sustainability

MDPI

Article

Development of a Risk Framework for Industry 4.0 in the Context of Sustainability for Established Manufacturers

Hendrik S. Birkel [1], Johannes W. Veile [2], Julian M. Müller [3,*], Evi Hartmann [1] and Kai-Ingo Voigt [2]

[1] Chair of Supply Chain Management, Friedrich-Alexander-University Erlangen-Nürnberg, Lange Gasse 20, 90403 Nürnberg, Germany; hendrik.birkel@fau.de (H.S.B.); evi.hartmann@fau.de (E.H.)
[2] Chair of Industrial Management, Friedrich-Alexander-University Erlangen-Nürnberg, Lange Gasse 20, 90403 Nürnberg, Germany; johannes.veile@fau.de (J.W.V.); kai-ingo.voigt@fau.de (K.-I.V.)
[3] Department of Logistics and Operations Management, Salzburg University of Applied Sciences, Urstein Süd 1, 5412 Puch bei Hallein, Austria
* Correspondence: julian.mueller@fh-salzburg.ac.at

Received: 24 December 2018; Accepted: 8 January 2019; Published: 14 January 2019

Abstract: The concept of "Industry 4.0" is expected to bring a multitude of benefits for industrial value creation. However, the associated risks hamper its implementation and lack a comprehensive overview. In response, the paper proposes a framework of risks in the context of Industry 4.0 that is related to the Triple Bottom Line of sustainability. The framework is developed from a literature review, as well as from 14 in-depth expert interviews. With respect to economic risks, the risks that are associated with high or false investments are outlined, as well as the threatened business models and increased competition from new market entrants. From an ecological perspective, the increased waste and energy consumption, as well as possible ecological risks related to the concept "lot size one", are described. From a social perspective, the job losses, risks associated with organizational transformation, and employee requalification, as well as internal resistance, are among the aspects that are considered. Additionally, risks can be associated with technical risks, e.g., technical integration, information technology (IT)-related risks such as data security, and legal and political risks, such as for instance unsolved legal clarity in terms of data possession. Conclusively, the paper discusses the framework with the extant literature, proposes managerial and theoretical implications, and suggests avenues for future research.

Keywords: Industry 4.0; Industrial Internet of Things; digital transformation; sustainability; Triple Bottom Line; risk management; small and medium-sized enterprises; qualitative study

1. Introduction

Industry 4.0, internationally also referred to as the Industrial Internet of Things (IIoT), describes the integration of Internet of Things (IoT) technologies into industrial value creation. The aim is to create fully digitalized, networked, intelligent and decentralized value creation networks [1]. It is assumed that this will initiate a new paradigm shift in industrial value creation, following the previous industrial revolutions. The application of IoT technologies can address current challenges in industrial value creation, such as shorter technology and innovation cycles, rising market volatility, and a highly dynamic environment in the face of increasing competitive pressure [1–3].

Furthermore, society and policy makers expect the industry to continue creating sustainable value in the future, i.e., to pursue economic, ecological, and social goals [4]. These three dimensions are summarized in the so-called Triple Bottom Line of sustainability [5,6]. Only by generating value in all three dimensions, while carefully balancing the challenges between them, will unfold the full benefits of the concept of Industry 4.0 [7].

The actual effects of Industry 4.0 on the dimension of sustainability are still uncertain, and little attention has been paid to the risks in particular [7–9]. In managerial practice, detailed observations have not yet been executed to a sufficient extent, as a comprehensive implementation of Industry 4.0 is still pending. Researchers, politicians, and representatives of business practice contradict each other in their statements on the potential benefits and risks [7]. The current scientific literature and research studies are mainly devoted to the technical foundations and technical challenges of Industry 4.0 [10,11]. Overall, the potential risks of Industry 4.0 are one of the main topics in public debates, hampering or questioning Industry 4.0 implementation. This is especially true for economic concerns, such as the loss of competitive advantage through diminishing business models, resulting in decreasing profits or even a relocation of manufacturing [12]. Further, social risks are mentioned, including required training and the requalification of the workforce or expected job losses, especially for routine or simple occupations [13]. This leads to a decreasing acceptance of the existing workforce, and impedes organizational transformation [14,15]. However, so far, the risks have only been considered in isolation without structure, meaning that little knowledge has been gained about them and their interdependencies [7].

Further, small and medium-sized enterprises (SMEs) in particular, which, in the European Union, are described as companies with an annual turnover of up to 50 million euros and a maximum of 250 employees, have been considered less when regarding the risks in the context of Industry 4.0. However, SMEs in particular doubt or even fear the concept of Industry 4.0 [16,17]. In addition, the empirical results show that risks in the context of Industry 4.0 are perceived differently by SMEs, especially as they do not fully grasp the opportunities of new business models in contrast to larger enterprises [8,18]. However, relating to the large importance of SMEs, their integration is a key success factor to the concept of Industry 4.0 [17].

Against the background of the research gap of a comprehensive risk framework regarding Industry 4.0, this paper attempts to empirically and theoretically derive such a framework and specifically focus on the requirements of SMEs.

The remainder of the paper is organized as follows: Section 2 describes the theoretical background regarding Industry 4.0, the Triple Bottom Line of sustainability, and risk management. Section 3 presents the state of research, and Section 4 states the method used. Then, Section 5 describes the results, followed by a discussion in Section 6, and a conclusion in Section 7.

2. Theoretical Background

In the following, Section 2.1 gives a brief overview of the concept of Industry 4.0. Section 2.2 introduces the Triple Bottom Line of sustainability, whereas Section 2.3 introduces risk management to the reader.

2.1. Industry 4.0

Industry 4.0 refers to a paradigm shift. It integrates IoT technologies into industrial value creation, and thus achieves digital interconnection across company boundaries in real time [1,2]. Industry 4.0 can be defined as a real-time, intelligent, horizontal, and vertical networking of people, machines, objects, and information and communication systems with the aim of dynamically controlling complex systems [8,11]. The exact and comprehensive definition of the concept is disputed among different research disciplines, as each research discipline tends to highlight individual characteristics [19].

The technological core of Industry 4.0 is formed by Cyber-Physical Systems (CPS) that are composed of sensors, data processors, and actuators [1]. These merge the real and the virtual world, and enable data to be transferred between people and objects along the entire value chain in real time [17]. Similar approaches have been developing worldwide, e.g., the “Internet Plus” initiative within the concept "Made in China 2025", or the "Industrial Internet Consortium" in the United States (USA), among others [11,20].

Industry 4.0 has the potential to help companies meet the current challenges of industrial value creation [7]. Thus, Industry 4.0 can help companies adequately meet the increasing volatility of the markets, the increasing demands and complexity of products and services, as well as the shortening of innovation cycles. Furthermore, it is expected that the flexibility and adaptability of products and services will be increased, raising the overall efficiency of industrial value creation. Finally, the potential for ecological and social benefit following the concept of Industry 4.0 is predicted, e.g., reduced energy and material consumption, the reduction of exclusion and waste, as well as adaptive working environments [1,2].

2.2. Triple Bottom Line of Sustainability

Society has recently become aware of the environmental impacts of industrial value creation, particularly since the "Brundtland Report" of the World Commission on Environment and Development [21,22]. As a result, a corporate philosophy that exclusively aims to maximize profits and completely neglects other stakeholders is no longer accepted [23]. This change in awareness has helped Corporate Social Responsibility reach its current and ongoing relevance [24].

The Triple Bottom Line of sustainability includes the three dimensions profit, planet, and people, which represent economic, environmental, and social aspects [6,21]. Economic success is the basis of a company's profitability and liquidity, which ensures its existence [25–27]. From an ecological point of view, companies act sustainably if they exclusively use resources that can be reproduced and if they only produce emissions that can be managed by the natural ecosystem [28,29]. The social perspective includes economic action that respects the human and social capital of a society, and complements the Triple Bottom Line [25,28,30].

Due to the interdependencies between the economic, environmental, and social aspects, the different dimensions of sustainability should be taken into account within strategic and organizational considerations in the implementation of Industry 4.0 [6,27,31].

2.3. Risk Management

Until today, uncertainty about a universal understanding of the term "risk" persists, which is reflected by numerous attempts to define it [32–34]. This it is not surprising, since the term "risk" is multifarious, and can be categorized by diverse attributes [35]. Deloach defined risk as "the level of exposure to uncertainties that the enterprise must understand and effectively manage as it executes its strategies to achieve its business objectives and create value" [36]. March and Shapira referred to the classical decision theory and defined it as "the distribution of possible outcomes, their likelihoods, and their subjective values", whereas Miller stated that "the label 'risk' has also commonly been assigned to factors [that are] either external or internal to the firm that impact on the risk experienced by the firm". In this sense, "risk" actually refers to a source of risk. Some common examples of risk referring to risk sources are terms such as "political risk" or "competitive risk" [37,38].

However, the lack of consensus on the definition of "risk" impairs communication and collaboration between researchers, as well as practitioners [39]. To enhance the understanding of the term "risk", this work follows the prevalent classification, defining risks as measurable and objective [40]. The quantitative interpretation allows a numerical calculation, and thus the definition as the sum of uncertainty and damage [41].

In business, each process and decision is affected by risk and uncertainty, leading to potential incorrect assessments, misjudgments, or unexpected changes, with versatile consequences for a company [42]. In addition, risks are not limited to the boundaries of a single enterprise, but rather are spread across an ecosystem, leading to interdependencies between suppliers, customers, competitors, and the company itself [43].

This is amplified through digital advancements such as CPS, IoT, and Cloud Computing, which are subsumed under the term Industry 4.0 or IIoT. Identifying potential threats, analyzing them, and developing the necessary responses are the key objectives of risk management [44,45]. The process consists of four steps: identification, assessment, mitigation, and monitoring [46]. The sequence of these elements can either be displayed as a successive progression or as a continuous circle. As an extension to traditional risk management approaches, this work is characterized by an additional cross-company orientation that is aimed at the identification and reduction of risks on a company level as well as in the business ecosystem [47].

3. State of Research

The extant literature contains assumptions that, through digitalization and the interconnection of industrial value creation—supported by comprehensive data analysis, machine learning, and artificial intelligence—potential can be tapped in all three dimensions of sustainability [7,48]. Previous studies on Industry 4.0 have essentially examined the topic from a technical point of view [20,49].

Furthermore, existing studies have described the individual, specific aspects without discussing the interdependencies [7]. However, the adaptation and balancing of these dimensions among themselves represents a decisive mechanism for adopting and disseminating technologies [50,51]. An analysis of sustainability in the context of Industry 4.0, especially regarding the risks, is still lacking in the extant literature.

From an economic point of view, process transparency and networking in the context of Industry 4.0 can lead to an optimization of value creation [52]. The efficiency and flexibility of manufacturing processes, as well as the quality and the degree of individuality of products and services, can be increased [1,2]. As a result of the increased process transparency in internal and inter-company logistics, throughput and storage times, and therefore logistics costs, can be reduced [53–55]. New business models are also expected as a result of database-driven products and services [56].

In relation to the ecological dimension of sustainability, Industry 4.0 creates further potential benefits [57]. The intelligent planning of tasks and processes, which is achieved by demand and process transparency, can optimize load distribution in a company. This can reduce the energy consumption of the industrial value chain [58–60].

A company's energy consumption can also be reduced through using process simulations and intelligent energy management [61,62]. Digitization and networking technologies can also improve product life cycle management and recycling processes, resulting in lower resource consumption and less waste [63–65]. This also applies to the recycling of raw materials and tools, and the retrofitting of machines [66].

Furthermore, Industry 4.0 can help companies avoid unnecessary material flows and reduce the volume of internal and external freight transport, as errors in deliveries, unnecessary waiting times, and damaged goods are averted by data transparency throughout the supply chain [63,67]. In this way, Industry 4.0 can help reduce greenhouse gas emissions, and therefore a company's CO_2 footprint [47].

Industry 4.0 is also expected to create benefits with regard to the social dimension. For example, intelligent assistance systems and adequate human–machine interfaces can lead to increased employee satisfaction [48,68]. Another aspect of digitalization is the greater flexibility in the processing of certain tasks. One example is working from home, which promotes the integration of business and family [69].

On the downside, Industry 4.0 risks are expected to occur in all of the dimensions of sustainability [7]. However, research in the area of risks and their interdependencies have been sparse. Initial indications can be found with regard to the economic dimension. For example, it is assumed that the implementation of Industry 4.0 requires large investments with uncertain success as well as profitability, leading to a high implementation barrier [70].

In the social dimension, it is discussed how occupational profiles and working habits will change, how some tasks will fall to autonomous systems, and how the automation of simple tasks will continue to progress, which can lead to job losses [49,71,72].

In addition, most companies lack the knowledge that is required for an appropriate implementation of Industry 4.0-related technologies [73]. Still, there is broad disagreement as to whether Industry 4.0 will lead to an increase or decrease in jobs [71]. Statements and figures in this context are disparate, and sometimes even contradictory [48].

In sum, there is still a research gap in the area of Industry 4.0-related risks, as there has been no holistic framework that gives an overview of the possible risk dimensions of Industry 4.0. However, a holistic approach that provides an overview is essential for research and practice. While future research can build upon such a framework in order to better understand the implementation of Industry 4.0 in specific cases, managerial practice can use the framework in order to transfer their own situation to this overview.

4. Method

The aim of the study is to identify the risks that arise within the framework of Industry 4.0. For this purpose, a qualitative, empirical study design was chosen, since a comprehensive and systematic analysis of the risks is still lacking, and this research design is particularly suitable in this context.

In order to create a general and comprehensive overview of risks, which already involves presenting an extensive topic for the expert interviews, it was decided to solely focus on the risks rather on the benefits of Industry 4.0, which are better understood [7,8].

The study is based on in-depth interviews conducted with experts from business practice [74,75]. This approach is used for a number of reasons. First, case studies provide well-founded information, and help explore facts in depth [76,77]. Secondly, a case study design in the context of information and communication systems has already been proven to be successful on several occasions [78,79]. Third, the approach is particularly appropriate in the context of complex, new, and evolving phenomena [77,80]. The application of multiple case studies supports the accuracy, robustness, reliability, and generalizability of the results [74,77,81]. Semi-structured expert interviews serve as a data basis, which allow data to be collected in a structured way while maintaining the necessary openness to include new and unexpected information [77,82].

The data sample of the study consists of interviews conducted between October 2017 and January 2018 with 14 managers from German industrial companies. All 14 companies come from established industry sectors, and are not from purely information technology (IT)-related sectors. Six out of 14 enterprise representatives that were interviewed can be classified as SMEs, according to the definition of the European Union [16]. The companies come from 13 different industries, and have all already gained experience with Industry 4.0. Thereby, the paper attempts to generate a broad overview of the risks that are related to Industry 4.0, and relevant to different industries and company sizes. The only limitation was that all of the companies had to be active in business-to-business (B2B) contexts. German companies were chosen due to the importance of Germany as an industrial nation, as well as the acquired knowledge with Industry 4.0-related technologies, which is already available. The heterogeneity in the sample allows the results to be generalized, and the potential negative effects of the sample distortion to be counteracted [77]. The interviews lasted between 36 and 73 min, and were conducted in German. For reasons of confidentiality, the names and entrepreneurs of the interviewees, as well as their characteristics, were made anonymous. Table 1 gives an overview of the sample.

Table 1. Data sample. ICT: information and communication technology.

Expert	Industry Sector	Employees
E1	Mechanical and plant engineering	Below 100
E2	Textile industry	Below 100
E3	Medical engineering	Below 100
E4	Electrical and ICT industry	100–1000
E5	Metrology	Below 100
E6	Metal and steel industry	100–1000
E7	Aviation	1000–100,000
E8	Electrical and ICT industry	Above 100,000

Table 1. *Cont.*

Expert	Industry Sector	Employees
E9	Automotive	10,000–100,000
E10	Mechanical and plant engineering	10,000–100,000
E11	Food industry	1000–10,000
E12	Electrical and ICT	Above 100,000
E13	Automation industry	10,000–100,000
E14	Automotive	Above 100,000

The interview guide is based on the scientific literature, but followed the principles of openness and flexibility [83,84]. In order to check the length, comprehensibility, content, and plausibility, two interviews were conducted in advance with two independent managers. After minor adjustments were made, the interview guide consisted of two parts. In the first part, questions about the company and the person were asked, e.g., the current position and career of the interviewee. In the second part, a risk assessment of Industry 4.0 was carried out.

Thereby, interviewees were specifically asked to refer to risks that they had encountered in their practical experience with Industry 4.0, rather than quote knowledge that they had acquired from third parties. Inspired by the overview of the potentials and challenges of Industry 4.0 by Kiel et al. [7], the following six questions were asked:

- Which economic risks did you encounter when implementing Industry 4.0?
- Which ecological risks did you encounter when implementing Industry 4.0?
- Which social risks did you encounter when implementing Industry 4.0?
- Which technical risks did you encounter when implementing Industry 4.0?
- Which IT-related risks did you encounter when implementing Industry 4.0?
- Which legal or political risks did you encounter when implementing Industry 4.0?

In order to prevent falsification and be able to concentrate fully on the conversation, all of the interviews were audio recorded and transcribed. The transcripts were then examined using a qualitative content analysis [85]. As much supplementary secondary data as possible was also collected to verify the statements from the expert interview (e.g., company websites or annual reports) [77,86].

In the qualitative content analysis, inductive coding was applied. The coding process of Gioia et al. was used [87]. As an initial step, first-order categories were developed. In the second step, these categories were synthesized into superordinate categories. Finally, the topics were summarized in the risk dimensions: economic, ecological, social, technical, information and security risks, and political/legal risks. The developed categories were simultaneously enriched by the scientific literature [77,88]. This was done in order to allow new trains of thought to emerge, and not limit the approach by predefined hypotheses [89,90].

The entire process was conducted by a research team comprising all five authors of this article in order to increase the validity and objectivity of the coding procedure [91]. Prior to this process, all of the team members separately suggested coding categories. Using these, we calculated inter-coder reliability that resulted in a high value following Holsti [92]. Following this, we compared and carefully discussed the individual coding, rethought and if necessary revised the categories, and lastly consolidated them into our final framework.

The categories and risk dimensions can be found in Tables 2 and 3.

5. Results

The results of the study reveal six risk dimensions with 27 sub-dimensions that occur during the implementation of Industry 4.0. Risks exist for individuals, for SMEs, and for entire national economies. Table 2 gives an overview of the dimensions and categories identified in the study, including exemplary statements by the interviewed experts that are related to the Triple Bottom Line of sustainability. Further, Table 3 summarizes the risk dimensions that were derived in the context of technological, IT-related, and legal or political risks.

Table 2. Topcodes and subcodes within risk dimensions of the Triple Bottom Line.

Dimension	Topcode [a]	Subcode [b]	Exemplary Expert Statement
Economic risks			
[7,8,14,17,19,20,70]	Financial (14)	Long and uncertain amortization (12) High investments (8) Personnel costs (5)	"... high costs with long and unclear amortization." (E1) "SMEs (small and medium-sized enterprises) are reluctant with respect to investments." (E2) "Higher investments need to be amortized [...] Will I get this investment back?"
	Time and manner of investments (10)	Risk of false investments (8) Decision in what to invest when (6) Too late investments (6)	"The whole concept is difficult to predict. When should one invest where?" (E11) "Many technologies are not at a mature stage yet; we are unsure where to invest." (E13)
	Changing business models (9)	Loss of core competencies (5) Customer demands/acceptance (3) Transformation of business models (2) Lacking understanding of data-driven business models (3) Business model will only continue in niche (1)	"From our point of view, as a company with a SME culture, it is a risk that we will not generate any ideas [...] regarding new business models [...] especially transferring B2C [Business-to-Customer] business models to B2B [Business-to-Business] contexts." (E7)
	Competition (5)	New competitors (4) Diminishing barriers to market entrance (4) Competitive pressure (3) Transparency of data can be misused (2)	"Let's take an established mechanical engineering enterprise, that is now overtaken by a software firm [...] This generates new competition, which would otherwise not exist." [E9] "... that a competitor, or an unknown disruptor, gets in between us and our customer." [E10]
	Dependencies (4) [3]	Power shifts (3) System suppliers (2)	"There is a large dependence on some suppliers. Only this supplier has the knowledge and can therefore ask for any price." (E4)
Ecological risks			
[9,47,49,57–63,67]	Consumption (3)	Raw materials (2) Energy (2)	"Following digital transformation, our power costs have risen by a factor of five." (E1)
	Pollution (2)	Waste (2) Emissions (1)	"For new machines required, new resources will also be required." (E2)
	Lot size one (1)		"Anyone can configure everything free of choice [...] many products will not be reused, as those are highly customized, producing additional waste." (E8)
Social risks			
[7–9,13,15,17,19,20,48,49,63,65,67–69,71,72]	Job losses (14)	Shifts of competencies (9) Automation (8) Reduction of process steps (6)	"Many jobs will disappear completely." (E1) "Society has to provide an answer to people whose jobs will not be required anymore." (E4) "More skilled workers will be required; unskilled workers might not find a job anymore." (E8)
	Organizational structure and leadership (11)	Organizational transformation (7) Communication (4) Awareness (3)	"Where should I place the topic, where should it be led? If there is no clear communication, it will be dead in a short time." (E8) "Leading the employees to new tools and methods requires organizational change." (E14)

Table 2. *Cont.*

Dimension	Topcode [a]	Subcode [b]	Exemplary Expert Statement
	Internal resistance and corporate culture (9)	Older employees (9) Resistance (4) Error culture (2) Fear (2)	"One has to realize that without digitization, we will not succeed in the market." (E5) "We often hear 'we have done this like that forever' or 'the machines have run like that for several years'." (E10) "Employees are reluctant toward this topic; they simply fear losing their jobs." (E13)
	New requirements for training (9)	Training on the job (5) Apprentices (4)	"We need special skills, especially for workers in the IT area. They need to be appropriate for the job and receive training." (E7) "It is a huge risk that employees cannot become qualified quickly enough." (13)
	Stress (5)	Mental stress (3) Missing social interaction (2) Permanent availability (1)	"Our employees are stressed anyway. How should they be able to focus on further tasks?" (E2)
	Lack of qualified personnel (7)	Information technology (IT) (5) Interdisciplinary thinking (3)	"Computer programmers can go anywhere they want." (E2)
	Concerns regarding Artificial Intelligence (AI) (4)	Distrust in AI (2) Traceability (2) Liability (2)	"What happens if machines decide by themselves?" (E11) "A first company writes an algorithm, a second one uses it, and a third one does not receive suppliers." (E12)
	Manufacturing relocation (3)		"Industry 4.0 could lead to factories being shut down or relocated." (E9)

[a] (number of mentions), [b] (number of mentions), multiple answers possible.

5.1. Economic Risks

5.1.1. Financial

Industry 4.0 technologies require large investments, with an unknown duration for amortization together with uncertain success. Technically, it would be possible to automate, digitize, and network many processes of operational value creation. However, this requires large expenditures for the infrastructure, implementation, and maintenance. It is assumed that the digitization and interconnection of industrial value creation is characterized by a high degree of complexity. It is questionable which processes will actually be economically profitable in the long term.

The short to medium-term profitability of investments in Industry 4.0 technologies can often be negative. This is due to several reasons. First, high investments are required, which come along with complex implementations. Second, the benefits only occur with a time lag. Third, the total benefit cannot be measured in monetary terms. Ultimately, this leads to a balancing of costs and benefits, which can only be decided on a company-specific and case-by-case basis. It should also not be forgotten that pressure can be built up from outside a company, for example by important customers and long-standing partners, forcing the company to digitize and link the value-added process. The latter case requires a decision under strategic considerations; however, it does have a direct influence on profitability.

There is also a high risk with regard to the necessary provision of resources. The implementation of digitization and networking technologies requires large monetary investments such as complex machines and systems. On the one hand, this means a high financial risk, as there is a time lag between the investment and the amortization, which must be covered by the company's own financial resources. On the other hand, these investments are highly uncertain.

In this context, there is a particular risk for SMEs that such investments may exceed their available resources and opportunities. In this case, these companies may be driven out of the market by large companies. In addition, such investments for SMEs usually mean that an entire enterprise is "betted", with a potentially life-threatening outcome.

Furthermore, the development, implementation and use of digitization and networking technologies require large amounts of raw materials. The global reserves of these raw materials are limited. It is questionable to what extent the economy can be supplied with sufficient resources in the future, and what the global price of development will be. Therefore, companies are exposed to the risk that raw materials may become more expensive, raw materials may become scarce, and supplies may be uncertain, or raw materials may not even be available.

High investments are also expected regarding experts with new and rare skills, for instance, computer science, programming, data security, or data scientists. The scarcity of such experts is a risk that will be discussed in detail within Section 5.3, social risks. From a purely financial perspective, those skill sets are hard to obtain, as they are rare on the market, and therefore require large investments. This becomes especially relevant for SMEs, as they cannot afford IT-related experts in many cases. Further, the variety of IT experts that is needed is huge, which cannot be accomplished by a single IT expert. For instance, SMEs would require expertise in various fields, such as data security for programming. However, the small size of SMEs does not allow them to employ ever type of required expert. Therefore, SMEs tend to have a trade-off between general IT experts and specialists, as they would require the latter, but can only afford the former.

5.1.2. Time and Importance of Investments

Based on the aspects mentioned above, many interviewees raise concerns over whether to invest in certain technologies. Especially for SMEs, which tend to have a limited resource base, it remains a challenging task to grasp the importance and relevance of specific technologies. Hereby, interviewees face the risk of false investments, for instance in poor and often immature technologies. The technologies are fraught with uncertainty, which will be truly necessary and will succeed. As the new technologies that are associated with Industry 4.0 require large investments, focusing on the wrong technologies can be a fatal decision, especially for SMEs with a small resource base.

Building on the risk of false investments, many companies are confronted with the decision of when to invest in certain technologies. The difficulty for the right time and manner of investments, which need to be distributed between different technologies and the different departments of a company, can be seen as a crucial success factor regarding Industry 4.0. Especially smaller enterprises, which often do not possess the needed expertise for this decision, seem to be overwhelmed with the possible choices.

Concomitant with the risk associated with false investments that drive companies to delay investments, postponing them too much is seen as an equally important risk associated with Industry 4.0. As a result, the risk of late investments arises, leading companies to miss trends as well as the opportunity to position themselves on the market. Overall, this circumstance is identified as a major factor that delays the implementation of Industry 4.0.

5.1.3. Changing Business Models

The appearance of Industry 4.0 leads to changes in a multitude of layers. It can fundamentally change the ways that enterprises work, as well as the required skills. Therefore, companies can, for example, lose vital core competencies, market success, or profitability. Among others, mechanical quality and expertise, personal contact, and highly flexible solutions that do not build on digitized solutions are in particular named by the experts. These core competencies are especially highlighted by SMEs who fear that their key assets might no longer be attractive to customers. Instead, the IT capabilities of products or purely IT-based services might be what customers are willing to pay for, but SMEs struggle to develop these competencies.

In the same regard, changing customer demands and lacking customer acceptance of Industry 4.0-related technologies must be regarded. As named above, customers might increasingly focus on the new capabilities of products and services. However, another group of customers might be reluctant to pay for new technologies. Furthermore, investments in such new technologies need to be amortized by the providers of such technologies, requiring customers to pay for it. Therefore, the emergence and success of Industry 4.0 technologies depend on a two-sided phenomenon: on the one hand, the providers of such technologies can only develop these if customers are willing to pay for them. However, customers are not yet willing to pay for the new technologies, possibly leading to the entire supply chain missing the trend. SMEs in particular are highly dependent on their customers to deliver the required financial resources in order to finance their research and development (R&D) activities. Therefore, this risk needs to be regarded from an ecosystem perspective.

As a further aspect, Industry 4.0 promotes the emergence of new business models, such as platforms. These have the potential to cannibalize existing business models, making implementation difficult. At present, many companies are (still) focused on marketing their products. In the future, the focus will rather be on providing solutions and addressing customer problems. Therefore, companies are faced with the risk that their business model will not be able to adapt quickly enough to these future requirements. At the same time, radical changes are necessary in order to implement new models, which inherently creates severe challenges for companies with a variety of potential issues. Since these developments are difficult to predict, there are particularly considerable risks for the existence of a company.

Further, lacking expertise in developing data-driven business models can be derived from the expert statements. Relating to the non-IT nature of several of the enterprises regarded in his paper, there is a tendency toward traditional thinking, which is product-driven rather than data-driven. This means that many of the decision makers do not know how to generate value from data. SMEs especially describe that their current business models are not compatible with deriving value from data, which is related to the small amount of data that can be collected within their value creation. Also, a single interviewee expresses the risk of being driven into a niche segment following the developments housed under the term Industry 4.0. If data is the "new gold" in Industry 4.0, old competencies might only be valuable in niches.

5.1.4. Competition

Although Industry 4.0 was originally intended as a countermeasure, geographical borders seem to disappear, increasing the competition from previously unnoticed regions. This is accompanied by lowering entry barriers, whereby new competitors can emerge from the market very quickly and unnoticed. As previously described, these could stem from IT-related disciplines that attempt to enter traditional industrial markets. Therefore, established manufacturers need to react to new market entrants from other industries, with entrance barriers diminishing or shifting toward conditions that are favorable for new market entrants.

The paradigm shift of Industry 4.0 will also lead to an increase in performance, price, and cost pressure. With the help of digitization and networking technologies, individualized services can be provided at the cost of mass production. Traditional manufacturers in particular expect that their products will be in markets with even more competitive pressure. This also relates, as explained above, to customers' decreasing willingness to pay for certain capabilities—particularly, non-IT related capabilities.

Another aspect raised by several interviewees is that the increased transparency of data, which is also visible to other stakeholders within a supply chain, can lead to increased pressure from their side. For instance, knowing key figures such as the overall equipment effectiveness, cycle times, scrap rates, or similar might be used in order to negotiate prices and conditions. SME representatives in particular have mentioned here that their lower bargaining power—expressed by a smaller share in the value chain, especially in terms of data—might be used to their disadvantage. Hence, SMEs see it as a risk to share information and data digitally with other stakeholders in a supply chain.

5.1.5. Dependencies

Several interviewees raise concerns regarding whether Industry 4.0 will raise new dependencies from certain key suppliers, especially in purely IT-related fields. Traditional manufacturers fear that their competencies might be less valued, whereas new competencies will lead to customers' higher willingness to pay, as explained above, which is also related to the rarity of these new competencies. Hence, traditional manufacturers fear a loss of power, leading to power shifts that are unfavorable for them.

The integration of external partners helps compensate for a lack of skills or resources, but leads to a high degree of dependency. SMEs, in particular, usually do not have sufficient skills or resources of their own to develop the technologies independently and implement them. They often have to fully rely on external partners.

For example, the development of suitable software solutions is often outsourced. In the short term, this approach is certainly effective and time-saving, but in the long run, it leads to a dependency from which it is difficult for the companies to escape. This is mainly because knowledge remains with the partner, and further work—such as repairs or updates—can no longer be carried out independently.

The result is a sort of monopoly position by the provider vis-à-vis the procuring company, and the provider company can demand a correspondingly high price. This phenomenon occurs with all types of solution providers, but the effect is even more pronounced with so-called system suppliers.

5.2. Ecological Risks

5.2.1. Consumption

The implementation of Industry 4.0 in business practice and the application of digitization and new technologies involves various ecological risks. For example, they require and consume a large amount of raw materials. The extraction, transport, and processing of raw materials have mostly negative effects on the environment. One example is the extraction of rare earths in China, where the extraction process produces acidic sludge, radioactive substances, and other toxic waste, all of which pose a threat to the environment.

New machines are needed in order to transform the company's value chain, and their production requires raw materials as well. In this respect, it is assumed that the use of digitization and networking technologies will have a negative impact on the environment.

The application of Industry 4.0-related technology also leads to high energy consumption. It is questionable to what extent the increases in efficiency as a result of digital networking exceed the financial expenditure for energy. In addition, companies will become progressively dependent on energy producers and suppliers, and thus on their prices. From a holistic perspective, the question is also raised as to what extent efficiency gains, in the context of digitization and interconnection, exceed the energy required to promote them ("energy balance").

If, for example, the generation, transport, and storage of energy for the implementation and use of Industry 4.0 technologies consumes more energy than the efficiency gains that would be generated, then assuming the complete internalization of all external effects is at least questionable from a macroeconomic point of view. This relates especially to data transmission, decentralized systems such as blockchain, or required server capabilities that consume a large amount of energy.

5.2.2. Pollution

Among the ecological risks, as stated by the interviewees, are increased waste generation and emissions. The implementation of Industry 4.0 requires the machinery and equipment within an enterprise to be made Industry 4.0-capable. The economy is already making efforts to retrofit the existing machinery and equipment to save costs and resources. However, this will not be possible for the vast majority, due to the great complexity and required new technological capabilities.

Many of the existing machines and systems will have to be replaced by a new generation. Although attempts can be made to recycle at least parts of the old machines or plants and install them in the new ones, the majority has to be discarded and ends up in landfills.

This represents a burden on the global environment, especially since the decomposition and degradation of many waste materials takes a very long time. In addition to waste, it is conceivable that Industry 4.0 will cause further environmental pollution. It is being discussed as to what extent Industry 4.0 promotes, among other things, the emission of environmentally harmful gases and thus has a negative environmental impact. This relates to, for example, CPS that need to be manufactured.

High-tech machinery in particular can be named in terms of creating high levels of pollution, especially in the manufacturing process.

5.2.3. Lot Size One

Another point raised by the interviewees is that the concept of "lot size one", mass customization, and a high degree of individualization cannot only be seen from a positive side. A higher level of standardization of products also includes the possibility of using the product again, for instance, by reselling it.

However, the more individualized products become, the more difficult it is for another firm or person to reuse those products. Therefore, waste might be increased, and recycling might become more difficult with non-standardized products.

5.3. Social Risks

5.3.1. Job Losses

A social risk is the possible loss of jobs. The employees expect there to be a shift in the necessary competencies within companies in the future. This particularly affects those activities, which can be automated as well as activities within the range of the information and communication technology.

This shift can lead to job losses if employees are not able to adapt quickly enough and satisfy the new requirements. Hereby, it has to be noted that, in addition to the roles performed by personnel with low qualifications such as repetitive tasks, planning and decision-making could also become automated, meaning that more highly qualified personnel could also be at risk of job loss. Therefore, personnel with different competencies need to be able to develop new competencies, which is a major risk in the social dimension of Industry 4.0.

Based on this shift of competencies and the reduction of process steps, the integration of Industry 4.0 can lead to an opening of the social gap. Part of the workforce will be able to meet the changed requirements and prepare adequately for the challenges of the future through further training and education. It is unclear what will happen to those who do not succeed in this development—either because they do not want to, or because they cannot. It can be assumed that this will lead to social tensions within enterprises as well as in society. Therefore, society is encouraged to discuss this challenge and possible solutions.

5.3.2. Organizational Structure and Leadership

In order to successfully transform an organization, the organizational structure needs to be adapted to the requirements of Industry 4.0. Giving IT-related departments more influential power, for instance through the establishment of a Chief Digital Officer (CDO) function or similar, is only one of the most prominent examples named by the interviewees. The interviewees further name it as a risk to stick to existing organizational structures, as well as transform existing organizational structures too radically. In particular, medium-level management representatives are named as hindrances to successful organizational transformation if their department receives cost cuttings or a loss of power. Therefore, successful organizational transformation is of vital importance that needs to be carried out thoroughly, but also with respect to the personal interests of several stakeholders in the existing organizational structure. Further, traditional manufacturers are described as requiring more flexibility in their organizational structures, as the development of business models or software cannot be accomplished by traditional R&D teams, but instead needs new, more flexible teams. Entrepreneurial spirit is an aspect that is often heard of, but is regarded as a major risk to Industry 4.0 being unsuccessful in traditional manufacturing enterprises.

Adequate communication within the company, especially from management and leading personnel, needs to be established. According to the interviewees, the necessities of change will only be accepted by employees if the requirements and a clear strategy can be presented. Otherwise, internal resistance will be a result of unclear or dishonest communication from management to employees.

A third aspect that is often raised by the representatives of SMEs is that management also has to be aware of the developments and necessities that are associated with Industry 4.0. Hereby, especially older decision makers—who are, in the case of SMEs, often also owners of the enterprise—are described as being reluctant or even resistant. In particular, the shift from traditional organizational structures, i.e., the integration of IT-related expertise and their influence on decision-making, is named to be a major risk in this context. Further, if the company seems to be running well, an augmented resistance against new change can be encountered.

5.3.3. Internal Resistance and Corporate Culture

Among others, additional risks arise from internal resistance and an inadequate corporate culture. Company employees should accept the changes that are described above and required, in particular toward digitalization and organizational transformation. However, several interviewees mention resistance from employees and also from medium-level management, especially relating to older employees. Here, it remains a risk that older employees or medium-level managers do not support the necessities of organizational transformation. However, their knowledge is regarded as essential in order to successfully transform the enterprise. Therefore, there has to be a careful balance between integrating older employees whilst maintaining the pace of change needed for Industry 4.0.

Additionally, a culture that constructively analyzes and does not conceal errors should be developed within the company to encourage the employees to try something new, even if they might fail. If failure is stigmatized, employees run the risk of falling into ignorance. The risk for an organization to be paralyzed and miss important developments due to a lack of openness and courage to do something new is critical. New systems and processes should be accepted and used. The company should arrange all of the necessary preparations, such as training. In particular, the management level should set a good example. Currently, traditional manufacturers are described as being all about preventing error and decreasing failure rates. However, new IT or data-related business models cannot be implemented without trying something new that could fail. Furthermore, vital features such as communication and the exchange of information have to be ensured. Otherwise, the risk of information and knowledge islands arises, especially in the organizational areas of information and communication technology.

Another aspect raised is that, as a result of social concerns, foremost job losses or the loss of influence and power, makes employees afraid, and therefore they do not support the concept. This is named as a further risk that needs to be counteracted by the several measures stated above, most of all communication and adaptive organizational structures.

5.3.4. New Requirements for Training

According to the interviewees, two measures need to be successfully developed in order to address the risk of skill shortages and necessary organizational transformation: training on the job for existing employees, and the training of apprentices. Both measures are regarded as necessary by the interviewees, but are also regarded as a risk. Whereas training on the job is expected to meet resistance by employees and lead to shortages in the existing tasks, adequate apprentices are noted as hard to find. Further, IT-inclined apprentices are described as rare and difficult to find on the market. SMEs, in particular, state that they do not have the capabilities to send employees on training courses for a long period of time, making them less attractive to potential apprentices in comparison to larger enterprises. Hence, it remains a significant risk for a company if it is not able to retrain its personnel and employ the required new apprentices.

5.3.5. Lack of Qualified Personnel

In order to successfully establish Industry 4.0, there is a call for a changed requirement profile for employees. In particular, IT-related skills will be in demand in the future, as will interdisciplinary thinking and acting. Training, advanced training, and new training programs are required to prepare employees, as described in the section prior. However, not all of the employees will have the necessary openness for this, which will lead to internal problems.

For the implementation of Industry 4.0, sufficient competencies have to be developed in order to ensure sufficiently skilled personnel. Due to the competitive pressure on the labor market and the large number of alternatives for specialists, skilled personnel in particular is associated with high costs. Alternatively, IT-related experts can be accessed via external service providers, which can be contracted, but also are expensive and generate new dependencies. In particular, SMEs describe that they would prefer to have IT competencies in their own enterprise, but this is hardly possible.

Further, it is necessary to create incentives for suitable specialists so that they remain in a company with their competence and expertise. Since competitive pressure and the supply of alternatives are high, it is becoming increasingly difficult to retain skilled workers, such as programmers, in a company in the long term.

SMEs in particular face this challenge, because they cannot provide the same monetary and non-monetary incentives, such as social benefits and pensions, as large companies. Additionally, several interviewees described that while it is important to have the adequate specialists in IT-related fields, generalists must be installed between traditional and new competence fields, and interdisciplinary thinking must be supported.

Several interviewees state that it is not only IT-related personnel who are beneficial, but also personnel who understand the traditional core business of the enterprises as well as new, IT-related fields in order to mediate between both. However, getting access to such generalists with expert knowledge in both fields is difficult, as those are hard to find on the market, especially for SMEs.

5.3.6. Stress and Overextension

New demands on employees and additional tasks at work can lead to overload and strain. As explained above, new competencies are required for employees. Among others, more competencies in the field of information and communication technology as well as a high degree of flexibility will be required. The handling of new systems and the use of technical components will place additional demands on employees, which will increase the pressure to learn and change.

There will be also further tasks for employees in the future. If previously manual tasks become completely automated, employees need to be able to obtain new tasks. For instance, an operator of a machine could become a "manager" of several machines. The new requirements, coupled with the new tasks, entail the risk that some employees will receive more responsibility, which is perceived as a heavy burden, and could result in the feeling of being overtaxed and overloaded in their job.

Further, the loss of social interaction, as tasks are given increasingly to computers and automated services, is named as a further social risk by the interviewees. Some employees might struggle to spend more time in front of the computer, and less time interacting with other humans. Especially for SMEs, their family-like structure with a strong social interaction is seen as a key asset that might be lost. Furthermore, the need for the permanent availability of employees, since their tasks could become more complex and they could be in charge of global supply chains, puts additional stress on employees that must be overcome.

5.3.7. Concerns Regarding Artificial Intelligence

Artificial Intelligence is a set of technologies that can raise distrust among employees and decision makers. Several interviewees stated that distrust in decisions, especially if they are incorrect, questionable, or with negative consequences, can be seen as a major hindrance for the acceptance of the technology by humans. Thus, giving power to Artificial Intelligence and losing human control is seen as a major social concern that must be addressed for implementing data-based Artificial Intelligence approaches.

Comparably, if mistakes occur, several interviewees wonder if it will be possible to track and clearly assign the error to the Artificial Intelligence, or the person who designed the Artificial Intelligence. Although such considerations might seem quite futuristic, interviewees stated that these are already concerns, and therefore must be considered from a social perspective on Industry 4.0.

In a similar regard, several interviewees questioned liability in a world where Artificial Intelligence makes decisions. Can an algorithm, including from a legal perspective, be blamed for a decision, or should the person who designed the algorithm be blamed? The interviews suspected social concerns heading in such directions, especially in an industrial supply chain with several stakeholders.

5.3.8. Manufacturing Relocation

Relating to several economic and social risks, interviewees expressed the risk that manufacturing relocation could be a result. This relates to economic considerations, such as an attempt to bundle investments, as well as social risks. For instance, employees' resistance or lack of qualified personnel could drive manufacturers to relocate their factories to areas of the world where both aspects do not play such a major role. Hence, several interviewees regarded factory closures or relocation of manufacturing facilities as a social risk that needed to be considered in the context of Industry 4.0.

Table 3 summarizes the topcodes and subcodes within the technological, IT-related, and legal or political risk dimensions.

Table 3. Topcodes and subcodes within risk dimensions.

Dimension	Topcode [a]	Subcode [b]	Exemplary Expert Statement
Technical risks			
[7,8,17,20,50,51,68,73]	Technical Integration (7)	Technical complexity (4) Retrofitting (3) Software (2)	"Saying "we need sensors" is easy, but in a tool that has a very high temperature, sensors will be destroyed." (E7)
	Dependency (4)	System failure (4)	"What if a data hub, which is vital for many parts, fails?" (E5)
	Standards (4)	Multitude of standards (4) Definition of interfaces (2)	"Where is the definition for standards worldwide?" (E5) "The market requires technological standards, especially regarding communication and interfaces. The customer does not want to run several systems." (E14)
IT risks			
[7,8,17,20,68,73]	Cyberattacks (8)	Technical solutions (6) Awareness and organizational structure (4)	"We have 500 to 600 cyberattacks per day" (E6) "Someone could cripple production from outside." (E7)
	Data possession (8)	Data ownership (8)	"If I use the data of a customer and gain more valuable data. [. . .] do I have to reward him or give him the data back?" (E10) "Who owns the additional value generated by data?" (E14)
	Data security (5)	Protection of intellectual property (5) Loss of competitive advantages (3)	"How can one protect against competitors if data becomes transparent and everyone is connected?" (E3) "Data security is required so that production figures and know-how do not leave the company." (E7) "If every address of each sensor is on the Internet, this becomes a problem." (E10)
	Data handling (4)	Data amount (2) Data quality (1) Multitude of data types (1) Data consistency (1) Data competence (1)	"You can receive so much data from production that the server can't handle it anymore." (E6) "Getting correlations from data is possible, but one needs the competencies to interpret them" (E12) "We don't know which data we will require. [. . .] We need data consistency from design to service." (E14)
	Cloud Computing (2)	Overextension (2) Data storage (1) Real-time capabilities (1)	"Are the networks stable, if I need real-time interconnection via the cloud?" (E12)
Legal/political risks			
[7,17,20,48,68]	Infrastructure (9)	Broadband internet (8) Mobile network (1)	"Suddenly, you realize that there is just a 10 Mbit line available in Berlin." (E6)
	Legal aspects (6)	Working time regulations (3) Data protection (2) International standards differ (2) Increasing legal complexity (1) Online contracts (1)	"Working time regulations are a major point that need to be changed for Industry 4.0" (E4) "Who owns the data? I don't think that our legal system has the right answers for that" (E7)

[a] (number of mentions), [b] (number of mentions), multiple answers possible.

5.4. Technological Risks

5.4.1. Technical Integration

The implementation and use of Industry 4.0 solutions involves technical risks. Several interviewees mentioned that technical complexity might increase once again, resulting from a merging of mechanical and IT systems across several stakeholders in a supply chain. The integrated approach of Industry 4.0—horizontal and vertical interconnection—might bring a great deal of potential, but also is associated with a high level of complexity in order to be implemented.

Not conquering those risks on a satisfactory level is a risk itself, as digital transformation needs to happen quickly in order to successfully unfold, but the technical complexity that arises from aspects mentioned below also needs to be considered.

The retrofitting of existing machinery is a possible way of decreasing the costs of Industry 4.0 implementation. However, from a technical point of view, this poses large technical challenges. For instance, purely mechanical machines must be converted so that they can be operated automatically.

In particular, SMEs are hereby hampered by the so-called "legacy barrier" that their successful path in the past—which was often achieved with only basic machinery, flexible solutions, and a low degree of automation—can no longer be the approach going forward in the concept of Industry 4.0. Such approaches might have secured niches for SMEs for years, but they do not provide the necessary data transparency that is required across the supply chain in Industry 4.0.

Another example is that sensors need to be integrated in existing machinery, which can be challenging, but is necessary in order to collect the data that is required for interconnection.

Software development that is compatible with existing technical solutions also represents a risk according to the interviewees. Whereas existing systems might not be easily compatible, new developments would cost a lot of resources. Therefore, making software compatible with existing IT solutions in the manufacturing industry is described as a large risk.

5.4.2. Dependency

According to the interviewees, there is a great dependency on technology and software in the concept of Industry 4.0. The experts argue that in the event of a software or a system failure, the entire operational value chain could break down. Accordingly, the enterprise or even the entire supply chain becomes highly dependent on the functionality of the technical systems.

Therefore, the interviewees argued that the systems must be as resilient and redundant as possible, and that there must be a "fall back" solution in order to ensure production in the event of a part of the system failing.

5.4.3. Standards

The technical integration of Industry 4.0 also poses risks related to unified standards. According to the interviewees, enterprise resource planning (ERP) systems and manufacturing execution systems (MES) alone pose a multitude of possible standards that must be unified or made compatible.

In particular, SMEs tend to have even less clear standards, often having non-standard solutions in place that require a lot of manual work in order to make data interchangeable across systems. However, in order to generate value from data and allow data analysis, data needs to be on a level that ensures quality and consistency, calling for unified standards across different functions that currently all have their own ones.

Further, the clear definition of interfaces, especially across companies, is of vital importance. It is not sufficient to approve extensive investments in machines and systems without anchoring the processing and interpretation of the acquired data in the organization. Rather, explicit areas of responsibility have to be defined, and the new technology needs to be integrated into the operational organization.

A technical integration into the operational processes requires the selection of the best-fitting system for the respective operational context. However, in the diversity of existing systems, this purpose is never easy. According to the interviewees, clear interfaces must be drawn between systems, and standards must be established. This becomes increasingly difficult if interfaces must be established across the supply chain, but already differ between departments within a company.

5.5. IT Risks

5.5.1. Cyberattacks

The use of information and communication technology in industrial value creation opens the gates to attacks from the virtual world. The larger the network and the more interfaces that exist, the larger the potential attack surface for cyberattacks. Therefore, preparations must be made in order to minimize these risks on a technical and organizational level.

For example, employee training courses are conceivable to raise awareness of cybercrime. Possible technical solutions include firewalls and virtual private network connections. Another example includes so-called "honeypots" that can be used to attract cyberattacks and thus distract from a company's core systems.

Furthermore, so-called "white hat hackers" can continuously search for security vulnerabilities. According to the experts, securely configured clouds are a method of storing data securely and remotely and making programs available virtually. Still, such systems are expensive, the required experts are hard to find, and existing systems have to be compatible with such solutions.

5.5.2. Data Possession

The issue of data protection is critical, as intellectual property has to be protected. Competitive advantages can be lost if information falls in the hands of competitors or third parties. This is not only a question of how to protect data from third parties, but also to know which kind of data belongs to whom.

SMEs in the sample in particular state that they want to keep their data and trade secrets to themselves at all costs, as their bargaining power is already lower and their share in data generation is less than that of larger enterprises. In the concept of Industry 4.0, data ownership remains a central question, because if data is shared along the entire supply chain and on clouds, it becomes hard to control where the data came from and who is allowed to use the data. Even if this can be controlled from a technical point of view, it remains a legal question.

For instance, the question remains that if one stakeholder of the supply chain generates value, but several stakeholders collected data, whether the profiteer must reward the other supply chain stakeholders. In the concept of Industry 4.0, it is deemed critical that data is shared across the supply chain, but this will only be done on a larger extent if all of the stakeholders feel that they will be rewarded for their efforts, and that someone else will not get the benefits alone.

In this regard, SMEs especially state that they fear that they might be the ones contributing to success, but the larger enterprises or original equipment manufacturers (OEMs) might collect the benefits. Therefore, for a successful implementation of Industry 4.0, legal and reward-based solutions must be found that also include SMEs.

5.5.3. Data Handling

Relating to data itself, the interviewees named several risks that they associated with this topic. The amount of data generated and handled must be controlled. For instance, if infrastructure is no longer able to cope with the large amount of data, server overloads are constantly increasing. Further, appropriate data quality must be ensured across a multitude of data types. This also relates to the aspects of technical integration and required standards.

Also, data consistency must be ensured horizontally and vertically across a supply chain, which requires large organizational as well as technical efforts. Finally, data competence must be built up, ensuring that the data that is generated is put to a meaningful purpose and interpreted in a right way, which can be especially challenging for SMEs, as they do not possess access to the required experts with profound knowledge in data handling.

5.5.4. Cloud Computing

Cloud computing is seen as a central feature of Industry 4.0, but is also associated with risks relating to the employees. The security of data storage on a cloud, the dependence if it fails, connection speeds, and that cloud servers are often situated in other countries are named in this context. Further, the real-time capabilities of cloud computing are questioned. Real-time capabilities are seen as a central feature of Industry 4.0, but are not easily achievable via cloud computing.

5.6. Legal and Political Risks

5.6.1. Infrastructure

According to the interviewees, politicians must ensure that an appropriate infrastructure is provided. According to the interview partners, the Federal Republic of Germany is lagging far behind its European neighbors in terms of network expansion, network coverage, and speed.

Additionally, the supply of sufficient energy must be ensured. If digitization and networking are to find their way into the economy, the infrastructure must support and positively influence these efforts. For companies, an inadequate infrastructure poses a major risk to their competitiveness in the global market. SMEs are disproportionately affected by these risks. Their headquarters are often located outside the major conurbations, where the infrastructure is underdeveloped.

For instance, this applies to 5G mobile networks. Therefore, the interviewees regarded the technical infrastructure as a major risk, and that the politicians here must better support digital transformation in the context of Industry 4.0, especially regarding SMEs.

5.6.2. Legal Aspects

From a legal point of view, open questions need to be clarified with regard to data protection, working time, jurisdiction, and the Occupational Health and Safety Act. In particular, software-related work would require different working time regulations than traditional industrial manufacturing. If no suitable data protection guidelines are in place, there will be major risks for companies that are to promote digitization and interconnection under these conditions. Digitization and increasing interconnection between companies are leading to global networking.

Another risk is the lack of standards, which hampers cross-border cooperation. Here, politicians are called upon to find solutions at the supranational level and define suitable standards. Against this background, some questions of jurisdiction remain unresolved, such as for example when a transaction with a foreign company is carried out via the Internet or the role of online contracts or even "smart contracts" that are made automatically.

The current legal situation also offers obstacles with regard to occupational health and safety. For example, there is a risk that the current legal situation will not allow the necessary flexibility and working hours. In terms of occupational safety, too, obstacles stand in the way of interconnection, for example, as far as human–machine interaction is concerned.

6. Discussion and Risk Framework

Industry 4.0 has the potential for an enormous change in the entire value creation, which would be both positive and negative. These changes would affect the entire supply chain, from large OEMs to small suppliers. In order to ensure successful implementation, risks have to be identified first. In the following, due to the sparse body of the current literature, we will systematically reflect and discuss our key findings by reference to our holistic model while considering the recent literature.

Tables 2 and 3 illustrate the manifold dimensions of Industry 4.0-related risks, including: economical, ecological, social, technical, IT-related, and legal or political. The further subdivision of the dimensions reflects the high variety of individual risks. These range from high financial investments with uncertain benefit, increasing pollution, and the fear of job losses to unresolved political questions.

However, not only the high number of risks, but also the ambiguous interrelationship between the dimensions and the individual risks, significantly increase the complexity. This is supported by further research findings, and can be considered an essential reason for the marginal practical implementation of Industry 4.0 [8,11,93].

In general, risks occur in all dimensions, which hampers the implementation of Industry 4.0. However, the uncertainty through risks is particularly high in the economic dimension, which is reflected by the frequency of denomination.

In order to not miss the trend or secure the advantage of the first mover, companies have to authorize high investments and show commitment. However, these economic decisions are influenced by a multitude of factors such as expensive technologies, changing business models, new competitors, and uncertain amortization periods, with a low number of reference projects or isolated applications.

In this regard, industrial manufacturers have to ensure that their existing customers value their efforts regarding Industry 4.0 in order to not be drawn into niche segments where system suppliers or platform providers get the most out of revenues. Accordingly, the communication of new product capabilities and the overall B2B marketing strategy has to be adapted [7,94].

In particular, SMEs, which do not have the monetary resources, suffer from this dichotomy, since they do not fully grasp the opportunities in contrast to larger enterprises [8,19,95]. This is in line with further literature emphasizing the importance of developing and commercializing customer-oriented novel business models. These should be based on innovative hybrid product and service solutions as well as individualization as another way to increase competitiveness. Especially for SME providers of Industry 4.0-based solutions, the retrofitting of existing machinery with customer-tailored service and an orientation to address actual customer requirements could represent a prosperous path [7,96].

Since Industry 4.0 is developing in multiple directions, it is also difficult to give a reliable forecast. A potential solution for SMEs could be networks and alliances, which help smaller companies overcome resource restraints and improve their capacity to take advantage of these new opportunities [17].

However, the linking of several partners in an ecosystem entails risks such as interdependencies and coordination difficulties, which calls for an alignment of the business model with the value network as well as strategic risk management in order to enable the ecosystem to be profitable, sustainable, and co-create value [12,43].

The ecological dimension is, in terms of citations, the least considered. This is surprising, because although the number is small, the long-term impact is even more important. This applies in particular to the risk of pollution and the increasing consumption of scarce raw materials, such as lithium and heavy rare earth, which are required for hardware [97]. These raw materials are particularly difficult to extract, treat, purify, and recycle, while the demand, through the dissemination of Industry 4.0 related technologies, is increasing.

Furthermore, the required implementation of new devices, such as sensors and actuators for the integrated production infrastructure, entails the disposal of obsolete equipment. This leads to an additional load of electronic waste [98]. The small number of mentions of ecological risks reflects the companies having dealt with these risks only to a very limited extent.

However, the authors regard this as an important issue, because sustainability aspects such as resource consumption and waste are becoming increasingly significant, and therefore should be included in the decision processes. In particular, focal firms, such as Nestlé, Zara, or Kimberly and Clark, are affected by ecological factors, as customers hold the focal firm responsible for incidents and behaviors in the upstream supply chain [4].

This shows that the responsibility in this regard could be primarily with large companies. However, this can be seen as an advantage, since on the one hand, financial resources are available, and on the other hand coordination can be carried out by the focal company, which could contribute to simplification in today's complex network structure. Still, SMEs could also profit from ecology-driven business models in the future, since public demand and opinion in particular have changed in this respect.

Further ecological concerns, such as increased energy consumption through server nodes and data hubs, are advised to be closely balanced with smart grids or microgrids that allow efficiently introducing renewable energy sources [26].

Therefore, we would like to raise the awareness for this dimension, as the long-term effects of Industry 4.0 related-risks could be tremendous. The link to other dimensions, such as legal/political as presented above, is supported by further literature that encourages public policy, society, academia, governmental institutions, and international organizations to address these problems through interdisciplinary cooperation [97].

Further, the interviewees perceived the social dimension as the most important, which reflects the strong influence of Industry 4.0 on the workforce. For example, the dimension comprises internal resistance resulting from the fear of changes in working habits, new job requirements, or the loss of jobs. These fears should receive great attention, as they tremendously reduce employee acceptance and thus hamper organizational transformation as well as the successful implementation of Industry 4.0 [7].

Also, macroeconomic factors, such as a relocation of manufacturing, must be considered [15]. Therefore, the creation of new business models should not only consider economic factors, but in particular social ones [7]. In this context, the complex connection to further dimensions, as visualized in Figure 1, becomes apparent. For example, the technological design of Industry 4.0-related technologies could be an aspect to reduce the fear of employee staff.

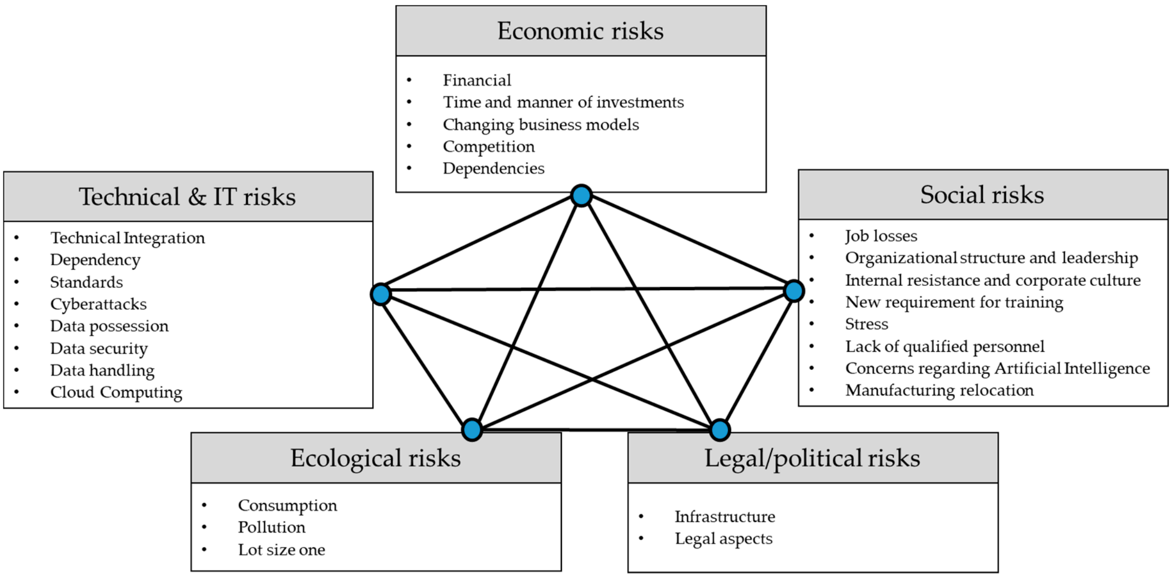

Figure 1. Industry 4.0 sustainable risk framework.

Further guidance, in addition to top management support, can be provided by political guidelines focusing on the reduction of the fear of the employees. For example, staff with a high degree of tacit knowledge working on simple tasks could take over supporting functions in the implementation of new machines, the training of new colleagues, or the guidance of customers.

However, not only are the requirements for current employees changing, but the search of the human resource department for new experts is also proving to be more difficult, which is reflected by the need for novel soft skills. For example, this includes better self-organization or complexity and thinking in terms of overlapping processes [13].

A further aspect to consider is the societal perspective, relating to data protection and privacy rights. These include concerns, such as privacy issues or surveillance caused by IoT applications. The usage of this data is a social as well as a legal concern, which requires clear statements from politics, legal institutions, and from, for instance, agreements between enterprises and workers' councils or comparable committees.

The technical and IT-related dimension contains fundamental risks that are primarily discussed in the literature [10,11]; however, this does not diminish their importance. These include, for example, dependence on providers, the integration of new technologies, cyberattacks, and data protection. Above all, technical and IT-related aspects play an essential role in the implementation, since only an agreement on standards and the reduction of interoperability problems will enable the widespread dissemination of Industry 4.0-related technologies.

In practice, the fear of dependence on individual providers leads to the emergence of a multitude of isolated solutions, which in turn impede interoperability. In particular, SMEs are required to have access to scalable solutions that are easy to implement and fit the characteristics of SMEs, but are compatible with the overall approach.

In the long term, the problem of, for instance, reconfiguring production facilities is likely to pose another major risk. Old and outdated machinery, which meets current production requirements, might not be sufficient for the interconnection and data capabilities that are required for Industry 4.0. Since replacing is not an option, technical challenges are posed in order to retrofit existing systems. On the other hand, this opens up the exciting possibility for SMEs to maintain their core strengths as well as their individual and tailor-made solutions to specific customer demands [7].

Regarding the social dimension, the political and legal dimension should help solve problems such as data ownership or standards. However, this is exacerbating the global nature of Industry 4.0. Therefore, a solution, alongside legal proposals, would be cooperation among the companies that includes considering the current state of research.

In addition to the supportive function of the political or legal dimension, it will be important to adapt the speed of Industry 4.0. As already discussed, standards and guidelines have to be obtained in order to promote the development. Therefore, they are seen by the authors as the main aspect for a successful implementation of Industry 4.0, especially across companies.

However, particularly in Germany, problems such as insufficient network expansion severely restrict the development of Industry 4.0 [17]. This is primarily a task for politics and public institutions. Still, enterprises and industry associations are well advised to highlight this problem and demand improvements.

Another interesting aspect that is notable is cross-border cooperation, which could also be helpful in order to mutually benefit from programs such as "Made in China 2025", or the "Industrial Internet Consortium". Since all programs have their distinct aims and characteristics, whilst highlighting or neglecting specific aspects, learning from each other could be a beneficial option from a macroeconomic and microeconomic perspective [20].

7. Conclusions

Industry 4.0 has the potential to change the industrial value chain and reveal many benefits. It is assumed that digitization and interconnection along the entire value chain will lead to numerous potential for all participants. However, in order to be able to implement Industry 4.0 holistically, a systematic consideration of the risks is also essential. Since the risks of Industry 4.0, especially with regard to SMEs, have not yet been systematically investigated, the aim of this contribution is to create an initial and holistic understanding of the risks expected by Industry 4.0.

The results of the study show economic, ecological, and social risks that arise in the implementation of Industry 4.0 in the context of SMEs. Further, technical, IT-related, and political or legal risks arise as a result of the concept.

From a theoretical point of view, this paper integrates risk dimensions within the Triple Bottom Line of sustainability with further associated risks to Industry 4.0. Hereby, the paper poses a framework for future research in order to investigate risks of Industry 4.0 systematically. The study contributes to the scientific discourse by not only considering the potential benefits, but also the risks of Industry 4.0. SMEs in particular have so far received little attention in research on Industry 4.0. Here, the present study succeeds in extending the discussion to SMEs as essential components of a value-added network and thus moving them into the focus of business research.

From a practical business perspective, the results of the study are also of great benefit. For example, the results can serve as a guideline for the risks that arise during the implementation of Industry 4.0. It is then necessary to decide, on a case and company-specific basis, which risks will be countered and how. Thus, this study lays the foundation for the discussion of how risks can be dealt with from the point of view of the entire value chain. For example, possible solutions here include cross-company and cross-sector cooperation with new and existing partners. Thus, this contribution stimulates the joint solving of the challenges of the future.

The results of the study should provide the initial foundation for further research and has some limitations. A general constrain is based on only 14 interviews from Germany being conducted. In the future, other industries that are not limited exclusively to the German market should be given particular consideration. In this way, the results of the existing studies can be confirmed in other contexts. Furthermore, at this stage, the study is not yet able to definitively make statements on the interplay and interactions of risks. Here, further investigations can help investigate interdependencies and thereby complete the risk assessment. Furthermore, although the study can identify and name risks, further research efforts should also address in more detail the question of how the identified risks can be adequately countered, depending on different corporate and environmental contexts.

Further, although the interviews revealed a certain number of the respective risks, it must be noted that this does not give quantitative information about their importance. Therefore, an extension of the framework to identify further aspects, such as for instance the significance of risks or their short, medium, and long-term management, would be an interesting perspective for future research. Also, their independence among each other, such as the frequent coexistence of risks or risks amplifying each other mutually, must be better understood.

Naturally, in order to better understand and support the implementation of Industry 4.0, the interplay of risks found within the framework provided in this paper with expected potentials of Industry 4.0 must be deepened.

Author Contributions: Conceptualization, J.M.M., E.H. and K.-I.V.; Data curation, H.S.B., J.W.V. and J.M.M.; Formal analysis, H.S.B., J.W.V. and J.M.M.; Funding acquisition, E.H. and K.-I.V.; Investigation, H.S.B. and J.W.V.; Methodology, J.M.M.; Project administration, K.-I.V.; Supervision, E.H. and K.-I.V.; Validation, J.M.M., E.H. and K.-I.V.; Visualization, H.S.B. and J.W.V.; Writing—original draft, H.S.B., J.W.V. and J.M.M.; Writing—review & editing, H.S.B., J.W.V. and J.M.M.

Funding: This research was developed within the Emerging Fields Initiative "Sustainable Smart Industry: Industry 4.0 as a model for future sustainable value creation" of the Friedrich-Alexander-University Erlangen-Nürnberg.

Acknowledgments: The authors thank the anonymous reviewers for their suggestions and recommendations.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Kagermann, H.; Wahlster, W.; Helbig, J. *Recommendations for Implementing the Strategic Initiative Industrie 4.0—Final Report of the Industrie 4.0 Working Group*; Communication Promoters Group of the Industry-Science Research: Frankfurt/Main, Germany, 2013.

2. Lasi, H.; Fettke, P.; Kemper, H.; Feld, T.; Hoffmann, M. Industry 4.0. *Bus. Inf. Syst. Eng.* **2014**, *6*, 239–242. [CrossRef]
3. Ben-Daya, M.; Hassini, E.; Bahroun, Z. Internet of things and supply chain management: A literature review. *Int. J. Prod. Res.* **2017**, *546*, 1–24. [CrossRef]
4. Hartmann, J.; Moeller, S. Chain liability in multitier supply chains? Responsibility attributions for unsustainable supplier behavior. *J. Oper. Manag.* **2014**, *32*, 281–294. [CrossRef]
5. Elkington, J. Partnerships fromcannibals with forks: The triple bottom line of 21st-century business. *Environ. Qual. Manag.* **1998**, *8*, 37–51. [CrossRef]
6. Norman, W.; MacDonald, C.; Arnold, D.G. Getting to the Bottom of "Triple Bottom Line". *Bus. Ethics Q.* **2004**, *14*, 243–262. [CrossRef]
7. Kiel, D.; Müller, J.M.; Arnold, C.; Voigt, K.I. Sustainable Industrial Value Creation: Benefits and Challenges of Industry 4.0. *Int. J. Innov. Manag.* **2017**, *21*, 1740015. [CrossRef]
8. Müller, J.M.; Kiel, D.; Voigt, K.I. What Drives the Implementation of Industry 4.0? The Role of Opportunities and Challenges in the Context of Sustainability. *Sustainability* **2018**, *10*, 247. [CrossRef]
9. Stock, T.; Obenaus, M.; Kunz, S.; Kohl, H. Industry 4.0 as enabler for a sustainable development: A qualitative assessment of its ecological and social potential. *Process Saf. Environ.* **2018**, *118*, 254–267. [CrossRef]
10. Atzori, L.; Iera, A.; Morabito, G. The Internet of Things: A survey. *Comp. Netw.* **2010**, *54*, 2787–2805. [CrossRef]
11. Liao, Y.; Deschamps, F.; De Freitas Rocha Loures, F.; Pierin Ramos, L.F. Past, Present and Future of Industry 4.0—A Systematic Literature Review and Research Agenda Proposal. *Int. J. Prod. Res.* **2017**, *55*, 3609–3629. [CrossRef]
12. Ghanbari, A.; Laya, A.; Alonso-Zarate, J.; Markendahl, J. Business Development in the Internet of Things: A Matter of Vertical Cooperation. *IEEE Commun. Mag.* **2017**, *55*, 135–141. [CrossRef]
13. Kazancoglu, Y.; Ozkan-Ozen, Y.D. Analyzing Workforce 4.0 in the Fourth Industrial Revolution and proposing a road map from operations management perspective with fuzzy DEMATEL. *J. Enterp. Inf. Manag.* **2018**, *31*, 891–907. [CrossRef]
14. Oesterreich, T.D.; Teuteberg, F. Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry. *Comput. Ind.* **2016**, *83*, 121–139. [CrossRef]
15. Müller, J.; Dotzauer, V.; Voigt, K.-I. Industry 4.0 and its Impact on Reshoring Decisions of German Manufacturing Enterprises. In *Supply Management Research: Aktuelle Forschungsergebnisse 2017*; Bode, C., Bogaschewsky, R., Eßig, M., Lasch, R., Stölzle, W., Eds.; Springer Gabler: Wiesbaden, Germany, 2017; pp. 165–179.
16. Airaksinen, A.H.; Luomaranta, H.; Alajääskö, P.; Roodhuijzen, A. Statistics on Small and Medium-sized Enterprises: Dependent and Independent SMEs and Large Enterprises. Available online: http://ec.europa.eu/eurostat/statistics-explained/index.php/Statistics_on_small_and_medium-sized_enterprises (accessed on 10 October 2018).
17. Müller, J.M.; Buliga, O.; Voigt, K.I. Fortune Favors the Prepared: How SMEs Approach Business Model Innovations in Industry 4.0. *Technol. Forecast. Soc.* **2018**, *132*, 2–17. [CrossRef]
18. Yan, R. Optimization approach for increasing revenue of perishable product supply chain with the Internet of Things. *Ind. Manag. Data Syst.* **2017**, *117*, 729–741. [CrossRef]
19. Piccarozzi, M.; Aquilani, B.; Gatti, C. Industry 4.0 in Management Studies: A Systematic Literature Review. *Sustainability* **2018**, *10*, 3821. [CrossRef]
20. Müller, J.M.; Voigt, K.-I. Sustainable Industrial Value Creation in SMEs: A Comparison between Industry 4.0 and Made in China 2025. *Int. J. Precis. Eng. Manuf. Green Technol.* **2018**, *5*, 659–670. [CrossRef]
21. Elkington, J. Towards the Sustainable Corporation: Win-Win-Win Business Strategies for Sustainable Development. *Calif. Manag. Rev.* **1994**, *36*, 90–100. [CrossRef]
22. World Commission on Environment and Development. *Our Common Future*; Oxford University Press: Oxford, UK, 1987.
23. McWilliams, A.; Parhankangas, A.; Coupet, J.; Welch, E.; Barnum, D.T. Strategic Decision Making for the Triple Bottom Line. *Bus. Strategy Environ.* **2016**, *25*, 193–204. [CrossRef]
24. Glavič, P.; Lukman, R. Review of sustainability terms and their definitions. *J. Clean. Prod.* **2007**, *15*, 1875–1885. [CrossRef]

25. Dyllick, T.; Hockerts, K. Beyond the business case for corporate sustainability. *Bus. Strategy Environ.* **2002**, *11*, 130–141. [CrossRef]
26. Markley, M.J.; Davis, L. Exploring future competitive advantage through sustainable supply chains. *Int. J. Phys. Distrib. Logist.* **2007**, *37*, 763–774. [CrossRef]
27. Schulz, S.A.; Flanigan, R.L. Developing competitive advantage using the triple bottom line: A conceptual framework. *J. Bus. Ind. Mark.* **2016**, *31*, 449–458. [CrossRef]
28. Hubbard, G. Measuring organizational performance: Beyond the triple bottom line. *Bus. Strategy Environ.* **2009**, *18*, 177–191. [CrossRef]
29. Jamali, D. Insights into triple bottom line integration from a learning organization perspective. *Bus. Process Manag. J.* **2006**, *12*, 809–821. [CrossRef]
30. Pfeffer, J. Building Sustainable Organizations: The Human Factor. *AMP* **2010**, *24*, 34–45. [CrossRef]
31. Beckmann, M.; Hielscher, S.; Pies, I. Commitment Strategies for Sustainability: How Business Firms Can Transform Trade-Offs Into Win-Win Outcomes. *Bus. Strategy Environ.* **2014**, *23*, 18–37. [CrossRef]
32. Cohen, M.A.; Kunreuther, H. Operations Risk Management: Overview of Paul Kleindorfer's Contributions. *Prod. Oper. Manag.* **2007**, *16*, 525–541. [CrossRef]
33. Tang, O.; Nurmaya Musa, S. Identifying risk issues and research advancements in supply chain risk management. *Int. J. Prod. Econ.* **2011**, *133*, 25–34. [CrossRef]
34. Tummala, R.; Schoenherr, T. Assessing and managing risks using the Supply Chain Risk Management Process (SCRMP). *Supply Chain Manag.* **2011**, *16*, 474–483. [CrossRef]
35. Norrman, A.; Jansson, U. Ericsson's proactive supply chain risk management approach after a serious sub-supplier accident. *Int. J. Phys. Distrib. Logist.* **2004**, *34*, 434–456. [CrossRef]
36. DeLoach, J.W. *Enterprise-Wide Risk Management: Strategies for Linking Risk and Opportunity*; Financial Times Prentice Hall: London, UK, 2000.
37. March, J.G.; Zur, S. Managerial Perspectives on Risk and Risk Taking. *Manag. Sci.* **1987**, *33*, 1404–1418. [CrossRef]
38. Miller, K.D. A Framework for Integrated Risk Management in International Business. *J. Int. Bus. Stud.* **1992**, *23*, 311–331. [CrossRef]
39. Ho, W.; Zheng, T.; Yildiz, H.; Talluri, S. Supply chain risk management: A literature review. *Int. J. Prod. Res.* **2015**, *53*, 5031–5069. [CrossRef]
40. *Risk: Analysis, Perception and Management*; Royal Society: London, UK, 1992.
41. Kaplan, S.; Garrick, B.J. On the Quantitative Definition of Risk. *Risk Anal.* **1981**, *1*, 11–27. [CrossRef]
42. Heckmann, I.; Comes, T.; Nickel, S. A critical review on supply chain risk—Definition, measure and modeling. *Omega* **2015**, *52*, 119–132. [CrossRef]
43. Dellermann, D.; Fliaster, A.; Kolloch, M. Innovation risk in digital business models: The German energy sector. *J. Bus. Strategy* **2017**, *38*, 35–43. [CrossRef]
44. Ghadge, A.; Dani, S.; Kalawsky, R. Supply chain risk management: Present and future scope. *Int. J. Logist. Manag.* **2012**, *23*, 313–339. [CrossRef]
45. Guo, Y. Research on Knowledge-Oriented Supply Chain Risk Management System Model. *JMS* **2011**, *2*. [CrossRef]
46. Sodhi, M.S.; Son, B.-G.; Tang, C.S. Researchers' Perspectives on Supply Chain Risk Management. *Prod. Oper. Manag.* **2012**, *21*, 1–13. [CrossRef]
47. Wiengarten, F.; Humphreys, P.; Gimenez, C.; McIvor, R. Risk, risk management practices, and the success of supply chain integration. *Int. J. Prod. Econ.* **2016**, *171*, 361–370. [CrossRef]
48. Hossain, M.S.; Muhammad, G. Cloud-assisted Industrial Internet of Things (IIoT)—Enabled framework for health monitoring. *Comput. Netw.* **2016**, *101*, 192–202. [CrossRef]
49. Beier, G.; Niehoff, S.; Ziems, T.; Xue, B. Sustainability aspects of a digitalized industry—A comparative study from China and Germany. *Int. J. Precis. Eng. Manuf. Green Technol.* **2017**, *4*, 227–234. [CrossRef]
50. Hansen, E.G.; Grosse-Dunker, F.; Reichwald, R. Sustainability innovation cube—A framework to evaluate sustainability-oriented innovations. *Int. J. Innov. Manag.* **2009**, *13*, 683–713. [CrossRef]
51. Kuhl, M.R.; Da Cunha, J.C.; Maçaneiro, M.B.; Cunha, S.K. Relationship beteen innovation and sustainable performance. *Int. J. Innov. Manag.* **2016**, *20*, 1650047. [CrossRef]

52. Peukert, B.; Benecke, S.; Clavell, J.; Neugebauer, S.; Nissen, N.F.; Uhlmann, E.; Lang, K.-D.; Finkbeiner, M. Addressing Sustainability and Flexibility in Manufacturing Via Smart Modular Machine Tool Frames to Support Sustainable Value Creation. *Procedia CIRP* **2015**, *29*, 514–519. [CrossRef]
53. Hofmann, E.; Rüsch, M. Industry 4.0 and the current status as well as future prospects on logistics. *Comput. Ind.* **2017**, *89*, 23–34. [CrossRef]
54. Zhong, R.Y.; Huang, G.Q.; Lan, S.; Dai, Q.Y.; Chen, X.; Zhang, T. A big data approach for logistics trajectory discovery from RFID-enabled production data. *Int. J. Prod. Econ.* **2015**, *165*, 260–272. [CrossRef]
55. Zhou, W.; Piramuthu, S. Remanufacturing with RFID item-level information: Optimization, waste reduction and quality improvement. *Int. J. Prod. Econ.* **2013**, *145*, 647–657. [CrossRef]
56. Whitmore, A.; Agarwal, A.; Da Xu, L. The Internet of Things-A survey of topics and trends. *Inf. Syst. Front.* **2015**, *17*, 261–274. [CrossRef]
57. Sarkis, J.; Zhu, Q. Environmental sustainability and production: Taking the road less travelled. *Int. J. Prod. Econ.* **2018**, *56*, 743–759. [CrossRef]
58. Ding, K.; Jiang, P.; Zheng, M. Environmental and economic sustainability-aware resource service scheduling for industrial product service systems. *J. Intell. Manuf.* **2017**, *28*, 1303–1316. [CrossRef]
59. Fysikopoulos, A.; Pastras, G.; Alexopoulos, T.; Chryssolouris, G. On a generalized approach to manufacturing energy efficiency. *Int. J. Adv. Manuf. Technol.* **2014**, *73*, 1437–1452. [CrossRef]
60. Weinert, N.; Chiotellis, S.; Seliger, G. Methodology for planning and operating energy-efficient production systems. *CIRP Ann.* **2011**, *60*, 41–44. [CrossRef]
61. Herrmann, C.; Thiede, S.; Kara, S.; Hesselbach, J. Energy Oriented Simulation of Manufacturing Systems-Concept and Application. *CIRP Ann. Manuf. Technol.* **2011**, *60*, 45–48. [CrossRef]
62. Shrouf, F.; Miragliotta, G. Energy management based on Internet of Things: Practices and framework for adoption in production management. *J. Clean. Prod.* **2015**, *100*, 235–246. [CrossRef]
63. Stock, T.; Seliger, G. Opportunities of Sustainable Manufacturing in Industry 4.0. *Procedia CIRP* **2016**, *40*, 536–541. [CrossRef]
64. Parry, G.C.; Brax, S.A.; Maull, R.S.; Ng, I.C.L. Operationalising IoT for reverse supply: The development of use-visibility measures. *Supply Chain Manag.* **2016**, *21*, 228–244. [CrossRef]
65. Zhao, W.-B.; Jeong, J.-W.; Noh, S.D.; Yee, J.T. Energy simulation framework integrated with green manufacturing-enabled PLM information model. *Int. J. Precis. Eng. Manuf. Green Technol.* **2015**, *2*, 217–224. [CrossRef]
66. Chu, W.-S.; Kim, M.-S.; Jang, K.-H.; Song, J.-H.; Rodrigue, H.; Chun, D.-M.; Cho, Y.T.; Ko, S.H.; Cho, K.-J.; Cha, S.W.; et al. From design for manufacturing (DFM) to manufacturing for design (MFD) via hybrid manufacturing and smart factory: A review and perspective of paradigm shift. *Int. J. Precis. Eng. Manuf. Green Technol.* **2016**, *3*, 209–222. [CrossRef]
67. Gabriel, M.; Pessel, E. Industry 4.0 and sustainability impacts: Critical discussion of sustainability aspects with a special focus on future of work and ecological consequences. *Ann. Fac. Eng. Hunedoara Int. J. Eng.* **2016**, *1*, 131–136.
68. Veza, I.; Mladineo, M.; Gjeldum, N. Managing Innovative Production Network of Smart Factories. *IFAC-PapersOnLine* **2015**, *48*, 555–560. [CrossRef]
69. Araujo, B.F.; Tureta, C.A.; Araujo, D.A. How do working mothers negotiate the work-home interface? *J. Manag. Psychol.* **2015**, *30*, 565–581. [CrossRef]
70. Lee, I.; Lee, K. The Internet of Things (IoT): Applications, investments, and challenges for enterprises. *Bus. Horizons* **2015**, *58*, 431–440. [CrossRef]
71. Bonekamp, L.; Sure, M. Consequences of Industry 4.0 on Human Labour and Work Organisation. *J. Bus. Media Psychol.* **2015**, *6*, 33–40.
72. Kong, X.T.R.; Fang, J.; Luo, H.; Huang, G.Q. Cloud-enabled real-time platform for adaptive planning and control in auction logistics center. *Comput. Ind. Eng.* **2015**, *84*, 79–90. [CrossRef]
73. Rymaszewska, A.; Helo, P.; Gunasekaran, A. IoT powered servitization of manufacturing—An exploratory case study. *Int. J. Prod. Econ.* **2017**, *192*, 92–105. [CrossRef]
74. Eisenhardt, K.M.; Graebner, M.E. Theory Building From Cases: Opportunities And Challenges. *AMJ* **2007**, *50*, 25–32. [CrossRef]
75. Edmondson, A.C.; Mcmanus, S.E. Methodological fit in management field research. *AMR* **2007**, *32*, 1246–1264. [CrossRef]

76. Stokes, D.; Bergin, R. Methodology or "methodolatry"? An evaluation of focus groups and depth interviews. *Qual. Mark. Res. Int. J.* **2006**, *9*, 26–37. [CrossRef]
77. Yin, R.K. *Case Study Research: Design and Methods*; Sage: Thousand Oaks, CA, USA, 2009.
78. Franco, M.; Almeida, J. Organisational learning and leadership styles in healthcare organisations. *Leadersh. Org. Dev. J.* **2011**, *32*, 782–806. [CrossRef]
79. Dubé, L.; Paré, G. Rigor in Information Systems Positivist Case Research: Current Practices, Trends, and Recommendations. *MIS Quart.* **2003**, *27*, 597. [CrossRef]
80. Benbasat, I.; Goldstein, D.K.; Mead, M. The Case Research Strategy in Studies of Information Systems. *MIS Quart.* **1987**, *11*, 369. [CrossRef]
81. Eisenhardt, K.M. Better Stories and Better Constructs: The Case for Rigor and Comparative Logic. *AMR* **1991**, *16*, 620–627. [CrossRef]
82. Cannell, C.F.; Kahn, R.L. Interviewing. In *The Handbook of Social Psychology*, 2nd ed.; Lindzey, G., Aronson, E., Eds.; Addison-Wesley: Reading, MA, USA, 1968; pp. 525–595.
83. Ananthram, S.; Chan, C. Challenges and strategies for global human resource executives: Perspectives from Canada and the United States. *Eur. Manag. J.* **2013**, *31*, 223–233. [CrossRef]
84. Kasabov, E. Start-Up Difficulties in Early-Stage Peripheral Clusters: The Case of IT in an Emerging Economy. *Entrep. Theory Pract.* **2015**, *39*, 727–761. [CrossRef]
85. Miles, M.B.; Huberman, M.A. *Qualitative Data Analysis*; Sage: Thousand Oaks, CA, USA, 1994.
86. Maxwell, J.A. *Qualitative Research Design*; Sage: Thousand Oaks, CA, USA, 1996.
87. Gioia, D.A.; Corley, K.G.; Hamilton, A.L. Seeking Qualitative Rigor in Inductive Research: Notes on the Gioia Methodology. *Organ. Res. Methods* **2013**, *16*, 15–31. [CrossRef]
88. Krippendorff, K. *Content Analysis*; Sage: Los Angeles, CA, USA, 2013.
89. Graebner, M.E.; Eisenhardt, K.M. The Seller's Side of the Story: Acquisition as Courtship and Governance as Syndicate in Entrepreneurial Firms. *Adm. Sci. Q.* **2004**, *49*, 366–403.
90. Kelley, D.J.; Peters, L.; O'Connor, G.C. Intra-organizational networking for innovation-based corporate entrepreneurship. *J. Bus. Venturing* **2009**, *24*, 221–235. [CrossRef]
91. Weston, C.; Gandell, T.; Beauchamp, J.; McAlpine, L.; Wiseman, C.; Beauchamp, C. Analyzing interview data: The development and evolution of a coding system. *Qual. Sociol.* **2001**, *24*, 381–400. [CrossRef]
92. Holsti, O.R. Content Analysis. In *The Handbook of Social Psychology*; Lindzey, G., Aronson, E., Eds.; McGraw-Hill: New York, NY, USA, 1968; pp. 596–692.
93. Ryan, P.; Watson, R. Research Challenges for the Internet of Things: What Role Can OR Play? *Systems* **2017**, *5*, 24. [CrossRef]
94. Müller, J.M.; Pommeranz, B.; Weisser, J.; Voigt, K.I. Digital, Social Media, and Mobile Marketing in industrial buying: Still in need of customer segmentation? Empirical evidence from Poland and Germany. *Ind. Mark. Manag.* **2018**, *73*, 70–83. [CrossRef]
95. Musa, A.; Dabo, A. A Review of RFID in Supply Chain Management: 2000–2015. *Glob. J. Flex. Syst. Manag.* **2016**, *17*, 189–228. [CrossRef]
96. Müller, J.M.; Däschle, S. Business Model Innovation of Industry 4.0 Solution Providers Towards Customer Process Innovation. *Processes* **2018**, *6*, 260. [CrossRef]
97. Marscheider-Weidemann, F.; Langkau, S.; Hummen, T.; Erdmann, L.; Espinoza, L.T. *Raw Materials for Emerging Technologies*; German Mineral Resources Agency: Berlin, Germany, 2016.
98. Bonilla, S.; Silva, H.; Terra da Silva, M.; Franco Gonçalves, R.; Sacomano, J. Industry 4.0 and Sustainability Implications: A Scenario-Based Analysis of the Impacts and Challenges. *Sustainability* **2018**, *10*, 3740. [CrossRef]