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Journal of Cleaner Production 389 (2023) 135722

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Risk assessment for circular business models: A fuzzy Delphi study application for composite materials

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ARTICLE INFO

Handling Editor: Yang Liu

Keywords:
Circular economy
Business models
Risk assessment
Risk management
Composite materials
Fuzzy Delphi

ABSTRACT

Circular economy (CE) implementation requires the transition from linear business models (BMs) to circular ones, with related uncertainties and multi-disciplinary risks, which often discourage organisations. However, there is still a lack of understanding of risks associated with this process. This work thus aims to identify, classify and prioritise key risk factors for innovative circular BMs in order to enable the development of appropriate risk management strategies.

A fuzzy Delphi method was tailored to assess the risk factors obtained from the literature and was applied to the industrial case of composite materials. 24 major risk factors for innovative circular BMs were identified and classified into six categories. The probability and impact of the risk factors were evaluated by experts and the risk factors were then ranked by calculating their risk scores. The resultant major risks appeared to be related to the external context in which organisations operate. Among those risks, the greatest were those generated by take-back systems and low customers' acceptance of CE products.

This research is the first to address risks for circularity in a structured way and contributes to the field of CE by providing an extensive list and classification of risk factors for innovative circular BMs as they are perceived by industry, acting as a reference for academics and practitioners. Furthermore, it provides the first evaluation and prioritisation of risk factors within the CE domain, highlighting critical risks within the specific industrial context of composite materials and suggesting action priorities for the establishment of circular BMs.

1. Introduction

The industrial revolution introduced a linear economic model, which led to economic prosperity and improved standards of living in developed economies, but at the expense of nature (Tu et al., 2020). In the linear economy approach, also known as "take-make-dispose", companies consume natural resources to produce goods which are used by the customers and then disposed as waste, leading to excessive consumption of finite resources and depletion of natural capital (Pitt and Heinemeyer, 2015). The consumption of natural resources is expected to grow to unsustainable levels in the future, given the increasing pace of consumption in developed countries and the rapid accelerations of demand for manufactured products in industrialising countries (Hoornweg et al., 2013), coupled with a growing world population (United Nations, 2017). It is therefore critical to move from the current linear economy approach to a more sustainable model, combining global requirements for economic and social advancement with environmental protection, i.e. sustainable production and consumption, thus enabling future generations to also meet their own needs (WCED, 1987).

The Circular Economy (CE) is most commonly defined as "an industrial system that is restorative or regenerative by intention and design. It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the

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https://doi.org/10.1016/j.jclepro.2022.135722
Received 29 January 2022; Received in revised form 18 December 2022; Accepted 21 December 2022
Available online 6 January 2023
0959-6526/

superior design of materials, products, systems, and, within this, business models" (Kirchherr et al., 2017). The CE paradigm decouples economic growth from resource consumption and aims to reduce pressure on the environment, mainly because it considers waste as a resource for production in a closed-loop perspective (Ghisellini et al., 2016). This restorative and regenerative economic system can be achieved through either recycling, remanufacturing, reuse or repair, and slowing, closing and narrowing the material and energy loops (Geissdoerfer et al., 2017; Lieder and Rashid, 2016).

Multiple organisations have embraced CE practices in their production processes and have improved their reverse material and product flows to create closed-loop supply chains (Esain et al., 2016). However, CE implementation can be further strengthened at a strategic level by moving from conventional business models (BM) to circular business models (CBM). Under this strategic perspective, businesses need to find new ways of creating, delivering and capturing value, while incorporating activities such as reverse logistics, reuse, remanufacturing and recycling (Dalhammar, 2016; Kirchherr et al., 2017; Schenkel et al., 2015; Teece, 2010; Wells and Seitz, 2005), and to find new ways for consumers to use products (Selvefors et al., 2019).

Circular business model innovation is an uncertain process posing significant challenges and having potentially significant economic consequences for organisations (Linder and Williander, 2017). Embedding CE into the BM of an organisation is risky, due to factors such as the novelty of CBMs and technologies, potential customers' reluctance and the lack of enabling legislation (Linder and Williander, 2017). However, a structured investigation of the risk factors associated with the transition to CBMs is still lacking. Perceived risk factors are still preventing organisations from making the transition to CBMs, which is key to reduce the depletion of natural resources and to lower the environmental impacts of production systems. Based on the above, the following research question was formulated to guide this work:

RQ: What are the main perceived risk factors for the transition from linear business models to circular business models?

Consequently, the aim of this work is to address this research gap by identifying, classifying and prioritising risk factors for innovative CBM in order to enable appropriate risk management strategy development and support the CBM innovation process. The aim was attained by investigating the specific case of composite materials, used in product manufacturing. Composite materials are light and have some advantageous mechanical properties, such as high strength to weight ratio, and are therefore widely used in many sectors such as aerospace and automotive sectors (Naqvi et al., 2018). Composite manufacturing and end-of-life management are both economically and environmentally costly, and landfilling is the predominant end-of-life option. Alternative end-of-life management of composites is one of the challenges for the manufacturing industry (European Commission, 2017; Rybicka et al., 2016), making the wider composite industry a relevant case of transition towards CBMs. CBMs for glass and carbon-based composite material were thus the focus of the risk assessment process.

This research contributes to CE literature by (a) offering a structured intersectoral review and classification of risk factors associated with the transition from linear to circular business models; (b) providing the first evaluation and prioritisation of risk factors within the CE domain, specifically for industries using composite materials; (c) offering an in-depth investigation related to CE transition within the specific industrial application of composite materials.

The remaining part of this paper is structured as follows. Circular business models are introduced in Section 2, while Section 3 reviews the literature, by identifying risk factors specific to the CE and to BM innovation. Section 4 illustrates the principles of the Fuzzy Delphi method, while Section 5 displays the step-by-step development of the method used in this study. Results arising from the application of the method to the case of composite materials are presented and discussed in Section 6. Finally, Section 7 concludes this paper by highlighting the main contribution to knowledge and to practice, and identifying directions for future research.

2. Circular business models

CBMs need to be specifically designed in order to successfully implement the CE (Rashid et al., 2013). A BM can be described as an architecture consisting of the product, service and data flow (Timmers, 1998) as well as the "design or architecture of the value creation, delivery, and capture mechanisms" (Teece, 2010). Similarly, Osterwalder and Pigneur (2010) defined the BM as the way a firm generates, delivers and monetises its value. As a result, "value proposition", "value creation and delivery" and "value capture" are considered the three main components of a BM, which need to be aligned with organisations' strategies in order to successfully develop innovative BMs (Richardson, 2008).

Business model innovation (BMI) captures the speed and ability of an organisation to develop a novel business model (Geissdoerfer et al., 2018b), reflecting the capability of the organisation to foresee changes and to successfully address them (Osterwalder and Pigneur, 2010). Developing a novel BM can either be the result of incremental change in one or more dimensions of a BM or the outcome of radical changes that affect the whole business ecosystem (Demil and Lecocq, 2010; Geissdoerfer et al., 2020). From the point of view of organisations' value proposition, BMI is the process through which organisations propose new offerings in the market in terms of products and services (Mitchell and Bruckner Coles, 2004).

BMI that incorporates CE leads to the development of CBMs, which represent how a firm generates, delivers and captures value in order to extend the products' lifecycle (Nuβholz, 2017). According to this approach, the economic value of the product at its end-of-life is retained via various processes such as repair, maintenance, reuse, refurbishment and remanufacturing (Lüdeke-Freund et al., 2019; Copani and Behnam, 2020; Linder and Williander, 2017).

CBMs are a subset of sustainability-oriented business models, in which "the conceptual logic for value creation is based on utilizing economic value retained in products after use in the production of new offerings" (Linder and Williander, 2017), thus simultaneously putting economic, environmental and social sustainability at the heart of the value proposition (Boons and Lüdeke-Freund, 2013). CBMs are diverse in practice and can take various forms (Ertz et al., 2019). CBMs can adopt closing resource loop strategies through recycling, cascading and organic feedstock models (Bocken et al., 2016). In this approach, the economic value of the product is kept at the "material level" (Lüdeke-Freund et al., 2019). Alternatively, CBM can focus on impeding the use of resources (Bocken et al., 2016). CBMs that adopt slowing the loop strategies attempt to keep the economic value at the "product level" (Lüdeke-Freund et al., 2019). From an environmental perspective, CBMs that slow down resource loops have a lower positive environmental impact than CBMs that support closing loop strategies (Taps et al., 2013).

Finally, CBMs can take the form of Product–Service Systems (PSS) (Pieroni et al., 2019), which can be considered as a sub-group of CBMs (Geissdoerfer et al., 2020), where product non-ownership and performance-oriented schemes can be adopted to provide the product as a service to customers (Tukker, 2004). Retained ownership of the products by the producer can guarantee the return flow of products (Sundin et al., 2008). PSS-based BMs have the potential to guarantee longer product life and facilitate product take back, while concurrently providing customers with additional value (Lewandowski, 2016; Nuβholz, 2017). While there is a general consensus that organisations should adopt CBM to make production more sustainable, CBM innovation is extremely complex due to the significant challenges and uncertainties associated with the transition from linear to circular BMs. The main risk factors generating such uncertainties are presented in Section 3.

3. Risk factors for circular business model innovation

Circular business model innovation is characterised by two main elements, namely the introduction of CE practices within organisations (Geissdoerfer et al., 2020; Urbinati et al., 2017) and the transformation process of the business model itself, i.e. how the value is generated, delivered and captured by organisations (Geissdoerfer et al., 2018a). Therefore, the risk factors associated with CE transition are presented first in Section 3.1, while the risk factors associated with BM innovation are illustrated in Section 3.2, leading to the identification of the research gap in Section 3.3.

3.1. Circular economy risk factors

Multiple facets of the CE have been analysed, including definitions (Kirchherr et al., 2017), CBMs (Geissdoerfer et al., 2018a, 2020; Rosa et al., 2019), circularity metrics (Corona et al., 2019), CE practices (Govindan and Hasanagic, 2018), critical success factors (Khan et al., 2020), challenges (Sousa-Zomer et al., 2018), drivers (Gusmerotti et al., 2019; Ranta et al., 2018; Tura et al., 2019) and barriers (Guldmann and Huulgaard, 2020; Kazancoglu et al., 2020; Kirchherr et al., 2018; Vermunt et al., 2019). However, the risk factors associated with the transition towards CE have not been addressed in a structured way.

A fuzzy analytic hierarchy process (AHP) method was used by Yang and Li (2010) to evaluate green supply chain risks from a CE perspective, differentiating between organisational risks, control system risks, supply risks, demand risks and market risks. In their classification, organisational risks refer to goal conflicts between actors involved in the supply chain, deriving from unbalanced increased costs, lack of alignment between stakeholders and moral hazards. Control system risks are caused by the difficulty of monitoring and controlling complex circular processes, which involve recycling/remanufacturing activities, whereas supply chain risks associated with suppliers' quality and logistics management might undermine the continuity and quality of circular products. Demand and market risks mainly come from the market volatility and competitors. Risks were also linked to the market acceptance of CE products (Gatzert and Kosub, 2016; Guldmann and Huulgaard, 2020): customers are reluctant to purchase remanufactured products, since they believe original products have superior quality compared to recovered products (Arena et al., 2021; Govindan and Hasanagic, 2018). Additionally, the speed of market evolution is another source of risk for CBMs (Shao et al., 2020; Urbinati et al., 2021), because it requires high flexibility and effective take-back mechanism that avoids shortage of parts to be re-used, recycled and remanufactured (Chakraborty et al., 2019). Financial aspects are also critical for developing CBMs (Brillinger et al., 2020; Gatzert and Kosub, 2016; Gross et al., 2010; Guldmann and Huulgaard, 2020; Leisen et al., 2019). They can stem from the limited availability of funding compared to the high upfront costs of new CE technologies or from the costs associated with recycled materials (Govindan and Hasanagic, 2018). In addition, CBMs often have a lengthy payback period, which makes the business less attractive for financiers (Dulia et al., 2021).

Other authors adopted a supply chain perspective in investigating CE risk factors. Yazdani et al. (2019) developed a multi-criteria decision-making framework for CE supply chain risks, considering environmental risks, logistical and infrastructural risks, management and operational risks as well as risks associated with the macro-political environment and institutional risks. The latter were confirmed by Dulia et al. (2021), who emphasized the lack of vision from policy makers and the vagueness of objectives and targets, while the limitations of existing regulations in terms of ineffective recycling policies and lack of standards were also identified by Govindan and Hasanagic (2018) as factors preventing wider implementation of CE Ethirajan et al. (2021) focused on manufacturing circular supply chains and identified interrelationships among different risk categories. Operational, financial and reputational risks were identified as having a cascading effect on other risks, thus requiring to be tackled by supply chain managers. Dulia et al. (2021) instead identified the potential quality degradation of recycled products as a prominent risk for circular supply chains highlighting issues for product durability and performance across the products' lifetime.

Finally, additional risks include: the lack of transparent information about product origin (Prendeville and Bocken, 2016; Shao et al., 2020); the technological risk due to the novelty of CE technologies for disassembly, testing, remanufacturing and recycling and high investment costs (Chakraborty et al., 2019; Urbinati et al., 2021); the uncertain quality of returned products (Golinska and Kawa, 2011; Urbinati et al., 2021).

3.2. Innovative business models risk factors

CBMs are innovative business models, as they implement a new conceptual logic to create, deliver and capture value. Brillinger et al. (2020) argue that the uncertainties and risks inherent in innovative business models are due to their "complexity, modularity and integrative nature", since BMI can require the modification of multiple companies' business variables simultaneously. They highlight that organisations face both internal and external risks in areas such as customer, value proposition offering, and infrastructure. These risks, coupled with political and regulatory risks, can affect the financial viability of innovative business models. Lack of financial support from governments can hamper the implementation of CBMs, whereas regulations to protect and improve the environment can generate disruptive changes to industry, as experienced by the energy sector (Gatzert and Kosub, 2016). Business models may become obsolete as incentives such as taxation exemptions are introduced or additional regulations define actors who are allowed to compete in the market due to environmental criteria (Leisen et al., 2019). Regulatory risks have also a direct effect on the revenue and cost structures of business models (Gross et al., 2010). Moreover, they display a cascading effect on other elements of business models creating potential additional risks, such as increased capital and operational costs, production and maintenance costs as well as technological, know-how, human resources and even market risks (Gatzert and Kosub, 2016). These risks need to be accurately evaluated to inform decisions about the development of innovative BMs (Brillinger et al., 2020).

CBMs are not immune from risks typically inherent in innovative BMs. Potential sources of risks have been identified in the form of barriers by Vermunt et al. (2019), who classified them into two categories: internal and external. Internal barriers refer to the firm itself (e.g. financial and technical), while external barriers refer to firm's external environment (e.g. supply, market, institutional). The analysis focused on organisations that have already implemented CBMs, i.e. ex-post, rather than on the ex-ante perception of risks by organisations, which may prevent the CBM transition process. The barriers are grounded on case studies in various industries, but the effect of the industrial context on the relevance of barriers and risks was not investigated.

3.3. Research gap

The risk factors for CE and business model innovation have predominantly been addressed in isolation from each other, lacking a joined-up approach to identification and evaluation within the context of the transition from linear to circular business models. Moreover, risk factors identification has mostly been generic, lacking a structured approach and an appropriate prioritisation of risks to support organisations in the transitions to CBMs in terms of identification of major sources of risks. Finally, risk factors identification has not been linked to specific industrial contexts, leading to heterogenous insights for risk management and limited context-specific insights. This work thus aims to identify, classify and prioritise risk factors for innovative CBM, as organisations perceive them ex-ante CBM implementation. The work specifically focuses on the case of industries using composite materials in Europe. In order to attain this aim, a fuzzy Delphi method was used, whose theoretical features are illustrated in Section 4.

4. Methodology

4.1. Delphi method

The Delphi method is a formalised method of communication that is designed to extract the maximum amount of unbiased information from a panel of experts on a specific issue (Okoli and Pawlowski, 2004). As a structured communication process, Delphi allows a group of individuals to deal with a complex problem in contexts where precise analytical techniques are inapplicable (Linstone and Turoff, 1975). The Delphi method aims to arrive at the most reliable convergence of opinion on a particular issue through a series of questionnaires (Chan et al., 2001), being able to collect information from experts from different geographical areas (Tseng et al., 2019). The method is particularly useful for exploratory research in complex and interdisciplinary research (Sauer and Seuring, 2018), such as the risk assessment for innovative CBM.

The Delphi method displays three main characteristics: anonymous response; iteration and controlled feedback; statistical group response (Bouzon et al., 2016). The anonymous response feature guarantees that participants are kept separate to each other and only interact with the moderating team, thus avoiding the potential negative effects of their direct interaction, which can lead to biased results due to the emergence of opinion leaders (Sauer and Seuring, 2018). The iterative nature of the Delphi method is applied by designing the study in multiple rounds of questionnaires enabling experts to modify their opinions throughout successive rounds based on the responses put forward by the other experts (Slack et al., 2013). At each round, replies are analysed, summarised and returned to the experts with controlled feedback (Slack et al., 2013). The iterative feature of Delphi also enhances the validity of results, as experts can build on previous rounds of questionnaires and the feedback generated, differently from one-off surveys (Sauer and Seuring, 2018). Finally, the statistical group response feature allows the aggregation of experts' opinions on the researched topic (Sauer and Seuring, 2018).

Three key tasks need to be performed to complete a Delphi study (Linstone and Turoff, 1975).

1. Definition and selection of experts: this is the most critical task in a Delphi study, as the knowledge and experience of experts are central to the outcome of the study (Chan et al., 2001). The number of experts is not fixed, with recommendations ranging from a minimum of 3 up to a maximum of 50 experts (Reefke and Sundaram, 2017), although most studies suggest keeping the number of participants between 10 and 18 (Okoli and Pawlowski, 2004). Eighteen experts were selected for this work (see Section 5.2).
2. Definition of the number of rounds: the maximum number of rounds needed is not fixed, as the method dictates that a stable and reliable convergence of answers is reached among experts or sufficient information is obtained (Reefke and Sundaram, 2017; Urbinati et al., 2017). The majority of studies employ two or three rounds (Seuring and Müller, 2008). Two rounds were used in this work (see Sections 5.3 and 5.4).
3. Development and testing of the questionnaire structure in each study round: appropriate guidelines are necessary to ensure the reliability of the study. Each questionnaire was therefore tested by seven academics/practitioners in order to check comprehensibility and identify mistakes, in line with Reefke and Sundaram (2017).

The Fuzzy Delphi method, first developed by Ishikawa et al. (1993), strengthens the traditional Delphi method by resolving potential vagueness and uncertainties associated with the traditional Delphi method where it is not possible to extend the number of questionnaire rounds (Singh and Sarkar, 2020). The Fuzzy Delphi method improves the efficiency and quality of traditional Delphi (Padilla-Rivera et al., 2021) and offers advantages compared to traditional Delphi (Tseng et al., 2019). It reduces the number of rounds required to carry out the study and the overall investigation time, and it better supports the transformation of the knowledge of experts into quantitative figures, thus providing benefits to decision-making (Tseng et al., 2019). As the fuzzy Delphi method integrates fuzzy set logic within the Delphi method, an overview of fuzzy set theory is presented in Section 4.2.

4.2. Fuzzy set theory

Under many conditions, exact data is not adequate to model real-life problems, because human judgements and preferences cannot be estimated with exact numerical values (Shen et al., 2013). Fuzzy set theory, first developed by Zadeh in 1965, is a mathematical theory which has been designed to solve problems of uncertain and imprecise nature (Kannan et al., 2015). Fuzzy set theory is designed to capture the fuzziness associated with the human cognitive process (Tseng, 2011), in order to address ambiguity, subjectivity, vagueness and uncertainty associated with human judgement in decision-making processes (Govindan et al., 2013; Kannan et al., 2013).

Fuzzy set theory is based on the assumption that "the main factors in human judgement and thought are not numbers, but linguistic terms" (Rostamzadeh et al., 2015) and that words or sentences in a natural or artificial language are more suitable to express complex situations compared to conventional quantification (Mirhedayatian et al., 2014; Zadeh, 1975). Fuzzy theory supports the linguistic assessment of data by decision-makers and concurrently handles the ambiguity associated with such linguistic data by exploiting the mathematical property of partial set membership (Shen et al., 2013). Fuzzy theory transforms qualitative linguistic evaluation into fuzzy values, which are subsequently transformed into quantitative outcomes (Wang et al., 2012).

From a mathematical perspective, fuzzy set theory is a generalisation of set theory, where classes of objects lack sharp boundaries (Tseng and Chiu, 2013). A fuzzy set is a class of objects, with continuum grades of membership, where the membership grade can have an intermediate value between 0 and 1 (Mohammed et al., 2019). A fuzzy subset N of a universal set of items X is defined by a membership function $\mu_N(x)$, which maps each element x contained in X to a real number, generally scaled between 0 and 1 (Mangla et al., 2015; Shen et al., 2013). Membership functions are the mechanism adopted to capture the uncertainties of fuzzy sets with fuzzy logic (Mohammed et al., 2019).

An expert's uncertain evaluation is an example of such uncertainty and can be represented by a fuzzy number (Tseng and Chiu, 2013). A triangular fuzzy number (TFN) is a fuzzy number, whose membership function is defined by a triplet of real numbers (a, b, c), where a,b,c are real numbers and $a \leq b \leq c$ (Tseng and Chiu, 2013). The triplet is defined as follows: a is the lower limit and smallest possible value, b represents the middle and most promising value and c is the upper limit and largest possible value (Mangla et al., 2015; Tseng et al., 2019). The triangular membership function $\mu_N(x)$ is mathematically defined according to Eq. (1) and is depicted in Fig. A1 (Appendices).

$$\mu_N(x) = \begin{cases} 0 & x < a \\ \dfrac{x-a}{b-a} & a \leq x \leq b \\ \dfrac{c-x}{c-b} & b \leq x \leq c \\ 0 & x > c \end{cases} \tag{1}$$

The following operations are valid for triangular fuzzy numbers (Jia et al., 2015), given two TFNs, $\widetilde{N}_1 = (a_1, b_1, c_1$ and $\widetilde{N}_2 = (a_2, b_2, c_2$:

$$\widetilde{N}_1 (+) \widetilde{N}_2 = (a_1, b_1, c_1) (+) (a_2, b_2, c_2 = (a_1 + a_2, b_1 + b_2, c_1 + c_2) \tag{2}$$

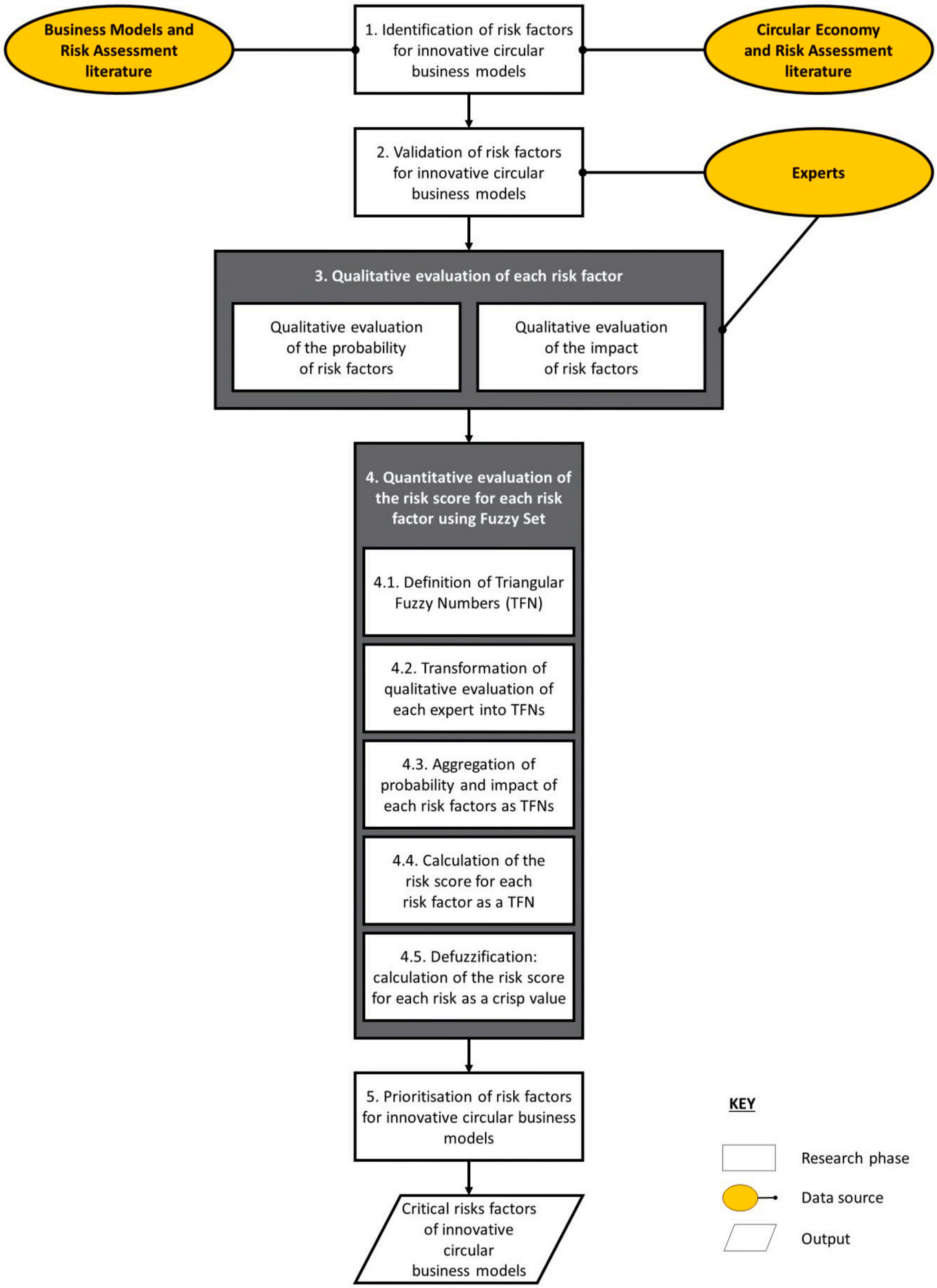

Fig. 1. Fuzzy Delphi Risk Assessment approach.

$$\widetilde{N}_1(-)\widetilde{N}_2 = (a_1, b_1, c_1)(-)(a_2, b_2, c_2 = (a_1 - a_2, b_1 - b_2, c_1 - c_2) \quad (3)$$

$$\widetilde{N}_1(\times)\widetilde{N}_2 = (a_1, b_1, c_1)(\times)(a_2, b_2, c_2 = (a_1a_2, b_1b_2, c_1c_2) \quad (4)$$

$$\widetilde{N}_1(\div)\widetilde{N}_2 = (a_1, b_1, c_1)(\div)\left(a_2, b_2, c_2 = \left(\frac{a_1}{a_2}, \frac{b_1}{b_2}, \frac{c_1}{c_2}\right)\right. \quad (5)$$

5. Fuzzy Delphi Risk Assessment method

The Fuzzy Delphi method was applied to assess the risk factors associated with innovative CBMs, as it generates a robust consensus among a group of experts (Padilla-Rivera et al., 2021; Tseng et al., 2019), while addressing information complexity and avoiding the distortion of individual expert opinions (Tseng et al., 2015). The risk assessment process, illustrated in Fig. 1, aimed to identify the critical risk factors that need to be prioritised for the innovative CBMs. First, risk factors for innovative CBMs were identified through secondary sources, as illustrated in Section 5.1. Second, a panel of experts, whose backgrounds and experience are summarised in Section 5.2, validated these risk factors (Section 5.3). Third, the shortlisted risk factors emerging from the validation stage, were qualitatively evaluated by the experts and the resultant judgements were converted into quantitative risk scores, as explained in Section 5.4. This led to the prioritisation of risk factors, which is integral to identifying major sources of uncertainty potentially affecting the economic viability of innovative CBMs, and to the identification of critical risk factors for innovative CBMs, which is the main output of this research.

5.1. Identification and classification of risk factors

The first step in the risk assessment process depicted in Fig. 1 is the identification and classification of risk factors. A structured literature review was carried out to identify the risk factors, based on the following research question:

What are the risk factors for innovative business models based on CE principles?

The literature at the intersection of CE and risk management was reviewed to identify CE-specific risk factors, while literature at the intersection of business modelling and risk management was reviewed to identify risk factors associated with innovative business models (Section 3). Risk factors emerging from the screening of the literature were then reviewed through keyword analysis to eliminate duplicates and aggregate overlapping ones (Tuni et al., 2018). The remaining risk factors were clustered into seven risk categories using a thematic analysis based on keyword analysis (Ahi and Searcy, 2015).

- M – Market (Leisen et al., 2019; Vermunt et al., 2019; Yang and Li, 2010): includes risk factors related to sales, market forces, competitors and customers;
- S – Supply (Govindan and Hasanagic, 2018; Yang and Li, 2010): includes risk factors related to the upstream supply chain and logistics;
- F – Finance (Brillinger et al., 2020; Gross et al., 2010; Vermunt et al., 2019): includes risk factors related to the financial aspects of CBMs;
- OM - Operations and Management (Gatzert and Kosub, 2016; Leisen et al., 2019; Yazdani et al., 2019): includes risk factors related to the organisational structure and its impact on the organisational operations;
- PR – Political and Regulatory (Gatzert and Kosub, 2016; Yazdani et al., 2019): includes risk factors related to changes in public policies, regulations and political context;
- T – Technical (Gross et al., 2010): includes risk factors related to the knowledge, technologies and methods required to implement the CBMs in the industrial context; and the impact on product quality or generation.
- O – Other: includes all risk factors that could not be allocated to a specific category.

Wherever risk factors could not be aggregated and/or classified exploiting keyword analysis, axial coding was adopted to identify meaningful semantic relationships among risk factors to aggregate and/or classify them (Arekrans et al., 2022). Three researchers performed this activity independently: any disagreement regarding the aggregation of risk factors and their categorisation was discussed, until consensus among all researchers was reached (Tuni et al., 2018). This generated 66 risk factors relevant to innovative CBMs, and to the economic viability of such BMs. The list is available in the Appendices (Table A.2).

5.2. Selection of experts

The risk assessment process illustrated in Fig. 1 prescribes that judgement of experts is used as a data input to validate and evaluate the risk factors identified in Table A.2. As such, the selection of experts is a key preliminary step to assess the risk factors of innovative CBMs. In-line with the Delphi method recommendations to include between 10 and 18 experts (Okoli and Pawlowski, 2004; Urbinati et al., 2017), eighteen experts were selected to form the panel. Experts were selected to match objective inclusion criteria in order to avoid a non-representative sample (Reefke and Sundaram, 2017). Experts needed to meet the following criteria to be part of the panel, in line with Azevedo et al. (2013).

1. Have a current involvement in the areas of CE, innovative BM and/or composite materials through professional and/or academic practice;
2. Have experience in the areas of CE, innovative BM and/or composite materials, substantiated through a minimum of 2 years of experience in their organisation and in the industry
3. Demonstrate continuing professional interest in the areas of CE, innovative BM and/or composite materials, to guarantee the willingness of participants to be engaged in the study;

The panel represents a mixture of expertise with different backgrounds, in line with the requirements of the Delphi method (Reefke and Sundaram, 2017). The experts represent the various actors of reverse supply chains, such as waste material suppliers, waste management organisations, materials' recycling companies and manufacturers of CE products, as well as additional stakeholders from academia and relevant

Table 1
Profiles of experts.

Expert	Industry	Position	Years of experience	
			Organisation	Industry
E1	Automotive	Researcher	5	5
E2	Automotive	Project Manager/Leader	3	6
E3	ICT	Project Manager/Leader	4	10
E4	R&D	Researcher	4	4
E5	Aerospace	Project Manager/Leader	4	10
E6	Automotive	Senior Engineer	6	18
E7	Construction	Operations Manager	21	21
E8	Materials	Project Manager/Leader	11	11
E9	R&D	Project Manager/Leader	3	20
E10	Sport	Project Manager/Leader	25	25
E11	Aerospace	Materials and Processes Engineer	20	22
E12	Home Furnishing	Technical Department Manager	3	3
E13	Automotive	Project Manager/Leader	20	20
E14	Construction	Quality Manager	3	3
E15	R&D	Materials Manager	25	27
E16	Academia	Lecturer	10	15
E17	R&D	Project Manager/Leader	20	20
E18	Waste Management	Innovation Manager	4	2
Average			10.61	13.43

Table 2
Risk factors list.

Risk Category	Risk Factor		Risk Factor Description	Source
Market	M1	Consumer perception (quality vs. new products)	Resistance of end-users towards CE products due to customer perception about inferior quality compared to new products, resulting in low public acceptance and low market penetration	(Arena et al., 2021; Gatzert and Kosub, 2016; Govindan and Hasanagic, 2018; Guldmann and Huulgaard, 2020; Kissling et al., 2013; Planing, 2015)
Market	M2	Customer perception (ownership)	Resistance of end-users towards CE products due to preference of customers for ownership rather than access to service resulting in low public acceptance of products (applicable only to non-ownership business models)	(Govindan and Hasanagic, 2018; Planing, 2015; Sousa-Zomer et al., 2018)
Market	M3	Market forecast	Demand risk, namely the uncertainty about the market size	Yang and Li (2010)
Market	M4	Economic cycle	Risk in the business environment/market due to adverse economic cycle and/or uncertain financial stability, resulting in low demand for products at the global level	(Brillinger et al., 2020; Yazdani et al., 2019)
Supply	S1	Supply availability	Limited and/or not timely availability of recycled materials to support demand of CE final products	(Ethirajan et al., 2021; Govindan and Hasanagic, 2018; Guldmann and Huulgaard, 2020; Linder and Williander, 2017; Urbinati et al., 2021)
Supply	S2	Logistics	Risk associated with changes in the supply network and transportation determining an increase of the logistic costs	(Urbinati et al., 2021; Yang and Li, 2010; Yazdani et al., 2019)
Supply	S3	Supplier quality	Supplier quality risk, resulting in quality criteria for the input materials not being achieved	(Ethirajan et al., 2021; Golinska and Kawa, 2011; Guldmann and Huulgaard, 2020; Urbinati et al., 2021; Yang and Li, 2010)
Supply	S4	Take-back system	Lack of structured take-back systems, including the lack of accurate information about the tracking of materials in the reverse supply chain	(Chakraborty et al., 2019; Dulia et al., 2021; Govindan and Hasanagic, 2018; Guldmann and Huulgaard, 2020; Linder and Williander, 2017)
Finance	F1	Lifecycle revenues	Lifecycle risk and uncertainty factors related to a possible uncalculated change of revenues due to price volatility of the final product resulting in lower than expected revenues	(Brillinger et al., 2020; Gatzert and Kosub, 2016; Yang and Li, 2010)
Finance	F2	Capital costs	Risk associated with high up-front investment costs and capital costs required to create and deliver the value proposition of the innovative business models, including costs for production plants and inventory costs	(Brillinger et al., 2020; Dulia et al., 2021; Gatzert and Kosub, 2016; Govindan and Hasanagic, 2018; Gross et al., 2010; Guldmann and Huulgaard, 2020; Leisen et al., 2019; Matus et al., 2012; Rizos et al., 2016; Shao et al., 2020; Urbinati et al., 2021)
Finance	F3	Recycled material costs	Unforecasted increase of recycled material cost, affecting the economic viability of using recycled materials	(Dulia et al., 2021; Govindan and Hasanagic, 2018; Gross et al., 2010; Leisen et al., 2019)
Finance	F4	Virgin material costs	Unforecasted decrease of virgin materials cost, affecting the economic viability of using recycled materials	(Dulia et al., 2021; Govindan and Hasanagic, 2018)
Finance	F5	Production costs	Increased production costs, including increased costs for energy and maintenance within the production plant	Govindan and Hasanagic (2018)
Finance	F6	Financial resources	Factors impacting the capability to finance the CE business model, including access to finance	(Brillinger et al., 2020; Guldmann and Huulgaard, 2020)
Political and Regulatory	PR1	Regulatory standards	Lack of standards for CE products, potentially affecting compatibility, quality and sustainable branding	(Govindan and Hasanagic, 2018; Leisen et al., 2019)
Political and Regulatory	PR2	Legal and regulatory	Commitment of regulatory and legal circumstances, including the ineffectiveness of existing laws and/or their insufficient implementation	(Brillinger et al., 2020; Dulia et al., 2021; Govindan and Hasanagic, 2018; Gross et al., 2010; Guldmann and Huulgaard, 2020; Leisen et al., 2019; Linder and Williander, 2017; Yazdani et al., 2019)
Political and Regulatory	PR3	Public policy and institutional	Risk arising from adverse changes in policy support schemes or regulations, including economic incentives to shift from linear economy to CE, and/or uncertainty regarding changes in government policies	(Dulia et al., 2021; Gatzert and Kosub, 2016; Govindan and Hasanagic, 2018; Linder and Williander, 2017; Yazdani et al., 2019)
Political and Regulatory	PR4	Taxation	Risk arising from adverse changes in the taxation regulations, including declining or eliminated tax advantages for green products, and/or uncertainty regarding changes to the fiscal policies	(Brillinger et al., 2020; Dulia et al., 2021; Leisen et al., 2019; Linder and Williander, 2017; Yang and Li, 2010; Yazdani et al., 2019)
Political and Regulatory	PR5	Non-ownership Business Model	Legal issues emerging for non-ownership business models as service providers cannot legally retain ownership of a sold product (applicable only to non-ownership business models)	(Dulia et al., 2021; Govindan and Hasanagic, 2018; Sousa-Zomer et al., 2018)
Political and Regulatory	PR6	Intellectual property	Risks associated with the drainage of Intellectual Property (IP) or know-how, including sensitive data on the organisation's partners	(Brillinger et al., 2020; Urbinati et al., 2021)
Technical	T1	Human resources	Risks related to the lack of qualified human resources required to realise the CBM	(Agyemang et al., 2019; Brillinger et al., 2020; Dulia et al., 2021; Govindan and Hasanagic, 2018; Perron, 2005)
Technical	T2	Quality	Risks related to the quality of the final CE products, such as gaps in expected vs. delivered performance, durability and functionality throughout lifecycle of the CE product;	(Arena et al., 2021; Brillinger et al., 2020; Dulia et al., 2021; Ethirajan et al., 2021; Govindan and Hasanagic, 2018; Yazdani et al., 2019)
Technical	T3	Technology	All risk and uncertainty factors that are linked to the use of technologies that are new or still in a premature state, highly complex, or for which the company lacks experience, potentially leading to lower than expected technological efficiency	(Brillinger et al., 2020; Gatzert and Kosub, 2016; Govindan and Hasanagic, 2018; Guldmann and Huulgaard, 2020; Leisen et al., 2019; Linder and Williander, 2017; Shao et al., 2020)
Other	O1	COVID-19 Pandemic	Risk arising from the Covid-19 pandemic, including major supply chain disruptions, supplier failure and/or customer solvency	NA

research centres. All experts are based in Europe. Industrial experts were selected from companies that are currently designing and/or are involved in planning the transition towards CBMs, but have not yet reached the implementation stage. Thus, this research investigates risks that affect the decision to start the transition, i.e. perceived risks by experts, rather than those encountered during the CBM transition. From Table 1, 'Automotive' and 'Research and Development' are the most represented industries with four experts on the panel. 'Project Manager/Leader' within research and development is the most common position held by experts, with eight occurrences within the panel. The experts average 10.61 years of experience within the organisation they currently belong to and 13.43 years of experience in their respective industry, thus displaying sufficient experience to evaluate risk factors at the organisational level and industry-wide level.

Experts were involved in two rounds of online questionnaires, the first for risk factors validation (Section 5.3) and the second for risk factors evaluation (Section 5.4).

5.3. Validation of risk factors

The 66 risk factors obtained from the literature were validated by the panel of experts through an online questionnaire. Experts were asked to identify relevant risk factors to be forwarded to the evaluation stage as well as to identify risk factors, which are applicable to the context of innovative CBMs for composite materials and were not explicitly mentioned by the literature. Only risk factors that were identified as relevant by at least 50% of experts were selected to be forwarded to the evaluation stage. As a result, several risk factors were excluded as they were deemed not relevant for innovative CBMs. Moreover, 'COVID-19 Pandemic' risk factor was added to the list, following input from the experts, leading to a finalised list containing 24 risk factors, which were clustered in six categories and are displayed in Table 2. The results from the validation stage were communicated to the experts ahead of the evaluation stage in-line with the controlled feedback prescribed by the Delphi method. This involved inviting experts "to consider whether they would like to change any of their original choices in the light of the consolidated results from the first round" (Azevedo et al., 2013), however no change was recorded at this stage.

5.4. Fuzzy evaluation of risk factors

The 24 risk factors shortlisted from the validation stage were then evaluated by the panel of experts through a second online questionnaire. Experts were asked to qualitatively evaluate the probability and impact of each risk factor. The steps performed to transform such qualitative evaluations into quantitative risk scores allowing the ranking of risk factors are described in sections 5.4.1 to 5.4.6.

5.4.1. Design of a linguistic scale

Experts were asked to provide their judgement on the probability and the impact of each of the shortlisted risk factors listed in Table 2 using linguistic variables, "whose values are words or sentences in a natural or artificial language" (Zadeh, 1973). The probability and impact were evaluated using a five-points linguistic scale and the definitions associated with each linguistic variable are summarised in Table 3. Probability is here defined as the likelihood that a particular risk will occur during a specific time frame (Leisen et al., 2019; Yazdani et al., 2019), whereas impact is defined as the severity of the financial effect should the risk occur within the specified time frame (Leisen et al., 2019; Yazdani et al., 2019). The time frame for the risk factor evaluation was defined as five years, in line with Leisen et al. (2019), which is consistent with the timeline of future EU regulations, expected to tighten the limits for disposal of composite materials, such as carbon and fibre glass, hence introducing a disruptive regulatory change in the industry (WindEurope, 2020).

5.4.2. Definition of triangular fuzzy numbers (TFNs)

Calculations with fuzzy numbers are dependent on the shape of the membership functions (Yasin et al., 2016). Triangular fuzzy numbers, based on triangular membership functions, are used in this work to model the opinions of experts, due to their ease of usage and calculation (Jia et al., 2015; Mangla et al., 2015; Shen et al., 2013). The triplets associated with each point of linguistic scale, represented graphically in Fig. 2 and listed in Table 3, are standard fuzzy triangular membership functions available in the literature to represent five-points scale in the space between 0 and 1 (Jia et al., 2015; Mohammed et al., 2019; Shen et al., 2013; Wu et al., 2014).

5.4.3. Transformation of linguistic scale values into TFNs

Triangular fuzzy numbers are used to transform the judgements of the experts collected through questionnaires and expressed in linguistic terms into numerical values, as illustrated in Table 3 (Tseng et al., 2019).

5.4.4. Aggregation of probability and impact scores

The experts' scores are collated together to calculate an aggregated probability and an aggregated impact of each risk factor j in a TFN format. Assuming that a decision group has K decision-makers and the fuzzy evaluations of each decision maker $DM_k = 1, 2, \ldots, K$ can be represented as positive triangular fuzzy numbers P_{jk} $(1, 2, \ldots, K)$ and I_{jk} $(1, 2, \ldots, K)$, with membership functions $\mu_{Pjk}(x)$ and $\mu_{Ijk}(x)$ respectively, then the aggregated fuzzy evaluations for probability and impact of the risk factor j can be defined as:

$$P_j = (a, b, c), k = 1, 2, \ldots, K \tag{6}$$

$$I_j = (a, b, c), k = 1, 2, \ldots, K \tag{7}$$

Where $a = min_k\{a_k\}$, $b = \frac{1}{k} \sum_{k=1}^{K} b_k$ and $c = max_k\{c_k\}$.

5.4.5. Calculation of risk score

The risk score of each risk factor j is calculated by multiplying its aggregated probability P_j with its aggregated impact I_j. According to the rules of fuzzy operators, the multiplication of two TFNs does not necessarily result in a TFN, however the result is typically approximated to a TFN according to the operators illustrated in Section 4.2, as the introduced error is negligible (Govindan et al., 2013; Lee, 2005). The risk score of risk factor j is therefore expressed as:

$$RS_j = P_j \times I_j \tag{8}$$

5.4.6. Defuzzification

The final step to obtain a ranking of risk scores is defuzzification, which transforms the risk score of each risk factor j from a TFN format to a crisp value. The Centre of Gravity (COG) method is used to perform defuzzification, as it is the most common method of defuzzification (Padilla-Rivera et al., 2021; Wang et al., 2012) and does not require to introduce the preferences of any evaluators (Rostamzadeh et al., 2015). Eq. (9) illustrates the COG formula:

$$RS_j = \frac{[(c - a) + (b - a)]}{3} + a \tag{9}$$

6. Results

The overall risk score of each risk factor was calculated by multiplying the probability and impact of risk factors expressed as TFNs and was then converted into a single crisp value following defuzzification. The risk score and ranking of risk factors are summarised in Table 4.

'S4: Take-back system' was identified as the factor having the highest risk score (0.447) among all evaluated factors, in particular due to its high probability score. The reverse supply chain is key to obtaining parts to be reprocessed, as well as recycled materials of the correct quantity, forecastable quality and at the right time, confirming observations by

Table 3
Definition of the linguistic scale (adapted from Hallikas et al., 2004) and triangular fuzzy numbers.

Linguistic Scale	Probability	Impact	Triangular Fuzzy Number (TFN)
Very Low	Very unlikely: Very rare event	No impact: Insignificant financial impact for the whole organisation	(0; 0.1; 0.3)
Low	Unlikely: Indirect evidence of event	Minor impact: Isolated small financial losses	(0.1; 0.3; 0.5)
Medium	Moderate: Direct evidence of event	Medium impact: Short-term financial difficulties	(0.3; 0.5; 0.7)
High	Probable: Strong direct evidence of event	Serious impact: Long-term financial difficulties	(0.5; 0.7; 0.9)
Very High	Very probable: Event is expected	Catastrophic impact. Business discontinued	(0.7; 0.9; 1)

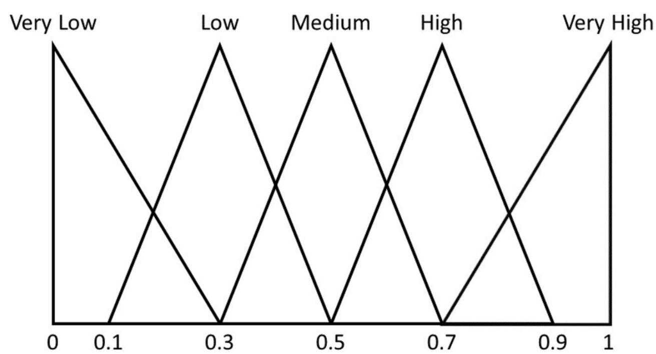

Fig. 2. Fuzzy triangular membership functions.

Govindan and Hasanagic (2018). Enhanced network coordination is required among the organisations within the reverse supply chain, e.g. re-processors and suppliers of recycled materials, which adds to supply chain complexity (Bocken et al., 2018; Bouzon et al., 2016; Govindan and Bouzon, 2018; Lopes de Sousa Jabbour et al., 2019). This coordination is necessary to track parts, material flows and quality along the reverse chain, in order to meet planned volumes and to guarantee the quality of remanufactured/recycled parts that the market requires (Singh et al., 2014; Singh and Ordoñez, 2016; Vermunt et al., 2019). In the case of composite materials, whose quality determines the performance of the final products, the existence of such an effective supply chain is a pre-requisite for any CBMs. Due to the very early stage of development of CE for composite materials, consolidated take-back systems or compliance scheme that can guarantee the return flow of waste products are not widely available yet, potentially explaining the high risk attributed to S4. Experts in the composite sector also perceive a lack of suppliers to provide materials and transformation services for the supply of CE products, evidenced by the positioning of ‘S1: Supply Availability’ among top-10 risk factors. The existence of green suppliers is critical to CE development and to the establishment of BMs aimed at circular supply, resource recovery and product life cycle extension (Rizos et al., 2016; Vermunt et al., 2019). However, composites CBMs are novel and circular suppliers are not available at industrial scale yet, potentially explaining the high risk attributed to S1.

The risk factors ‘M1: Consumer perception (quality vs. new products)’, ‘M3: Market forecast’ and ‘M4: Economic cycle’ follow in the ranking with risk scores of 0.439, 0.438 and 0.433 respectively. Concerns about potential market revenues are high, which align with Vermunt et al. (2019), who found that market-factors are relevant in all type of CBMs. Three major determinants of possible limited market revenues are perceived as significant sources of risk by experts. First, the acceptance of CE products by customers, due to perception of inferior quality or lack of safety, possibly associated with a still immature green culture, in line with previous observation by Kissling et al. (2013) and Planing (2015). Second, the level of acceptance of innovative non-ownership value propositions for the market, as previously outlined by Planing (2015) and Lewandowski (2016), who state that consumers prefer traditional owning and purchase models. This can determine additional difficulties and uncertainties in demand forecasting. Finally, the increased market turbulence and uncertainty about economic cycles, which may determine a reduction of the demand globally. The significant relevance of market risks in the case of composites materials can be explained considering the innovativeness of CE practices within this industrial context compared to others, meaning that they have not been introduced to the market yet. Customers’ response is thus uncertain and difficult to forecast.

‘PR1: Regulatory standards’ completes the top-5 risk factors: experts highlighted that the lack of regulation and of a standardisation framework is a major concern in relation to composite materials, suggesting that policy makers should direct actions towards the establishment of a common CE standardisation framework. This risk factor has multiple implications, both on the sourcing side, as the lack of standards may hamper the compatibility of CE parts with new products, and on the distribution side, where companies do not benefit from a CE labelling standard that can support their sustainability branding and marketing. Finally, the lack of such standards has implications for quality assurance regarding CE products which has a knock-on effect on market factors such as customer perception. This result confirms that the lack of proper regulation and standardisation for CE is critical for any sector, but its effect is even more severe in industrial contexts where the transition towards CBMs has started only recently, such as in the composites one (Oghazi and Mostaghel, 2018).

All of these top-risk factors are “external factors”, as classified by Vermunt et al. (2019) and Brillinger et al. (2020). By comparison, “internal risks”, i.e. factors that are directly controllable by companies, appear to be less critical, with only two risk factors represented in the top-10: ‘Quality’ (T2) and ‘Capital Costs’ (F2). Quality of CE products is a concern of experts, confirming that this is an important success factor to meet market requirements and that if CE products do not match the quality of new products, i.e. in terms of durability and functionality along the product lifecycle, this would potentially disrupt business

Table 4
Risk factors ranking.

Risk Factor	Probability	Impact	Total Risk	
	TFN	TFN	Score	Rank
S4	(0.10; 0.63; 1.00)	(0.00; 0.54; 1.00)	0.447	1
M1	(0.00; 0.56; 1.00)	(0.00; 0.57; 1.00)	0.439	2
M3	(0.10; 0.55; 1.00)	(0.10; 0.55; 1.00)	0.438	3
M4	(0.10; 0.54; 1.00)	(0.10; 0.54; 1.00)	0.433	4
PR1	(0.00; 0.56; 1.00)	(0.00; 0.51; 1.00)	0.429	5
F2	(0.00; 0.51; 1.00)	(0.00; 0.55; 1.00)	0.427	6
S1	(0.00; 0.49; 1.00)	(0.00; 0.57; 1.00)	0.425	7
T2	(0.00; 0.43; 1.00)	(0.30; 0.62; 1.00)	0.423	8
O1	(0.00; 0.50; 1.00)	(0.00; 0.54; 1.00)	0.423	9
M2	(0.10; 0.53; 1.00)	(0.10; 0.60; 0.90)	0.408	10
S3	(0.00; 0.43; 1.00)	(0.00; 0.51; 1.00)	0.407	11
PR2	(0.00; 0.56; 0.90)	(0.00; 0.54; 1.00)	0.401	12
F4	(0.00; 0.39; 1.00)	(0.00; 0.46; 1.00)	0.392	13
F3	(0.00; 0.50; 1.00)	(0.00; 0.53; 0.90)	0.388	14
F5	(0.00; 0.35; 1.00)	(0.00; 0.46; 1.00)	0.386	15
T3	(0.10; 0.52; 0.90)	(0.10; 0.58; 0.90)	0.375	16
PR4	(0.00; 0.42; 1.00)	(0.10; 0.50; 0.90)	0.370	17
F6	(0.00; 0.44; 1.00)	(0.00; 0.46; 0.90)	0.368	18
PR3	(0.00; 0.36; 1.00)	(0.00; 0.51; 0.90)	0.361	19
PR5	(0.00; 0.41; 1.00)	(0.00; 0.42; 0.90)	0.358	20
T1	(0.00; 0.35; 1.00)	(0.00; 0.49; 0.90)	0.356	21
S2	(0.00; 0.46; 0.90)	(0.00; 0.55; 0.90)	0.355	22
F1	(0.10; 0.43; 0.90)	(0.00; 0.51; 0.90)	0.343	23
PR6	(0.00; 0.31; 0.90)	(0.00; 0.38; 0.90)	0.310	24

continuity. Access to efficient and robust technologies for CE (T3), as well as to qualified human resources (T1), are considered moderately critical. The technological complexity and knowledge required for processing composite materials is considered manageable in the medium-term in light of major advances that are being made in composites CE research (Romani et al., 2021). This finding, potentially industry-specific, is in contrast with the general emphasis of existing literature on technical risks as a significant hindrance to CBM development (Agyemang et al., 2019; Perron, 2005; Urbinati et al., 2021).

Financial risks are also considered less critical than supply chain, market and legislative ones. The scale of investments needed to start the production of CE products and to establish CBMs was the main source of financial risk identified (F2). The high ranking of F2 suggests that experts are concerned about the scale of investments envisaged for new high-volume composites materials circular production plants, as well as for establishing the innovative circular value propositions. This may be particularly the case of PSS as upfront investments have to be anticipated, while market revenues are diluted in time (Vermunt et al., 2019). Other financial risks associated with the operations of CBMs are not ranked highly (F3, F4, F5) and access to funding for CBM implementation is not of major concern either (F6). These findings, potentially specific to the composite materials industrial context, offer a new perspective regarding CBM risks as previous studies have frequently identified financial/economic factors as major risks for CBMs (Rizos et al., 2016; Matus et al., 2012).

Finally, risks associated with intellectual property in CBM innovation were negligible in the investigated case. This is contrary to previous studies that found that weak intellectual property management (IPM) can discourage firms to adopt CBMs. This was in particular reference to supply chain partners in charge of products remanufacturing or recycling operations, that might have access to product know-how that is traditionally retained and kept confidential by OEMs (Despeisse et al., 2017; Mathiyazhagan et al., 2013; Whalen et al., 2018). A potential explanation is that, in the specific cases of composites, the type of product and process information required to implement CE are of limited complexity compared to other type of products and industries, making thus IPM less critical than in other contexts.

7. Discussion

This research contributes to CE literature in three ways. First, it offers a structured review and classification of risk factors associated with transitioning from linear to circular business models, which is applicable to any industrial context. Risk factors obtained from the literature were identified and clustered in relevant categories, leading to a wide portfolio of risks that can affect the transition to a circular business approach. Scholars and practitioners of any industry can equally access this list to enrich the CBM transition discussion in future studies or to shortlist relevant risks for specific industrial cases.

Second, it provides the first evaluation and prioritisation of risk factors within the CE domain. This is achieved within a specific industrial context, the one of industries using composite materials, by highlighting critical risk factors to be managed by organisations willing to implement the transition towards CBMs. Identified risks are not equally relevant in all industrial contexts, but rather depend on the features of particular industrial context, such as supply chain dynamics, technological complexity and business drivers. Therefore, risks need to be prioritised considering the specificities of the investigated industrial context in order to identify critical risks and allocate investments for risk management accordingly. In the case of composite materials, external risks deriving from weak take-back systems, negative consumer perception, difficulty of market forecast, turbulent economic cycles and lack of regulatory standards are more relevant than internal risks such as technological and financial ones, differently from previous non-industry specific observations (Agyemang et al., 2019; Rizos et al., 2016; Urbinati et al., 2021).

Third, by looking at a specific industrial application, this study offers a more in-depth investigation into CE transition, thus increasing the level of granularity compared to generic CE-approaches. It also allows for hypotheses regarding the relevance of particular risks to the case of composite materials. It was inferred that the novelty and immaturity of circular approaches applied to composites products is the reason for the relevance of take back systems, market and regulatory risks, while the relatively low complexity of composite materials compared to other type of assembled products makes technology risks less important at this stage in the maturity of the CBM. This seems to suggest that the novelty of circular approaches in the considered industry and the product complexity are variables influencing risk priorities.

This study also has managerial implications. The findings can support companies producing composite materials and using composites for the production of their products in the identification and management of the most relevant risks affecting the transition towards CBMs. The CE framework for composite materials is still immature, compared to other sectors. As a result, there is no structured collection/takeback scheme, recycling/remanufacturing technologies are not widely available and recycled/remanufactured products made from composites are not established in the market. In summary, the supply chain framework is still immature for companies willing to embrace CBMs involving composite materials. The creation of a suitable business framework entails the effort of the entire industrial ecosystem and of policy makers, not just the actions of companies. At the same time, companies have more controllable leverages to develop proper technologies, implement high-quality processes and access the financial resources needed to make their business model circular. The nature of the circular products made from composite materials can also partly explain the findings. Composite products are characterised by lower technology complexity and shorter supply chains compared to other types of assembled manufactured items. Consequently, IPR, technology, and cost are factors which generate a relatively limited risk with respect to other more complex types of products.

Finally, this work also provides insights for policy makers, as six risk factors relate to the political and regulatory domain. The results highlight that the development and implementation of enabling legislation for CE is required. The lack of a CE standardisation framework is particularly critical, as it generates uncertainties for industries in multiple domains, such as sourcing, distribution and quality assurance, and it is an area that policy makers should prioritise in their actions.

8. Conclusions

CBMs are key enablers to the successful implementation of CE principles within organisations and so sources of uncertainties and risks need to be understood to sustain the economic viability of such BMs. This is a fundamental part of maximising the length of time products and materials are kept in use such that maximum value is extracted from them, thus reducing the depletion of natural resources and the production of waste.

By taking a specific industrial perspective, i.e. focusing on the case of composite materials, it was possible to overcome the currently dominating general approach to circular transition research. Risk factors were identified, classified, and, subsequently, the most critical risks hindering the transition to CBMs for composite materials were prioritised. External risk factors related to the reverse supply chain dynamics, market response and regulation issues were perceived as more critical than internal risk factors such as technology, quality, finance and IPR. In particular, specific risk factors explaining the relevance of these macro-risk categories were prioritised: the lack of take-back systems among reverse supply chain risks; the low customer acceptance of CE products and innovative business models among market risks; the lack of a proper standardisation framework for CE products among regulation risks. These results are not totally aligned with the general emphasis given by literature to technology, financial and IPR risks.

As with every piece of research, this study is not without limitations. Some limitations are embedded in the methodology adopted. While this work adopted two sources of data for the identification of the risk factors, namely secondary data from the literature and primary data collected from the panel of experts, some risk factors may still have been overlooked. Additionally, as the Delphi method relies on the subjective judgement of experts in multiple steps of the research process, the results are not bias-free. The fuzzy Delphi method was functional to validate and evaluate risk factors, but its structured methodology did not allow respondents to further elaborate on their answers or emerging issues. Future research may complement this work by capturing additional qualitative information, adopting semi-structured interviews and/or case study research to gain additional in-depth knowledge about the perceived risk factors for CBM transition. Further research is also required to advance the results of this work and to identify the most suitable risk management strategies to tackle the prioritised risks, preferably including an economic quantification in monetary values for prioritised risk factors. Scenario analysis and bow-tie analysis are potential, effective methods suitable for exploring a wide range of CBMs in industrial scenarios and performing a more detailed probabilistic economic assessment of innovative CBMs, while considering both uncertainties associated with prioritised risk factors and risk management responses. The identification of risk management strategies can also progress to suggest direct actions to successfully establish CBMs. In addition, the results of this work, i.e. risks perceived by organisations ex-ante, may be compared with risks emerged in practice after the transition to CBMs is completed, adopting a longitudinal approach. Future research may also replicate this study in a different industrial context to distinguish risk factors applicable across different industries and case-specific risk factors as well as use the validated list of risk factors provided from this study as an input for a large-scale quantitative method, such as a survey, to enhance the statistical value of the results of this work. Finally, this work provided an aggregated overview of risk factors for CBMs, although certain risks may only be applicable to certain CBM types or CBM strategies. Additional research is required to investigate whether risk factors are equally perceived across different CBMs or are influenced by specific CBM strategies.

Credit author statement

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Declaration of competing interest

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

Data availability

The data that has been used is confidential.

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730323–1 (H2020; 730323–1).

Appendices.

A.1 Membership Function of a Triangular Fuzzy Number

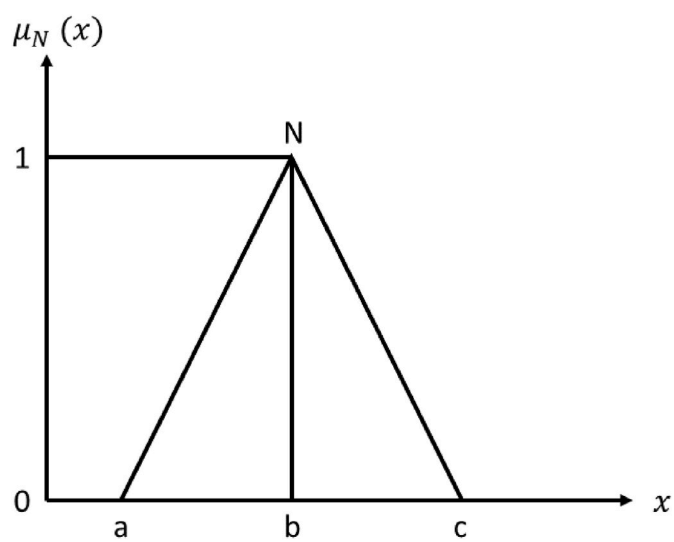

Fig. A.1. Membership Function of a Triangular Fuzzy Number N

A.2 Extended list of risk factors

Table A.2
Extended list of risk factors identified from the literature

Risk Category	Risk Factor	Source
Market	Bullwhip effect	Yang and Li (2010)
Market	Competition	(Brillinger et al., 2020; Leisen et al., 2019; Yang and Li, 2010)
Market	Consumer knowledge and awareness	(Dulia et al., 2021; Govindan and Hasanagic, 2018)
Market	Consumer perception (quality vs. new products)	(Arena et al., 2021; Gatzert and Kosub, 2016; Govindan and Hasanagic, 2018; Guldmann and Huulgaard, 2020; Kissling et al., 2013; Planing, 2015)
Market	Customer perception (ownership)	(Govindan and Hasanagic, 2018; Planing, 2015; Sousa-Zomer et al., 2018)
Market	Customer preference	(Govindan and Hasanagic, 2018; Guldmann and Huulgaard, 2020; Linder and Williander, 2017; Shao et al., 2020; Urbinati et al., 2021)
Market	Customer access	(Brillinger et al., 2020; Leisen et al., 2019)
Market	Customer demand	(Brillinger et al., 2020; Guldmann and Huulgaard, 2020)
Market	Customer relationship risk	Brillinger et al. (2020)
Market	Customer solvency	(Brillinger et al., 2020; Yang and Li, 2010)
Market	Distribution channel control	Linder and Williander (2017)
Market	Distributors selection	Yang and Li (2010)
Market	Economic cycle	(Brillinger et al., 2020; Yazdani et al., 2019)
Market	Limited volumes	(Govindan and Hasanagic, 2018; Guldmann and Huulgaard, 2020)
Market	Market evolution speed	(Shao et al., 2020; Urbinati et al., 2021)
Market	Market forecast	Yang and Li (2010)
Market	Multiple business models' portfolio	Brillinger et al. (2020)
Market	Product cannibalisation	(Guldmann and Huulgaard, 2020; Linder and Williander, 2017; Shao et al., 2020; Sousa-Zomer et al., 2018)
Market	Variability of revenue due to price volatility	(Gatzert and Kosub, 2016; Yang and Li, 2010)
Supply	Logistics	(Urbinati et al., 2021; Yang and Li, 2010; Yazdani et al., 2019)
Supply	Supplier failure	Yang and Li (2010)
Supply	Supply availability	(Ethirajan et al., 2021; Govindan and Hasanagic, 2018; Guldmann and Huulgaard, 2020; Linder and Williander, 2017; Urbinati et al., 2021)
Supply	Supplier quality	(Ethirajan et al., 2021; Golinska and Kawa, 2011; Guldmann and Huulgaard, 2020; Urbinati et al., 2021; Yang and Li, 2010)
Supply	Supplier selection	Yazdani et al. (2019)
Supply	Take-back system	(Chakraborty et al., 2019; Dulia et al., 2021; Govindan and Hasanagic, 2018; Guldmann and Huulgaard, 2020; Linder and Williander, 2017)
Finance	Capital costs	(Brillinger et al., 2020; Dulia et al., 2021; Gatzert and Kosub, 2016; Govindan and Hasanagic, 2018; Gross et al., 2010; Guldmann and Huulgaard, 2020; Leisen et al., 2019; Matus et al., 2012; Rizos et al., 2016; Shao et al., 2020; Urbinati et al., 2021)
Finance	Capital immobilisation	(Linder and Williander, 2017; Shao et al., 2020)
Finance	Electricity price	Gross et al. (2010)
Finance	Financial resources	(Brillinger et al., 2020; Guldmann and Huulgaard, 2020)
Finance	Lifecycle costs	Brillinger et al. (2020)
Finance	Lifecycle revenues	(Brillinger et al., 2020; Gatzert and Kosub, 2016; Yang and Li, 2010)
Finance	Monetisation	(Brillinger et al., 2020; Sousa-Zomer et al., 2018)
Finance	Operating and maintenance costs	(Gross et al., 2010; Leisen et al., 2019)
Finance	Pricing	(Brillinger et al., 2020; Gross et al., 2010; Leisen et al., 2019)
Finance	Procurement costs	Yang and Li (2010)
Finance	Production costs	Govindan and Hasanagic (2018)
Finance	Recycled material costs	(Dulia et al., 2021; Govindan and Hasanagic, 2018; Gross et al., 2010; Leisen et al., 2019)
Finance	Revenue	Govindan and Hasanagic (2018)
Finance	Revenues mechanism	Brillinger et al. (2020)
Finance	Virgin material costs	(Dulia et al., 2021; Govindan and Hasanagic, 2018)
Operations and Management	Availability and maintenance	Brillinger et al. (2020)
Operations and Management	Inventory control	Yang and Li (2010)
Operations and Management	Operational	(Brillinger et al., 2020; Ethirajan et al., 2021; Guldmann and Huulgaard, 2020; Linder and Williander, 2017; Shao et al., 2020; Sousa-Zomer et al., 2018; Yazdani et al., 2019)
Operations and Management	Relationship	(Brillinger et al., 2020; Yang and Li, 2010)
Operations and Management	Strategic bias	Yang and Li (2010)
Operations and Management	System design	Yazdani et al. (2019)
Political and Regulatory	Custom	Brillinger et al. (2020)
Political and Regulatory	Economic incentives	Govindan and Hasanagic (2018)
Political and Regulatory	Intellectual property	(Brillinger et al., 2020; Urbinati et al., 2021)
Political and Regulatory	Legal and regulatory	(Brillinger et al., 2020; Dulia et al., 2021; Govindan and Hasanagic, 2018; Gross et al., 2010; Guldmann and Huulgaard, 2020; Leisen et al., 2019; Linder and Williander, 2017; Yazdani et al., 2019)
Political and Regulatory	Non-ownership Business Model	(Dulia et al., 2021; Govindan and Hasanagic, 2018; Sousa-Zomer et al., 2018)
Political and Regulatory	Political	(Brillinger et al., 2020; Gatzert and Kosub, 2016; Yazdani et al., 2019)

(*continued on next page*)

Table A.2 (*continued*)

Risk Category	Risk Factor	Source
Political and Regulatory	Public policy and institutional	(Dulia et al., 2021; Gatzert and Kosub, 2016; Govindan and Hasanagic, 2018; Linder and Williander, 2017; Yazdani et al., 2019)
Political and Regulatory	Regulatory standards	(Gatzert and Kosub, 2016; Govindan and Hasanagic, 2018; Leisen et al., 2019)
Political and Regulatory	Taxation	(Brillinger et al., 2020; Dulia et al., 2021; Leisen et al., 2019; Linder and Williander, 2017; Yang and Li, 2010; Yazdani et al., 2019)
Technical	Capabilities and resources	(Brillinger et al., 2020; Govindan and Hasanagic, 2018; Guldmann and Huulgaard, 2020)
Technical	Data	(Brillinger et al., 2020; Leisen et al., 2019)
Technical	Design	(Govindan and Hasanagic, 2018; Linder and Williander, 2017; Yang and Li, 2010)
Technical	Human resources	(Agyemang et al., 2019; Brillinger et al., 2020; Dulia et al., 2021; Govindan and Hasanagic, 2018; Guldmann and Huulgaard, 2020; Perron, 2005)
Technical	Innovativeness	(Brillinger et al., 2020; Gatzert and Kosub, 2016)
Technical	Quality	(Arena et al., 2021; Brillinger et al., 2020; Dulia et al., 2021; Ethirajan et al., 2021; Govindan and Hasanagic, 2018; Yazdani et al., 2019)
Technical	Technology	(Brillinger et al., 2020; Chakraborty et al., 2019; Gatzert and Kosub, 2016; Govindan and Hasanagic, 2018; Guldmann and Huulgaard, 2020; Leisen et al., 2019; Linder and Williander, 2017; Shao et al., 2020)
Technical	Technological change	(Brillinger et al., 2020; Govindan and Hasanagic, 2018; Guldmann and Huulgaard, 2020; Yazdani et al., 2019)
Other	Environmental	(Brillinger et al., 2020; Ethirajan et al., 2021; Gatzert and Kosub, 2016)
Other	Exchange rates	Brillinger et al. (2020)
Other	Security	Yazdani et al. (2019)

A.3 List of Abbreviations

Table A.3
List of abbreviations

Abbreviation	Meaning
AHP	Analytical Hierarchy Process
BM	Business Model
BMI	Business Model Innovation
CBM	Circular Business Model
CE	Circular Economy
COG	Centre of Gravity
IP	Intellectual Property
IPM	Intellectual Property Management
PSS	Product Service System
TFN	Triangular Fuzzy Number

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