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What Drives the Implementation of Industry 4.0? The Role of Opportunities and Challenges in the Context of Sustainability

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Abstract: The implementation of Industry 4.0 has a far-reaching impact on industrial value creation. Studies on its opportunities and challenges for companies are still scarce. However, the high practical and theoretical relevance of digital and connected manufacturing technologies implies that it is essential to understand the underlying dynamics of their implementation. Thus, this study examines the relevance of Industry 4.0-related opportunities and challenges as drivers for Industry 4.0 implementation in the context of sustainability, taking a differentiated perspective on varying company sizes, industry sectors, and the company's role as an Industry 4.0 provider or user. A research model comprising relevant Industry 4.0-related opportunities and challenges as antecedents for its implementation is hypothesized. In order to test the model, partial least square structural equation modeling is applied for a sample of 746 German manufacturing companies from five industry sectors. The results show that strategic, operational, as well as environmental and social opportunities are positive drivers of Industry 4.0 implementation, whereas challenges with regard to competitiveness and future viability as well as organizational and production fit impede its progress. Moreover, it is shown that the perception of Industry 4.0-related opportunities and challenges as antecedents to Industry 4.0 implementation depends on different company characteristics.

Keywords: Industry 4.0; Industrial Internet of Things; sustainability; implementation; structural equation modeling; German industry sectors

1. Introduction

Growing attention is being paid to the implications of integrating Internet of Things and Services (IoTS) technologies into industrial value creation. This new paradigm of digitized and connected manufacturing is referred to as "Industry 4.0" or "Industrial Internet of Things" (IIoT) and is transforming established factories into smart and autonomous production [1]. It enables real-time-capable horizontal and vertical Internet-based connectedness of people, machines, and objects, as well as information and communication technologies for the dynamic management of complex business processes [2]. Associated with this flexibility, Industry 4.0 aims at overcoming contemporary challenges, such as intensifying global competition, volatile markets and demands, required customization, as well as decreasing innovation and product life cycles. Industry 4.0 serves as a useful and targeted approach to deal with these challenging requirements [1,3].

Nevertheless, there is still considerable uncertainty and confusion since researchers, consultancies, politicians, and practitioners frequently make contradictory statements on Industry 4.0 implications. On the one hand, it promises to provide manufacturers with profitable business models, higher efficiency and quality, as well as improved workplace conditions. On the other hand, it exposes them to, among other things, increasing competition and challenging change management [4]. In this context, research and practice disclose a reluctant and slow realization of this novel manufacturing paradigm, which is ascribable to unclear opportunities and challenges perceived by industrial manufacturers [5].

Despite the growing body of economic research on Industry 4.0, little attention has been paid to an examination of opportunities and challenges that are considered relevant for the implementation of Industry 4.0. It is still not clear which opportunities and challenges are perceived as antecedents of Industry 4.0 implementation in manufacturing companies [6]. Particularly, the current discussion lacks a differentiated analysis with regard to varying company sizes, industry sectors, or manufacturers' roles as providers or users of Industry 4.0 solutions [3]. However, given the high practical and theoretical relevance of digital and connected manufacturing technologies, it is essential to understand the underlying dynamics of their implementation. As for its three proceeding Industrial Revolutions, Industry 4.0 is expected to transform industrial production as well as society [7], aiming at economic, ecological, and social achievements [3,8]. These dimensions and objectives referring to the Triple Bottom Line of sustainability [9,10] are the outcome of a development since the World Commission on Environment and Development's "Brundtland report" [11]. It has been developed into UN's current "Sustainable Development Goal 12—Ensure sustainable consumption and production patterns". As a result, societal expectations towards decreasing environmental impacts of industrial manufacturing have steadily increased, expecting companies to not solely focus on profit maximization [12,13]. So far, a multitude of programs within industrial enterprises as well as scientific literature can be found, mainly regarding environmental impacts [14]. However, the Triple Bottom Line requires a holistic consideration of its three dimensions, while also investigating its interdependencies in order to fully unfold benefits in these dimensions [15].

Current literature examines the research area regarding Industry 4.0 predominantly from a technical perspective, whereas only few articles consider aspects of sustainability, of which the most ones only refer to a single dimension of sustainability rather than to all dimensions of the Triple Bottom Line [3,16,17]. However, such considerations are of high importance, as balancing the three dimensions against each other has been found to be a critical success factor for successful technology adoption and diffusion as well as achieving sustainable benefits [18,19]. In general, digitization and interconnection of industrial processes intended by Industry 4.0 are facilitated by data analytics, machine learning, and artificial intelligence, leading to potentials in all three dimensions of sustainability [3,20,21]. However, the achievement of sustainable benefits is accompanied by several challenges respectively, especially in the implementation phase of Industry 4.0 [3].

Referring to the economic perspective of Industry 4.0, transparency and interconnection of processes allow their optimization [22], increasing efficiency, flexibility, quality, and customization [4,21,23]. These are enabled by smart manufacturing technologies [24–26], new value propositions [27], and increased demand orientation that enables load balancing [28,29]. For this, smart products are required [30], which increase a company's competitiveness [17]. In a same regard, increasing process transparency in intra- and inter-firm logistics can be achieved [31], allowing to lower logistics costs [32–34]. Further, new business models emerge through data-based products and services as well as equipping existing production equipment for a transformation in CPS, also known as "retrofitting" [1,35–37], including increased customer orientation and service-based business models enabled by data transparency [27,38–40]. However, such processes as well as the implementation of Industry 4.0 in general pose threats with regard to large investments required and uncertain profitability [1,3,4,17,41,42]. Further, manufacturers perceive the transformation of their current business models towards Industry 4.0 as challenging [8,43]. Further, Industry 4.0 requires standardization of processes within and among companies [44]. Both ventures, i.e., business model transformation as well as standardization can become particularly challenging for SMEs due to their low degree of process standardization, more flexible but less automated production equipment as well as resource limitations, among others [45,46].

Regarding the ecological dimension of sustainability, Industry 4.0 enables several benefits [1,3,47]: Demand and process transparency allows intelligent scheduling of tasks and processes. Hereby, load balancing can be optimized that leads to reduced energy consumption [48–50]. This is based on improved process simulations [8] as well as prediction of energy consumption via smart energy systems [51]. Further, manufacturing design can be improved through direct data interconnection from product usage back to design [14,52], leading to improved product lifecycle management including recycling [53]. Thereby, Industry 4.0 assists to highlight and reduce greenhouse gas emissions [23]. Accordingly, reduction of waste and resource consumption can be enhanced [8,30,33]. In logistics, reduction of transport processes as well as unnecessary material flows can be achieved as well [54]. Further, the number of wrong deliveries, unnecessary waiting time, and damaged goods can be reduced by data transparency throughout the entire supply chain [55,56]. Decentralized production close to where products are consumed further reduces logistics costs as well as environmental impacts [57–59]. In the same manner, new production technologies such as additive manufacturing can help to reduce waste of production and logistics processes, e.g., for spare parts [25,60].

Regarding the social dimension of Industry 4.0, several benefits for employees are named, such as enhanced human learning through intelligent assistance systems as well as human machine interfaces that lead to increased employee satisfaction in industrial workplaces [8,23]. However, current literature cannot provide a unified perspective on whether Industry 4.0 will cause an increase or decrease of employee numbers in industry [61]. In this regard, concrete numbers named differ to a large extent [3,16]. In general, a further replacement of simple tasks is expected, whereas tasks such as monitoring, collaboration, and training will still be required [3]. Hereby, new job profiles with novel requirements for training and education are expected to emerge, mostly referring to decreasing importance of manual labor in contrast to IT-skills [62,63]. On the other hand, tasks that include planning and monitoring as well as decision-making could fall to autonomous systems, therefore possibly replacing jobs in this area [61]. As a result, organizational implementation of Industry 4.0 requires purposeful transformation processes, often referred to as "digital transformation" [3,64]. It requires new mindsets for handling challenges of digital transformation [65] as well as a common strategy for addressing employee qualification and acceptance [2–4,42,43,66].

Motivated by the research gap that literature so far has scarcely investigated all three dimensions of the Triple Bottom Line of sustainability regarding Industry 4.0, this paper has two objectives. First, it explores the opportunities and challenges that are considered as antecedents for the implementation of Industry 4.0 by manufacturing companies, referring to all three dimensions of sustainability. Second, it analyzes differences with respect to company characteristics, such as size, industry sector, and role as provider or user. Hence, the present study proposes a research model comprising critical opportunities and challenges as antecedents of the implementation of Industry 4.0 in manufacturing companies. The hypothesized research model is tested by using the results of an empirical study based on partial least squares structural equation modeling (PLS-SEM).

This study makes the following contributions to the literature. First, a research model is proposed based on the Triple Bottom Line of sustainability, comprising Industry 4.0-related strategic, operational, environmental, and social opportunities, as well as challenges in terms of competitiveness and future viability, organizational and production fit, as well as employee qualifications and acceptance as significant antecedents of Industry 4.0 implementation.

Second, the study provides a differentiated look at varying company sizes, industry sectors, and companies' roles as Industry 4.0 providers or users. In doing so, it finds that strategic opportunities are the main antecedents of Industry 4.0 implementation for large companies, mechanical and plant as well as electrical engineering manufacturers, and for Industry 4.0 providers. Operational opportunities are particular drivers for small and medium-sized enterprises (SMEs), for automotive, chemical and plastics as well as steel manufacturers, and for Industry 4.0 users. Environmental and social opportunities are relevant for all company sizes, industry sectors (except for the automotive industry), and roles towards Industry 4.0, with a slightly stronger effect for Industry 4.0 users. Furthermore, the challenge of competitiveness and future viability prevents particularly mechanical and plant engineering companies from implementing Industry 4.0, quite apart from company size.

Organizational and production fit mainly challenges large companies and automotive, electrical engineering, and steel manufacturers in the context of Industry 4.0 implementation.

Third, the empirical analysis reveals that the effect of challenging competitiveness and future viability on new technology and innovation implementation is negative for the Industry 4.0 scenario, but has to be evaluated from case to case, since previous studies revealed the opposite [67]. Furthermore, further research should examine the role of challenges regarding employee qualifications and acceptance for Industry 4.0 implementation, since the study at hand shows a positive relationship, which is unexpected.

The paper is organized as follows. Based on the state of research presented in Section 1, Section 2 illustrates most commonly named opportunities and challenges of Industry 4.0, on the basis of which the research model and hypotheses are developed. Section 3 describes the research design, followed by the empirical results displayed in Section 4. Finally, Section 5 discusses the findings, reveals theoretical and practical implications as well as limitations, and suggests future research areas.

2. Development of Research Model and Hypotheses

In line with the exploratory nature of this study, we searched the comparably sparse bodies of scientific Industry 4.0 literature for the most frequently mentioned opportunities and challenges related to this novel manufacturing concept. After two discussion sessions between the authors of this article and two independent research fellows from the same department, three major categories for opportunities and challenges have each been identified. Opportunities are classified into the categories of strategy, operations, as well as environment and people, based on the state of research related to the Triple Bottom Line in Section 1. Likewise, challenges are grouped into competitiveness and future viability, organizational and production fit, as well as employee qualifications and acceptance. Most relevant literature on the opportunities of Industry 4.0 as well as its main contributions is presented in Table 1, whereas Table 2 presents most relevant literature regarding challenges of Industry 4.0 as well as its main contributions.

Table 1. Exemplary literature on opportunities of Industry 4.0.

Category	Exemplary Literature	Main Contributions
Strategy	Arnold et al., 2016; Arnold et al., 2017; Brettel et al., 2014; Burmeister et al., 2016; Kagermann et al., 2013; Laudien et al., 2017; Rennung et al., 2016	• New business models through Industry 4.0 • New value offers for enhanced competitiveness
Operations	Erol et al., 2016; Kagermann et al., 2013; Lee et al., 2014; Meyer et al., 2014; Oettmeier and Hofmann, 2017; Rehage et al., 2013; Rogers and Trombley, 2014; Rudtsch et al., 2014; Saberi and Yusuff, 2011; Schmidt et al., 2015; Stock and Seliger, 2016	• Increased efficiency • Decreasing costs • Higher quality • Increased speed & flexibility • Load balancing & stock reduction
Environment and people	Berman, 2012; Gabriel and Pessel, 2016; Herrmann et al., 2014; Hirsch-Kreinsen, 2014; Kagermann et al., 2013; Kiel et al., 2017; Oettmeier and Hofmann, 2017; Peukert et al., 2015; Stock and Seliger, 2016	• Reduction of monotonous work • Age-appropriate workplaces • Reduction of environmental impact

Table 2. Exemplary literature on challenges of Industry 4.0.

Category	Exemplary Literature	Main Contributions
Competitiveness and future viability	Arnold et al., 2016; Brettel et al., 2014; Kiel et al., 2017; Müller et al., 2018; Porter and Heppelmann, 2014	• Existing business models endangered • Loss of flexibility • Standardization • Transparency
Organizational and production fit	Erol et al., 2016; Hermann et al., 2016; Hirsch-Kreinsen, 2014; Müller et al., 2018	• High implementation efforts regarding, e.g., costs and standardization
Employee qualification and acceptance	Bauer et al., 2015; Bonekamp and Sure, 2015; Dombrowski and Wagner, 2014; Erol et al., 2016; Kagermann et al., 2013; Kiel et al., 2017	• Employee fear and concerns • Lack of expertise

In the following, we explain the developed six categories of opportunities and challenges of Industry 4.0, thereupon proposing six hypotheses.

2.1. Opportunities of Industry 4.0

2.1.1. Strategy

From a strategic perspective, literature agrees that Industry 4.0 has far-reaching implications for business models. These comprise both change in established business models as well as emerging new business models [1,40]. Recent research emphasizes the potential of business model innovation based on digital, technology-, and data-centered business logic. Research identifies some of the main areas with regard to Industry 4.0-related business model changes, for example, data-based value creation and propositions, transition from product to system offerings, enhanced customization, intensified customer relationships, IT and software know-how as key resources, and increasing interconnection as well as collaboration with key partners [36].

Data play a critical role in this context, since an increasing fusion of physical products and services with digital, data-centered enhancements and solutions is expected. A consequent orientation towards services is expected, which accelerates the vanishing separation between product manufacturing and service provision. Companies can use these services to offer highly individualized and customized solutions [4,41]. Here, significant opportunities for manufacturing companies' global competitiveness are expected [18]. In general, the literature agrees that business model innovation is a major source of unique selling propositions and strategic differentiation, particularly in highly competitive market environments [68–72]. As the positive impact of perceived strategic advantages on innovation implementation is shown in recent research [25,73,74], we propose the following hypothesis:

Hypothesis 1 (H1). *Strategic opportunities of Industry 4.0 have a positive effect on manufacturing companies' tendency to implement Industry 4.0.*

2.1.2. Operations

From an operational perspective, Industry 4.0 facilitates process optimization even before value creation is realized in practice. This is mainly due to virtual simulations of production activities or even entire supply chains. Based on them, vertical and horizontal connection enable shorter lead times and accelerated time-to-market [28]. This allows manufacturing companies to respond faster and more flexibly to volatile market demand or last-minute changes in customer orders [30]. Thanks to flexibility, manufacturing companies only produce exactly what customers need. Due to a consequent make-to-order value creation and availability of real-time data across entire supply chains, materials are coordinated in line with demand and stock levels decrease [25].

Smart components and products are aware of their current state and monitor critical process parameters as well as variations in quality autonomously. This results in reduced process faults, a lower scrap rate, more reliable production systems, and minimized downtime. Eventually, the overall quality level of manufacturing increases [3,75]. Furthermore, connected goods enable the collection and analysis of information about product use and features over the product's entire life cycle. These can be used to further develop and improve product quality continuously [42,59]. The potentials in terms of, for example, efficiency, time, quality, and stock levels are directly and positively related to significant cost reductions [28].

Literature has revealed that operational opportunities of new Industry 4.0-related manufacturing technologies and production processes have a positive effect on their implementation [25,59]. Since established manufacturing companies continuously strive for operational improvements to achieve corporate success, we hypothesize the following:

Hypothesis 2 (H2). *Operational opportunities of Industry 4.0 have a positive effect on manufacturing companies' tendency to implement Industry 4.0.*

2.1.3. Environment and People

From an ecological and social perspective, Industry 4.0 promises several opportunities. With respect to the former, Industry 4.0 enables the reduction of greenhouse gas emissions by data-centered and traceable carbon footprint analyses [23]. In addition, it aims at reducing waste as well as resource and energy consumption [56,60]. Examples include closed value creation networks, reuse of resources and tools, as well as retrofitting of machines [30]. Furthermore and due to the opportunities of, for example, additive manufacturing, which is considered as one of the core technologies in the Industry 4.0 era, physical transport and logistics processes are reduced [25,54].

With regard to social aspects, Industry 4.0-related flexibility and improvement of management processes and decisions due to transparency are enabled by the availability of real-time data throughout entire supply chains [3]. Likewise and based on the digitized connection of corporate functions, including home office and tele-work approaches, working time models are expected to become more adaptable and susceptible to individualization.

The implementation of smart devices and robot assistance systems in workstations that are ergonomically unfavorable and physically demanding preserve employees' health and productivity in the long view [43]. Smart and autonomous production systems take care of monotonous and repetitive tasks, resulting in higher employee satisfaction and motivation. These approaches qualify for meeting current demographic challenges since work environment is designed age-appropriately [4].

In line with literature that confirms the positive influence of environmentally and socially beneficial innovations on their implementation [25,76,77] we propose the following hypothesis:

Hypothesis 3 (H3). *Environmental and social opportunities of Industry 4.0 have a positive effect on manufacturing companies' tendency to implement Industry 4.0.*

2.2. Challenges of the Industrial Internet of Things

2.2.1. Competitiveness and Future Viability

Despite aforementioned opportunities, Industry 4.0 is related to several challenges and takes place in a highly dynamic competitive environment [17]. It reshapes industry boundaries, creates entirely new industries, and exposes established manufacturing companies to new competitive challenges. For instance, new competitors that offer smart and connected product solutions or even entirely new business models, such as platforms, can emerge quickly, threatening the current market position of established players. Likewise, increasingly competitive dynamics and facilitated market entrance of new competitors are among the most critical challenges in the Industry 4.0 era [3].

Moreover, digital connectivity implies sharing of data and opening up to a competitive market environment, resulting in transparent business ecosystems that are largely facilitated by (online) platforms. In this regard, companies have to deal with two issues. First, a high level of transparency exposes manufacturers to the risks of cyber-attacks and industrial spying, and the challenge of securing data rights and access. Second, companies that set platform standards may hamper established companies' unique selling propositions and eventually drive them out of the market [35]. In order to meet these challenges, literature advises manufacturing companies to reflect and systematically innovate their current business models [1,17,18,78].

Several studies have examined the relation between a competitive market environment and the implementation of novel technologies, but there is no agreement about its positive or negative effect. A positive influence for competition on the application of new technologies can be found, since new technologies give the opportunity to outperform competitors [67]. On the other hand, a negative relationship between competition and the adoption of particularly online technologies is revealed [79]. Other studies show that data security and transparency are further relevant issues [80]. Since Industry 4.0 is largely based on online and Internet-based connectivity, for which we have explained the seriousness of transparency and data security, we accord with these findings and hypothesize the following:

Hypothesis 4 (H4). *Industry 4.0-related challenges with regard to competitiveness and future viability have a negative effect on manufacturing companies' tendency to implement Industry 4.0.*

2.2.2. Organizational and Production Fit

The implementation of Industry 4.0 has to be designed specifically for varying organizational and production scenarios, for example regarding different production structures or company size [45,56]. This is quite challenging, particularly if companies do not have enough financial resources to employ a greenfield approach. Thus, retrofitting of established production and logistics systems is required [42]. In this context, industrial manufacturers should avoid implementing Industry 4.0 in the form of isolated applications [43]. Otherwise, synchronization and coordination with existing production equipment and processes may result in high complexity levels and costs, which can become especially challenging for SMEs [46].

Since several studies have already shown the relevance of organizational characteristics, such as complexity of existing systems [81], integration [82], and organizational readiness [83] for the implementation of new (manufacturing) technologies, we include this challenge in our framework. We hypothesize that the difficulty of integrating Industry 4.0's novel manufacturing paradigm into existing organizational and production systems influences its implementation negatively:

Hypothesis 5 (H5). *Industry 4.0-related challenges with regard to organizational and production fit have a negative effect on manufacturing companies' tendency to implement Industry 4.0.*

2.2.3. Employee Qualifications and Acceptance

Industry 4.0 is expected to pose a far-reaching impact on employees' roles within manufacturing companies [2,4,61]. Employees need to be qualified in order to approach this new technology concept, emphasizing the relevance of Industry 4.0-adequate personal (e.g., willingness to learn), social/interpersonal (e.g., creative problem solving in social settings), action-related (e.g., ability to find practical solutions), and domain-related competencies (e.g., understanding network technologies as well as data analysis and processing) [42]. Developing or sourcing these qualifications represents a major challenge and obstacle for manufacturers [3].

Another aspect in this context is the acceptance of new Industry 4.0 technologies by employees [42,66]. Companies are well-advised to address employees' concerns and anxieties regarding data transparency, dependency on technical assistance systems, and workplace safety in human-machine interaction systems in order to enhance trust. The effect of trust on implementation of new online technologies underlines this fact [84]. Users' anxieties play a significant negative role in the decision to adopt a new technology [78,85]. Justified by the fact that employees, that is, technology users, are critical success factors and play a decisive role for the implementation and diffusion of a new technology, we add the challenge of achieving Industry 4.0-specific employee qualifications and acceptance to our research model. The challenge of overcoming this obstacle may prevent industrial manufacturers from implementing the Industry 4.0.

Hypothesis 6 (H6). *Industry 4.0-related challenges with regard to employee acceptance and qualifications have a negative effect on manufacturing companies' tendency to implement Industry 4.0.*

Figure 1 exhibits the hypothesized relationships of Industry 4.0-related opportunities and challenges with the implementation of Industry 4.0.

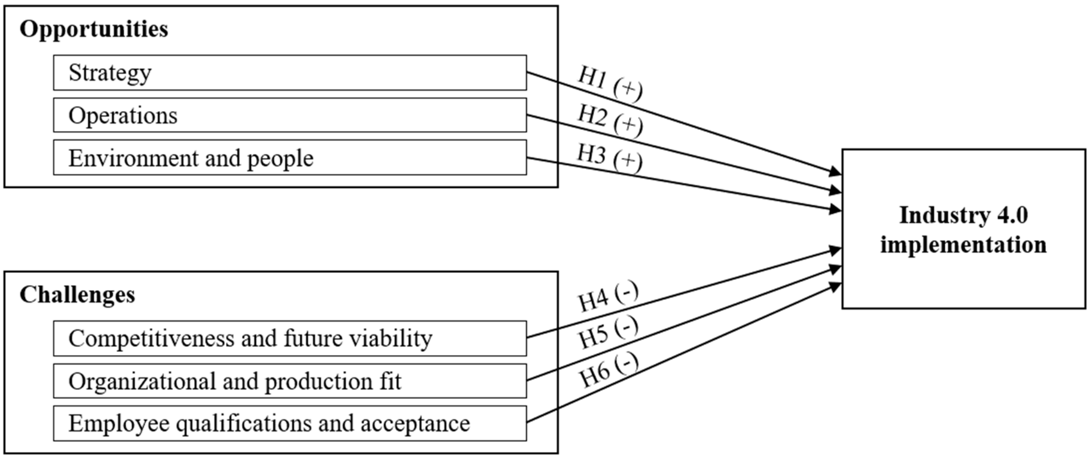

Figure 1. Hypothesized research model.

3. Methodology

3.1. Data Collection and Sample

In this paper, the results of a quantitative study are used to examine the effect of Industry 4.0-related opportunities and challenges on its implementation. This approach is reasonable as this paper attempts to derive differences with respect to varying company characteristics that can be evaluated purposefully by applying a quantitative research design.

This research focuses on German industrial manufacturers as the German future concept "Industry 4.0" aims at implementation of Industry 4.0 within German industry sectors. Consequently, leading Industry 4.0 personnel with German manufacturers were asked to fill out an online questionnaire. In contrast to operational employees, this target group is considered as most suitable to oversee and assess Industry 4.0-related opportunities and challenges as well as their relevance for Industry 4.0's implementation.

Data was collected between January and March 2017. It resulted in 838 returned questionnaires, which equals a response rate of 33.14%. We addressed data cleaning by applying case wise replacement [86]. Since data was missing systemically, 10.98% of questionnaires were removed from the sample, resulting in a final sample of 746 manufacturing companies. More concretely, the sample comprises 220 mechanical and plant engineering companies, 145 manufacturers from the chemical and plastics industry, as well as 139 electrical engineering, 132 automotive, and 110 steel industry manufacturers.

3.2. Measures

By systematically reviewing extant literature on Industry 4.0, no concise quantitative measurement scales regarding Industry 4.0 were found. Thus, new measurement scales were developed in accordance with extant methodological literature [87] based on existing literature discussing Industry 4.0 and its economic, environmental, and social aspects.

Economic benefits from a strategic perspective were derived from literature regarding Industry 4.0-based business models [1,36,40,41] and their positive influence on companies' competitiveness [25,68–72]. Economic benefits from an operational perspective were derived from literature regarding different aspects that are enabled by Industry 4.0 based on data availability in real-time across the supply chain [3,28,30,42,74,75], manufacturing quality [3,75], mainly enabling cost benefits. Environmental and social benefits through Industry 4.0 are taken from literature discussing Industry 4.0 in environmental [23,30,43,54,56,60] and social [43,76,77] contexts. Challenges regarding competitiveness and future viability stem from literature that discusses companies potentially losing their unique selling propositions and market shares as well as diminishing industry boundaries that threaten incumbents [17,79,80]. Measures for organizational and production fit were derived from literature investigating company characteristics that impede Industry 4.0 implementation [42,43,57,81–83]. Challenges concerning employee qualifications and acceptance lay the basis for items within the respective construct [2–4,61,66,78,84,85].

As a next step, pretests were conducted with several company representatives, confirming that scales are understandable and resemble the research objective in managerial practice. Additionally, the wording of several items was adapted and refined.

All constructs were measured with multiple items on 5-point Likert scales, ranging from 1 (strongly disagree) to 5 (strongly agree). Appendix A gives an overview of the measurement items for the six constructs used as independent variables and the construct for Industry 4.0 implementation used as the dependent variable. Subsequently, an exploratory factor analysis was conducted that proved high loadings for all items onto seven constructs as well as low cross-loadings (below 0.3), as illustrated in Appendix B.

3.3. Data Analysis

In order to evaluate the six hypotheses developed in Section 2, variance-based PLS-SEM was used [88–92]. PLS-SEM has been used significantly in recent years of management research [90].

This study aims at predicting the relevant constructs of opportunities and challenges for Industry 4.0 implementation. A PLS-SEM approach is particularly reasonable and beneficial for this purpose [93,94], as it offers a high level of statistical power for relatively small sample sizes [95]. This feature is required for multi-group analyses that are meant to reveal differences regarding the relevance of opportunities and challenges for the decision to implement Industry 4.0 due to various company characteristics. The software package Smart PLS 3.0 [96] was utilized for the analysis. As suggested by [86] the measurement model was evaluated before interpreting the path coefficients and assessing the significances by bootstrapping at structural model level. Furthermore, each indicator's *t*-statistic was examined. A bootstrapping procedure with 5000 samples was used, and sign changes during the bootstrapping process were not accepted [86].

3.4. Validation of the Measurement Model

For validation of the measurement models, we follow the established procedures for PLS-SEM reflective models [86]. All values that are referred to in the following steps are illustrated in Table 3.

Addressing indicator reliability in terms of factor loadings in a first step, a threshold of 0.7 was applied [97]. Furthermore, loadings of a minimum of 0.5 were accepted if other questions measuring the same construct had higher reliability scores [98–100]. Hence, one question was deleted in the construct of competitiveness. Internal consistency reliability was tested using composite reliability (CR), applying a threshold of 0.7 [97] which was achieved by all constructs.

Table 3. Construct measurement, composite reliability, and convergence validity.

Construct	CR	AVE	Item	Loading	*t*-Value
Strategy (Str)	0.839	0.634	Str_1	0.81	41.591
			Str_2	0.83	35.066
			Str_3	0.783	41.638
Operations (Op)	0.962	0.719	Op_1	0.867	58.712
			Op_2	0.836	45.788
			Op_3	0.857	60.347
			Op_4	0.838	51.48
			Op_5	0.846	51.287
			Op_6	0.882	52.917
			Op_7	0.839	42.516
			Op_8	0.777	35.62
			Op_9	0.873	58.857
			Op_10	0.859	61.194
Environment and people (Env)	0.85	0.653	Env_1	0.827	32.82
			Env_2	0.763	43.28
			Env_3	0.799	29.107
Competitiveness and future viability (Com)	0.942	0.698	Com_1	0.818	39.106
			Com_2	0.83	38.477
			Com_3	0.846	43.005
			Com_4	0.796	35.251
			Com_5	0.894	39.383
			Com_6	0.91	59.505
			Com_7	0.744	26.928
Organizational and production fit (Org)	0.896	0.684	Org_1	0.872	56.934
			Org_2	0.877	46.224
			Org_3	0.78	42.471
			Org_4	0.773	44.786
Employee qualifications and acceptance (Emp)	0.91	0.668	Emp_1	0.859	44.519
			Emp_2	0.82	33.917
			Emp_3	0.796	34.986
			Emp_4	0.783	26.809
			Emp_5	0.826	40.56
Relevance for implementation (Imp)	0.763	0.52	Imp_1	0.632	25.814
			Imp_2	0.779	42.427
			Imp_3	0.774	33.071

CR = composite reliability, AVE = average variance extracted; Note: $N = 746$.

Convergent validity was examined using average variance extracted (AVE), setting an initial threshold of 0.5 [100]. As a result, all constructs fulfill this criteria. As the Fornell-Larcker criterion has been found as not reliable for discriminant validity for variance-based PLS-SEM in some cases [101], we apply the heterotrait-monotrait (HTMT) criterion to address discriminant validity. The conservative threshold of 0.85 is fulfilled in all cases. Table 4 presents the results of the HTMT.

Table 4. Discriminant validity.

Construct	Str	Op	Env	Com	Org	Emp	Imp
Str							
Op	0.723						
Env	0.697	0.698					
Com	0.466	0.62	0.412				
Org	0.543	0.667	0.504	0.801			
Emp	0.579	0.712	0.484	0.556	0.658		
Imp	0.742	0.816	0.714	0.653	0.709	0.697	

4. Results

4.1. Hypothesis Evaluation

Figure 2 illustrates the results of the PLS-SEM analysis. In the following, each hypothesis result is presented for the entire sample of 746 companies in detail.

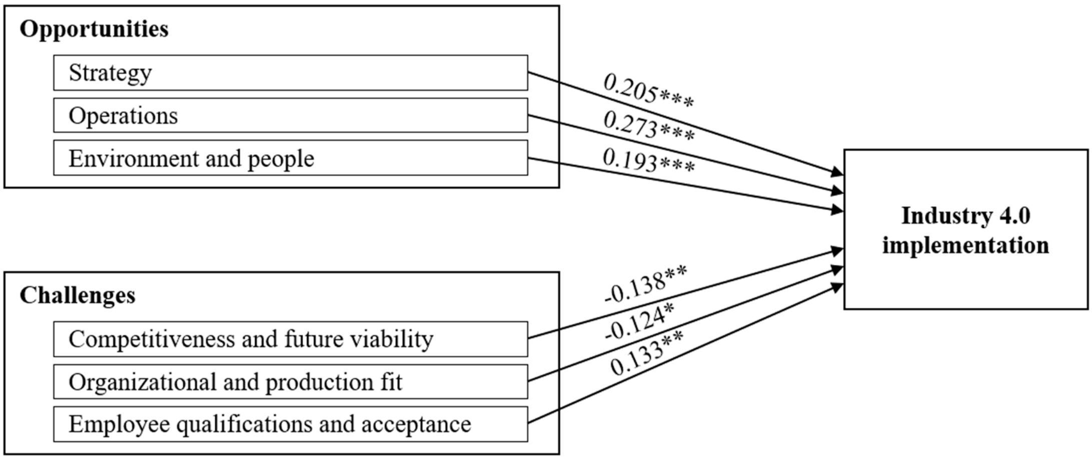

Figure 2. Results of the model using PLS-SEM. Note: $N = 746$; * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Hypothesis 1 (H1) proposes that strategic benefits of Industry 4.0 have a positive effect on manufacturing companies' implementation of Industry 4.0. The empirical results indicate a highly significant and positive relationship between strategic benefits and implementation of Industry 4.0 ($\beta = 0.205$, $t = 3.498$, $p < 0.01$). Hence, H1 is supported.

Hypothesis 2 (H2) states that operational benefits of Industry 4.0 have a positive effect on manufacturing companies' Industry 4.0 implementation. The empirical results reveal a highly significant and positive relationship ($\beta = 0.273$, $t = 4.555$, $p < 0.01$). Thus, H2 is supported.

Hypothesis 3 (H3) suggests that Industry 4.0-related environmental and social benefits have a positive effect on manufacturing companies' implementation of Industry 4.0. Again, the empirical results show a highly significant and positive relationship between environmental and social benefits of Industry 4.0 and its implementation ($\beta = 0.193$, $t = 3.568$, $p < 0.01$). Consequently, H3 is supported.

Hypothesis 4 (H4) proposes that Industry 4.0-related challenges with regard to competitiveness and future viability have a negative effect on manufacturing companies' implementation of Industry 4.0. The empirical results indicate a significant and negative relationship ($\beta = -0.138$, $t = 2.525$, $p < 0.05$). Accordingly, H4 is supported.

Hypothesis 5 (H5) suggests that Industry 4.0-related challenges with regard to organizational and production fit have a negative effect on manufacturing companies' implementation of Industry 4.0. The empirical results indicate a significant and negative relationship between challenges with regard to organizational and production fit and Industry 4.0 implementation ($\beta = -0.124$, $t = 1.857$, $p < 0.1$). Hence, H5 is supported.

Hypothesis 6 (H6) proposes that Industry 4.0-related challenges with regard to employee qualifications and acceptance have a negative effect on manufacturing companies' Industry 4.0 implementation. The empirical results show a significant, but positive effect of Industry 4.0-related employee qualifications and acceptance on Industry 4.0 implementation ($\beta = 0.133$, $t = 2.539$, $p < 0.05$). Thus, H6 is opposite the prediction.

4.2. Multi-Group Analysis

We tested hypotheses H1 to H6 by applying the Multi-Group analysis function of Smart PLS 3.0 in order to reveal group-specific differences to address our second research objective. The following paragraphs focus on specific differences of the subgroups constituting the sample.

4.2.1. Company Size

According to the definition by the European Union [102], the total sample of 746 enterprises has been divided into SMEs (n = 172) and large enterprises (n = 574).

For hypothesis H1, the empirical results indicate that large enterprises (β = 0.192, t = 4.534, $p < 0.01$) show a higher positive and more significant relationship than SMEs (β = 0.071, t = 1.744, $p < 0.1$).

For hypothesis H2, the empirical results show that operational benefits have a slightly higher positive effect on Industry 4.0 implementation for SMEs (β = 0.308, t = 6.603, $p < 0.01$) than for large enterprises (β = 0.249, t = 5.436, $p < 0.01$).

For hypothesis H3, empirical results do not reveal group-specific differences. The same is true for hypothesis H4.

For hypothesis H5, empirical results indicate a negative and highly significant effect for large enterprises ($\beta = -0.110$, t = 2.631, $p < 0.01$). In contrast, there is no significant relationship for SMEs.

For hypothesis H6, empirical results reveal that SMEs (β = 0.391, t = 6.237, $p < 0.01$) have a higher positive and more significant relationship than large enterprises (β = 0.078, t = 2.046, $p < 0.05$).

4.2.2. Industry Sector

To derive industry sector-specific differences, the total sample of 746 enterprises was divided into the industry sectors described in Section 3.1: mechanical and plant engineering companies (n = 220), manufacturers from the chemical and plastics industry (n = 145), and electrical engineering (n = 139), automotive (n = 132), and steel industry manufacturers (n = 110).

For hypothesis H1, the empirical results show that mechanical and plant (β = 0.269, t = 4.951, $p < 0.01$) and electrical engineering enterprises (β = 0.233, t = 2.825, $p < 0.01$) show a higher and more significant effect. The remaining industry sectors show no significant relationships.

For hypothesis H2, empirical results indicate stronger relationships for chemical and plastics (β = 0.329, t = 3.029, $p < 0.01$), steel (β = 0.280, t = 2.780, $p < 0.01$), as well as for automotive manufacturers (β = 0.266, t = 3.121, $p < 0.01$).

For hypothesis H3, the empirical results do not reveal industry-specific particularities, except for the automotive sector, which does not show a significant result.

For hypothesis H4, a significant and negative relationship for enterprises in mechanical and plant engineering ($\beta = -0.180$, t = 2.836, $p < 0.01$) is indicated. No further industry sector has any significant relationship.

For hypothesis H5, the empirical results disclose that electrical engineering enterprises ($\beta = -0.218$, t = 2.616, $p < 0.01$) and steel ($\beta = -0.213$, t = 2.037, $p < 0.05$) and automotive manufacturers (β = 0.178, t = 2.188, $p < 0.05$) show significant and negative effects. As opposed to these, there are no significant results for the remaining industry sectors.

For hypothesis H6, the empirical results indicate positive and significant relationships for electrical engineering enterprises (β = 0.209, t = 2.698, $p < 0.01$) and automotive companies (β = 0.216, t = 2.331, $p < 0.05$). In contrast, the remaining sample industries do not reveal any significant correlations.

4.2.3. Role towards Industry 4.0

Attempting to uncover differences between providers and users of Industry 4.0, the total sample of 746 enterprises was divided into users (n = 258), providers (n = 161), and enterprises taking both roles towards Industry 4.0 (n = 66). 259 companies have not been considered for this analysis since they could not clearly assess their role towards Industry 4.0.

For hypothesis H1, a highly significant and positive relationship can be observed for providers (β = 0.230, t = 2.919, p < 0.01). In contrast, users of Industry 4.0 and enterprises taking both roles do not show significant relationships.

For hypothesis H2, empirical results indicate that particularly Industry 4.0 users show a highly significant and positive effect (β = 0.275, t = 5.249, p < 0.01). Manufacturers taking both roles have less significant and lower positive correlations (β = 0.172, t = 1.876, p < 0.1), whereas there are no significant results for Industry 4.0 providers.

For hypothesis H3, the empirical results indicate that users of Industry 4.0 (β = 0.250, t = 4.168, p < 0.01) and companies taking both roles (β = 0.266, t = 2.560, p < 0.05) have higher positive relationships than pure providers (β = 0.165, t = 2.313, p < 0.05). For users, the relationship is also more significant than for providers.

For hypothesis H4, empirical results indicate that enterprises taking both roles towards Industry 4.0 show a significant and negative correlation (β = −0.237, t = 2.346, p < 0.05). In contrast, no significant correlations for users and providers of Industry 4.0 can be observed.

For hypothesis H5, the empirical results reveal no role-specific differences. The same is true for hypothesis H6. Table 5 summarizes the empirical results of the research model.

Table 5. Overall results.

Characteristics	H1	H2	H3	H4	H5	H6
Total sample	+	+	+	+	+	−
Large companies	+	+	+	+	+	−
SMEs	+	+	+	+	0	−
Automotive	0	+	0	0	+	−
Chemical and plastics	0	+	+	0	0	0
Electrical engineering	+	+	+	0	+	−
Mechanical and plant engineering	+	+	+	+	0	0
Steel	0	+	+	0	+	0
Providers	+	0	+	0	0	−
Users	0	+	+	0	0	−
Both	0	+	+	+	0	−

+ = supported; 0 = rejected; − = opposite the prediction.

5. Discussion

5.1. Interpretation of the Key Findings

First, this study explores the opportunities and challenges that are considered as antecedents for the implementation of Industry 4.0 by German manufacturing companies. Second, it analyzes differences with regard to varying company characteristics. Thereby, it contributes to the understanding of relevant opportunities and challenges of Industry 4.0. In general, the empirical findings indicate that Industry 4.0-related opportunities and challenges do have significant relationships with companies' tendency for Industry 4.0 implementation, while the relationships are stronger for opportunities than for challenges. Additionally, we observe interesting distinctions with respect to company sizes, industry sectors, and a company's role towards Industry 4.0. In the following, we interpret these findings for the entire sample as well as with regard to company-specific characteristics.

With regard to strategic opportunities, the empirical findings comply with our theoretical assumption that there is a positive effect on the tendency to implement Industry 4.0. Strategic advantages are relevant since companies strive for competitive advantages and long-term success.

As has been shown in Section 2.1.1, Industry 4.0 offers far-reaching strategic and business model opportunities for maintaining and expanding a company's competitive position [1]. This is in accordance with previous studies that underlined the importance of strategic advantages for implementing novel manufacturing technologies [25,73,74].

The findings reveal a stronger positive relationship for large companies than for SMEs, which is not surprising since the former usually take a strategic and prospective view, operate from a business model perspective, and are long-term oriented, whereas the latter frequently focus on short- or medium-term activities related to creating and offering their products [103,104]. Flat hierarchies, short decision-making processes, and overall flexibility allow them to react more quickly to changing market environments [105–107]. Thus, for them operational advantages are more relevant as antecedents than strategic ones, which is also in line with the findings regarding hypothesis H2.

The findings also indicate a positive relationship between strategic potentials and tendency for Industry 4.0 implementation for providers of Industry 4.0. There is no significant relationship for users. The same applies to mechanical and plant engineering as well as to electrical engineering companies in contrast to the other examined industries. This is justified by the fact that those two industry sectors are the major providers of Industry 4.0 technologies and solutions. These value propositions are premised to pose the largest strategic benefits [1]. Users of the Industry 4.0 experience considerably less change in the value propositions of their business model, but rather operational effects that are ascribed to the application of Industry 4.0 technologies and solutions within their manufacturing processes and value creation. This can also be observed regarding the industry sectors automotive, steel, as well as chemical and plastics manufacturing, which are mostly users of Industry 4.0 and therefore particularly efficiency-driven, mainly focusing on Industry 4.0-enabled value creation processes instead of Industry 4.0-enabled product and service offerings.

Operational opportunities influence the tendency for Industry 4.0 implementation positively; that is, Industry 4.0-related benefits in terms of, for example, enhanced efficiency, timing, flexibility, and quality are considered relevant antecedents to implementation of Industry 4.0-related manufacturing technologies, which is in line with current research [25,31].

In line with the discussion regarding strategic opportunities and their influence on the tendency for Industry 4.0 implementation, the findings also reveal that SMEs, users of Industry 4.0, and the steel, chemical and plastics industries, as well as automotive companies are mainly driven by operational opportunities. On the other hand, large enterprises, Industry 4.0 providers, mechanical and plant engineering businesses, as well as electrical engineering industries are particularly driven by strategic benefits.

This study discloses that environmental and social opportunities are another relevant driver for a tendency towards Industry 4.0 implementation. Facilitated by Industry 4.0, the reduction of waste, energy and resource consumption, as well as improved working conditions [43,57,60] lead to a tendency towards Industry 4.0 implementation. Thus, previous studies' findings on the positive impact of ecologically and socially beneficial innovations on their implementation are approved [76,77].

Companies that both provide and use Industry 4.0-related solutions as well as those that are merely Industry 4.0 users show a slightly higher positive relationship between environmental and social opportunities and tendency for Industry 4.0 implementation than pure Industry 4.0 providers do. This seems reasonable because users focus on operational processes and related benefits, which are closely related to waste and energy reduction as well as workplace improvements. The positive relationship proves also true for all examined industry sectors except for the automotive industry. Apparently and interestingly, the automotive industry strongly focuses on economic and operational opportunities, whereas ecologic and social aspects do not seem to be drivers and antecedents of Industry 4.0 implementation.

This article's findings reveal that challenges concerning competitiveness and future viability have a negative effect on tending towards Industry 4.0 implementation. Emerging new market players and competitors threaten established manufacturing companies' market positions and competitive advantages [3,17]. Consequently, and particularly in the context of Internet-based (manufacturing) technologies and online platforms, the combination of highly competitive markets as well as data security and transparency issues prevents industrial manufacturers from implementing Industry 4.0, regardless of their size [79,80].

A differentiated perspective on different industry sectors shows that exclusively mechanical and plant engineering companies are put off from implementing Industry 4.0 due to experiencing challenges regarding competitiveness and future viability. The other examined industry sectors do not consider such challenges as relevant for their implementation decision. This result is justified by the fact that mechanical and plant engineering companies are largely confronted with insufficient IT and software know-how due to their strong focus on hardware, machinery and products [1,4]. Implementing Industry 4.0 would pose the threat of exposure to experienced IT and software companies within platform ecosystems. Instead of perceiving this as an opportunity to source external knowledge, they might fear the threat of becoming dependent on companies that possess more contemporary data, software, virtualization, and IT competencies.

The survey at hand discloses that organizational and production fit are considered as relevant antecedents for manufacturers' decision not to implement Industry 4.0. The complexity of integrating Industry 4.0-related technologies into existing organizational hierarchies and structures as well as into production and logistics systems, that is, retrofitting, prevents companies from pursuing the novel manufacturing paradigm. In the context of Industry 4.0, this underlines previous insights [81–83].

Interestingly, this finding is particularly true for large companies. SMEs do not show such a significant negative relationship between challenges regarding organizational and production fit and tendency towards Industry 4.0 implementation. Due to the aforementioned higher flexibility and ability to respond to changing market environments compared to large companies [104–107], this challenge may be perceived to be less relevant for the decision to implement Industry 4.0 or not.

Furthermore, and by having a closer look at the different manufacturing sectors, it is worth noticing that mechanical and plant engineering enterprises do not show a significant relationship between the challenge of an organizational and production fit and a tendency towards Industry 4.0 implementation, in contrast to the remaining sample industries. In line with this study's findings concerning strategic opportunities, operational opportunities, as well as challenges with regard to competitiveness and future viability, this sector takes a strategic as well as long-term perspective on Industry 4.0-related opportunities and challenges. Thus, operational aspects in general are of minor relevance for these companies' decisions to implement Industry 4.0.

With regard to employee qualifications and acceptance, the overall findings show that this challenge has a positive effect on tending to Industry 4.0 implementation, which is opposite to our prediction. Due to the reasoning presented in Section 2.2.3, a negative relationship was expected. Consequently, previous findings [43,85] are contradicted in the context of implementing Industry 4.0. At first glance, this is surprising and not reasonable. Both current Industry 4.0 literature as well as this article's insights do not provide any convincing justification for this result. One possible but not necessarily correct explanation might be ascribed to the survey participants, who mainly represent Industry 4.0-related management functions. It is questionable if these are the right target group for assessing the level of employee acceptance. Employees are usually cautious about sharing their true beliefs and feelings concerning innovations that are promoted by managers, in order to prevent job-related disadvantages [108]. Justified by this interesting inconsistency, we suggest elaborating further on the relationship between employee qualifications as well as acceptance and Industry 4.0 implementation in future research projects.

5.2. Concluding Implications for Theory

As previously shown and discussed, this study contributes to literature on Industry 4.0 as well as on technology and innovation acceptance. By displaying the current state of economic Industry 4.0

research and revealing empirical insights from a broad sample of five major German industry sectors, four contributions and conclusions are derived.

First, this study proposes a research model comprising important opportunities and challenges as antecedents of Industry 4.0 implementation. It shows that both Industry 4.0-related opportunities and challenges have a significant influence on its tendency towards implementation. We provide a generally better understanding and clarification with regard to Industry 4.0-related opportunities and challenges that are considered as relevant for Industry 4.0 implementation in industrial value creation. An analysis of varying company sizes, industry sectors, as well as roles towards Industry 4.0 allows painting a differentiated and specific picture in this context. By doing so, we shed light on an important research gap [3,18]. Further, this paper adds to the sparse body of literature investigating all dimensions of sustainability within the Triple Bottom Line with respect to Industry 4.0.

Second and more concretely, the study at hand shows that strategic opportunities are main antecedents for large companies, mechanical and plant as well as electrical engineering industries, and for Industry 4.0 providers. Operational opportunities are considered as particular drivers for SMEs, automotive, chemical and plastics, as well as steel companies, and for Industry 4.0 users. Environmental and social opportunities are perceived as antecedents of Industry 4.0 implementation for all company sizes, roles towards Industry 4.0 with a slightly stronger relationship for Industry 4.0 users, and industry sectors except for the automotive industry.

Challenges with regard to competitiveness and future viability do prevent industrial manufacturers from implementing Industry 4.0 independent of company size. This challenge plays a particular role for mechanical and plant engineering companies. With regard to the challenge of organizational and production fit, especially large enterprises as well as automotive, electrical engineering, and steel industry sectors are prevented from implementing Industry 4.0.

Third, this article confirms several previous studies on the influence of strategic advantages [25,73,74], operational benefits [25,31], as well as ecological and social opportunities [76,77] on technology and innovation acceptance. In addition, the influence of the challenging organizational and production fit on the implementation of novel technologies and innovations, which has previously been revealed [81–83], is confirmed in a more contemporary context.

The effect of competitiveness and future viability on the acceptance and implementation of new technological innovations is in line with extant literature [79,80]. As opposed to this, the results of other studies, for example [67], are contradicted in the context of Industry 4.0. Consequently, we argue that there is no single source of truth, so we suggest assessing the effect of competitiveness and future viability on technology implementation for each application scenario individually. The identification of contextual characteristics for which the effect is positive or negative is a promising field for future research activities. Likewise, as the positive influence of employee qualifications and acceptance on Industry 4.0 implementation could not be explained reasonably in the article at hand, further studies are recommended. In particular, employee acceptance should be evaluated using a sample consisting of operative employees as opposed to managers.

5.3. Implications for Practice

Besides theoretical implications, the study at hand provides several implications for managers. As has been shown, both Industry 4.0-related opportunities and challenges play an important role for its implementation. We claim that Industry 4.0 will not fulfill its entire potential until the benefits and risks related to this concept are well understood. In particular, implementation requires that opportunities compensate for challenges. Hence, managers should clarify and clearly assess whether potentials or risks dominate. The article at hand shows that implementing Industry 4.0 is able to provide far-reaching benefits and opportunities. These opportunities can only be exploited if challenges are accepted and addressed consciously. Thus, companies should promote opportunities and should not be discouraged from pursuing the digitization and (Internet-based) connection of industrial value creation by related challenges or risks. Needless to say, concerns about data security and property raised by Industry 4.0 should be taken seriously, but have to be accepted to achieve the benefit of collaboration, openness, and success for entire business ecosystems. In terms of the open innovation paradigm, this serves as a driver of competitive advantage [109].

In line with findings regarding strategic opportunities of Industry 4.0, we recommend industrial manufacturers to systematically reconsider and innovate their business models against the background of digitization. Novel and contemporary business logics that are based on information and data, such as cloud-based business models [110], service-oriented business models [111], and platform business models [17] prepare companies for competitive challenges. This applies particularly to the management of SMEs, which strongly focuses on short-term and operational activities. Further, companies should clearly address customers' demands and expectations in order to retain them in the future [112].

Furthermore, the implementation of the Industry 4.0 concept necessitates top management involvement that promotes comprehensive change management activities and processes to arrange organizational and production structures according to the requirements of connected value creation. A collaborative, explorative, and entrepreneurial mind-set is a success factor that has to be established among a company's most important resource: the employees. Managers should be eager to convince employees of the Industry 4.0's beneficial nature and address their concerns actively. In this regard, the training and development of employees should be tailored towards Industry 4.0-specific competencies and skills, such as data analytics, IT, software, and human-machine interaction know-how [1,113].

Finally, Industry 4.0 provides economic, environmental, and social benefits and opportunities [3]. Their integration and combination complies with the Triple Bottom Line concept of sustainability [114]. Creating sustainable industrial value requires manufacturers to pursue all three dimensions simultaneously [115]. Therefore, we recommend managers to consider Industry 4.0-related benefits comprehensively to create a solid foundation of sustainable long-term success and viability. Further, politics and public institutions need to promote legal conditions designed adequately [116].

5.4. Limitations and Suggestions for Future Research

As with any empirical study, the article at hand suffers from several limitations that are worth consideration for further research activities. First, Industry 4.0 represents a comparatively young technology and research field. Since there is no unified perspective on what the term implies, the generalizability of the empirical findings may be application-specific. Hence, further research should define clear, homogeneous application scenarios, such as additive manufacturing and cyber-physical production systems, within which the influence of Industry 4.0-related opportunities and challenges to its implementation may be tested.

Second, future research projects should take into consideration other variables that may influence the implementation of Industry 4.0, for example, top management support, environmental uncertainty, absorptive capacity, and so on. Moreover, it is not clear if the surveyed companies have actually and fully implemented Industry 4.0 into their value creation processes yet. Hence, we suggest validating the findings of this study by actual Industry 4.0 implementation as soon as the concept is adopted to a greater extent.

Third, and in line with the deliberations presented in Section 5.2, further research is needed on the role of employee qualifications and acceptance for Industry 4.0 implementation, since the findings at hand show a not fully reasonable positive influence of this challenge. Here, surveys should address rather operative employees than managers in order to obtain as reliable information as possible.

Fourth and in this regard, the use of a single source of data may inherit a potential common method bias [117]. To address this shortcoming and increase validity, future research projects should employ a multimethod research approach.

Fifth, the German sample may limit the generalizability of our findings since there are most certainly different cultural backgrounds, international Industry 4.0 approaches and political support, as well as industrial structures. Hence, it would be reasonable to carry out an international study, which allows for comparing different country-specific insights.

Sixth, the operationalization of sustainability dimensions applied in this paper can only serve as a first antecedent for Industry 4.0 implementation, which is still as its first stages. Further research should aim at a more concise delineation between expected and already experienced opportunities as well as challenges in the context of Industry 4.0.

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Appendix A. Measurement Items of Constructs

Table A1. Measurement items of constructs.

Construct	Item	Description
Strategy	Str_1	Industry 4.0 allows us to create new business models.
	Str_2	Industry 4.0 allows us to create leading solutions for our customers.
	Str_3	Industry 4.0 allows us to generate solutions that are hard to imitate.
Operations	Op_1	Industry 4.0 allows decreased costs through interconnection.
	Op_2	Industry 4.0 allows increased quality.
	Op_3	Industry 4.0 allows increased traceability.
	Op_4	Industry 4.0 allows decreased non-value-adding effort.
	Op_5	Industry 4.0 allows lowered stocking of goods.
	Op_6	Industry 4.0 allows decreased documentation and administration.
	Op_7	Industry 4.0 allows to increase the flexibility of production.
	Op_8	Industry 4.0 allows increased speed and reactive capabilities.
	Op_9	Industry 4.0 allows increased load balancing.
	Op_10	Industry 4.0 allows reasonable use of machinery data.
Environment and people	Env_1	Industry 4.0 allows age-appropriate working environments.
	Env_2	Industry 4.0 allows a decrease in monotonous and repetitive work.
	Env_3	Industry 4.0 allows decreased waste and environmental impact.
Competitiveness and future viability	Com_1	Industry 4.0 generates dependence on other enterprises for us.
	Com_2	Industry 4.0 makes us replaceable due to standardization.
	Com_3	Industry 4.0 makes us lose value creation of direct customer contact.
	Com_4	Industry 4.0 makes us replaceable due to anonymity.
	Com_5	Industry 4.0 makes us lose our market niche that ensures our success.
	Com_6	Industry 4.0 makes us lose our flexibility, requiring costly solutions.
	Com_7	Industry 4.0 makes us transparent, potentially usable as leverage.
	Com_8	Industry 4.0 generates technological dependence for us. (eliminated)
Organizational and production fit	Org_1	For us, implementing Industry 4.0 is not reasonable.
	Org_2	Customer demands are too individualized to implement Industry 4.0
	Org_3	We have too little standardization to implement Industry 4.0.
	Org_4	For us, the costs exceed the benefits of Industry 4.0.
Employee qualifications and acceptance	Emp_1	Our employees do not trust Industry 4.0 technologies.
	Emp_2	Our employees fear dependence on Industry 4.0 technologies.
	Emp_3	We expect nonacceptance of Industry 4.0 by employees.
	Emp_4	We expect lack of Industry 4.0 expertise among our employees.
	Emp_5	Our employees fear data transparency due to Industry 4.0.
Implementation	Imp_1	For our suppliers, Industry 4.0 is relevant for implementation.
	Imp_2	For us, Industry 4.0 is relevant for implementation.
	Imp_3	For our customers, Industry 4.0 is relevant for implementation.

Appendix B. Results of Exploratory Factor Analysis

Table A2. Exploratory factor analysis.

Item	1	2	3	4	5	6	7
Str_1	0.896						
Str_2	0.843						
Str_3	0.416						
Op_1		0.599					
Op_2		0.825					
Op_3		0.687					
Op_4		0.623					
Op_5		0.670					
Op_6		0.782					
Op_7		0.815					
Op_8		0.474					
Op_9		0.803					
Op_10		0.599					
Env_1			0.769				
Env_2			0.730				
Env_3			0.705				
Com_1				0.607			
Com_2				0.660			
Com_3				0.755			
Com_4				0.848			
Com_5				0.670			
Com_6				0.569			
Com_7				0.448			
Com_8 *		0.315		0.329			
Org_1					0.524		
Org_2					0.674		
Org_3					0.902		
Org_4					0.862		
Emp_1						0.726	
Emp_2						0.714	
Emp_3						0.634	
Emp_4						0.629	
Emp_5						0.547	
Imp_1							0.906
Imp_2							0.840
Imp_3							0.469

Factor analysis (principle-component method) with direct oblimin rotation; eigenvalues > 1 were considered; loadings below 0.3 are not shown; * not retained in final scale.

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