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Potentials of blockchain technology in supply chain management: Long-term judgments of an international expert panel

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ABSTRACT

Blockchain technology offers numerous fields of application, especially for supply chain management (SCM), as it could supersede the middleman activities in many transaction-based processes along the supply chain. Blockchain technology has a disruptive impact on supply chain design and operations, making the exploration of future application scenarios of great importance. However, knowledge in this field remains scarce, despite the subject's strategical value. This empirical study addresses this gap by conducting an interdisciplinary Delphi survey. Long-term judgments from an international panel of 108 designated experts from academia, industry, and politics/associations with different context-related backgrounds (blockchain, SCM, hybrid functions) were systematically analyzed. The results reveal prospective scenarios how blockchains will be applied in SCM by 2035 and which SCM-specific obstacles need to be solved in advance. One key finding reveals that even though blockchain technology is said to enable transactions between untrusted parties, trust-related advantages of blockchain technology are not directly transferable to SCM without additional conditions. Counterintuitively, active trust management between supply chain partners will still be needed. Nonetheless, this research reveals that blockchain technology will be strongly applied in SCM by 2035 and thus provides beneficial orientation and stimulating perspectives for decision-makers in the field.

1. Introduction

Blockchain has become a common buzzword, first gaining attention with the introduction of Bitcoin by Satoshi Nakamoto in 2008. The initiator's original aim with Bitcoin was the resolution of the financial double-spending problem (Nakamoto, 2008). Since then, various other cryptocurrencies have emerged, and the total market capitalization of cryptocurrencies grew from 1.3 billion USD in May 2013 to over 200 billion USD in March 2020 (CoinMarketCap, 2020). In addition to cryptocurrencies, further application possibilities for blockchain – Bitcoin's underlying technology – were discovered, including registration of electronic voting, certification of product quality, healthcare, verified consumer reviews, escrow, and tracing of products (White, 2017; Hsiao et al., 2018; Borioli and Couturier, 2018). Nowadays, blockchain technology is expected to fundamentally change companies, economies, and social systems (Iansiti and Lakhani, 2017), as the technology's potential impact is on the same level as game-changing innovations such as the wheel, the steam engine, and the Internet (Mettler, 2016).

Numerous blockchain-based use cases have been discussed in the context of supply chain management (SCM) as well (Wang et al., 2018; Wamba and Queiroz, 2020). By investigating selected blockchain-related cases, Kshetri (2018) found that blockchain technology has the potential to meet key SCM objectives such as costs, speed, dependability, risk reduction, sustainability, and flexibility. Despite these advantages, doubts about blockchain's real potentials for SCM have also been expressed. In this context, Ammous (2016, p. 1) stated that blockchain is "unlikely to offer economic advantages for any commercial problem other than the one it was specifically engineered to solve." There are also various barriers mentioned in the literature that could hinder the broad implementation of this technology for supply chain purposes. These include, blockchain's high electricity consumption (Foth, 2017; Sikorski et al., 2017), scalability problems (Foth, 2017; Tian, 2017; Preuveneers et al., 2017), the lack of blockchain-related regulations and laws (Yeoh, 2017), the interoperability of blockchain systems (Underwood, 2016), missing blockchain knowledge within organizations (Partida, 2018; Shanley, 2017), and the complex environment of global supply chains (Kshetri, 2018).

These contrary views indicate a high uncertainty regarding the

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future of blockchain technology in SCM. Nevertheless, managers and policymakers are currently confronted with strategic decisions regarding this technology, as they fear missing out on blockchain's potential benefits. In such uncertain situations, the judgments of experts are often the only source of information to reduce uncertainty and improve decision quality (Gray and Hovav, 2008; Skulmoski et al., 2007; Rowe et al., 1991). However, a comprehensive review[1] of existing research revealed that experts' opinions on this subject have not yet been systematically gathered. So far, blockchain's technical aspects have been studied, but empirical research is almost completely absent (Wamba and Queiroz, 2020). Empirical investigation into the technology's practical usefulness for broad implementation, as well as its actual influence on the current SCM regime, is therefore invaluable and needs to be expanded (Wang *et al.*, 2018). To create a clearer picture of its potentials and to close the existing gap in the literature by extending empirical knowledge on blockchain technology in SCM, the following research question (RQ) is proposed:

RQ: What application scenarios and potentials of blockchain technology are likely to be seen in supply chain management by 2035?

In order to answer the proposed RQ, a Delphi survey was conducted and the long-term judgments of an international panel of 108 designated experts from academia, industry, and politics/associations with different context-related backgrounds (Blockchain, SCM, hybrid functions) were analyzed. The expert panel evaluated the probability of occurrence, impact on the industry, and desirability of 15 far-future events related to application scenarios of blockchain technology. This approach was chosen because assessments of long-term expert judgments (e.g., through the application of the Delphi method) are an established process for studies of future scenarios and the investigation of complex and uncertain circumstances (Rowe and Wright, 1999; Winkler *et al.*, 2015). In addition, this approach has a long history as an accepted research method in the Journal of *Technol. Forecast. Social Change* (Schoeman and Mahajan, 1977; Melander et al., 2019) and in SCM in general (Klassen and Whybark, 1994; Ogden et al., 2005; Hirschinger et al., 2015), and it has also proved its added value in current managerial decision-making settings (Phadnis, 2019).

In order to provide a holistic picture of the likely future of blockchain technology in SCM based on the research findings, the paper is structured as follows. After a review of the relevant literature on blockchain technology, a detailed description of the research methodology is provided. Afterward, the quantitative and qualitative results of the long-term judgment analysis are presented and discussed, from which theoretical and practical implications are derived. The paper concludes with a summary of the main findings.

2. Background and literature review

2.1. Fundamentals of blockchain technology

A blockchain is, in essence, a distributed database or digital ledger that contains all records that result from transactions and events within a network of participants (Crosby et al., 2016). More specifically, records of network transactions are stored in blocks, which are chronologically linked to each other by cryptographic hashes and thus collectively create a chain of blocks (Bogart and Rice, 2015; Christidis and Devetsikiotis, 2016). Before a new block is added to the existing chain of blocks, its integrity has to be confirmed by the majority of network nodes according to pre-defined consensus-based validation protocols (Zheng et al., 2017). Once the verification takes place, the information within a block can no longer be altered (Nakamoto, 2008).

Due to the design principles of a blockchain, certain advantages emerge. First, a full copy of the blockchain is stored on every node of a network and not on a single server. This distributed nature of the technology increases information transparency, as data is visible to all network participants (Abeyratne and Monfared, 2016; Casey and Wong, 2017). Second, manipulation can be preempted, because data cannot be altered once written in a block, and validity has to be confirmed by the majority of network participants (Abeyratne and Monfared, 2016; Kshetri, 2017a, 2017b; Preuveneers et al., 2017; Khan and Salah, 2018). Third, the inalterability of blockchain data allows unrestricted traceability of transactions (Abeyratne and Monfared, 2016; Kshetri, 2017a; Lee and Pilkington, 2017). Fourth, as trust is replaced by cryptographic proof, untrusted parties can directly transact with each other without the attendance of a trusted third party (e.g., a financial institution) (Weber et al., 2016; Nakasumi, 2017). Fifth, due to the absence of an intermediating party, transaction costs can be reduced (Ahram et al., 2017; Korpela et al., 2017; Polim *et al.*, 2017).

Three main types of blockchain architecture can be distinguished: public blockchain, consortium blockchain, and private blockchain (Zheng et al., 2017). Table 1 compares their attributes.

The most famous example of a public (permissionless) blockchain is the Bitcoin system, where everyone is allowed to enter the network and participate in the consensus and verification process (Pilkington, 2016). A public or open blockchain gives reading permission to all system users and is a so-called decentralized network, as all records of transactions are stored on every node within the network (Zheng et al., 2017). A private (permissioned) blockchain, in contrast, limits reading permissions and access to the network to authorized users only (O'Leary, 2017). It is fully controlled by a central authority responsible for consensus finding and is therefore referred to as a centralized network (Zheng et al., 2017). Consortium blockchains are a combination of public and private blockchain architecture (Pilkington, 2016). This network type usually differs between decision-making nodes and read-only nodes, where the former are allowed to participate in the consensus process to add new blocks to the chain and the latter have permission to review the ledger but cannot participate in any other processes (Lu and Xu, 2017). Consortium blockchains are partially centralized (Zheng et al., 2017).

Blockchains are often mentioned in the same sentence as cryptocurrencies, but operating a blockchain does not necessarily imply a cryptocurrency. In fact, the original purpose of cryptocurrencies was to provide an economic incentive to a decentralized operating group to validate the transactions made in a blockchain (Tschorsch and Scheuermann, 2016). Cryptocurrencies may be useful for keeping public blockchains running, but they are not a necessity for operating private blockchains, as private blockchains are fully maintained by one organization. In addition to cryptocurrencies, smart contracts are another feature frequently referred to in blockchain discussions. Certain blockchain protocols (e.g., Ethereum) allow the execution of smart contracts. They are integrated into blockchains and can be characterized as programmed scripts that activate themselves when receiving pre-defined transactions (Christidis and Devetsikiotis, 2016). These scripts enable automated transactions – for example, automated purchasing or payments between two parties (Collomb and Sok, 2016).

2.2. Blockchain technology in supply chain management

As SCM has been identified as one of blockchain's promising application areas in addition to finance (White, 2017), it is not surprising that practitioners and scientists from this domain have started to engage with this topic. Famous prototypes and use cases include Walmart's food product tracking system and Maersk and IBM's collaboratively established platform, TradeLens, which enables information sharing and supply chain visibility. Nevertheless, blockchain

[1] Database selection: Scopus, Business Source Complete, and ScienceDirect; Time horizon: 2008 – March 2020; Search Terms: ("blockchain" OR "distributed ledger") AND ("supply chain" OR "supply network" OR "logistics" OR "production" OR "manufacturing" OR "operations" OR "procurement" OR "distribution" OR "delivery" OR "shipping")

Table 1
Attributes of public, consortium, and private blockchains.

Attribute	Public blockchain	Consortium blockchain	Private blockchain
Type of network	Decentralized	Partially decentralized	Centralized
Authorization to read	Public	Limited to authorized users	Limited to authorized users
Permission to participate	Permissionless	Permissioned	Permissioned
Consensus finding	All nodes of the network	Selected nodes with decision-making rights	Central authority

applications are not yet in general use in SCM, as industry participants are still working on proofing blockchain concepts and implementing pilots (Banker, 2018).

Scientific research on this topic is also still at an early stage, and no article on the subject was published before 2016 (Müßigmann et al., 2020). From the entirety of SCM-related blockchain papers, approximately one third of the articles can be labeled as magazine articles, where the topic of blockchain in SCM only receives superficial coverage. One third of papers were published at conferences, while the other third can be referred to as scientific journal articles. While magazine articles mostly deal with the advantages of blockchain technology for SCM in general (e.g., Loop, 2016; Garrett, 2017; Riley, 2017), conference and scientific journal articles mainly propose blockchain concepts for SCM-specific use cases. Table 2 provides an overview of research articles that have addressed blockchain technology in the field of SCM.

Different blockchain architectures may be needed for different use cases, the two most frequently used ones in SCM are Ethereum and Hyperledger Fabric (Wang et al., 2018). Both of these systems support the execution of smart contracts (not every blockchain has smart contract features), which opens the field for blockchain-based applications in SCM even more. Smart contracts may, for example, automate payments between a supplier and a buyer as soon as the purchased product is delivered (Swan, 2015) or transfer ownership rights as soon as a payment has been received (Wang et al., 2017).

Most of these research projects focus on the technical feasibility of blockchain applications. However, the exploration of blockchain's technical feasibility is insufficient to assess its potential for broad implementation in SCM, as technological transition does not depend on technology-related aspects alone. It also requires other shifts of a regime (e.g., changes related to culture, science, industry, user practices, and policy) (Geels, 2004). According to Geels (2002), radical innovations – which is how blockchain can be defined (Beck and Mueller-Bloch, 2017; Morabito, 2017; Crosby et al., 2016) – only break out of their niche-level when a window of opportunity is created. A window occurs when shifts at the macro-level (landscape developments) – such as changes related to macro-economics, deep cultural patterns, and macro-political development – put pressure on a regime such as SCM (Geels and Schot, 2007).

Some central trends can be identified that put pressure on the current SCM regime. One is the rising global competition, which is triggered by ongoing globalization and the geographical expansion of manufacturing networks (Ferdows *et al.*, 2016). Striving for efficiency is becoming increasingly important for survival in the global market, and supply chain processes thus have to be efficient regarding performance, quality, and costs (Christopher and Towill, 2001). Another global shift influencing SCM is the increasing customer demand for transparency, accountability, and social responsibility (Lee and Pilkington, 2017). Consequently, supply chain processes have to become transparent to fulfill customers' requests.

The described landscape developments show that a window of opportunity for blockchain technology is created, as blockchain is said to increase transparency as well as efficiency (Casey and Wong, 2017; Tian, 2017). Nevertheless, the question arises as to whether blockchain technology can be incorporated into the current SCM regime and whether it is capable of taking advantage of the window of opportunity. This study answers this question by considering experts' long-term judgments.

3. Research methodology

This research employed a Delphi survey to study forthcoming developments of blockchain technology in SCM. The study is structured in four individual phases, which are displayed in Fig. 1.

3.1. The Delphi method

The Delphi method has a proven record in judgmental foresight research (Torres, 2005) and is particularly suitable for long-term research objectives (15–30 years), where uncertainty is high or there is insufficient information available (Gray and Hovav, 2008; Skulmoski et al., 2007; Rowe et al., 1991), and expert knowledge describes the only source of data (Linstone and Turoff, 1975; Rikkonen and Tapio, 2009). The Delphi method provides an efficiently structured group communication process to obtain and exchange expert opinions concerning an uncertainty-bearing field, making it a highly suitable instrument for futures research (Winkler and Moser, 2016). As Dalkey defines, "Delphi is the name of a set of procedures for eliciting

Table 2
Classification of blockchain articles by application domain or context.

Blockchain application domain	References
General advantages of blockchain technology for SCM	Loop (2016); Garrett (2017); Riley (2017)
Track and Trace	Foth (2017); Alangot and Achuthan (2017); Haughwout (2018); Tse et al. (2017); Tian (2017); Tian (2016); Gao et al. (2018); Wu et al. (2017)
Temperature recording	Bocek et al. (2017)
Quality management	Chen et al. (2017)
Inventory management	Madhwal and Panfilov (2017)
Performance and usage monitoring	Madhwal and Panfilov (2017)
Proof of origin and originality	Foth (2017); Madhwal and Panfilov (2017); Mackey and Nayyar (2017)
Supply chain integration	Korpela et al. (2017); Weber et al. (2016)
Information sharing	Nakasumi (2017); Abeyratne and Monfared (2016); van Engelenburg et al. (2017)
Negotiation support regarding logistic contracts	Polim et al. (2017)
Blockchain-driven IoT services	Khan and Salah (2018); Liao et al. (2017); Christidis and Devetsikiotis (2016); Kshetri (2017a); Kshetri (2017b); Preuveneers et al. (2017)
Digital rights management for additive manufacturing	Holland et al. (2017); Kurpjuweit et al. (2019)

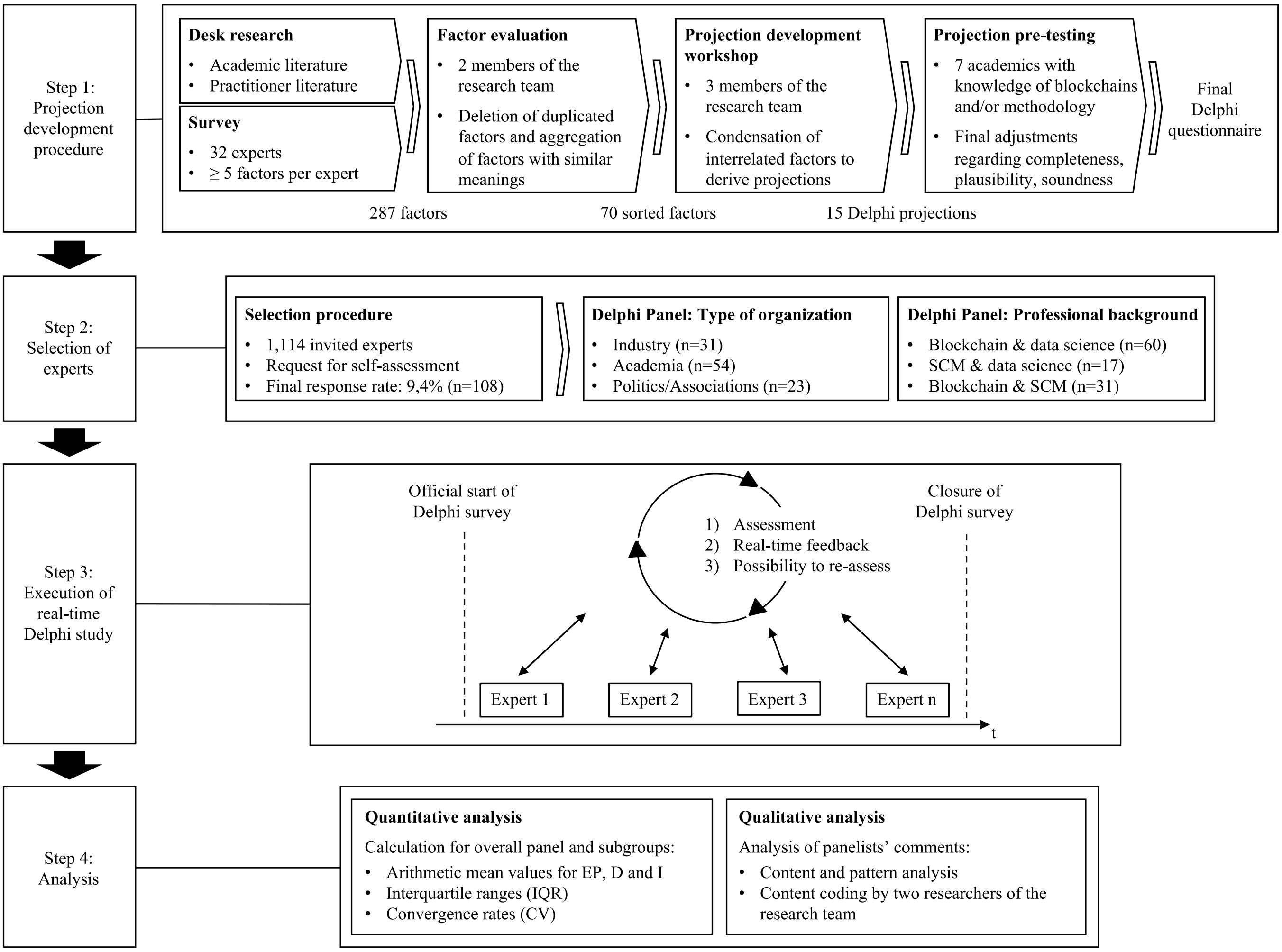

Fig. 1. Structure of the Delphi process applied in the study, own design based on Gnatzy et al. (2011).

and refining the opinions of a group of people" (Dalkey, 1967, p. 1). The Delphi procedure is divided into several sections. First, Delphi panelists anonymously evaluate future-oriented propositions (so-called projections) according to specific numerical variables such as their likelihood of occurrence or their impact (von der Gracht, 2012; Rowe and Wright, 2001). At this point, the panelists are also asked to enrich their quantitative assessments with written, qualitative justifications (Graefe and Armstrong, 2011). Subsequently, the participants receive feedback about the group opinion and have the option to adjust their initial answers based on the provided feedback (Rowe and Wright, 1999; Webler et al., 1991). These steps may be repeated several times. While this procedure was originally applied to create consensus among experts regarding particular propositions (Diamond et al., 2014; Linstone and Turoff, 1975), today the goal of Delphi studies is to foster a reliable group opinion (Landeta, 2006), which is also the focus of this research.

Although different types of Delphi exist, the general Delphi design builds on four principles: (1) anonymity; (2) iteration; (3) controlled feedback; and (4) statistical group response (Dalkey and Helmer, 1963; Rowe and Wright, 2001). The underlying anonymity enables mitigation of negative group constraints such as the bandwagon effect, the halo effect, or withholding of potentially unpopular opinions (Steinert, 2009; Dinwoodie et al., 2014). Iterations and controlled feedback enable systematic multi-rounded discussions, social learning, and the revising of prior judgments (Dunn, 2004). Statistical group responses may be returned numerically (typically in tabular format) or graphically (typically in boxplot format). In general, the presentation of results includes tendency measures such as a median or mean of the assessments, interquartile ranges as a measure of consensus, or the change in standard deviation as a measure for convergence during the single Delphi rounds (Gupta and Clarke, 1996; von der Gracht, 2012). Properly conducted Delphi studies show higher accuracy in forecasts than conventional surveys (Rowe and Wright, 1999; von der Gracht, 2008) and have proven their reliability and validity in various studies (Landeta, 2006; Parenté and Anderson-Parenté, 2011).

3.2. Step 1: development of Delphi projections

As with conventional surveys, the development and design of questions and projections is of particular importance for ensuring value, validity, and reliability in Delphi studies (Markmann et al., 2020; Mitchell, 1996; Loveridge, 2002). A rigorous and established multi-stage process was therefore performed to develop concise and thought-provoking projections (Jiang et al., 2017; Roßmann et al., 2018; Fritschy and Spinler, 2019; von der Gracht and Darkow, 2010). An overview of the projection development process is illustrated in step 1 of Fig. 1.

First, relevant journal and conference articles[2] along with online and blog posts were screened to identify relevant factors concerning the future of blockchain technology in SCM. Additionally, a small-scale

[2] Example of key sources: e.g. Abeyratne and Monfared (2016); Crosby et al. (2016); Tian (2016); Bocek et al. (2017); Korpela et al. (2017); Kshetri (2017b); Wang et al. (2018).

survey among industry experts and academics was performed to detect further factors and to triangulate the screening process, ensuring that all relevant issues were collected for projection development (Gausemeier et al., 1998). For the small-scale survey, international experts from industrialized countries who have published relevant papers or books, reported at a conference, or publicly talked about blockchain technology were invited to participate. Experts were contacted via email and were asked to share (a minimum) of five keywords that came to their minds when thinking about the future of blockchain technology. The survey was executed until redundancies and decreasing returns of new aspects were experienced at large scale. At this point, 32 of the 68 contacted experts had replied to the request, equivalent to a response rate of 48%. Altogether, a longlist of 287 factors concerning the future of blockchain technology in SCM was generated through desk research and the provision of the experts' keywords.

The longlist was then condensed into a shortlist by two members of the research team through the deletion of duplicated factors and the aggregation of factors with similar meanings. After this consolidation, 70 factors remained. Next, we followed the approach of Roßmann et al. (2018) and organized an internal projection development workshop with three members of the research team. The workshop was conducted to cross-validate the shortlist of the previous step and to develop initial projections. To ensure that the projections did not only relate to blockchain's technological features, Geels' (2004) multi-level perspective on technology transition was deployed to also include aspects regarding culture, science, industry, user practices, and policy. With the multi-level perspective in mind, 33 provisional projections were derived. To guarantee high validity and reliability of the obtained projections, methodical rules concerning the formulation (Rowe and Wright, 2001) and optimal number of words (Salancik et al., 1971; Linstone and Turoff, 1975) were applied. Moreover, since a high number of projections may lead to a reduced response rate and increase the probability of a sparse completion of the questionnaires (Parenté and Anderson-Parenté, 1987; Johnson, 1976), the number of projections was further decreased to 15. This is in line with (Parenté and Anderson-Parenté, 2011), who proposed limiting the number of projections to a maximum of 20. Factors that were not yet applied for projection formulation and factors linked to the eliminated projections were utilized to formulate starting pro and contra arguments for the first participating expert. Thus, no information was lost throughout the projection development process.

Finally, as proposed by Warth et al. (2013), the Delphi questionnaire was pre-tested by seven academics with deep methodological and/or subject-specific knowledge in this field, who checked the projections for precision, completeness, plausibility, and methodological soundness to ensure face and content validity. Their feedback resulted in slight adaptations to the questionnaire regarding wording and syntax. The final set included 15 projections regarding the future of blockchain in SCM for the year 2035, which are presented in Table 3.

3.3. Step 2: selection of experts

Reliability of Delphi survey results strongly depends on an adequate choice of panelists (Spickermann et al., 2014; Okoli and Pawlowski, 2004). Based on this fact, the expert panel was systematically selected in order to achieve a high level of heterogeneity and to reduce various participants' cognitive biases, such as framing bias and anchoring bias (Winkler and Moser, 2016), desirability bias (Ecken et al., 2011), and the bandwagon effect (Foerster and von der Gracht, 2014). Heterogeneity was achieved through the involvement of experts from various domains such as Logistics, SCM, and Information Technology (IT), a high spread of different countries, and through the inclusion of designated experts from academia, industry, and politics/associations. Consequently, 1114 potential experts with expertise related to the research topic were invited to participate in the expert panel. While some contacts can be clearly identified and classified as blockchain experts due to their presence in the media or through the publication of their studies, this is not evident for others, especially in the industrial sector. To ensure that the Delphi panel only covers experts, those participants for whom it was not immediately obvious whether they provide expert-level knowledge on blockchains were asked to provide an additional self-assessment. Only if their answers indicated considerable experience and knowledge in the field of blockchains were those participants' judgements further evaluated and processed in our study. After the self-assessment, we excluded the responses of seven panelists from further investigation in the study, resulting in a final total of 108 participating experts from 20 different countries[3]. The methodology of self-rating has been confirmed as a legitimate instrument for selecting panels (Rowe and Wright, 1996). By taking these steps, we ensured that the respondents we included were experts in the blockchain area.

The final response rate of 9.7% was found to be adequate for the research aim and is similar to of the rates in comparable Delphi studies (e.g. Spickermann et al., 2014; Warth et al., 2013). The responses of 54 experts from academia, 31 from industry, and 23 from politics/associations were analyzed in the Delphi study. Sixty of these panelists deal with blockchain technology from a data science perspective in their day-to-day business. Seventeen of them can be designated as SCM experts with a data science background, while 31 of the experts specifically concentrate on the intersection of blockchain technology and SCM through engagement in pilot projects or research studies (see step 2 in Fig. 1).

To verify a possible non-response bias, the Mann–Withney *U*-test was applied. In this process, the estimates of the early and late respondents were compared, as it can be assumed that late respondents demonstrate characteristics of non-respondents (Armstrong and Overton, 1977; Wagner and Kemmerling, 2010). By comparing the differences in responses for all 15 projections, no significant differences ($p < 0.05$), and thus no non-response bias, could be found.

3.4. Step 3: execution of the Delphi study

In this study, an internet-based real-time Delphi approach was deployed (Aengenheyster et al., 2017; Geist, 2010; Gnatzy et al., 2011; Gordon and Pease, 2006), where the quantitative analysis of the panelists' assessments (calculation of group opinion and boxplots indicating additional statistics) is executed immediately. This variant enables a faster return of group feedback to the participants compared to conventional "paper-and-pencil" Delphi studies. Research by Gnatzy et al. (2011) compared both types of Delphi studies and revealed that results are comparable, while the real-time approach is likely to have a more positive effect on response rates and validity due to its convenience in terms of process, appearance, and reduced effort (time).

Regarding the quantitative assessment, each expert was asked to rate the projections according to their

- Expected probability of occurrence (EP), based on a metric scale of 0–100%,
- Impact on the industry (I), based on a 5-point Likert scale, and
- Desirability of occurrence (D), based on a 5-point Likert scale.

Additionally, participants had the opportunity to add qualitative justifications for their given quantitative estimates. Immediately after their initial assessment, the real-time Delphi tool generated quantitative feedback (descriptive statistics and boxplot graphs for group opinion) and qualitative feedback (other experts' written justifications),

[3] Australia, Austria, Belgium, Canada, Cyprus, Denmark, Finland, France, Germany, India, Ireland, Italy, Japan, Korea, Netherlands, Singapore, Swiss, Taiwan, UK, and USA

Table 3
Analysis of experts' ratings.

No.	Projection	EP	IQR	CV	I	D
P1	2035: A global legal framework for the application of blockchain technology in supply chain management has been established.	55%	54	- 4.8%	4.0	3.8
P2	2035: Blockchain technology has fundamentally improved companies' compliance with sustainability standards.	56%	39	- 4.1%	3.6	4.2
P3	2035: Smart contracts have largely replaced operational supply chain tasks.	64%	30	- 5.1%	4.3	4.2
P4	2035: Blockchain technology has created end-to-end transparency within multi-tier supply networks.	64%	30	- 7.9%	4.2	4.2
P5	2035: Active trust management between supply chain partners has lost its relevance due to blockchain technology.	42%	26	- 7.7%	3.3	3.3
P6	2035: Blockchain technology has evolved into the dominant standard for tracing material flows.	62%	30	- 3.3%	3.9	3.9
P7	2035: Access to blockchain data has fundamentally improved demand planning.	54%	40	- 3.4%	3.7	3.7
P8	2035: Blockchain technology has been the key trigger for the revolutionary expansion of the digital interconnection of objects and devices (e.g., Internet of Things).	56%	40	- 3.4%	3.9	3.6
P9	2035: The exchange of product-related information (e.g., manufacturers' ID, price, CO2-emission, working conditions) through blockchain technology has become an imperative for supply chain management.	65%	*20*	- 4.1%	3.8	3.9
P10	2035: New job profiles in supply chain management have been created due to blockchain technology.	73%	30	- 12.2%	3.5	3.5
P11	2035: Blockchain technology has fundamentally improved supply chain risk management.	69%	*20*	- 2.6%	3.9	4.1
P12	2035: Former technological problems with blockchain technology have been resolved (e.g., scalability issues, limited data storage capacities, block creation times, high transaction costs, high power consumption).	72%	30	- 4.1%	4.1	4.5
P13	2035: The manipulation of data has become a serious threat to blockchain technology.	41%	40	- 4.3%	3.6	1.6
P14	2035: Multiple specialized blockchains (e.g., for financial transactions, tracing of goods, proof of origin) have been replaced by one integrated multi-purpose blockchain.	33%	40	- 7.4%	3.5	2.8
P15	2035: Cryptocurrencies have become the standard means of payment for business-to-business transactions.	46%	45	- 5.8%	3.6	3.2

Note: EP: Expected probability; I: Impact; D: Desirability; CV: Convergence (i.e., decrease in standard deviation); IQR: Interquartile Range; IQR ≤ 25 equals panel consensus, highlighted in italics

summarizing the estimations of previously participating experts. Based on this real-time feedback, panelists could reassess their provided estimates as often as desired until the end of the survey period (see step 3 in Fig. 1). Returning both the quantitative assessments and the qualitative justifications to the panelists increases the accuracy of the final results (Best, 1974). More detailed information on the deployed real-time Delphi approach can be found in the article by Gnatzy et al. (2011).

3.5. Step 4: survey analysis

In order to visualize the groups' long-term judgments regarding the expected probability, impact, and desirability of the projections under investigation, their respective arithmetic mean values were determined (Jiang et al., 2017; Roßmann et al., 2018; Fritschy and Spinler, 2019; von der Gracht and Darkow, 2010). Moreover, for further analysis of the experts' opinions about the projections' probabilities of occurrence, two additional measures were calculated for each projection:

- Convergence rates (CV), and
- Interquartile ranges (IQR).

Convergence rates provide information about the panels' shift in assessments and have been measured as the difference in standard deviation of the average probability expectations from the first to the last Delphi round. Interquartile ranges indicate the final consensus/dissent levels for each projection. This study followed Warth et al. (2013) and Keller and von der Gracht (2014) and defined an interquartile range of ≤ 25 as the threshold level for consensus about the probability of occurrence.

In addition to the quantitative assessment, the expert panel provided 1270 written comments, which is equivalent to 11.75 arguments per expert. Overall, 62% of the experts provided at least one rationale for their quantitative estimations, indicating a high level of participation. To enhance the qualitative analysis of these comments, a coding method based on Strauss and Corbin (1990) was applied. In this process, the content of the arguments was independently broken down by two members of the research team to identify categories to which the arguments could be assigned. Descriptive codes for the arguments were thus derived. Subsequently, all codes were discussed by the two researchers in order to re-adjust divergent coding results until consensus was achieved. The final set of codes and the quantitative estimations were utilized for the discussion of the expert's long-term judgments.

4. Results and discussion

4.1. Analysis of quantitative results

The experts' quantitative assessments were analyzed first. Table 3 illustrates the mean values of the projections' impact, desirability, and expected probability, as well as its convergence rate and interquartile range.

The results revealed that the occurrence of all reviewed projections would have a non-negligible impact on SCM, as the mean value for the estimated impact of every projection was rated higher than 3.0. Thus, all projections were further considered for analysis. With a mean value of 4.3 on the 5-point Likert scale, Projection 3 (smart contracts) is anticipated to have the highest influence on SCM. There are two projections, Projection 13 (data manipulation) and Projection 14 (integrated blockchain), whose occurrence is not desired by the majority of the participating experts. The occurrence of the remaining 13 projections is desired, as their average desirability values are higher than 3.0, ranging from 3.2 for Projection 15 (cryptocurrencies) to 4.5 for Projection 12 (technological problems). The average values of the projections' probability range from 33% for Projection 14 (integrated blockchain) to 73% for Projection 10 (job profiles). Calculating the interquartile ranges of the experts' probability expectations revealed that by applying the common threshold value of ≤ 25, Projection 9 (product-related information) and Projection 11 (risk management) yield consensus.

Furthermore, a closer look at the negative convergence rates of all projections (see Table 3) reveals that the experts' opinions converged over time. In total, standard deviation decreased by 5.3%, which indicates a convergence toward group consensus. Overall, 483 revisions conducted by the experts during the Delphi runtime were recorded, whereof 253 assessments (52%) were adjusted upwards and 230 (48%) downwards. On the individual projection level, experts increased their estimates regarding the probability of occurrence for ten projections and decreased them for the remaining five projections. The strongest convergence could be observed for Projection 10 (job profiles) with a 12.2% decrease in standard deviation. The lowest convergence rate, -2.6%, was measured for Projection 11 (risk management). This further indicates that the participating experts were the most confident with the assessment of this proposition.

Table 4a
Overview of significant deviations in ratings within the subgroup "type of organization".

		Academia			Industry			Politics/Associations		
No.	Projection	EP	I	D	EP	I	D	EP	I	D
P1	Global legal framework	**48%**	4.0	3.6	58%	4.2	4.1	**67%**	3.9	4.0
P5	Trust management	44%	**3.6**	3.3	34%	**3.0**	3.2	46%	3.2	3.4
P6	Tracing material flows	**56%**	3.7	3.8	**67%**	4.1	4.2	68%	3.9	4.0
P12	Technological barriers	71%	4.3	**4.8**	74%	3.8	**4.4**	72%	3.9	**4.1**

Note: EP: Expected probability; I: Impact; D: Desirability.
Statistically significant deviations marked in bold.

Table 4b
Overview of significant deviations in ratings within the subgroup "professional background".

		SCM			IT			SCM/IT		
No.	Projection	EP	I	D	EP	I	D	EP	I	D
P14	Integrated blockchain	36%	3.6	**3.5**	34%	3.5	**2.5**	31%	3.5	**3.1**
P15	Cryptocurrencies	37%	3.6	2.9	51%	**3.8**	**2.4**	41%	**3.0**	**2.7**

Note: EP: Expected probability; I: Impact; D: Desirability.
Statistically significant deviations marked in bold.

In addition to analysis on an aggregated panel level, further insights can be provided by a deep dive into the ratings of individual subgroups (see Tables 4a and 4b). The above analysis was therefore extended by two different subgroup comparisons. The idea behind subgroup comparisons is that experts with different backgrounds may show differentiating expectations regarding the future of blockchain technology in SCM. In line with Roßmann et al. (2018), the first subgroup comparison classified the panel members according to their type of organization – academia ($n = 54$), industry ($n = 31$), and politics/associations ($n = 23$) – and it was analyzed whether the stated expectations differ between these three types. The second subgroup comparison divided the panel into experts with experience in blockchain technology ($n = 60$), SCM ($n = 17$), and both domains ($n = 31$) and determined whether differences in ratings according to professional background appeared.

A Kolmogorov-Smirnov test confirmed a non-normal distribution for all six subgroups. A non-parametric Kruskal–Wallis H-test was then conducted for the first subgroup comparison. The results revealed that the estimates for the probabilities of Projection 1 (global legal framework) and Projection 6 (tracing material flows), the impact of Projection 5 (trust management), and the desirability of Projection 12 (technological problems) differ significantly from each other. In order to determine which of the three subgroups was responsible for the significant difference, a post hoc Mann–Whitney U-test was performed.

The comparison revealed that the probability estimations for Projection 1 (global legal framework) differ significantly between experts from academia and politics/associations ($p < 0.05$), with academia rating the probability of occurrence lower on average (48% compared to 67%). Furthermore, the estimates of academics and industry experts differ significantly for the impact of Projection 5 (trust management) (3.6 compared to 3.0) and for the probability of Projection 6 (tracing material flows) (56% compared to 67%). It was further revealed that the estimates of all three subgroups show significant differences for the desirability of Projection 12 (technological problems), which was rated at 4.1 by experts from politics/associations, 4.4 by industry experts, and 4.8 by academics.

The second subgroup comparison, which compared the estimates provided by experts with experience in blockchain technology, SCM, and both domains, was conducted in a similar manner to the first. It revealed that the estimates regarding the desirability of Projection 14 (integrated blockchain) differ significantly between all three subgroups. Thus, experts with experience in blockchain technology rate the evolution of one integrated multi-purpose blockchain the least desirable (with an average rating of 2.5), followed by hybrid experts with knowledge in both domains (with an average rating of 3.1) and SCM experts (with average estimates of 3.5). Moreover, the assessments of impact and desirability of Projection 15 (cryptocurrencies) indicate significant differences between the opinions of experts with experience in blockchain technology and those with expertise in both domains. In contrast to the estimates of blockchain experts, experts with expertise in both domains predict a lower impact on the industry if cryptocurrencies were to serve as a standard means of payment for business-to-business transactions (3.0 compared to 3.8). Additionally, the occurrence of this projection is rather undesirable for hybrid experts (2.7), while it is rather desirable for blockchain experts, who rated its desirability at an average of 3.4.

No further significant deviations were revealed within the individual subgroup ratings. This strengthens the credibility and validity of the Delphi results, as the expected future of blockchain technology is rated similarly for the remaining dimensions and topics regardless of the experts' backgrounds (Roßmann et al., 2018).

4.2. Discussion of experts' long-term judgments

This Delphi study aims to picture the future landscape of blockchain technology utilization in SCM and thus also investigate whether the existing barriers, currently faced by the technology will be overcome by 2035. The investigation was guided by the following research question: What application scenarios and potentials of blockchain technology are likely to be seen in supply chain management by 2035? Matching the experts' assessments of probability and impact for each projection provides the first insights regarding the experts' opinions on this issue (see Fig. 2). The subsequent analysis of the experts' qualitative comments is divided into three separate parts, as circled in Fig. 2, and will explain the respondents' assessments in more detail.

4.2.1. Qualitative analysis of high-probability projections

In order to picture the landscape of blockchain technology utilization in SCM by the year 2035, the projections with the highest probability of occurrence should be emphasized first of all. Combining them creates a high-probability scenario. Fig. 2 shows that seven projections share an expected probability of occurrence of over 60%, making them likely to occur within the investigated horizon. As all these projections, with the exception of Projection 10, have also been rated high in terms of their impact ($\geq$ 3.8), they are the ones that will shape future blockchain-related SCM to a high degree.

Technological barriers: With an expected probability of occurrence of 72%, the second highest in the sample, experts assume that the technological problems that are currently discussed in literature, such as scalability issues (Foth, 2017; Tian, 2017; Preuveneers et al., 2017), high transaction times (Christidis and Devetsikiotis, 2016; Tian, 2017), and high power consumption (Foth, 2017; Sikorski et al., 2017), will be mostly resolved by 2035 (Projection 12). The experts' anticipation is based on the ongoing development of new blockchain designs aimed at

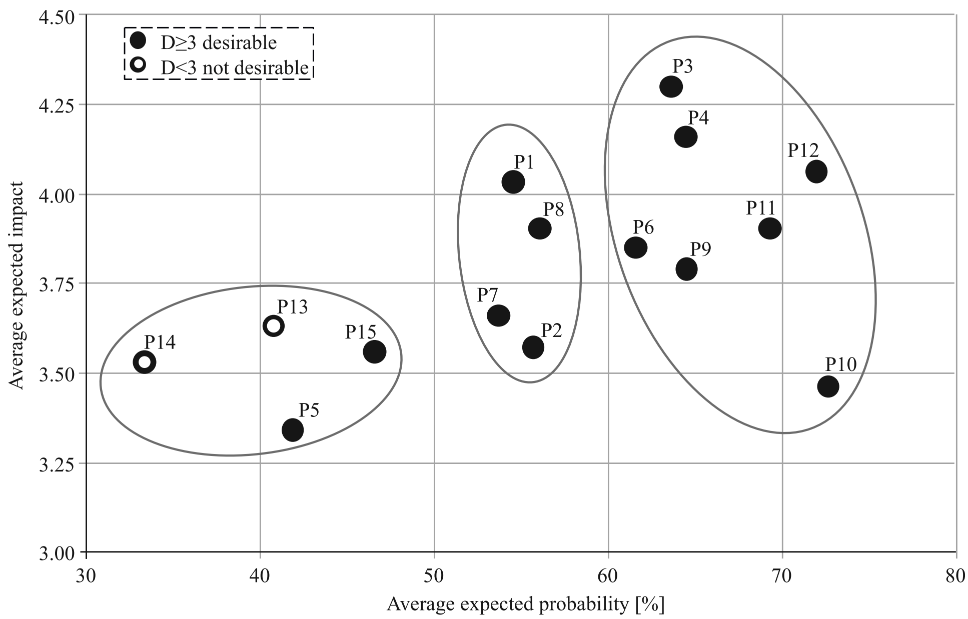

Fig. 2. Classification of projections based on expected probability and expected impact.

solving major technological problems. Through improved algorithms, transaction times are expected to be reduced, scalability to be enabled, and thus less power to be consumed. The Delphi panelists argue that overcoming the current technological barriers will enable the widespread use of blockchain technology in SCM, which is quantified by a high impact rate of 4.1 on the 5-point Likert scale.

Tracing material flows: One exemplary use case is its application for tracing product paths along a supply chain. From a technological perspective, blockchain technology is expected to be capable of providing end-to-end transparency due to the secure and trustworthy exchange of data. Referring to their own companies, some experts report that initial projects have already been realized. The majority of panelists describe the immutability of blockchain data as the main factor that makes the technology suitable for tracing applications and predict a substantially more extensive use by the year 2035. However, even though the experts agree on its suitability for tracing products, they are uncertain as to whether blockchain technology will evolve into the dominant standard for tracing material flows (Projection 6). As it was argued by the panelists, the main challenge of tracing is not necessarily keeping the information saved in a database but making sure that the actual physical item is traced. Thus, blockchain is not expected to be the standalone solution to the tracing challenge, but will instead be combined with other technologies, such as the Internet of Things (IoT), to become the standard for tracing.

Product-related information: In addition to the business-driven tracing of goods, panelists expect that sharing other product-related information will become an imperative as well (Projection 9), although they narrowed this projection to certain data only. According to the panelists' expectations, information regarding CO_2 emissions, price, or working conditions will be exchanged via blockchains in the future, while supply chain parties will not be interested in sharing other kinds of data publicly in a blockchain – particularly confidential data, as this would involve revealing business secrets. Consequently, the experts stress the challenges of smart access rights and data security that need to be resolved at the outset to ensure that data is accessible for the desired party only. Some panelists stated that the exchange of the above-mentioned data is mainly driven by societal pressure and not the intrinsic motivation of organizations. Even though blockchains would technologically be capable of providing absolute end-to-end transparency, due to the above reasons it is expected that blockchain technology will only create selected transparency within multi-tier supply networks (Projection 4). The panelists additionally justified their estimation by arguing that the integration of companies from the least developed countries and of firms in remote areas are expected to be particularly difficult, as these companies are unlikely to possess the necessary resources and knowhow to implement blockchain technology, at least in the short term.

Smart contracts: The highest contribution for efficiency improvements is attributed to smart contracts, as they enable the automation of supply chain processes. Due to the potential benefits of smart contracts – such as the guarantee of contract enforcement, the connection of unknown or untrusted parties, accuracy and efficiency gains, and cost savings – industries are assumed by the Delphi panelists to strive for their implementation. The disruptive character of smart contracts is also underpinned by the experts' high assessment of their impact for SCM (4.3), which is rated highest when compared to all other projections in this study. An increasing flexibility regarding human interaction when things do not go as planned and the resolution of smart contracts' security problems are expected to further increase their utilization. Thus, the majority of experts estimate that operational tasks will have been largely replaced by smart contracts by the year 2035 (Projection 3). Nevertheless, some barriers for their application are also predicted. Some experts believe that the world is too complex to translate the underlying processes into algorithms, which is why non-standard supply chain tasks are not expected to be automated. Smart contracts are also expected to be implemented at different speeds, with companies from developed countries implementing them more rapidly than those from developing countries, the reasons being the higher financial and human capital resources of the former. This inequality, say the experts, will limit the broad realization of global supply chain automation in the short run.

Risk management: In addition to smart contracts, another lever to increase supply chain efficiency is the enhancement of supply chain risk management. This has recently gained in relevance, as globalization not only triggers global competition but also increases the vulnerability of supply chains due to their increasing complexity (Ferdows et al., 2016; Vilko et al., 2014). According to this study's interviewees, there is a 70% probability that the use of blockchain technology will fundamentally improve supply chain risk management by 2035 (Projection 11). An interquartile range of 20 further indicates that there is a strong consensus among panelists on this issue. As data shared within a blockchain is usually more reliable, because it cannot be altered retrospectively, the majority of panelists foresee advantages for supply chain risk management through the technology's utilization. It is assumed that the resulting gapless stream of supply chain data will lead to increased transparency of supply chain processes. Due to the increased transparency, supply chain risks can be handled proactively, and supply chain interruptions can be identified and dealt with faster, increasing the overall resilience of supply chains. The strong reliability of data is also expected to lead to better anticipation and risk assessments. Consequently, all three supply chain risk management phases – identification, assessment, and management of risks – are assumed to be positively influenced through the availability of blockchain data. Even though the majority of experts agree on the potential of blockchain technology for supply chain risk management, a few also stated that not all types of risk (e.g., natural hazards) can be better managed with blockchain technology, and that this will not change by 2035. Additionally, new risks, especially information security and privacy risks, might occur through the application of blockchain technology.

Job profiles: When focusing on the human factor in SCM, experts confirm that the utilization of blockchain technology will require new skills in SCM departments (Projection 10). Within this study, it was rated as the projection with the highest probability of occurrence (73%). In particular, the need for skills related to IT and legal issues is assumed to increase. Experts agree that increasing IT knowhow is required for the implementation of contract-to-real-world interfaces and for understanding the applicability of blockchain technology for supply chain practices. There is an additional need for specialized experts with expertise in planning, development, integration, operation, controlling, and management of blockchain systems. Legal counseling in SCM will also change due to blockchain technology, as new aspects, such as the development of smarts contracts, will have to be considered. Furthermore, new auditing jobs focusing on the validity of incoming data will be generated, and new skills will be required to integrate supply chain partners. Due to the newly required job profiles, it is assumed that a highly specialized workforce will be needed in SCM, leading to a shortfall in expertise and corresponding re-skilling efforts within companies. Surprisingly, the impact of this projection was rated relatively low (3.5) compared to other projections (see Table 3), which could be explained by the fact that job profiles are changing continuously, especially due to the ongoing digitalization. Notwithstanding, investments should include a budget for re-skilling in order to ensure that the workforce is qualified for its new tasks. Overall, the experts' discussion reveals that the job-related barriers listed in the literature (Partida, 2018; Shanley, 2017) may challenge the implementation of blockchain technology in the short term, but they are not expected to hinder its broad implementation in SCM in the future.

4.2.2. *Qualitative analysis of medium-probability projections*

The second set under investigation bundles projections whose probability assessments concentrate in the narrow window of 54-56% (see Fig. 2). All four projections are characterized by large interquartile ranges, indicating a high degree of disagreement among experts. Nevertheless, although the experts were not in agreement and their assessments do not show any tendency toward a high or low probability of occurrence, their comments reveal essential points that may influence the future landscape of blockchain technology utilization in SCM.

Global legal framework: Regarding a global legal framework for the application of blockchain technology in SCM, experts have differing opinions on how regulations will be configured by the year 2035 (Projection 1). Many experts stated that the global alignment of regulatory agreements is difficult due to complex national and international laws and regulations (e.g., tax and trade agreements) along with different economic systems and cultures. Thus, blockchain technology is not expected to be important enough to justify the enormous effort of developing and agreeing on a universal international law. Others expect that there will be legal agreements between certain countries only or general frameworks that guide countries to develop comparable legal constructs. Other experts believe that existing regulations and laws only require slight adaptations, if any at all, to use blockchains in globally connected supply chain networks. One panelist stated that, when technology evolves, smart contracts could also be fully recognized as law.

Regardless of the stated dissent on how regulations will be configured in the future, all statements reveal that regulations are expected to be necessary for a broad implementation of blockchain technology in SCM, which is why the impact of this projection was rated one of the highest (4.0). According to the experts, these regulations do not have to be international, as companies and involved countries will find ways to regulate the application of blockchain technology by themselves. This will be the standard approach, especially for private or consortium blockchains, which only consist of a limited number of members. Guided by their respective country-specific legal laws and data protection regulations, member organizations will regulate the application of blockchains individually. Altogether, the panelists' comments revealed that legal issues are not expected to constitute a critical barrier to blockchain's implementation in SCM in the future. Furthermore, it can be concluded that, even though experts are still divided over the exact configuration of blockchain regulations, they agree that regulations will be established in the future. This is in line with the study by Schweizer et al. (2020), where experts predicted a legal framework for blockchain applications within the European Union by the year 2028.

Digital interconnection: In addition to the experts' differing opinions on the probability and nature of a global legal framework by the year 2035, they are also are divided on blockchains role as a key trigger for an IoT connected digital world (Projection 8), its ability to improve companies' demand planning capabilities (Projection 7), or companies' compliance with sustainability standards (Projection 2).

As the panelists stated, the use of blockchain technology will foster the expansion of the IoT, especially as they foresee new solutions and innovations regarding process automation; however, it will not act as the key trigger. According to their argument, objects and devices may be digitally connected by other technologies as well. Nevertheless, it is also expected that by the year 2035, new business models combining blockchain technology and IoT will be established.

Demand planning: In regard to Projection 7, the analysis revealed that combining open access blockchain data and big data analytics might have the potential to improve demand planning through the provision of detailed insights into demand patterns. However, some experts stated that not all demand factors are contained in blockchain data (e.g., weather data) and that cybersecurity and privacy concerns are additional barriers for data availability that will still exist in 2035. Overall, other technologies, such as artificial intelligence and big data analytics, are predicted to have a more significant impact on the improvement of demand forecasts.

Sustainability standards: Through the improved transparency triggered by the utilization of blockchain technology in SCM, organizations' incentives to provide high-quality products through sustainable working practices are predicted to increase (Projection 2). However, with regard to accountability, it is mentioned that, even though blockchain technology can prevent the manipulation of data that has already been written into the blockchain, the authenticity of data inputs cannot be ensured. To solve this issue in the context of sustainability, physical evidence (e.g., working conditions, use of toxic material, etc.) would have to be securely transferable into digital information, which is currently described by experts as a bottleneck. Since no complete and globally applicable solutions are expected in this regard by 2035, it is assumed that future compliance with sustainability standards will be ensured and reported by traditional means and selective blockchain-based support in parallel.

4.2.3. *Qualitative analysis of low-probability projections*

The remaining four projections were evaluated with a probability of occurrence of less than 50% (see Fig. 4); nevertheless, they do provide valuable insights regarding the future utilization of blockchain technology in SCM. The discussion of these issues reveals a variety of shortcomings and barriers that still need to be addressed and further indicates under which circumstances the Delphi panelists expect blockchain technology to be used by the year 2035.

Trust management: As the creation of trust is mentioned as one of the most promising advantages of blockchain technology in the literature (Weber et al., 2016; Nakasumi, 2017), it is surprising that the experts relativize the predictions that blockchain technology will concomitantly increase trust levels between SCM partners. Their assessment is based on the fact that SCM differs in one important characteristic from other areas such as finance, where trust between business partners can be increased by using blockchains – namely, the link with the physical world. The qualitative analysis of Projection 5 (trust management) reveals that experts agree unanimously on blockchains' ability to increase trust for solely digital transactions, but at the same time they are concerned that data might be manipulated before it is entered into the blockchain. While the use of blockchains can foster trust in certain business processes, experts believe that this is not ensured across the entire inter-organizational SCM process chain. Thus, active trust management (Projection 5) is not expected to be replaced by blockchain technology by the year 2035, but rather to change its focus, as only some areas of trust management, including financial monitoring or tactical-spend related topics, might be completely supported by blockchain technology. Areas such as tracing of goods or the tracking of quality and social standards will stay vulnerable to data entry manipulation. Due to this fact, interpersonal relationships and the therewith associated high trust level are expected to be areas particularly relevant in encouraging supply chain partners to share data and in ensuring the authenticity of data entered into the blockchain. This risk of fraud when entering data from the physical world into a blockchain led the experts in this study to regard lack of trust as a barrier for blockchain implementation in SCM. To overcome this barrier, active trust management is needed, which is why losing its relevance only shows a low rate of desirability (3.3).

Data manipulation: Information security was mentioned by the experts as a barrier for the implementation of blockchain technology in SCM. This may be counterintuitive, as data immutability is a design feature of the technology and one of the key reasons for its implementation. In the context of this study, experts agree that the manipulation of data written in the blockchain will most probably not be possible by the year 2035, as cybersecurity is expected to improve with the massive adoption of the technology (Projection 13). Nonetheless, as long as businesses are concerned that data might be manipulated before it is entered into the blockchain, blockchain's security advantage as proposed in the literature cannot be fully exploited in SCM. Based on the analysis of Projections 5 and 13, it can be concluded that, in comparison to other branches such as finance, active trust management is a factor that could help to overcome these barriers and therefore is a necessary factor for the successful implementation of blockchains in SCM. Even though blockchain technology is evaluated as beneficial to increasing transparency and improving supply chain efficiency, the SCM-specific barriers related to data availability and data authenticity are regarded as critical for the exploitation of blockchain's full potential.

Integrated blockchain: Projection 14 focused on the interoperability of blockchains, as the three trends of an increasing number of public blockchain ecosystems, a growing variety of blockchain applications, and the development toward private, company-owned blockchains were discussed in the literature as technologically challenging for the implementation of blockchain technology in SCM, raising the question of inter-blockchain data exchange. Despite the increasingly fragmented blockchain landscape, to exploit the full potential of this technology, blockchains should be integrated in such a way that, for example, a transaction on Hyperledger can retrieve information from Ethereum. In an SCM context, paying a supplier via one blockchain that first requires additional data from another blockchain to approve the transaction is an apt example. Nevertheless, according to the majority of experts, standardization of blockchain applications is not a preferred solution to tackling this challenge. Thus, an integrated multi-purpose blockchain that combines the features, abilities, and application areas (e.g., financial transactions, tracing of goods, quality control) of several specialized, task-specific blockchains into one comprehensive blockchain and operates as a standardized one-size-fits-all solution, is neither desired (2.8) nor expected (33%) (Projection 14). Instead, an integrated blockchain solution is evaluated as a threat to democracy, personal freedom, as well as innovation, and is assumed to represent a target for all kinds of criminal and terrorist actions. Furthermore, it is expected to be too complex and too energy-consuming due to the high number of network partners. Application-specific and sector-specific requirements will also not be covered in one single blockchain. Consequently, multiple task-specific blockchains are expected to co-exist in the future, regardless of whether they are organized as public, private, or consortium blockchains. As the need for pooling the various data of such specialized blockchains increases, experts assume that in the year 2035, exchanging data will be facilitated by virtual platforms. These platforms would interlink different blockchains via parent/child relationships in such a way that specialized blockchains – so-called sub-blockchains – would be docked to these platforms, creating a network of networks that allows different blockchains to communicate with each other. According to the experts, even though the standardization of blockchains might not be realized in the future, there will be suitable ways to connect the increasing number of blockchains in order to exploit the technology's full potential. It can thus be concluded that the technological problem of interoperability stated in the literature (Underwood, 2016) is not expected to be a barrier for the implementation of blockchains in SCM in the future.

Cryptocurrencies: In addition to the interoperability of blockchains, the introduction of cryptocurrencies as the standard means of payment for business-to-business transactions (Projection 15) is discussed by the literature as another possibility for reducing transaction costs in SCM. Although cryptocurrencies are expected to lower costs, speed up transactions, and lead to promising use cases in combination with smart contracts, the experts' assessments suggest a divisive situation. Practical hurdles and barriers predominated the experts' evaluations. Lack of governmental control, being one of cryptocurrency's potential advantages, as well as confidentiality issues and volatility, are stated as serious drawbacks. Hence, some experts assume that only if cryptocurrency evolves and is controlled by a central bank, or if fiat money becomes available in crypto form, will there be a chance that it will become the standard means of payment for business-to-business transactions until the year 2035. With regard to this opinion, it is also mentioned that cryptocurrencies are not necessarily required as the means of payment for financial, blockchain-secured business-to-business transactions, and the technical features of a blockchain could therefore be used without the uncertainties associated with a cryptocurrency.

4.3. Implications for practice and future research

The analysis of the projections on the basis of their probability of occurrence and expected impact reveals which scenarios could arise for the future application of blockchains in SCM and also reveals which combined projections represent the highest-probability scenario. This outlook will be of great value to researchers and managers alike, especially as the quantitative results confirmed a high relevance for all projections under investigation (indicated by an impact of 3.3 or higher).

As this study looks ahead to the year 2035, it can support businesses in their long-term strategic decisions, with the scenario data acting as a starting point for long-term blockchain-related efforts. The derived implications are valuable as guiding principles for the development of new strategies as well as reassessing existing ones. For example, managers should not solely look at the technological aspects of blockchain solutions, as most technological barriers such as high energy consumption or transaction times are expected to be solved in the long run. Rather, they need to focus on a secure and thorough integration of supply chain partners into the blockchain network. Organizations must pay particular attention to the interface between the physical world and the blockchain to ensure that the data fed into the system is correct. Incorrect data has a negative impact on the application of smart contracts and product tracing, hampers the success of risk management activities, and reduces trust in sustainability tracking. As long as the secure import of data is not guaranteed, trust management should be further expanded by the organizations, even though the literature and general expectations consider blockchain technology to be trust-building. Regarding the legal aspects relating to the application of blockchains in SCM, there was significant disagreement among experts on whether a global legal framework will be established, and consequently – especially when operating private or consortium blockchains that only consist of a limited number of members – organizations should also think about legal aspects. Furthermore, the experts were confident that job profiles in SCM will change or will be newly created due to blockchain technology. As a highly specialized workforce is therefore anticipated, companies should ensure that the necessary personnel are hired and also take early action to initiate the required re-skilling.

From a theoretical point of view, the study reveals areas for future research. In line with other studies (Abeyratne and Monfared, 2016; Kshetri, 2018; O'Leary, 2017; Bumblauskas et al., 2020), this research supports the idea that blockchain technology has the potential to increase transparency and improve efficiency in supply chains. The future-oriented approach of the underlying study, however, revealed that SCM-specific barriers related to data availability and data authenticity can be regarded as critical for the exploitation of blockchain's full potential. Therefore, procedures and mechanisms for a secure and tamper-proof transfer of information about physical transactions into digital data need to be conceptually developed and tested in practice. The results of this study also suggest that further research is needed on how to combine blockchains with other technologies, for example the IoT or Cyber Physical Systems – to increase the blockchain's value for tracing (Projection 6). Moreover, as smart contracts (Projection 3) have been rated as the application with the highest impact for SCM, the operation of smart contracts in SCM should be addressed more in future research. Further research should also be carried out on the contrasting assessments of the projections given by experts from academia, industry, and politics/associations. For example, the estimations of academics and industry experts differ significantly on the probability of Projection 6 (tracing material flows) (56% compared to 67%) and the impact of Projection 5 (trust management) (3.6 compared to 3.0), which leads to the question of why such large differences of opinion exist. It should also be noted that some projections were discussed and evaluated very controversially, which resulted in a lack of consensus in the experts' opinions (e.g., Projection 1). Future research projects should therefore examine these projections in greater detail.

5. Conclusion

A blockchain, sometimes referred to as distributed ledger technology, records the history of transactions between networked actors in an immutable and decentralized manner; and even though a blockchain has further attributes, these characteristics already indicate the potential of the technology for SCM. In a supply chain context, blockchain technology is often attributed to improvements in transparency, trust, efficiency, accountability, or cost reduction (Casino et al., 2019; Kshetri, 2018; O'Leary, 2017; Yong et al., 2020). However, since research on blockchain technology in the field of SCM is still in its early stages and highly theoretical, there is a call for additional empirical research to better understand its potential, implementation processes, and future application areas (Wamba and Queiroz, 2020). This research paper therefore applies a real-time Delphi methodology to gather profound long-term judgments of an international expert panel on how blockchain technology will influence the future of SCM and to identify potential application scenarios for the year 2035. In contrast to existing scientific papers on blockchain technology in SCM, it does not only consider the technical perspective, but regards policy, economics, and societal aspects, taking a multi-level perspective, as these factors also affect technology transition. Moreover, it involves experts with heterogeneous backgrounds, providing a holistic picture of blockchain's future in SCM. The study developed and discussed projections that have been rated by the Delphi panelists according to their probability of occurrence, impact, and desirability.

Through the analysis of the experts' long-term judgments, and in accordance with existing literature, transparency and efficiency are confirmed as the main benefits of blockchain's utilization in SCM. Moreover, the highest-ranked projections in regard to their probability have been combined in a scenario, which is likely to occur within the investigated horizon, offering businesses a validated starting point for their blockchain strategies. The study further identifies data availability and data authenticity as two major SCM-specific barriers that could prevent the exploitation of potential benefits. These barriers indicate that two of blockchain's promising advantages – namely manipulation safety and negligibility of trust – are not entirely transferable to SCM without additional conditions, as the authenticity of data entered into a blockchain cannot be guaranteed. This is because SCM not only deals with digital transactions, but also with physical ones that have to be transferred into digital information. However, the transfer process is prone to manipulation, and thus manipulated data could be entered into the blockchain. Ensuring the transmission of truthful data into the blockchain is therefore a crucial prerequisite for increasing the level of trust and for ensuring the accuracy of all related applications, including smart contracting or tracing of goods. Consequently, this study adds to the existing literature by revealing that trust among business partners in SCM will not be replaced by cryptographic proof alone, but that active trust management at the interface between the physical and digital worlds of SCM acts as the enabler. In summary, the research contributes to the transfer of general technical-driven blockchain knowledge to SCM-specific blockchain knowledge, which is essential, as technology transition does not depend on technological aspects alone (Geels, 2002).

As with any research, the study at hand has limitations, which provide opportunities for future research. Although a systematic process was followed to develop the projections involving political, economic, social, and technological aspects, the number of projections was limited to 15 to ensure an appropriate survey-processing time and to reduce drop-off rates. There is therefore scope for further research, in which aspects that were not explicitly considered in this Delphi study could be assessed.

CRediT authorship contribution statement

Matthias Kopyto: Methodology, Validation, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Project administration. **Sabrina Lechler:** Conceptualization, Methodology, Formal analysis, Investigation, Writing - original draft. **Heiko A. von der Gracht:** Conceptualization, Methodology, Writing - original draft, Writing - review & editing. **Evi Hartmann:** Methodology, Validation, Writing - original draft.

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