravelling and consensually redrawing the analysis. Hence, this process increased the internal validity of the results. Theoretical abstraction and de-contextualisation provided a certain degree of generalisability and hence external validity to the results. Finally, a careful documentation of the entire review process ensured research transparency and replicability (Seuring and Gold 2012).

### *3.3. Frequency and contingency analyses*

The resulting data from the content analysis was first subjected to frequency analysis. This technique served as an analytical instrument for filling the R-imperatives, uncertainties, and sustainability performance indicators with details on the individual construct level. Methodologically, each construct evidenced in a paper was coded in a binary manner. Yawar and Seuring (2017, 628) acknowledged that frequency analysis is not only useful for identifying the most important issues but also for showing which issues have been neglected so far, and the frequency count of the constructs is expressed in percentage and is calculated using the formula below:

$$\text{Percentage of papers} = \frac{\text{No. of papers in which the construct is identified}}{\text{Total no. of papers}} \times 100$$

Moreover, contingency analysis was employed to identify associations from co-occurrences of R-imperatives, uncertainties, and sustainability performance indicators in the reviewed literature. The development of contingency analysis can be traced back to Osgood (1959), a key proponent of this technique (Krippendorff 2004; Mayring 2014). Mayring (2014) stressed that the objective of contingency analysis is to establish whether particular text elements occur with particular frequency in the same context and whether they are connected with one another in any way in the text, i.e. whether they are contingent. By identifying such contingencies, one may extract a structure of interrelated text elements from the analysed material. Many scholars have acknowledged that contingency analysis is a suitable technique for identifying association patterns between pairs of constructs, particularly in literature reviews that elaborate on interrelationships between two or more conceptual frameworks (Kache and Seuring 2014; Khalid and Seuring 2019; Rehman et al. 2020; Sauer, Orzes, and Davi 2021; Sauer and Seuring 2017; Siems, Land, and Seuring 2021; Troester and Hiete 2018; Zhu, Krikke, and Caniëls 2017). According to Gold, Seuring, and Beske (2010), contingency analysis identifies pairs of constructs that occur relatively more or less frequently together in one paper than the product of their single probabilities would suggest. Nevertheless, a positive association between two constructs does not necessarily correspond to a semantically positive one in a paper's argumentation. Therefore, the resulting association patterns need to be explained against the content-analysed material and theoretical background, whereby the researcher infers why these association patterns may have occurred (Gold, Seuring, and Beske 2010). Contingencies that are significantly above chance suggest the presence of associations, while contingencies that are significantly below chance suggest the presence of dissociations (Krippendorff 2004). Contrastingly, the frequencies of non-significant contingencies remain within the product of their single probabilities and thus represent relations of mainstream constructs, which are already revealed by the frequency analysis. This observation highlights a key limitation of contingency analysis: the technique may overlook certain relationships when inferences are provided post hoc.

Notwithstanding this limitation, employing contingency analysis in addition to content and frequency analyses may provide a better understanding of the constructs and their association patterns in the reviewed literature. While content and frequency analyses focus on a single code across different papers, contingency analysis enlarges the investigation to all potential code combinations across the entire paper sample that would otherwise not be conducted (Sauer, Orzes, and Davi  2021). Additionally, applying the standardised contingency analysis technique (Mayring 2014) enables a statistically sound justification of the association patterns. So, contingency analysis adds another analytical level to fill the gap and refine theory in CSC research in terms of R-imperatives, uncertainties, and sustainability performance indicators.

The first step in identifying statistically significant contingencies was calculating all possible pairs of constructs in IBM SPSS Statistics version 27. In this step, a contingency table was analysed using the Crosstabs function in SPSS. The strength of each pair of constructs was evaluated based on the phi-coefficient (φ), which was calculated using a chi-square test. Specifically, there were two quality measures: only constructs with frequencies of at least 10% of the base sample were considered (Khalid and Seuring 2019; Rehman et al. 2020), and the φ must be higher than 0.3 (Fleiss, Levin, and Paik 2003). Next, all identified contingencies were analysed in a visual model, which gives simultaneous representation to all identified contingencies (Osgood 1959). Finally, the identified contingencies were collated and interpreted accordingly (Mayring 2014). This process was conducted using literature evidence and theory-based interpretation to derive more precise information regarding each identified contingency.

In Stage III, the synthesis and reporting of the results were discussed with the authors' research team to revise and refine the results.

## 4. Results

This section presents the descriptive characteristics of the investigated topic and a detailed analysis of the content, frequency, and contingency results, hence populating the conceptual framework shown in Figure 1.

### *4.1. Descriptive results*

The number of articles published per year was 2 (2014), 2 (2015), 3 (2016), 5 (2017), 21 (2018), 35 (2019), and 38 (2020). There is a strong increase from 2017 onwards, so it can be argued that scholars have devoted significant attention to investigating the management of CSCs under uncertainty. If this trend persists, one may expect a high number of published papers in the foreseeable future.

Table 4 displays the most relevant journal titles regarding the number of publications. It underlines that CSCs are mainly investigated in journals explicitly positioned at the intersection of sustainability and SCM, while mainstream SCM does not play a significant role despite the relevance of the CE paradigm.

Table 4. Journal frequency.

| Journal title | Frequency | % |
|---|---|---|
| *Journal of Cleaner Production* | 30 | 28.30% |
| *International Journal of Production Research* | 9 | 8.49% |
| *Resources, Conservation & Recycling* | 9 | 8.49% |
| *Sustainability* | 6 | 5.66% |
| *International Journal of Production Economics* | 4 | 3.77% |
| *Management Decision* | 4 | 3.77% |
| *European Journal of Operational Research* | 3 | 2.83% |
| *Journal of Remanufacturing* | 3 | 2.83% |
| *Science of the Total Environment* | 3 | 2.83% |
| *Business Strategy and the Environment* | 2 | 1.89% |
| *Journal of Industrial Ecology* | 2 | 1.89% |
| *Production Planning & Control* | 2 | 1.89% |
| *Resources* | 2 | 1.89% |
| Journals with 1 article | 27 | 25.47% |
| **Total** | **106** | **100%** |

The articles were classified by research typology as well. As recommended by Wacker (1998), the classifying procedure concentrated on the predominant methodology used in the study. Thirty-nine articles fell under *analytical conceptual research*, which is represented by conceptual papers and literature reviews. Thirty-four drew upon *analytical mathematical research*, namely simulation and mathematical modelling. Nineteen articles adopted the *empirical case study* approach. Six articles employed *analytical statistical research* (models which were developed for future statistical tests) and six others, *empirical statistical research* (surveys). Two papers relied on *empirical experimental research* (experiments). One can see that academics have predominantly adopted conceptual research, followed by models that used deterministic or simulated data to draw conclusions. Moreover, there is relatively less work regarding case studies, integrated models for empirical statistical testing, surveys, and experiments. One critical implication of these findings is that future studies could adopt empirical methodologies to verify existing conceptual frameworks and analytical mathematical models and integrate theory. Nevertheless, much more research needs to be performed with multiple methodologies to explore the full potential of CSCs.

The analysis of the CE implementation by geographical region shows that Europe was considered in 29 articles, led by the United Kingdom (UK) (10 articles), France and the Netherlands (4 articles), and Italy and Poland (3 articles). Asia was mentioned in 16 articles, predominantly represented by China (8 articles), whilst North America was in 8 articles, in particular the United States (US) (7 articles). Africa (South Africa), Australia, and South America (Brazil) were considered by one article each. The CE implementation in Europe and the UK has been increasingly catalysed at the European policy level, while the British Ellen MacArthur Foundation has advocated the CE amongst business circles (Howard, Hopkinson, and Miemczyk 2019). The increased academic interest in investigating the CE in China is mainly attributed to the environmental, human health, and social problems caused by its rapid and continuous development patterns (Ghisellini, Cialani, and Ulgiati 2016). In this regard, the Chinese government has adopted the CE as a top-down approach, in which more environmentally responsible development strategies are encouraged at different levels (Geng and Doberstein 2008; Ghisellini, Cialani, and Ulgiati 2016). Hence, governments' legislation and push on CE can be of great importance for the transition towards CSCs. North America has started to gain scholarly attention, wherein the US is considered the biggest market for automotive remanufacturing (Kalverkamp 2018). Academics should contemplate the perspective of emerging economies as companies and SCs may lack a legal framework to achieve the appropriate level of CE development, hence requiring managerial capabilities to restructure business relations in highly uncertain environments and develop infrastructures which facilitate circularity (Silva et al. 2019).

In order to further comprehend the reviewed papers' industry coverage, the classification depicted by Rebs et al. (2018) was adopted, complemented with sectors that inductively emerged from the analysis. The top five industries were multiple (12 articles), automotive (11 articles), electronics (11 articles), construction (10 articles), and plastic (5 articles). With a frequency of 4 articles, agriculture, household appliances, and rare earth elements should be mentioned, followed by 3 articles concerning chemicals/pharmaceuticals, and 2 articles regarding biofuel, energy, food/beverages, furniture, and metal/mining. The apparel/textile, durable goods, glass, procurement, retail, tourism, and transportation sectors had a frequency of 1 article only, while 25 articles alluded to a generic setting. From a practical perspective, this result evidences the increasing business interest in implementing the CE into production systems and SCs (Ellen MacArthur Foundation 2021). It also points to the necessity of analysing the implementation of CSCs and related challenges in different sectors (Govindan and Hasanagic 2018; Khandelwal and Barua 2020; Tsolakis et al. 2019).

### *4.2. Results of content and frequency analyses*

This subsection provides insightful patterns and future research opportunities based on the reviewed literature.

*4.2.1. R-imperatives*

The frequency count of R-imperatives is provided in Figure 3.

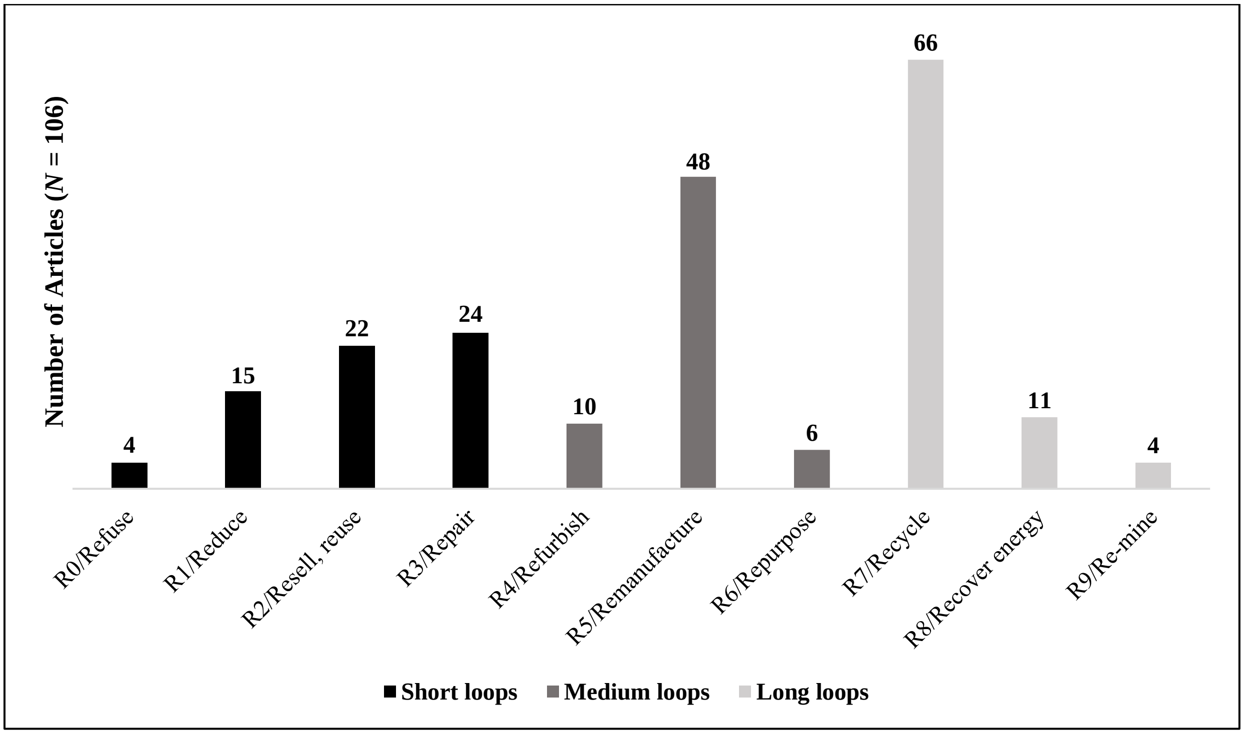


Figure 3. Frequency results of R-imperatives.

In short loops (R0–R3), *R3/Repair* was the most frequently studied R-imperative. This reveals its key role in extending the lifespan of products which can be repaired and hence used more than once to the same application (e.g. Sadrnia, Langarudi, and Sani 2020). Next, the analysis regarding *R1/Reduce* and *R2/Resell, reuse* revealed two gaps. First, Jabbour et al. (2019) noted that the results-oriented product-service system promotes significant dematerialisation because the focus is to deliver value without materialising it as a physical asset. This process may contribute to reducing material consumption by focusing on services rather than products, yet new capabilities, work procedures, and technology are necessary for organisations and SC operations to realise such potential in the CE (Jabbour et al. 2019). Second, further research could analyse how material reuse can be beneficial for firms, thus increasing manufacturers' confidence in the grade and quality of reused materials (Tingley, Cooper, and Cullen 2017). The R-imperative that received the least attention was *R0/Refuse*. This result confirms its lack of consideration when it comes to the role of organisations in refusing hazardous materials and components in product designs and manufacturing processes.

Regarding medium loops (R4–R6), *R5/Remanufacture* was the most frequently addressed R-imperative. It is recognised as one of the cornerstones of closed-loop systems in the CE and is gaining strategic importance among policymakers and businesses as a stepping stone towards environmental and financial sustainability (Ponte, Naim, and Syntetos 2019). Nevertheless, the implementation of remanufacturing systems still requires careful scrutiny to shed light on their dynamics and make their deployment widespread and sustainably viable. Future research can investigate the joint optimisation of pricing decisions along with capacity, inventory decisions for a hybrid manufacturing-remanufacturing system (Reddy and Kumar 2021). Future research may also consider the impact of economic incentives and legal policies on promoting the remanufacturing industry (Zhou and Yuen 2020). The less frequently analysed circularity strategies were *R4/Refurbish* and *R6/Repurpose*. First, refurbishment networks have faced uncertainties due to the lack of technical capabilities, skilled people, and quality standards as well as consumers' preference for new products (Govindan and Hasanagic 2018; Van Weelden, Mugge, and Bakker 2016). Second, there has been business interest around repurposing due to financial gains and social opportunities for entrepreneurs who can build partnerships with customers and other companies (Veleva and Bodkin 2018). Academics could assess the sustainability impacts of refurbishing and repurposing to leverage their implementation at businesses and hence foster circularity in CSCs.

In terms of long loops (R7–R9), *R7/Recycle* was the most quoted R-imperative (Luo et al. 2019; Machacek et al. 2015; Machacek, Richter, and Lane 2017; Rogetzer, Silbermayr, and Jammernegg 2019; Tan and Guo 2019). It has been argued that the recycling of critical materials from end-of-life and end-of-use products will eventually reduce the need for mining raw materials (Lapko et al. 2019). Scholars have highlighted the role of digital technologies in effectively managing recycling systems (Nascimento et al. 2019; Sandvik and Stubbs 2019; Veleva and Bodkin 2018) and appropriate mechanisms, e.g. SCM, to establish effective waste management and recycling infrastructures for discarded products (Tansel 2020). Nevertheless, it would be interesting to understand how novel product designs can reduce the demand for recycling (De Angelis, Howard, and Miemczyk 2018). According to Prakash et al. (2021), the use of recycled material as an alternative constituent material in products replacing natural aggregate, if done at an industrial scale, can expose the SC to several issues, such as demand and supply uncertainties.

*R8/Recover energy* and *R9/Re-mine* received little attention in the reviewed literature. Paes et al. (2019) provided a comprehensive analysis of energy recovery via bioenergy and biofuels SCs. The lack of scholarly attention to re-mining confirms that this R-imperative is still ignored in the retrieval of materials after the landfilling phase. Technical studies are suggested to classify the uncertainties of urban mining according to technical, economic, and societal criteria (Habib 2019).

### *4.2.2. Uncertainties*

Figure 4 shows the frequency count of uncertainties.

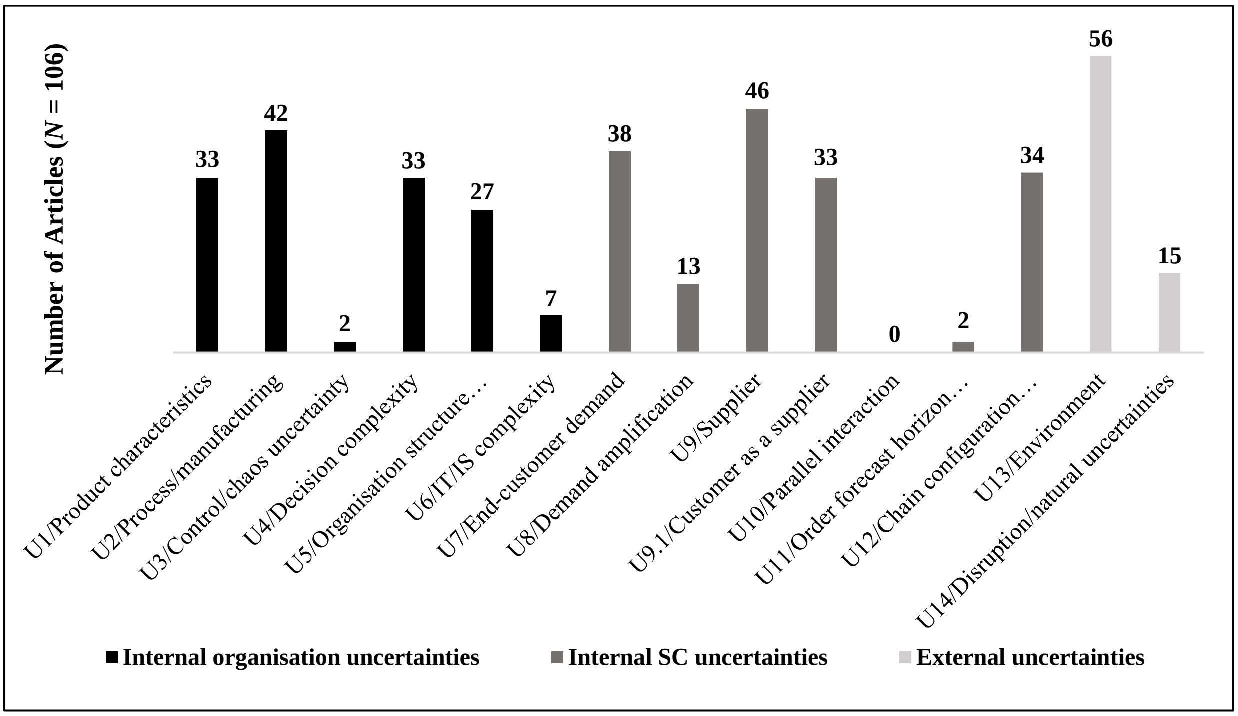


Figure 4. Frequency results of uncertainties.

The internal organisation uncertainties *U2/Process/manufacturing*, *U1/Product characteristics*, *U4/Decision complexity, and U5/Organisation structure and human behaviour* attracted significant academic attention. Regarding *U2/Process/manufacturing*, CE-inspired operations are susceptible to technical difficulties in dealing with recycled materials (Barbaritano, Bravi, and Savelli 2019) and disassembly of returns (Bag, Gupta, and Foropon 2019). For *U1/Product characteristics*, complex product characteristics and packaging design will prevent proper product recovery, such as reuse and recycling (Veleva and Bodkin 2018). The result concerning *U4/Decision complexity* demonstrates that conflicting goals often hinder the CE implementation in organisations, thereby increasing cost and time uncertainties (e.g. Akinade and Oyedele 2019). For *U5/Organisation structure and human behaviour*, longitudinal case studies could shed light on organisational cultural resistivity to implement the CE (Werning and Spinler 2020). The uncertainties which received less attention but pinpointed research gaps are *U6/IT/IS complexity* and *U3/Control/chaos uncertainty*. These gaps are as follows. Jabbour et al. (2018) found that organisations might face difficulties in integrating IT/IS systems between SC partners and lack technical knowledge of the CE cycles and the so-called Industry 4.0 technologies like the Internet of Things, Cloud Manufacturing, and Additive Manufacturing (3D printing). In-depth case studies should be conducted to identify potential organisational limitations concerning the implementation of Industry 4.0 technologies and propose ways to overcome them (Kouhizadeh, Sarkis, and Zhu 2019). Based on the analysed literature, the low frequency concerning *U3/Control/chaos uncertainty* points to the necessity for future empirical investigation. In this regard, control uncertainty was found to disrupt remanufacturing processes due to issues in material requirements planning systems (Kurilova-Palisaitiene, Sundin, and Poksinska 2018).

In terms of internal SC uncertainties, great attention was given to *U9/Supplier*, *U9.1/Customer as a supplier*, *U7/End-customer demand*, and *U12/Chain configuration, infrastructure, and facilities*. Note that uncertainties related to quality, timing, and availability of supply are so far the most common issues which can affect circular operations (Bag, Gupta, and Foropon 2019; Islam and Huda 2018; Liao et al. 2020; Tsiliyannis 2016). These uncertainties also affect product returns in reverse SCs (Tsiliyannis 2019; Tsiliyannis 2020). The increased interest in *U7/End-customer demand* uncertainty may refer to consumers' willingness to pay for CE products, as they might have a poor opinion about their quality and performance (Low and Ng 2018; Peng et al. 2020; Wang and Hazen 2016). A research lacuna regarding *U12/Chain configuration, infrastructure, and facilities* points to CSC network design studies which consider the inventory-location-routing problem (Govindan et al. 2020). Moreover, a research gap remains regarding *U8/Demand amplification* in the CE for which, amongst others, Braz et al. (2018) provided a systematic review of 56 papers and found that bullwhip effect features are present in both closed and forward SCs and whose causes are demand and information distortion; however, the quality of the returns is different and adds further complexity to CLSCs, thus causing higher variability and the bullwhip effect. Qualitative empirical studies should focus on the strategic and managerial causes of the bullwhip effect and how to mitigate it, considering the different contexts and the different types of SCs in the CE. In the analysed literature, *U11/Order forecast horizon/lead-time gap* received little attention (e.g. Rijal, Gautam, and LeBel [2020]). Consequently, there is still room for research to analyse the critical causes of forecasting errors in CSCs. *U10/Parallel interaction* was not identified in the reviewed papers, thereby pointing out a gap which can be investigated by future empirical research in the CE.

At the external level, *U13/Environment* was the most frequently analysed uncertainty (Daou et al. 2020). For example, scholars pinpointed fragmented and non-existent institutional frameworks (De Jesus and Mendonça 2018) and external factors that challenge the transition towards the CE, e.g. legal barriers to market exit or entry (Veleva and Bodkin 2018). *U14/Disruption/natural uncertainties* were acknowledged as an imperative research topic due to the current scenario of climate change (e.g. Yazdani, Gonzalez, and Chatterjee 2021). Bleischwitz (2020) suggested that bottom-up studies and comparative assessments could generate strategic options and pathways for key actors in CSCs by considering climate change adaptation and resource implications.

*4.2.3. Uncertainty management strategies*

Figure 5 provides the frequency count of uncertainty management strategies (i.e. reducing and coping with uncertainty strategies).

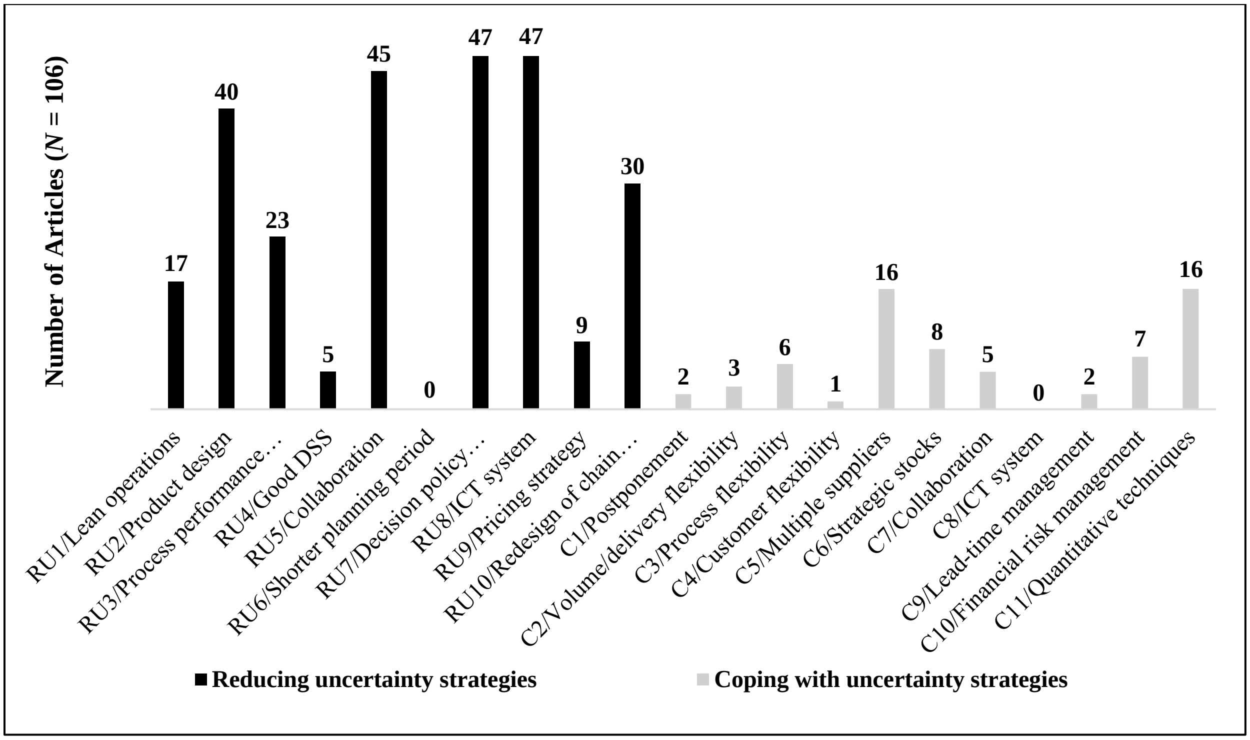


Figure 5. Frequency results regarding uncertainty management strategies.

One can see a great emphasis on reducing management strategies, particularly *RU7/Decision policy and procedures*, *RU8/ICT system*, *RU5/Collaboration*, *RU2/Product design*, *RU10/Redesign of chain configuration or infrastructure*, *RU3/Process performance measurement*, and *RU1/Lean operations*. Some patterns and gaps in this regard are as follows. First, managers can take advantage of research showing how decision-making tasks and unnecessary steps can be mitigated by decision policy and procedures (Kurilova-Palisaitiene, Sundin, and Poksinska 2018), thereby enhancing the operational performance of CSCs. Second, there is great interest in the role of technologies in reducing uncertainties in CSCs (Ge and Jackson 2014)—e.g. 3D printers to manufacture modules, parts, and even products on demand with minimised demand uncertainty and logistics costs (Nascimento et al. 2019). Under *RU5/Collaboration*, an interesting gap refers to the application of e-procurement to facilitate information sharing and reduce uncertainties. Kalverkamp (2018) noted that more research is needed to understand how e-procurement tools can reduce the shortage of cores as well as the potential for e-procurement in other reuse industries, such as electronics. By exchanging waste, companies may benefit from, on the one hand, profits, green jobs, and cost savings. On the other hand, they may face additional costs (e.g. waste recycling and transportation costs) and uncertainties concerning demand and waste quantities which cause uncertainties on economic benefits. For Yazan and Fraccascia (2020), this complexity hinders the development of waste markets, in which companies could enhance economic and environmental opportunities. So, they proposed a decision-support model for companies so that they are able to profile their situation and develop cooperation strategies during the run of real-time negotiations. As a potential gap, the benefit-sharing schemes should also be analysed in future research, particularly from SC design and contracting perspectives. These schemes refer to designing contracts that specify the conditions and economic benefits to be shared between the parties involved in the exchange. For *RU2/Product design*, a practical gap concerns the development of a product substitution framework to support the product design activity (Peck, Kandachar, and Tempelman 2015). This framework should contemplate the range of materials and components used in CE products, allowing for easy replacement when an organisation faces supply challenges. Krystofik et al. (2018) studied adaptative remanufacturing for multiple life cycles in the office furniture industry and advised more studies of market and technology barriers in other product sectors to identify opportunities for an improved product design strategy. The use of modular design can facilitate refurbishment and the ability to repair. In order to reduce design challenges (e.g. materials and components are not designed to be reused after end-of-life) and materials selection (e.g. technical challenges for material recovery) in the construction industry, Hossain et al. (2020) respectively considered necessary to adopt design-for-adaptability guidelines for configuration and interaction of different elements (e.g. modular or prefabricated elements) and encourage the modular design of components/elements to ease the material selection process during design. Regarding the redesign of SCs, there is still little information on the practical side of how to redesign linear SCs for the CE and hence introduce them in a real-world context. This gap evidences that the points of manufacture and recovery activities are in dispersed and very distant regions (De Angelis, Howard, and Miemczyk 2018). For *RU3/Process performance measurement*, future research could show how strategic planning tools such as the balanced scorecard can be beneficial when quantity uncertainty arises in the development of reverse logistics networks (Islam and Huda 2018). Through the lens of industrial ecology, case studies could provide further empirical evidence of how companies decrease production costs, material criticality concerns, and reduced waste by adopting lean manufacturing (Gaustad et al. 2018). The least studied reducing uncertainty strategies are *RU9/Pricing strategy* and *RU4/DSS*. Regarding *RU9/Pricing strategy*, Liao (2018) indicated that it could be beneficial for manufacturers to charge appropriate prices to attract price-sensitive and loss-averse consumers to prefer remanufactured products; research can identify the impact of this strategy in competing markets. Lechner and Reimann (2020) suggested that integrated *RU4/DSS* in reverse logistics and CLSCs is limited and therefore provides research opportunities in this field as a crucial aspect for managers to act sustainably. The analysis revealed no evidence of *RU6/Shorter planning period* in the reviewed articles, so future research may navigate into this topic.

*C5/Multiple suppliers* and *C11/Quantitative techniques* are the two coping with uncertainty strategies which seem to be promising topics. Regarding *C5/Multiple suppliers*, Fraccascia et al. (2020) suggested investigating redundancy strategies from a dynamic perspective, i.e. companies can vary their redundancy strategy over time considering the heterogeneous character in symbiotic networks. For *C11/Quantitative techniques*, it has been argued that operations research techniques can be paramount in accurately estimating the returns volume in the CLSC, which faces new challenges that must be overcome in order to strengthen the shift from a linear to a CE model (Ponte, Naim, and Syntetos 2020). In CLSCs, Tsiliyannis (2018) argued that an emerging challenge is real-time forecasting of product return flow, age distribution, stock, and end-of-life flow under heterogeneous variability in return distribution, without explicitly employing mean return/end-of-life distributions in the forecasting scheme. The least investigated coping with uncertainty strategies were *C6/Strategic stocks*, *C10/Financial risk management*, *C3/Process flexibility*, *C7/Collaboration*, *C2/Volume/delivery flexibility*, *C1/Postponement*, *C9/Lead-time management*, and *C4/Customer flexibility*, yet the analysis revealed the following insights and gaps. In the CE, increasing stocks of resources to cope with uncertainties is a question that deserves careful consideration. This practice can generate additional storage costs for companies (Rakhshan et al. 2020). Scholars might analyse how financial instruments such as market hedging, long-term contracts, and funds can minimise the risk of investment projects executed in compliance with the CE (Gaustad et al. 2018; Górecki et al. 2019). Regarding *C3/Process flexibility*, it should be noted that highly qualified staff is vital to coping with the requirements of varied and flexible services. Adopting such a flexible orientation is also crucial in a remanufacturing environment (Bag, Gupta, and Foropon 2019). Future research could consider process flexibility regarding other R-imperatives, investigating how a flexible orientation affects operational performance vis-à-vis the required manufacturing layout and multi-skilled workforce. *C7/Collaboration* fosters information sharing between SC actors but does not mitigate the uncertainty at its source. In the CLSC context, enabling downstream information transparency was found to improve the manufacturers' dynamic performance. Additionally, it allows the manufacturer to obtain significant benefits from increased return rates in the form of reduced order and inventory variability. Nonetheless, there might be a slight increase in the average inventory (Dominguez, Cannella, Ponte, et al. 2020). Scholars could offer an in-depth understanding of *C2/Volume/delivery flexibility* by considering CE-target performances in different industries as the flexibility of each SC function is difficult to encompass complete system flexibility (Bai et al. 2020). They may investigate the features of *C1/Postponement* by considering the nature and impact of risks and uncertainties faced in the CE (De Angelis, Howard, and Miemczyk 2018). *C4/Customer flexibility* may be a fruitful topic to be investigated in CSC research. This coping with uncertainty strategy refers to exploiting relationships with customers that are less sensitive to uncertainty issues and can adapt their plans. This issue could be investigated from a repurposing perspective, which transforms discarded goods or materials to a new purpose or use, different from what was initially designed or planned—e.g. repurposing waste and by-products for animal feed (Dossa et al. 2020). This practice would require the organisation's flexibility to explore relationships with different actors and industries that absorb low-quality products, waste, and by-products. It must be highlighted that *C8/ICT system* was not identified in the review literature. Future studies could address this coping with uncertainty strategy by considering the CSC domain.

#### *4.2.4. Sustainability performance indicators*

The frequency results of sustainability performance indicators are set out in Figure 6.

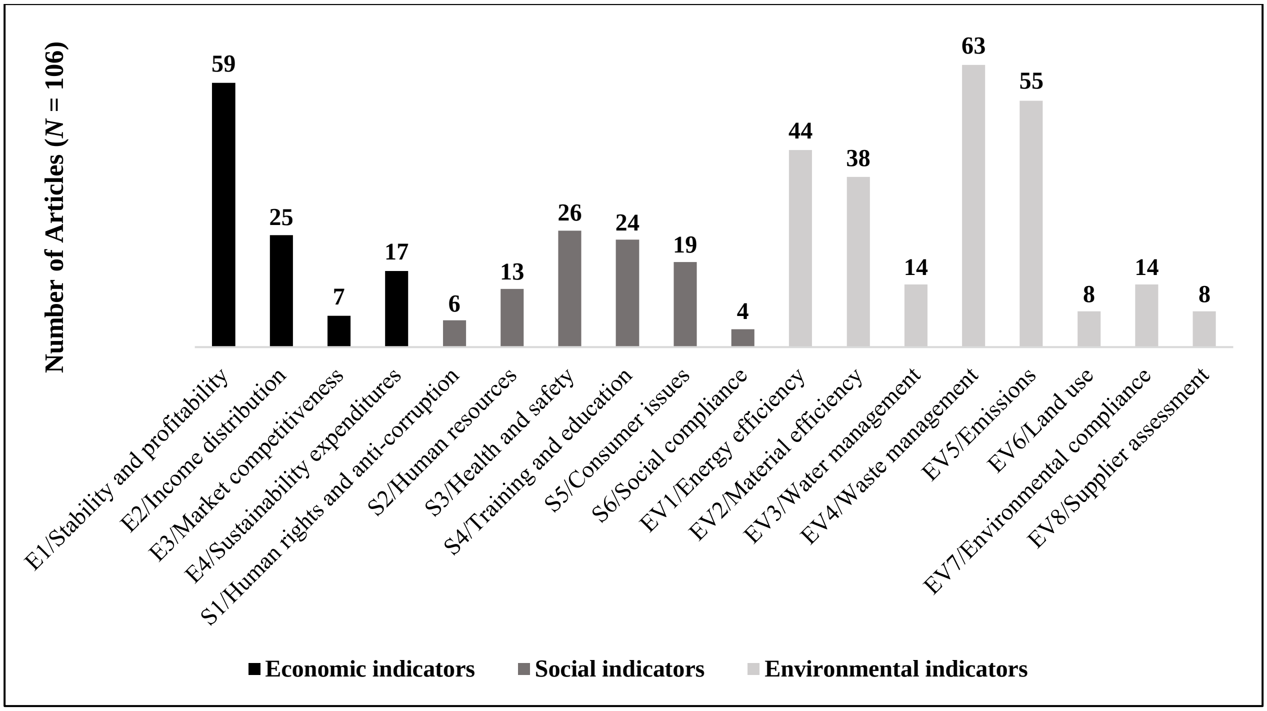


Figure 6. Frequency results concerning sustainability performance indicators.

*E1/Stability and profitability* were the most frequent economic indicators considered in the analysed literature (Habibi et al. 2019; Hao et al. 2018; Lin et al. 2018). In open- and closed-loop network-design studies, Islam and Huda (2018, 60) identified that 'the economic dimension was given the highest priority in designing the networks, whereas social and environmental issues are poorly addressed.' Another frequent economic indicator was *E2/Income distribution*, which revealed an interesting gap. The implementation of circular manufacturing was found to develop business networks that contribute to generating jobs (Bressanelli, Perona, and Saccani 2019b; Govindan and Hasanagic 2018; Kazancoglu et al. 2020; Nascimento et al. 2019). This indicates that CE is more labour intensive due to the diversified activities performed by companies (collecting, processing, manufacturing, and selling products) and their need for consulting services such as regulatory advice. However, more empirical data is needed to validate this assertion and offer rich evidence about the CE impact in terms of income generation and distribution. *E4/Sustainability expenditures* are needed to promote and support research and development (R&D), training, and education in the CE, thereby increasing awareness and creating the required skill base (De Jesus and Mendonça 2018). Hosseini-Motlagh, Nami, and Farshadfar (2020) studied the challenges of a pharmaceutical case that implements CE principles through a closed-loop system design, takes sustainability issues into account, and seeks effective management of collection disruption. The case includes a manufacturer that invests in green R&D and two retailers competing on corporate social responsibility efforts to boost the collection amount and market demand. Specifically, the analysed company applies green R&D (e.g. considering environmental issues in drug formulation, manufacturing, and packaging) as an eco-friendly policy that affects the market demand. According to Barbaritano, Bravi, and Savelli (2019), technology and investments in R&D play a crucial role in CE development as they allow the implementation of new innovative and creative processes by companies. However, their actual management requires financial investments that could sometimes discourage firms, especially those of small size that usually face resource scarcity issues. In the reviewed literature, *E3/Market competitiveness* received scant attention. Agyemang et al. (2019) found that many companies are keen to adopt CE initiatives in pursuit of the shareholders' benefit, to increase market share, and to maximise profits through increased competitiveness and overall sales.

The frequency analysis revealed that social indicators were scantily addressed, yet some interesting patterns could be observed. Regarding *S3/Health and safety*, Barbaritano, Bravi, and Savelli (2019) found that one Italian furniture company has proactively adopted the OHSAS 18001:2007 to control organisational health and safety issues as a CE practice. According to Osobajo et al. (2020), a potential area for future CE research in the construction industry refers to health and safety management issues considering the number of fatalities in the industry. For *S4/Training and education*, firms in the CE context need to consider how to prepare those entering the workforce with 3D printing skills and how to ensure that those already in the workforce can extend their existing capabilities (Despeisse et al. 2017). In terms of *S5/Consumer issues*, companies need to consider consumer evaluations about CE products to protect their brand and reputation (Ciulli, Kolk, and Boe-Lillegraven 2020; Singhal, Jena, and Tripathy 2019; Singhal, Tripathy, and Jena 2019). The least studied social indicators were *S2/Human resources*, *S1/Human rights and anti-corruption*, and *S6/Social compliance*. Regarding *S2/Human resources*, Jones and Wynn (2019) suggested that SCs in the tourism and hospitality industry could benefit from in-depth studies that seek to understand how CE principles are embraced and related to employees' engagement and understanding of the concept. For *S1/Human rights and anti-corruption*, Shemfe, Gadkari, and Sadhukhan (2018) offered a comprehensive analysis of social issues inherent in the SC of requisite components of a technological solution for resource recovery. Under the increasing pressure of material criticality, *S6/Social compliance* may be crucial for assessing the stages in the life cycle of minerals when people matter: at the cradle when social standards are required, in SCs for management decisions, and after processing minerals into products when purchasing decisions are being made, and sharing and reuse concepts are applied (Bleischwitz 2020).

*EV4/Waste management*, *EV5/Emissions*, *EV1/Energy efficiency*, and *EV2/Material efficiency* were the most frequently quoted environmental indicators, yet there are crucial future research opportunities. Schraven et al. (2019) argued that a different perspective should be integrated into understanding *EV4/Waste management*. Rather than landfilling or incinerating waste, companies could create more supply and demand for waste as input. Empirical case studies could investigate how organisations perceive waste as valuable resources in the CE. Further research could be conducted on the intersection between the CE and the *EV5/Emissions* reduction paradigm, via greenhouse gas emissions (Kondo, Kinoshita, and Yamada 2019; Pishchulov et al. 2018). Besides, scholars could assess the impact of recovery activities in terms of CO2 emissions (Ren et al. 2020)—e.g. Van Loon and Van Wassenhove (2018) showed that the production of new products can result in more CO2 emissions, whereas remanufacturing has a positive effect on the environment. *EV1/Energy efficiency* demands further scrutiny of recovery activities for which Vogtlander et al. (2017) claimed that remanufactured products employ substantially less primary raw materials, but some products (e.g. cars, refrigerators) demand high amounts of energy to be remanufactured; consequently, managers need to pay attention to functional recovery, physical appearance, and a modern approach to manufacturing that is more eco-efficient than the technology of the past. *EV2/Material efficiency* should be assessed in consonance with reduced generation of industrial waste and consumption of resources, energy, and carbon emissions in different industries (Farooque et al. 2019). The least studied environmental indicators were *EV3/Water management*, *EV7/Environmental compliance*, *EV6/Land use*, and *EV8/Supplier assessment*, but the analysis of these topics revealed existing lacunae. Contributions linking *EV3/Water management* to circular operations could be adapted into various industries in the CE (Didenko, Klochkov, and Skripnuk 2018). Large-scale surveys may explore the motivating factors related to the adoption of voluntary standards and certification of *EV7/Environmental compliance* in CE (Barbaritano, Bravi, and Savelli 2019). *EV6/Land use* was found to be a common indicator in the tourism and hospitality industry (Jones and Wynn 2019). It would be interesting to address land management issues in different production sectors in the CE, as the misuse of land can negatively impact the ecological configuration of companies and SCs (De Souza, Bloemhof-Ruwaard, and Borsato 2019). Govindan et al. (2020) observed that further research could integrate circular specifications into *EV8/Supplier assessment*. *EV8/Supplier assessment* and environmental influence are two less considered elements in SC network modelling that could be interesting for future research (Islam and Huda 2018).

### ***4.3. Contingency results***

Contingency analysis adds substantial value to the previous qualitative content analysis. It yields connections between the constructs just described and identifies hot topics and research gaps in the reviewed literature. Here, the theoretical interpretation of the observed connections is provided to interlink R-imperatives with uncertainty management and sustainability performance indicators. The statistical results related to contingency analysis are given in Appendix 4, and the connections between constructs are illustrated in Figures 7, 8, 9, and 10. Logical contingencies are shortly explained in the text.

#### *4.3.1. Managing uncertainties in CSCs*

Twenty-three contingencies regarding uncertainty management are shown in Figure 7.

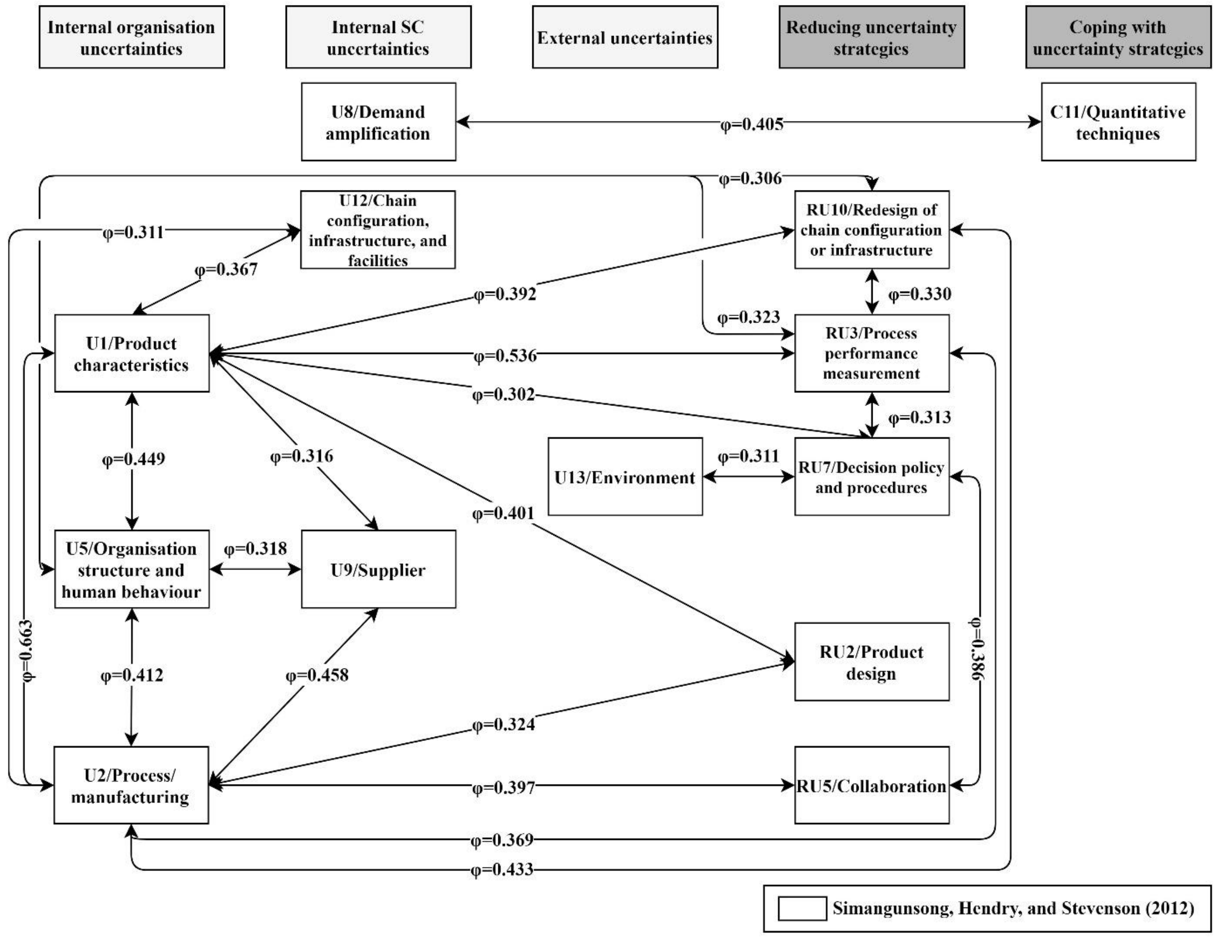


Figure 7. Contingencies between uncertainties and uncertainty management strategies.

*U1/Product characteristics* uncertainty is connected to four uncertainties; the strongest contingency is between *U1/Product characteristics* and *U2/Process/manufacturing* (φ=.663). It can be inferred from the analysed literature that intricate product design poses operational challenges to manufacturers. For example, Lapko et al. (2019) argued that the small concentration and complex mixes of materials affect the thermodynamic viability for recycling processes. The contingency—*U1/Product characteristics* and *U5/Organisation structure and human behaviour*—highlights that resistance to change and the lack of perception between interested parties about the characteristics of CE products may impede the successful CE implementation in organisations. Capacity gaps such as money, time, and resources are acknowledged as critical factors in this regard (Velenturf and Jopson 2019). An interesting insight was observed for the contingency between *U1/Product characteristics* and *U12/Chain configuration, infrastructure, and facilities*.

According to Tansel (2020), the lack of appropriate infrastructure for collection and disassembly of discarded goods for materials recovery increases the stress on available resources and the likelihood of contamination of water supplies and soil and potential health effects due to exposure to toxic and hazardous compounds. *U1/Product characteristics* uncertainty is connected to *U9/Supplier*, pinpointing the inaccurate suppliers' information sharing on the characteristics of MCPs primarily due to intellectual property concerns. A critical gap refers to intellectual property rights. Shi, Zhou, and Zhu (2019) identified the barriers of a closed-loop cartridge remanufacturing SC for urban waste recovery governance in China. Two elemental barriers were identified at the enterprise level, namely restrictions for the use of remanufactured cartridges by original manufacturers of new cartridges and lack of self-owned intellectual property and innovative technology patents. The authors argued that the gathered data can be still not enough to portray a whole remanufacturing SC. Add to this observation that 'the implications of intellectual property rights on the strategic management of remanufacturing in a global perspective remain underdeveloped and unexamined' (Kurilova-Palisaitiene, Sundin, and Poksinska 2018, 3229). Three contingencies are related to *U2/Process/manufacturing*, of which the linkage between *U2/Process/manufacturing* and *U9/Supplier* is the strongest ($\varphi$=.458). In this regard, the uncertain quantity, quality, and timing of inputs can complicate or delay the manufacturing process (e.g. Islam and Huda 2018). Another contingency is observed between *U2/Process/manufacturing* and *U5/Organisation structure and human behaviour*. It shows that organisations may be reluctant to make profound changes to their SC operations owing to several reasons, e.g. organisation culture of risk aversion, lack of training and technical support, lack of consideration for design for disassembly (Frost et al. 2020), and stakeholders' linear mindset (Mańkowska, Kotowska, and Pluciński 2020). Some of the required changes in SC operations for the CE demand financial investments, which can be a hurdle for under-capitalised companies. Regarding *U2/Process/manufacturing* and *U12/Chain configuration, infrastructure, and facilities*, manufacturers may implement production, planning, and control to coordinate CE efforts in designing production processes, distribution, and recovery activities at the SC level. For the contingency between *U5/Organisation structure and human behaviour* and *U9/Supplier*, it is interesting to note the necessity to investigate how risk-averse and risk-taker measures affect the entire SC (Baptista et al. 2019).

The linkage between uncertainty and uncertainty management strategies are discussed as follows. *U1/Product characteristics* uncertainty has four contingencies. The strongest one appears between *U1/Product characteristics* and *RU3/Process performance measurement* (φ=.536). This contingency is unsurprising but might become relevant if academics adopt the environmental, economic, and social sustainability dimensions to evaluate mix specification, packaging, and product life cycle in the CE. Another contingency is observed between *U1/Product characteristics* and *RU2/Product design*. For instance, Krystofik et al. (2018) argued that adaptive remanufacturing offers a flexibility that enables market viability even given current preferences that favour linear product flow models. The ability to adapt the design of incoming end-of-life products enables remanufacturers to fulfil the demand for a product even if the supply of that product's original equipment manufacturer core is uncertain—e.g. while the type, condition, and availability of particular office workspace product cores are unavoidably variable, adaptive remanufacturing capabilities may allow the remanufacturer to adapt cores from similar, non-identical systems in order to continue producing and offering the favoured product. Conversely, by allowing the creation of new product types from a given core family, adaptive remanufacturing skills can allow remanufacturers to diversify product offerings even if the supply of cores is nearly homogeneous. Thus, adaptive remanufacturing provides a degree of insulation against uncertainties in the office furniture industry, lending economic viability under present market structures. Krystofik et al. (2018) stressed that while this viability is critical to succeeding in new markets, adaptive remanufacturing also holds promise to serve as a transformative product design strategy in pursuit of a more comprehensive CE. *U1/Product characteristics* uncertainty is connected to *RU10/Redesign of chain configuration or infrastructure*, highlighting the necessity of rethinking the SC to deal with CE products via repairing, refurbishment, remanufacturing, and recycling networks. In this regard, key performance indicators and standards may be tantamount to ensure the quality of products and processes (*RU3/Process performance measurement* and *RU10/Redesign of chain configuration or infrastructure*). At a tactical level, circular operations will likely require decision policies and procedures to assist firms in designing, manufacturing, and recovering CE products (*U1/Product characteristics* and *RU7/Decision policy and procedures*). *U2/Process/manufacturing* has four contingencies, of which the strongest occurs between *U2/Process/manufacturing* and *RU10/Redesign of chain configuration or infrastructure* (φ=.433). Interestingly, this contingency points to the role of integrating circular operations into localised value chains. There is considerable potential for SC integration in the surrounding geographic area and the potential to contribute positively to biodiversity, animal welfare, and local employment in the CE (Colley et al. 2020). Santander et al. (2020) explored the economic and environmental feasibility of CLSC network for local and distributed plastic recycling for 3D printing via a mixed integer linear programming model. The authors noted that uncertainty regarding available plastic waste, and the optimal location of one or many recycling facilities in accordance with the capacities of recycling facilities, should be considered in the model. Another revelatory contingency is observed between *U2/Process/manufacturing* and *RU5/Collaboration*. SC operations for the CE—including, for example, reverse logistics and CLSCs for value recovery—require an integrated approach to the SC, where suppliers and buyers work collaboratively within and across the SC to accomplish the transition to CSCs and circular business models. In a case study of hard disk drives and rare-earth magnets, Frost et al. (2020) pointed out that circular business models require close collaboration among multiple stakeholders globally due to the distributed nature of materials supply, hard disk drives manufacturing, and end-user consumption. Borrello et al. (2020) argued that due to the challenge to engage consumers in novel business models based on CSCs, policies should support circular business models in which the customer relation component is tailored to customers' needs. *U2/Process/manufacturing* is connected to *RU3/Process performance measurement*, which is contingent on *RU7/Decision policy and procedures*. In the construction industry, a remarkable instance is developing standard test procedures to test, evaluate, and certify the recovered building components, which can improve the stakeholders' perception of the recovered building components (Rakhshan et al. 2020). Such standards and guidelines can address the reported concerns and resistance in the construction sector against the recovered building components and help develop a reuse market by offering quality products (Rakhshan et al. 2020). Furthermore, the changes in the design of housing and its components in future may be another foreseeable challenge for the manufacturer who remade the components (Hossain et al. 2020) (*U2/Process/manufacturing* and *RU2/Product design*). *U5/Organisation structure and human behaviour* uncertainty is connected to *RU3/Process performance measurement* and *RU10/Redesign of chain configuration or infrastructure*. This twofold contingency is unsurprising yet reinforces the necessity of monitoring and linking employee performance with SC objectives to reduce behavioural issues and support the change towards CSCs. Regarding the contingency between *U8/Demand amplification* and *C11/Quantitative techniques*, it should be noted that managers can cope with demand amplification by using forecasting techniques. However, they need to be aware of the leading causes of the bullwhip effect to employ adequate forecasting countermeasures. The contingency—*U13/Environment* and *RU7/Decision policy and procedures*—may refer to the potential advantages for firms dealing with external uncertainties based on strategic, responsive, and well-designed decisions. Bai et al. (2020) argued that strict environmental regulations and increased society green concerns might cause companies to adopt flexible measures to become more CE capable, thus leading to satisfied customers at low costs. The contingency between *RU5/Collaboration* and *RU7/Decision policy and procedures* reveals an interesting pattern. For example, Sandvik and Stubbs (2019) found that circular fashion SCs in Scandinavia have pursued collaboration with various stakeholders for enabling textile recycling, but importantly, they have adopted systematic procedures in the recycling process in order to enhance its quality and performance.

### *4.3.2. R-imperatives and uncertainty management in CSCs*

Figure 8 shows six contingencies regarding R-imperatives and uncertainty management.

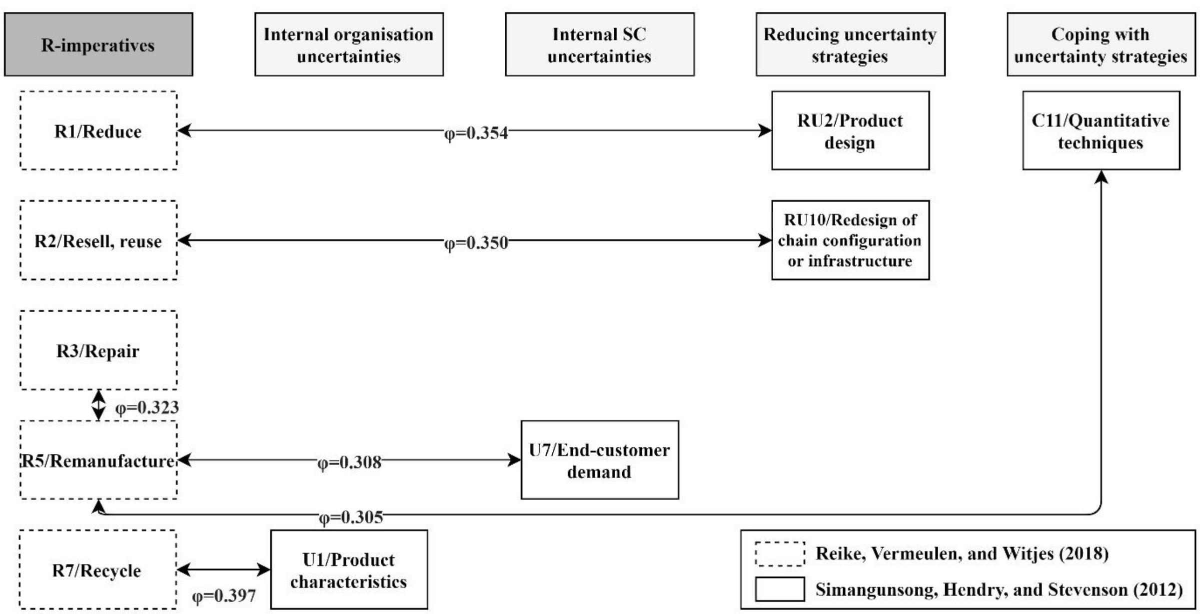


Figure 8. Contingencies between R-imperatives and uncertainty management.

The contingency between *R1/Reduce* and *RU2/Product design* reveals that this R-imperative can inspire managers in making product life cycles and SC operations more sustainable by using fewer resources. Kuo et al. (2019) observed that the European Commission's Packaging and Packaging Waste established important environmental goals related to improving the efficiency, safety, and convenience of logistics activities (i.e. product marketing, material handling, warehousing, and transporting) and reducing the resource consumption and environmental impacts of packaging usage in the activities. And the European Commission proposed an ambitious CE package for plastics. Whether companies can minimise packaging materials and energy consumption and prevent waste, it is necessary to enhance packaging design for reuse, thereby requiring a dedicated design for durability. The contingency—*R2/Resell, reuse* and *RU10/Redesign of chain configuration or infrastructure*—indicates that CSCs may require reverse logistics and adequate infrastructure to bolster secondary markets. Sadrnia, Langarudi, and Sani (2020) designed and developed a mathematical optimisation model of a reverse logistic network for reusing a variety of second-hand appliances in small sizes (electronic devices and small tables), medium (oven, table, and chair), and bulky goods (furniture and big refrigerator). They suggested that the complexity of the mathematical problem could be improved, and heuristic solution procedures can be investigated for the proposed problem. The contingency between *R3/Repair* and *R5/Remanufacture* points to an interesting pattern. Design for maintenance and repair enables products to be maintained in tip-top condition (Bocken et al. 2016). Remanufacture is labour-intensive because the full structure of a multi-component product needs to be disassembled, checked, cleaned and when necessary, replaced or repaired in an industrial process (Reike, Vermeulen, and Witjes 2018). In the case of product returns, companies may decide to repair them depending on their current condition. For example, Frei, Jack, and Krzyzaniak's (2020) research in multichannel retail showed that, *inter alia*, a clothing company's store staff will make small repairs like fixing a loose button or seam themselves in store. Besides, for items that need more serious work to be sellable again, companies may engage in remanufacturing products themselves or partnering with organisations that do. Remanufacturing may be performed by manufacturers, retailers, or a third-party network ideally backed by the brand (Frei, Jack, and Krzyzaniak 2020). The link between *R5/Remanufacture* and *U7/End-customer demand* suggests that consumers may be uncertain about the remanufactured product performance when compared to brand-new products (Liao 2018). The contingency—*R5/Remanufacture* and *C11/Quantitative techniques*—reveals the relative importance of forecasting, simulation, and mathematical modelling in the context of remanufacturing, mainly to reduce the impact caused by related uncertainties. For example, Ponte, Framinan, et al. (2020) investigated the dynamics and performance of CLSCs through the lens of the bullwhip effect. As a potential gap, given that the analysis is restricted to independent and identically distributed demand and minimum mean square error forecasting, future research could be directed towards understanding other demand characteristics and forecasting methods. Another contingency is observed between *R7/Recycle* and *U1/Product characteristics*. Complex MCPs may challenge the recycling process, especially if one considers the technical feasibility and economic and environmental viability of recycling. According to Frei, Jack, and Krzyzaniak (2020), products should be designed in a way that materials and components can be easily separated for recycling.

### *4.3.3. R-imperatives and sustainability performance indicators in CSCs*

Figure 9 displays three contingencies between R-imperatives and sustainability performance indicators.

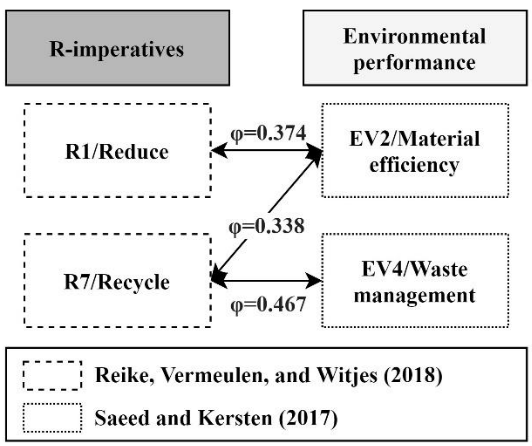


Figure 9. Contingencies between R-imperatives and sustainability performance indicators.

*R1/Reduce* is contingent on *EV2/Material efficiency*. This contingency is straightforward as it highlights the potential for improving material efficiency as a result of enhanced product life cycle and dematerialisation strategies. *R7/Recycle* is contingent on *EV2/Material efficiency* and *EV4/Waste management*. This twofold connection is not surprising from the environmentally perspective of the CE. However, it suggests that companies have overlooked socially and economically beneficial advantages of recycling. It also indicates an explicit environmental focus of publications regarding recycling.

*4.3.4. Uncertainty management and sustainability performance indicators in CSCs*

As shown in Figure 10, contingency analysis yielded 13 linkages regarding uncertainty management and sustainability performance indicators.

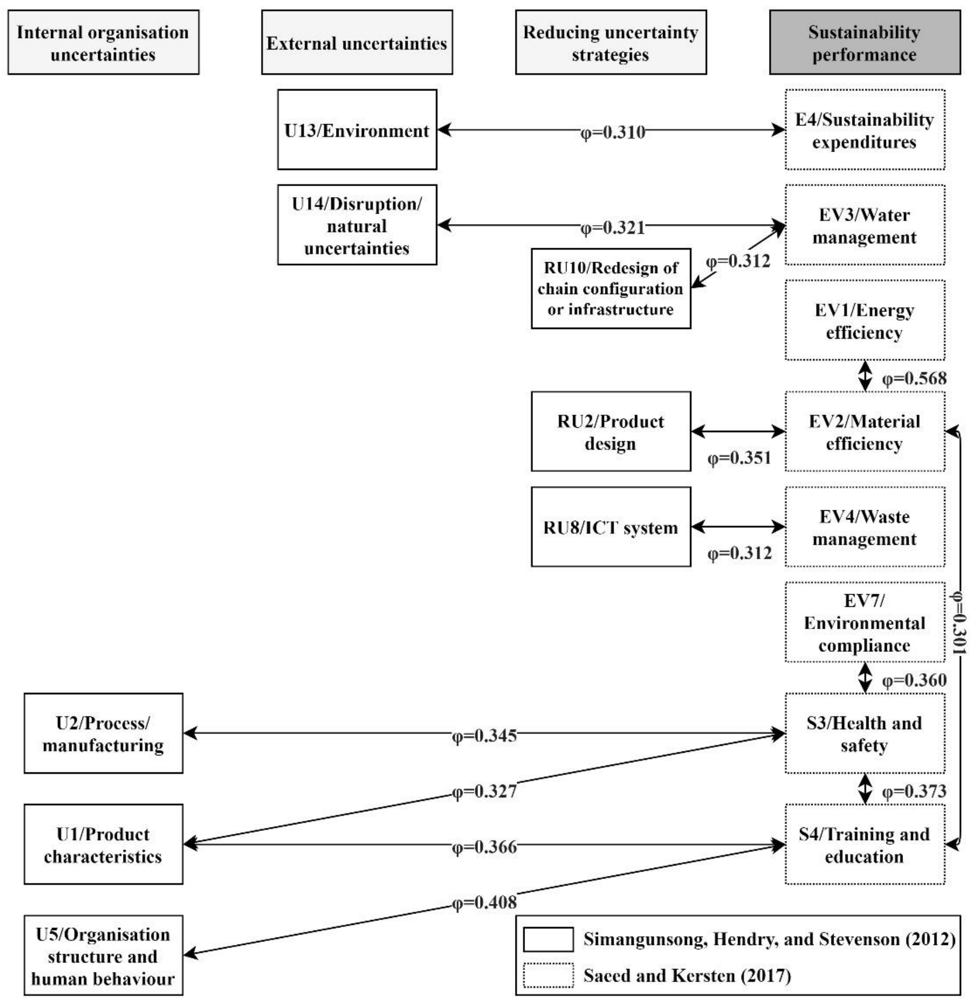


Figure 10. Contingencies between uncertainty management and sustainability performance indicators.

*U13/Environment* is connected to *E4/Sustainability expenditures*. This contingency indicates that competitive advantage can be achieved in the CE if companies invest in sustainable initiatives by introducing green products, novel recycled resources, and environmental practices and technologies (Bai et al. 2020). Note that *EV3/Water management* is connected to both *U14/Disruption/natural uncertainties* and *RU10/Redesign of chain configuration or infrastructure*. There is growing concern about water consumption in business operations, especially if one considers water scarcity. Chen et al. (2020) provided remarkable insights regarding the development of the water-energy-food nexus framework with green chemistry principles towards sustainability and the CE. Specifically, the authors noted that the water resources and water reclamation were grained to lead a great concern in the chemical and agricultural sectors. Consequently, a huge amount of water utilisation could cause an insufficient water supply. Therefore, it is paramount for organisations to adopt water management (e.g. rainwater collection, wastewater recycling) to reduce their water consumption. By considering the CE in the tourism and hospitality sector, Jones and Wynn (2019) affirmed that it is evident that water management is increasingly recognised as one of the key activities in an emerging strategy for sustainability management and that this will require appropriate systems support for the capture, processing, analysis, and reporting of related data and information. This perspective is also important for agricultural enterprises, wherein planning and designing for proper water management is vital (Colley et al. 2020; Silva et al. 2019). *RU2/Product design* is connected to *EV2/Material efficiency*, which is contingent on *EV1/Energy efficiency*. This twofold contingency is straightforward and reveals that implementing enhanced product design is key if organisations and CSCs aim to reduce material and energy usage in production processes. This process requires the development of adequate training programmes aimed at enhancing the SC actors' skills on design for sustainability and the CE (*S4/Training and education*). *RU8/ICT system* is connected to *EV4/Waste management*. Online platforms that allow companies to facilitate interaction and managing waste exchange are an essential strategy to symbiotic relationships (Fraccascia et al. 2020). As such, they can reduce search costs for SC actors and increase energy efficiency by avoiding the use of non-renewable materials. Thus, digitalisation is a crucial aspect that can facilitate waste exchange and enhance the sustainability of CSCs (Jabbour et al. 2018). *U2/Process/manufacturing* is linked to *S3/Health and safety*, and this latter construct is connected to *S4/Training and education* and *EV7/Environmental compliance*. Redesigning SCs for the CE demands training on health and safety at work to improve operations and environmental performance (Silva et al. 2019) and compliance with environmental regulations (e.g. certification and auditing) (Dossa et al. 2020). In waste recovery, for example, manufacturers need to follow standards controlling the recovery of MCPs up to the appropriate levels of human health protection and safety (Iacovidou, Velenturf, and Purnell 2019). To this end, as noted earlier, the topic of training and education for the CE becomes necessary. Note that *U1/Product characteristics* uncertainty is connected to both *S3/Health and safety* and *S4/Training and education*. As some CE products contain recovered materials and components, consumers' perception might be negatively influenced if quality, safety, or health criteria are not met accordingly (Magnier, Mugge, and Schoormans 2019). Besides adopting standards and performance indicators in designing CE products (Govindan and Hasanagic 2018; Wang and Hazen 2016), companies can also build awareness and educate consumers by providing transparent information regarding CE product characteristics and quality. The connection between *U5/Organisation structure and human behaviour* and *S4/Training and education* reinforces the necessity of training and educating SC members and stakeholders on the advantages of CE practices to adapt to the CE. For example, in the construction industry, training is essential among actors to help them understand the aim, indicators, frameworks, guidelines, and policies of the CE (Hossain et al. 2020), while educating the stakeholders on the advantages of deconstruction and reuse may be an effective measure to cope with some of the social resistance against material reuse (Rakhshan et al. 2020). Within CSCs in the Indian plastic industry, Khandelwal and Barua (2020) argued that managers should conduct training and awareness programmes to enhance stakeholders' knowledge and skills for recyclability.

### *4.4. Revisiting the framework*

Following the recommendations by Durach, Kembro, and Wieland (2017), the conceptual framework (Figure 11) is revisited and populated with the results of the review.

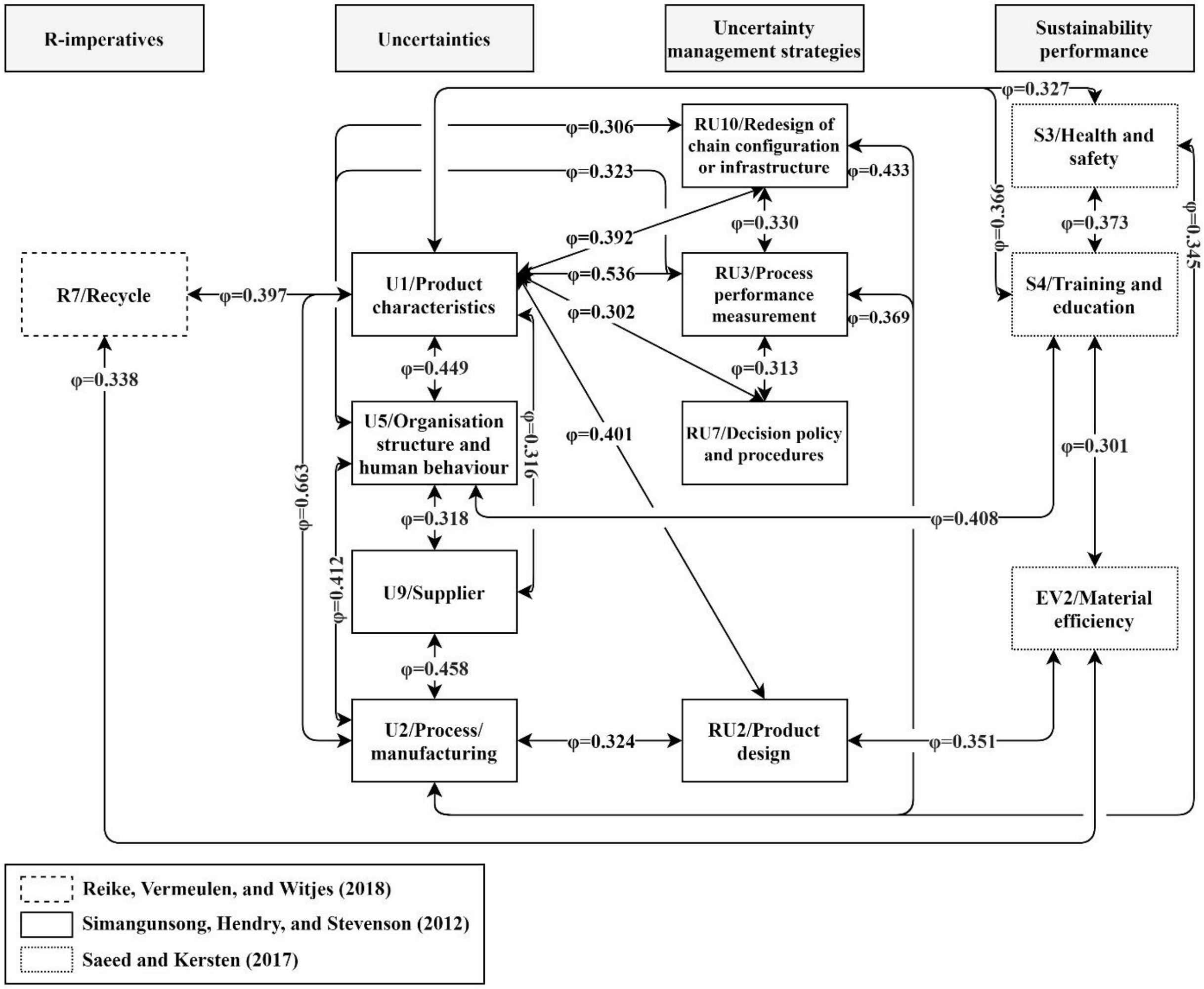


Figure 11. A framework of the core constructs and contingencies in the management of CSCs under uncertainty.

The contingency analysis of the 29 constructs revealed a total of 45 connections between pairs of constructs leading to 90 construct appearances. For revisiting the framework and identifying the core lines of argument in the literature, the 29 constructs were reduced to those that appeared in at least three contingencies, yielding 12 constructs and 26 contingencies among them, as illustrated in Figure 11. This represents, of course, a loss in detail and data, but the main constructs and their interlinks populate the conceptual framework and reveal the core lines of discussion in the reviewed literature.

*U1/Product characteristics* uncertainty is at the heart of the framework. This construct has ten linkages. The contingency between *U1/Product characteristics* and *R7/Recycle* pinpoints a significant focus on the characteristics of CE products, including product life cycle and packaging, which may enable or hinder the recycling process. Three contingencies connect *U1/Product* *characteristics* to *U2/Process/manufacturing*, *U5/Organisation structure and human behaviour*, and *U9/Supplier*. These uncertainties are frequently considered in consonance with product characteristics and unveil the likelihood of interrelated issues in CSCs. Further evidence shows that *U1/Product characteristics* uncertainty can be reduced via *RU2/Product design*, *RU3/Process performance measurement*, *RU7/Decision policy and procedures*, and *RU10/Redesign of chain configuration or infrastructure*. In the pertinent literature (Simangunsong, Hendry, and Stevenson 2012, 2016), there is support to the connection between *U1/Product characteristics* & *RU2/Product design*; *U1/Product characteristics* & *RU3/Process performance measurement*; and *U1/Product characteristics* & *RU10/Redesign of chain configuration or infrastructure*. The novel connection is between *U1/Product characteristics* and *RU7/Decision policy and procedures*. This contingency indicates that well-defined policies and procedures are needed to reduce issues related to product characteristics, such as defining guidelines that specify the (e.g. recycled) content of products. *U1/Product characteristics* uncertainty is connected to *S3/Health and safety* and *S4/Training and education*. These connections suggest that companies transitioning to the CE need to consider health and safety guidelines to design their products due to customers' quality concerns about recovered materials and components. Companies also need to create awareness about CE products to increase customers' acceptance (Van Weelden, Mugge, and Bakker 2016).

*U2/Process/manufacturing* has six linkages. *U2/Process/manufacturing* is connected to *U5/Organisation structure and human behaviour* and *U9/Supplier*. The risk-averse nature of companies can be highlighted as an issue that hampers the CE implementation within CSCs. Also, the high variability in the quality and quantity of returns can complicate the remanufacturing process (Dominguez, Cannella, Ponte, et al. 2020). Three contingencies connect *U2/Process/manufacturing* to *RU2/Product design*, *RU3/Process performance measurement*, and *RU10/Redesign of chain configuration or infrastructure*; the novel connection is between *U2/Process/manufacturing* and *RU10/Redesign of chain configuration or infrastructure* (see subsection 4.3.1 for a detailed description). *U2/Process/manufacturing* is connected to *S3/Health and safety*. This contingency reinforces the need for adopting health and safety standards in circular operations.

The contingency between *U5/Organisation structure and human behaviour* and *U9/Supplier* evidences the lack of support and commitment from management within the company and across the SC to shift towards circular practices. This issue requires executives' close attention to align CE principles with SC objectives and offer training and education activities for increasing stakeholders' awareness (*U5/Organisation structure and human behaviour* & *RU3/Process performance measurement*; *U5/Organisation structure and human behaviour* & *S4/Training and education*). For the contingency between *U5/Organisation structure and human behaviour* and *RU10/Redesign of chain configuration or infrastructure*, some organisations have pursued coordination efforts towards circular practices by arranging themselves into remanufacturing and recycling networks and industrial eco-parks. This process requires close collaboration and systematic change at all levels.

*RU10/Redesign of chain configuration or infrastructure* is connected to *RU3/Process performance measurement*, which is contingent on *RU7/Decision policy and procedures*. These linkages reveal that redesigning SCs for the CE are frequently aligned with key performance indicators and decision policies and procedures to reduce uncertainties. It is strategically important for companies to monitor operational performance and sustainability.

*EV2/Material efficiency* is connected to *RU2/Product design*, highlighting that CE has inspired manufacturers to design sustainable, circular, and long-lasting products by incorporating principles such as design for disassembly or design for reuse. Regarding the contingency between *EV2/Material efficiency* and *R7/Recycle*, there is a growing interest in securing the long-term availability of materials via recycling (Lapko et al. 2019). This process may help companies increasing material efficiency, given the price volatility of virgin inputs and supply shortages of critical materials (Busch et al. 2014). Two contingencies reveal the emergent interest for health and safety standards, training and education programmes, and indicators aligned with the CE to optimise resource efficiency (*S3/Health and safety* & *S4/Training and education*; *EV2/Material efficiency* & *S4/Training and education*).

## 5. Discussion

This paper systematically reviewed the operationalisation of CE practices in SCs, its related uncertainties, and uncertainty management strategies that can enhance the sustainability performance of CSCs. To this end, content, frequency, and contingency analyses were conducted to capture existing gaps and future research routes. This paper then makes the following contributions to the body of literature:

Firstly, it is observed that the analysed literature gave less attention to circular design and waste prevention approaches. This result is consistent with that of Reike, Vermeulen, and Witjes (2018), who call policymakers to set targets and direct economic activities towards short loops like *R0/Refuse*, *R1/Reduce*, *R2/Resell, reuse*, and *R3/Repair*. Likewise, Suzanne, Absi, and Borodin (2020) argued that governments could provide companies with competitive benefits by bolstering eco-designing products and waste prevention measures. The reverse is true for long loops such as *R7/Recycle*. This result corroborates that recycling is still the most adopted practice in CSCs, yet it requires high energy inputs for collection, pre-treatment, and conversion, which may supersede the retained value (Ghisellini, Cialani, and Ulgiati 2016; Reike, Vermeulen, and Witjes 2018). Consequently, more research on the short and medium loops of the CE and its integration with the SCM field would be required to advance understanding of how CSCs can be sustainably managed.

Secondly, the content analysis of uncertainty management in CSCs reveals some patterns worthy of discussion. Industry 4.0 technologies are characterised as enablers of the CE (Ozkan-Ozen, Kazancoglu, and Mangla 2020), but it is observed that they can increase technology and information uncertainties. If organisations and SCs are to successfully transition towards the CE, attention should be given to the uncertainties that may hinder the implementation and management of CSCs. As discussed, intricate product characteristics pose uncertainties for value recovery and therefore require an improved design to enhance easy maintenance and disassembly for repairing, refurbishment, remanufacturing, repurposing, or recycling. Uncertainty can challenge manufacturers in the form of technical bottlenecks, thereby demanding organisations to design SC operations and offer training activities in order to enhance technical capacity and capabilities. Managers' resistance to implementing the CE in the organisation culture is another critical uncertainty that can slow the paradigm shift from linear to circular production systems. Conflicting decision-making goals within organisations may increase cost and time uncertainties, indicating that executives need to appropriately define the firm's objectives in CE terms to reduce internal conflicts and facilitate a shared understanding of the CE principles. Supplier-related uncertainties such as performance issues can cause delays, disrupt processes, or increase costs if not managed appropriately. Consumers may be uncertain about purchasing CE products due to quality and performance concerns. So, CE products require robust quality standards to manage the usage of restored materials and components. The adoption of tighter standards is likely to reduce customer complaints and achieve resource circularity simultaneously. Another critical uncertainty in redesigning SCs for the CE seems to be the dispersed location of facilities due to globalisation trends. SC actors and customers should be connected through an integrated reverse logistics infrastructure to enable optimised transport, collection, and value recovery. External factors such as legal barriers and lack of directives, metrics, and regulatory frameworks can also beget uncertainty. In this regard, governments and policymakers should adjust legal barriers and inconsistencies and develop directives for responsible changes in SCs. Furthermore, it was observed that the bullwhip effect can occur in both forward and closed flows, but the varying quality of returns increases the bullwhip effect. This finding was also reported by Dominguez, Cannella, and Framinan (2021), who showed that the adopted remanufacturing configuration impacts on the bullwhip effect if there is a significant volume of returns. All in all, these results reiterate the necessity of employing uncertainty evaluations to reduce the likelihood of delays and disruptions, enhance the stability of CSCs, and smooth the challenging but envisioned CE implementation.

Thirdly, a relatively low frequency for the uncertainties *U3/Control/chaos uncertainty* and *U11/Order forecast horizon* was observed, while no evidence could be assigned to *U10/Parallel interaction*. This result may be explained by the fact that CSCs are a relatively novel approach within SCM. It also underlines the differences between forward SCM and circular SCM. For example, only one type of parallel interaction is widely known in the traditional SCM and is caused by interaction across companies at the same tier of a supply network. A second type was identified by Simangunsong, Hendry, and Stevenson (2016), who applied an ethics lens to study the phenomenon. Specifically, the collected evidence suggested that suppliers sometimes collude by forming a cartel and withhold the supply of a material, thereby artificially claiming there is a scarcity to create hype for the product and increase the price customers are willing to pay. No evidence in the reviewed literature was found to the uncertainty management strategies *RU6/Shorter planning* and *C8/ICT system*, highlighting the possibility for further investigation in the CE. Coping with uncertainty strategies appear to be seldom considered by managers. A possible justification for this result concerns that CSC research lacks a risk management analysis (Lahane, Kant, and Shankar 2020).

Fourthly, an imbalance of the TBL perspective in measuring SC sustainability performance in the reviewed literature was observed, in particular the social dimension. Indeed, great emphasis is given to economic performance indicators related to *E1/Stability and profitability*, while the most frequent environmental performance indicators regarded *EV4/Waste management* and *EV5/Emissions*. The most frequent social performance indicator was *S3/Health and safety*. This finding was also reported by Sehnem et al. (2019), who found that social sustainability issues are poorly addressed in CSCs. This seems to be in line with the slower uptake of social issues in sustainable SCM (e.g. Yawar and Seuring 2017), so the social dimension of CSCs would warrant future research.

Additionally, as shown in Figure 7, ten contingencies confirm the assumption that for internal organisation uncertainties, the methods of managing uncertainty are concentrated under the reducing category. Another connection reinforces that coping strategies have a similarly important role in managing SC uncertainties internally, i.e. *U8/Demand amplification* and *C11/Quantitative techniques*. Interestingly, it was observed that external uncertainty is linked with reducing uncertainty strategy, i.e. *U13/Environment* and *RU7/Decision policy and procedures*. This outcome differs from Simangunsong, Hendry, and Stevenson (2012), who found that coping with uncertainty strategies are employed to deal with external uncertainties. A possible justification for this result would be that, given the novelty of CE in regulatory frameworks, it can be difficult for companies to decide what legal instruments should be adopted to manage their operations accordingly. Thus, the adoption of internal decision policies should reduce uncertainties caused by external factors. Another interesting pattern observed is the eight linkages between uncertainties themselves, pointing to the existence of multiple uncertainties in CSCs (see Figure 7). It is likely that CE practices introduce complex operations and consequently increase uncertainties at different levels of the organisation and SC (Islam and Huda 2018; Jabbour et al. 2019). So, executives can also combine multiple uncertainty management strategies. In this regard, three contingencies between uncertainty management strategies were identified (see Figure 7). Further empirical evidence is needed to understand how organisations manage different uncertainties simultaneously and the effect of multiple uncertainty management strategies on the firm's sustainability performance. Furthermore, 5 out of 12 contingencies add new evidence to the linkage between uncertainties and uncertainty management strategies (Simangunsong, Hendry, and Stevenson 2012, 2016); see in Figure 7 the contingencies *U1/Product characteristics* & *RU7/Decision policy and procedures*; *U2/Process/manufacturing* & *RU5/Collaboration*; *U2/Process/manufacturing* & *RU10/Redesign of chain configuration or infrastructure*; U8*/Demand amplification* & *C11/Quantitative techniques*; and *U13/Environment* & *RU7/Decision policy and procedures*.

Finally, this review contributes to CSC research by providing fruitful linkages between CE practices, uncertainty management, and sustainability performance indicators (see Figures 8, 9, and 10). In this regard, valuable theoretical underpinnings were highlighted so that scholars can advance the field. This review provides rich evidence of what, how, and why different constructs are interlinked. For instance, CE practices cause managers to change forward operations and adapt the SC for market demands of CE products and services, thereby increasing uncertainty. This finding suggests that managers need, for example, to invest in post-consumption services, warranty programs, and marketing strategies as consumers may think CE products do not have the same quality as new products (Singhal, Jena, and Tripathy 2019; Van Weelden, Mugge, and Bakker 2016). It is also observed that circularity thinking can be integrated into product designs to reduce uncertainty and increase sustainability performance. This result adds further evidence to the argument that in CSCs profit maximisation and cost minimisation are no longer the sole objectives of management (Ozkan-Ozen, Kazancoglu, and Mangla 2020). Further expenditures in CE training programmes and initiatives can have an additional benefit in improving the knowledge base for circular operations.

## 6. Conclusion

Following a rigorous, transparent, and reproducible process, this review aimed to answer three research questions—*What are the uncertainties found in CSCs? Which uncertainty management strategies can be used to mitigate them? How are uncertainties and uncertainty management strategies related to the sustainability performance of CSCs?* This review provided systematic evidence for understanding the main characteristics of CSCs under uncertainty and how the literature has evolved in terms of publications across the years and scientific journals as well as the adopted research methodologies, contextual perspectives, and industry coverage. A structured content analysis captured the most important topics and existing gaps related to CE practices, the uncertainties inherent in CSCs, and sustainability outcomes. Future research could empirically explore why companies may be reluctant to adopt CE practices such as refuse, reduce, refurbish, and repurpose. It could also identify the uncertainties associated with implementing these practices in real-world cases (De Angelis, Howard, and Miemczyk 2018). CSC research and practice may benefit from studies which evaluate the technology-related uncertainties at the nexus between the CE and Industry 4.0 technologies (Nascimento et al. 2019). In order to support the implementation of circular production systems, academics should assess the optimal location, the number of facilities for recovery activities, and the CSC configuration. The TBL of sustainability can be employed to analyse real-world applications of repair networks, remanufacturing operations, and re-mining activities.

Furthermore, given the novelty of CSCs and that companies are still working out ways of operationalising this concept, uncertainties may arise and hence impact the company's sustainability performance. In this review, contingency analysis confirmed this trend by unveiling connections between R-imperatives, uncertainties, and sustainability performance indicators. The contingent models justified the combined theoretical framework and pointed to various research opportunities. For example, under the prism of collaboration, partnership programmes between universities and SC actors may result in knowledge exchange aimed at increasing the organisation's technical capacity and reducing operational uncertainties in the CE. This association could be investigated through a stakeholder theory perspective for managerial and societal implications (Jabbour et al. 2019). In summation, future research can provide empirical evidence to the developed contingent models by drawing on contingency theory (Simangunsong, Hendry, and Stevenson 2012). Therefore, this review will not only guide academia in developing relevant research on CSCs to discover further implementation issues but will also inform the ideal CE operationalisation for practitioners.

Herein, managerial implications are offered for practitioners who want to better understand and manage the uncertainties in CSCs. Given the rising interest in CE and the need to address resource scarcity, CSCs will have to get applied far more widely. This process should take sustainability outcomes into account, asking managers for not only designing products and SCs accordingly, but with a lower environmental burden, yet achieving economic efficiency. This review offers not only evidence of circularity implementation in CSCs but also gaps that have not been addressed. In summary, the complexity of introducing CSCs is mainly due to redesign challenges, decision-making issues, and external factors that hinder CE development and impact organisations' sustainability performance. As uncertainty is an inherent and inevitable characteristic of CSCs, managers will likely need to reduce the complexity of the management practice (e.g. Peng et al. 2020). This necessity points to the adoption of strategic decisions but it is usually confronted by the challenge of achieving economic gains. The implementation of the CE within SCs becomes even more difficult if one aligns it to a commercial strategy in the absence of government support (Masi, Day, and Godsell 2017). Therefore, one can see that governments have an essential role in making the transition towards CSCs feasible and widespread.

Although scientifically rigorous methodology was adopted, this review has acknowledged limitations. First, specific conceptual frameworks were adopted, albeit widely recognised in the SCM field. By relying on these frameworks, along with the lines of arguments considered, the analysis might not reveal further issues. This approach seems justified, as it enabled detailed insights and analysis of the body of literature. It is also consistent with the goal of refining and advancing theory, as this review adopted deductively derived frameworks to analyse the research domain (Seuring et al. 2021). Future research could adopt an inductive theory-building approach to develop and propose new constructs and concepts that broaden the understanding of CSCs. For instance, scholars may critically evaluate how CE activities in CSCs generate rebound effects and how CE rebound is tackled. CE rebound represents a serious obstacle to creating meaningful environmental improvement (see Zink and Geyer 2017). Second, the selective approach to conducting the systematic literature review focused on the key contributions of the investigated topic, and the literature search may have been too restricted, overlooking other relevant articles in the area. However, Durach, Kembro, and Wieland's (2017) recommendations were followed to reduce bias in the selection process, i.e. two independent researchers assisted the authors in this process. Further research could also include grey literature, given that there have been many CE-related publications from the business community, think tanks, policymakers, and other prominent organisations, such as the Ellen MacArthur Foundation. According to Adams, Smart, and Huff (2017), grey literature is produced by authors who may, but often do not, have academic training or interest in publishing in outlets that follow the norms of scholarly journals. They argued that expanding literature reviews to include purposefully selected material from the varied sources, though difficult, is increasingly important. Third, a single author content analysed the literature, yet further ambiguities were constantly discussed with the research team, and the contents were coded with their definitions in mind and methodologically operationalised in the qualitative analysis software MAXQDA 2020 Analytics Pro. Fourth, each adopted framework was used at a time to ensure meticulous reflection and interpretation of the material. At last, due to the sample size and the number of constructs, the research directions provided might not be comprehensive for all domains and gaps. Regardless of this limitation, the highlighted topics and the detailed analysis can be sufficient to give additional information and interpretation.

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## Appendix (Supplementary Material)

Appendix 1. 10 resource value retention options, adapted from Reike, Vermeulen, and Witjes (2018).

| **R-imperative**<br>Frequency (%) | **Definition** | **Examples in the review** |
|---|---|---|
| *Short loops* | | |
| R0/Refuse<br><br>4 (3.77%) | Consumers choose to buy less. Besides, producers can refuse to use specific materials and designs to avoid waste. | Iacovidou, Velenturf, and Purnell (2019); Peck, Kandachar, and Tempelman (2015). |
| R1/Reduce<br><br>15 (14.15%) | Linked to producers and their role in the concept and design life cycle of products, thereby using less material per unit of production, i.e. dematerialisation. | Barbaritano, Bravi, and Savelli (2019); Jabbour et al. (2019). |
| R2/Resell, reuse<br><br>22 (20.75%) | Second consumer of a product that hardly needs any adaptation and works as new. Buying second hand or finding a buyer for a product that was not or hardly in use, possibly after some cleaning or minor adaptations for quality restoration by the consumer. | Sadrnia, Langarudi, and Sani (2020); Tingley, Cooper, and Cullen (2017). |
| R3/Repair<br><br>24 (22.64%) | Making it as good as new by replacing items after minor defects. This is done by the customer in their vicinity, at the customer's location, or | Bressanelli, Perona, and Saccani (2019b); Kalverkamp (2018). |

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| | through a repair company. Businesses can send recollected products to their repair centres or third-party repair centres. | |
| *Medium loops* | | |
| R4/Refurbish<br><br>10 (9.43%) | The overall structure of a large multi-component product remains intact while components are replaced or repaired, resulting in an overall upgrade of the product. | Govindan and Hasanagic (2018); Van Weelden, Mugge, and Bakker (2016). |
| R5/Remanufacture<br><br>48 (45.28%) | The full structure of a multi-component product is disassembled, checked, cleaned and when necessary, replaced or repaired in an industrial process. | Reddy and Kumar (2021); Singhal, Tripathy, and Jena (2019). |
| R6/Repurpose<br><br>6 (5.66%) | Popular in industrial design and artistic communities. By reusing discarded goods or components adapted for another function, the material gets a distinct new life cycle. | Farooque et al. (2019); Veleva and Bodkin (2018). |
| *Long loops* | | |
| R7/Recycle<br><br>66 (62.26%) | Processing of mixed streams of post-consumer products or post-producer waste streams using expensive technological equipment, including shredding, melting, and other processes to capture (nearly) pure materials. Materials do not maintain any of the original product structure and can be re-applied anywhere. Primary recycling takes place in business-to-business relations, and secondary recycling is based on end-of-life products that are collected by municipal waste collectors. | Busch et al. (2014); Tan and Guo (2019). |
| R8/Recover energy<br><br>11 (10.38%) | Capturing energy embodied in waste, linking it to incineration in combination with producing energy or use of biomass. | Paes et al. (2019); Tsolakis et al. (2019). |
| R9/Re-mine<br><br>4 (3.77%) | Landfill re-mining and urban mining. For example, in developing countries, people try to earn a living by scrapping valuable materials and items from landfills. | Habib (2019); Shi, Zhou, and Zhu (2019). |

Appendix 2. Supply chain uncertainty management, adapted from Simangunsong, Hendry, and Stevenson (2012).

| **Sources of uncertainty** | **Definition** | **Examples in the review** |
|---|---|---|
| *Internal organisation uncertainties* | | |
| U1/Product characteristics<br><br>33 (31.13%) | Physical characteristics of a product (e.g. colour, length, size, and packaging) and product attributes (e.g. perishability and life cycle). For example, long-life cycles may cause uncertain product returns. | Krystofik et al. (2018); Lapko et al. (2019). |
| U2/Process/manufacturing<br><br>42 (39.62%) | Process/manufacturing-related uncertainties, such as lack of skilled labour, process reliability, and machine breakdowns, which affect an organisation's ability to meet its production targets. | Bag, Gupta, and Foropon (2019); Sandvik and Stubbs (2019). |
| U3/Control/chaos uncertainty<br><br>2 (1.89%) | The chaos resulting from the implementation of control systems. For example, the use of wrong control rules when transforming customer orders into production plans and raw material requirements. | Kurilova-Palisaitiene, Sundin, and Poksinska (2018); Prakash et al. (2021). |

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| U4/Decision complexity<br><br>33 (31.13%) | Uncertainty arising because of multiple dimensions in decision-making process (e.g. conflicting goals, constraints, and long-term plans). | Akinade and Oyedele (2019); Górecki et al. (2019). |
| U5/Organisation structure and human behaviour<br><br>27 (25.47%) | Behavioural issues that disrupt supply chain processes (e.g. risk-taker versus risk-averse behaviour, and resistance to change). | Agyemang et al. (2019); Werning and Spinler (2020). |
| U6/Information technology/systems (IT/IS) complexity<br><br>7 (6.60%) | Issues related to data/information security, IT/IS performance. | Jabbour et al. (2018); Kouhizadeh, Sarkis, and Zhu (2019). |
| *Internal supply chain uncertainties* | | |
| U7/End-customer demand<br><br>38 (35.85%) | Irregular changes in end-customer demand patterns (e.g. seasonal demand variability, sporadic events, and changes in consumer preferences). | Peng et al. (2020); Yazan and Fraccascia (2020). |
| U8/Demand amplification<br><br>13 (12.26%) | The amplification of demand due to the bullwhip effect. | Braz et al. (2018); Ponte, Naim, and Syntetos (2019). |
| U9/Supplier<br><br>46 (43.40%) | Supplier performance issues (e.g. quality problems, late delivery, and unavailability of supply). | Islam and Huda (2018); Pishchulov et al. (2018). |
| U9.1/Customer as a supplier<br><br>33 (31.13%) | The uncertain quality, timing, and quantity of customers' returns. | Sadrnia, Langarudi, and Sani (2020); Tsiliyannis (2016). |
| U10/Parallel interaction | The uncertainty caused by the interaction between channels of a supply chain in the same tier. | *Not identified in the analysed literature.* |
| U11/Order forecast horizon/lead-time gap<br><br>2 (1.89%) | The longer the horizon, the larger the forecast errors and, hence, the greater the uncertainty in the demand forecasts. | Dominguez, Cannella, Ponte, et al. (2020); Rijal, Gautam, and LeBel (2020). |
| U12/Chain configuration, infrastructure, and facilities<br><br>34 (32.08%) | Supply chain geographical coverage (difficult terrain and long distances), communication infrastructure (number and strategy of involved parties), and transportation infrastructure. | Machacek, Richter, and Lane (2017); Masi, Day, and Godsell (2017). |
| *External uncertainties* | | |
| U13/Environment<br><br>56 (52.83%) | External factors to an organisation's supply chain (the actions of competitors, regulatory changes, political instability, and macroeconomic factors such as price inflation and fluctuations in exchange rates and raw material prices). | Bai et al. (2020); Daou et al. (2020); Tsiliyannis (2020). |
| U14/Disruption/natural uncertainties<br><br>15 (14.15%) | The uncertainties related to natural causes (e.g. earthquakes, storms, and tsunami). | Didenko, Klochkov, and Skripnuk (2018); Yazdani, Gonzalez, and Chatterjee (2021). |
| **Uncertainty management strategies** | | |
| *Reducing uncertainty strategies* | | |
| RU1/Lean operations<br><br>17 (16.04%) | Making a process leaner so that it becomes simpler and has less inherent uncertainty. | Gaustad et al. (2018); Kurilova-Palisaitiene, Sundin, and Poksinska (2018). |
| RU2/Product design<br><br>40 (37.74%) | Establishing a robust design or changing the design of a product to enable a better and more sustainable manufacturing process. | Magnier, Mugge, and Schoormans (2019); |

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| | | Mishra, Hopkinson, and Tidridge (2018). |
| RU3/Process performance measurement<br><br>23 (21.70%) | Using process performance measures (e.g. quality measures and key performance indicators) to detect and hence reduce uncertainty. | Govindan and Hasanagic (2018); De Souza, Bloemhof-Ruwaard, and Borsato (2019). |
| RU4/Good decision support system (DSS)<br><br>5 (4.72%) | The use of DSS as a problem-solving strategy for complex decision-making situations. | Govindan et al. (2020); Lechner and Reimann (2020). |
| RU5/Collaboration<br><br>45 (42.45%) | Proactive initiatives, whereby people play a dominant role, to reduce uncertainty within the scope of the following activities: (i) Internal integration to provide synchronised decision and control functions in the organisation. (ii) Vertical integration to control supply or demand uncertainties. (iii) Contractual agreements with suppliers or buyers to reduce uncertainty. (iv) Voluntary restraint of competition by alliances, joint ventures, franchising agreements, technology licensing agreements, and participation in consortia. (v) Partnership programmes by working more closely with suppliers or customers—e.g. in terms of collaborative planning, forecasting, and replenishment initiatives—to reduce uncertainty regarding problems of other supply chain members. (vi) E-intermediation to facilitate information sharing so that adequate information is available for key tasks. | De Angelis, Howard, and Miemczyk (2018); Wang and Hazen (2016). |
| RU6/Shorter planning period | Runs a planning system in a shorter period than the forecast horizon, thereby reducing the number of last-minute changes to the schedule. | *Not identified in the analysed literature.* |
| RU7/Decision policy and procedures<br><br>47 (44.34%) | The use of better decision policy and procedures to improve supply chain processes. | Ponte, Naim, and Syntetos (2020); Tsiliyannis (2016). |
| RU8/Information and communication technology (ICT) system<br><br>47 (44.34%) | Strategy of using application software, computer hardware, and communication technology to improve technological-related processes and hence reduce uncertainty. | Ge and Jackson (2014); Nascimento et al. (2019). |
| RU9/Pricing strategy<br><br>9 (8.49%) | The use of pricing strategy or other incentives to reduce demand uncertainty. | Liao (2018); Tan and Guo (2019). |
| RU10/Redesign of chain configuration or infrastructure<br><br>30 (28.30%) | The process of redesigning the supply chain configuration or infrastructure (the plants, distribution centres, transportation modes, production processes, and network relationships) to be more sustainable and satisfy customer demands. | Baptista et al. (2019); Ren et al. (2020). |
| *Coping with uncertainty strategies* | | |
| C1/Postponement<br><br>2 (1.89%) | Delaying activities or processes until the latest possible point in time, making it possible to manufacture products according to known rather than forecast demand. | De Angelis, Howard, and Miemczyk (2018); Lapko et al. (2019). |

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| C2/Volume/delivery flexibility<br><br>3 (2.83%) | The agility to manufacture a product despite changes to volume, mix, and lead times. | Bai et al. (2020); Low and Ng (2018). |
| C3/Process flexibility<br><br>6 (5.66%) | The flexibility of the workforce, plant, and equipment enabling a company to cope with the uncertainty caused by frequent product changeovers on the shop floor. | Bag, Gupta, and Foropon (2019); Low and Ng (2018). |
| C4/Customer flexibility<br><br>1 (0.94%) | Exploiting relationships with customers that are less sensitive to uncertainty issues and can adapt their plans. | Dossa et al. (2020). |
| C5/Multiple suppliers<br><br>16 (15.09%) | Exploiting the availability of potential suppliers and their willingness to help an organisation manage its sources of uncertainty. | Fraccascia et al. (2020); Rogetzer, Silbermayr, and Jammernegg (2019). |
| C6/Strategic stocks<br><br>8 (7.55%) | The use of inventory to buffer against uncertainty. | Low and Ng (2018); Rogetzer, Silbermayr, and Jammernegg (2019). |
| C7/Collaboration<br><br>5 (4.72%) | Basic or limited information sharing internally within an organisation or with supply chain partners (suppliers and customers). In contrast to RU5/Collaboration, this strategy does not affect the source of uncertainty. | Dominguez, Cannella, Ponte, et al. (2020); Lapko et al. (2019). |
| C8/ICT system | The availability of a computer-based information system to provide information transparency between supply chain partners, enabling better and faster information flow but without reducing the source of uncertainty, in contrast to RU8/ICT system. | *Not identified in the analysed literature.* |
| C9/Lead-time management<br><br>2 (1.89%) | The quoting of longer lead times for customer orders compared with expected manufacturing lead times. | Dominguez, Cannella, Ponte, et al. (2020); Kalverkamp (2018). |
| C10/Financial risk management<br><br>7 (6.60%) | Techniques of financial risk mitigation, such as purchasing insurance (e.g. business interruption insurance) and buying and selling financial instruments (e.g. forward and futures contracts). | Gaustad et al. (2018); Rogetzer, Silbermayr, and Jammernegg (2019). |
| C11/Quantitative techniques<br><br>16 (15.09%) | Employing operations research techniques (e.g. forecasting, simulation, and mathematical modelling) to reduce the impact caused by a source of uncertainty. | Hao et al. (2018); Tsiliyannis (2018). |

Appendix 3. Sustainability performance indicators, adapted from Saeed and Kersten (2017).

| **Sustainability indicator** | **Definition** | **Examples in the review** |
|---|---|---|
| *Economic indicators* | | |
| E1/Stability and profitability<br><br>59 (55.66%) | The financial health of an organisation (total sales/revenue, operating profit, free cash flow, and the total number of produced goods). | Habibi et al. (2019); Lin et al. (2018). |
| E2/Income distribution<br><br>25 (23.58%) | Employees' salaries and benefits, and payments made to the government/community (employees' wages and benefits, community investments, taxes, and operating costs). | Luo et al. (2019); Velenturf and Jopson (2019). |
| E3/Market competitiveness<br><br>7 (6.60%) | The organisation's market share performance, competitive wages, and the earning per share performance. | Agyemang et al. (2019); Luo et al. (2019). |
| E4/Sustainability expenditures | The organisation's expenditures on sustainable initiatives, local procurement, and research and development for a particular period. | De Jesus and Mendonça (2018); Lapko et al. (2019). |

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| 17 (16.04%) | | |
| *Social indicators* | | |
| S1/Human rights and anti-corruption<br><br>6 (5.66%) | Corruption and violation of human rights (discrimination, forced and child labour, and violation of the rights to the freedom of association). | Rogetzer, Silbermayr, and Jammernegg (2019); Shemfe, Gadkari, and Sadhukhan (2018). |
| S2/Human resources<br><br>13 (12.26%) | Human resources management (the number of jobs created, the ratio of male and female employees, the number of local and national employees, turnover rates, employees' benefits, employees' satisfaction, and employees' performance evaluations). | Govindan and Hasanagic (2018); Low and Ng (2018). |
| S3/Health and safety<br><br>26 (24.53%) | Health and safety issues due to business operations (the number of injuries, illness, and fatalities, and the days lost due to occupational accidents). | Barbaritano, Bravi, and Savelli (2019); Kazancoglu et al. (2020); Shemfe, Gadkari, and Sadhukhan (2018). |
| S4/Training and education<br><br>24 (22.64%) | It deals with the training and education opportunities offered to employees. | Despeisse et al. (2017); Silva et al. (2019). |
| S5/Consumer issues<br><br>19 (17.92%) | Consumers' complaints, product returns, and incidents of misleading, deceptive, or fraudulent business information to the consumer. | Ciulli, Kolk, and Boe-Lillegraven (2020); Singhal, Jena, and Tripathy (2019). |
| S6/Social compliance<br><br>4 (3.77%) | Compliance with social standards and certificates. | Bleischwitz (2020); Machacek et al. (2015). |
| *Environmental indicators* | | |
| EV1/Energy efficiency<br><br>44 (41.51%) | The total energy consumption from renewable and non-renewable energy sources and specific energy consumption. | Silva et al. (2019); Vogtlander et al. (2017). |
| EV2/Material efficiency<br><br>38 (35.85%) | It deals with the usage of renewable, hazardous, and recycled material input. | Farooque et al. (2019); Peck, Kandachar, and Tempelman (2015). |
| EV3/Water management<br><br>14 (13.21%) | It describes all forms of water consumption, including total water discharge and quality of water discharge. | Didenko, Klochkov, and Skripnuk (2018); Jones and Wynn (2019). |
| EV4/Waste management<br><br>63 (59.43%) | It classifies information about the waste produced and adequately managed. | Schraven et al. (2019); Tsiliyannis (2019). |
| EV5/Emissions<br><br>55 (51.89%) | It collects information related to all forms of GHG emissions, ozone-depleting substances. | Atabaki, Mohammadi, and Naderi (2020); Kondo, Kinoshita, and Yamada (2019); Van Loon and Van Wassenhove (2018). |
| EV6/Land use<br><br>8 (7.55%) | It deals with information related to the area of land used for conducting business operations. | Bressanelli, Perona, and Saccani (2019b); De Souza, Bloemhof-Ruwaard, and Borsato (2019). |
| EV7/Environmental compliance<br><br>14 (13.21%) | Compliance with environmental regulations (the number of fines for non-compliance, the number of environmental accidents, and the number of environmental standards and certificates). | Barbaritano, Bravi, and Savelli (2019); Tsiliyannis (2016). |

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| EV8/Supplier assessment<br><br>8 (7.55%) | It collects information related to supplier's environmental performance and their selection criteria. | Govindan et al. (2020); Kondo, Kinoshita, and Yamada (2019). |

Appendix 4. Statistical results of contingency analysis.

| **R-imperatives** | | **Phi-coefficient** | **Approx. significance** | **Exact significance (one-sided)** | **Observed frequency** | **Expected frequency** |
|---|---|---|---|---|---|---|
| R3/Repair | R5/Remanufacture | .323 | .001 | .001 | 16.98% | 10.28% |
| **Uncertainty management** | | | | | | |
| U1/Product characteristics | U2/Process/manufacturing | .663 | 0 | 0 | 27.36% | 12.36% |
| U1/Product characteristics | U5/Organisation structure and human behaviour | .449 | 0 | 0 | 16.98% | 7.92% |
| U1/Product characteristics | U9/Supplier | .316 | .001 | .001 | 20.75% | 13.49% |
| U1/Product characteristics | U12/Chain configuration, infrastructure, and facilities | .367 | 0 | 0 | 17.92% | 10.00% |
| U1/Product characteristics | RU2/Product design | .401 | 0 | 0 | 20.75% | 11.79% |
| U1/Product characteristics | RU3/Process performance measurement | .536 | 0 | 0 | 16.98% | 6.79% |
| U1/Product characteristics | RU7/Decision policy and procedures | .302 | .002 | .002 | 20.75% | 13.77% |
| U1/Product characteristics | RU10/Redesign of chain configuration or infrastructure | .392 | 0 | 0 | 16.98% | 8.77% |
| U2/Process/ manufacturing | U5/Organisation structure and human behaviour | .412 | 0 | 0 | 18.87% | 10.09% |
| U2/Process/ manufacturing | U9/Supplier | .458 | 0 | 0 | 28.30% | 17.17% |
| U2/Process/ manufacturing | U12/Chain configuration, infrastructure, and facilities | .311 | .001 | .001 | 19.81% | 12.74% |
| U2/Process/ manufacturing | RU2/Product design | .324 | .001 | .001 | 22.64% | 14.91% |
| U2/Process/ manufacturing | RU3/Process performance measurement | .369 | 0 | 0 | 16.04% | 8.58% |
| U2/Process/ manufacturing | RU5/Collaboration | .397 | 0 | 0 | 26.42% | 16.79% |
| U2/Process/ manufacturing | RU10/Redesign of chain configuration or infrastructure | .433 | 0 | 0 | 20.75% | 11.23% |
| U5/Organisation structure and human behaviour | U9/Supplier | .318 | .001 | .001 | 17.92% | 11.04% |
| U5/Organisation structure and human behaviour | RU3/Process performance measurement | .323 | .001 | .002 | 11.32% | 5.57% |
| U5/Organisation structure and human behaviour | RU10/Redesign of chain configuration or infrastructure | .306 | .002 | .002 | 13.21% | 7.17% |
| U8/Demand amplification | C11/Quantitative techniques | .405 | 0 | 0 | 6.60% | 1.89% |
| U13/Environment | RU7/Decision policy and procedures | .311 | .001 | .001 | 31.13% | 23.40% |
| RU3/Process performance measurement | RU7/Decision policy and procedures | .313 | .001 | .001 | 16.04% | 9.62% |

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|---|---|---|---|---|---|---|
| RU3/Process performance measurement | RU10/Redesign of chain configuration or infrastructure | .330 | .001 | .001 | 12.26% | 6.13% |
| RU5/Collaboration | RU7/Decision policy and procedures | .386 | 0 | 0 | 28.30% | 18.87% |
| **Sustainability performance** | | | | | | |
| S3/Health and safety | S4/Training and education | .373 | 0 | 0 | 12.26% | 5.57% |
| S3/Health and safety | EV7/Environmental compliance | .360 | 0 | .001 | 8.49% | 3.21% |
| S4/Training and education | EV2/Material efficiency | .301 | .002 | .002 | 14.15% | 8.11% |
| EV1/Energy efficiency | EV2/Material efficiency | .568 | 0 | 0 | 28.30% | 14.91% |
| **R-imperatives & uncertainty management** | | | | | | |
| R1/Reduce | RU2/Product design | .354 | 0 | 0 | 11.32% | 5.38% |
| R2/Resell, reuse | RU10/Redesign of chain configuration or infrastructure | .350 | 0 | .001 | 12.26% | 5.85% |
| R5/Remanufacture | U7/End-customer demand | .308 | .002 | .001 | 23.58% | 16.23% |
| R5/Remanufacture | C11/Quantitative techniques | .305 | .002 | .002 | 12.26% | 6.79% |
| R7/Recycle | U1/Product characteristics | .397 | 0 | 0 | 28.30% | 19.34% |
| **R-imperatives & sustainability performance** | | | | | | |
| R1/Reduce | EV2/Material efficiency | .374 | 0 | 0 | 11.32% | 5.09% |
| R7/Recycle | EV2/Material efficiency | .338 | 0 | 0 | 30.19% | 22.36% |
| R7/Recycle | EV4/Waste management | .467 | 0 | 0 | 48.11% | 36.98% |
| **Uncertainty management & sustainability performance** | | | | | | |
| U1/Product characteristics | S3/Health and safety | .327 | .001 | .001 | 14.15% | 7.64% |
| U1/Product characteristics | S4/Training and education | .366 | 0 | 0 | 14.15% | 7.08% |
| U2/Process/ manufacturing | S3/Health and safety | .345 | 0 | 0 | 16.98% | 9.72% |
| U5/Organisation structure and human behaviour | S4/Training and education | .408 | 0 | 0 | 13.21% | 5.75% |
| U13/Environment | E4/Sustainability expenditures | .310 | .001 | .001 | 14.15% | 8.49% |
| U14/Disruption/ natural uncertainties | EV3/Water management | .321 | .001 | .005 | 5.66% | 1.89% |
| RU2/Product design | EV2/Material efficiency | .351 | 0 | 0 | 21.70% | 13.49% |
| RU8/ICT system | EV4/Waste management | .312 | .001 | .001 | 33.96% | 26.32% |
| RU10/Redesign of chain configuration or infrastructure | EV3/Water management | .312 | .001 | .003 | 8.49% | 3.77% |