

## Exploring Readiness of SMEs for Industry 4.0

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**Abstract.** Industry 4.0 is considered to be the fourth industrial revolution and involves virtual and physical systems that are interconnected and collaborate in an autonomous way. Industry 4.0 is a relatively new concept within computer science and raises interest on how to make use of technologies included in the concept and profit from them. This article investigates Industry 4.0 in the context of SMEs: the opportunities and challenges that Industry 4.0 poses upon SMEs, as well as readiness of SMEs for Industry 4.0 are considered. The data collection and analysis methods were literature review with grounded theory. In the result, the main challenges proved being of organizational nature: SMEs need help with company-specific strategies for implementing Industry 4.0; and SMEs need skilled employees. The opportunities are flexibility and openness to innovation, which are pertinent to SMEs; cloud computing; and public investments into technology and adoption of Industry 4.0 by companies. The readiness of SMEs for Industry 4.0 is still somewhat low – they are still learners.

**Keywords:** Industry 4.0, SME, IMPULS, Readiness Assessment.

### 1 Introduction

The fourth industrial revolution is transforming the technologies, economies and the society itself [1]. This study explores how this revolution impacts small and medium-sized enterprises (SMEs), according to a literature study.

“Industry 4.0”, also called the Fourth Generation Industrial Revolution, was first introduced in Germany in 2011 at the Hanover Fair. At the fair, discussions were made to describe how Industry 4.0 will revolutionize the creation of global value chains [2]. Industry 4.0 is a concept built on the digital revolution where smart machines communicate with each other using wireless connections and are connected to a system that can make decisions on its own by visualizing the entire manufacturing process [1]. Hence, computers can make decisions without human involvement. The virtual and physical systems are interconnected and collaborate in a flexible way. With these new intelligent solutions, Industry 4.0 can benefit any industry worldwide that is ready to make use of the technologies.

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Industry 4.0 is a term originally from the German word “Industrie 4.0”, it started as an initiative from the German government to increase competitiveness of the manufacturing industry in Germany [3]. Multiple countries have now followed Germany and started their own initiatives for moving towards Industry 4.0. For instance, Sweden launched its strategy for the new smart industrialization in 2015. The goal is that Swedish industries should be the leaders of the digital transformation worldwide and thus strengthen their competitiveness in the global market [4], [5].

Previous research mainly described the pillars of Industry 4.0 and focused on the definition of the term and where it was coined, rather than on the impact and the use of the actual technologies [6]–[10]. When searching Google Scholar for “Industry 4.0”, publication years 2016–2020, in top 100 links, we found mainly state of the art articles (25.5%), the fundamentals of Industry 4.0 (26.5%), some case studies (2.9%), discussions about how it impacts larger companies and the society (18.6%), and organizational transformation strategies on how to adapt to using Industry 4.0 on a high level (26.5%).

### 1.1 Fundamentals of Industry 4.0

Industry 4.0 includes many technologies and acts as an umbrella term. The four main technologies are cyber-physical systems (CPS), Internet of Services (IoS) and then Internet of Things (IoT) and smart manufacturing [11]. There notion of Industry 4.0 is somewhat vague; however, it is said to be a collection of disruptive technologies. According to the Cambridge Dictionary, disruptive technology is something that “...overturns a traditional business model, which makes it much harder for an established firm to embrace” [12]. Many authors put more weight on CPS or CPPS (cyber-physical production system) to be a major part of the term. Vaidya et al [8] mention that Industry 4.0 has four main drivers, namely, IoT, Industrial Internet of Things (IIoT), cloud-based manufacturing, and smart manufacturing. They also describe nine pillars of Industry 4.0:

1. *Big Data and Analytics*. Big Data consists of four V’s, namely; volume of data, variety of data, value of data and velocity of generation of new data and analysis. Analysis is the analysis of previous data used to forecast and find patterns.
2. *Autonomous Robots*. Autonomous robots are used for doing repetitive and autonomous production work in a precise manner, but also doing tasks where humans are not fit, such as restricted work. The robots can be used to complete tasks within given circumstances and put focus on important aspects, which could be safety, versatility, flexibility and collaboration with other robots or humans.
3. *Simulation*. Simulations can be in the shape of 2D or 3D simulations for creating a virtual reality of parts of a production. It can be used to simulate reality in a virtual space, including machines, products and humans and thus enable for a higher level of effectiveness via decreased setup time and increased quality at the same time, amongst other aspects.
4. *System Integration: Horizontal and Vertical Integration*. System integration can be horizontal, vertical or in an end to end manner, meaning across the value creation network, vertically down networked manufacturing systems or end to end across an entire lifecycle of a product.
5. *The Industrial Internet of Things (IIoT)*. Aazam, Zeadally and Harras [13], describe the differences between IoT and IIoT. Simply put, IoT brings the internet to a “thing”, whereas IIoT is when data is collected from sensors, actuators, and other machines in an environment of industrial character [13]. These technologies are enabling a connected network, making the connections intelligent and agile and thus setting a good foundation for Industry 4.0.
6. *Cyber Security and Cyber-Physical Systems (CPS)*. To keep up with the demanding nature of connected networks, cyber security must be a part of the process to secure reliable communications and advanced access management. This could also be done with the help of cyber-physical systems where humans and machines are closely working together. A CPS is

good for decentralization and autonomous behavior and can be used to monitor and overview a network of physical and cyber connections.

7. *The Cloud*. Cloud is a technique used for sharing data across an enterprise, and for storage. Cloud solutions are appropriate for retrieving data and could be used for linking multiple sensors at once to the cloud, connecting data together and sharing data between the devices.
8. *Additive Manufacturing*. Additive manufacturing means an enterprise can work with small batches of products with a high level of customization. Transportations distances can be reduced along with the need for storing many products at once.
9. *Augmented Reality (AR)*. For service and repair, AR is bringing big opportunities, allowing for repair to happen on the spot, by regular personnel. This is something the movement of Industry 4.0 can leverage and reduce time spent on waiting for repairs or for expertise.

This list can be extended to include blockchain and adding to the fourth pillar within industrial integration which includes enterprise architecture and application integration in the sense that industrial integration is a part of the fourth revolution process [9]. Disruptive technologies as the ones mentioned being a part of Industry 4.0 above, are not exclusive to large companies, but are also considered in smaller enterprises. SMEs are a substantial part of the global economy [14]. Industry 4.0 being a revolution affecting the entire globe indicates not only larger companies are touching upon these technologies, but SMEs also.

## **1.2 SMEs: Readiness for Industry 4.0**

The European Commission defines a SME based on the company's staff headcount and its annual turnover or balance sheet total. The criterion for being a small company is less than 50 employees and an annual turnover of less or equal to 10 million euros. A medium sized company should have less than 250 employees and an annual turnover of less or equal to 50 million euros. In the European Union, SMEs represent 99% of all companies [14]. According to some researchers, the size of the company matters when it comes to implementing Industry 4.0 [15], [16]. Sommer [16] argues that the smaller the company is, the more challenging it becomes to benefit from Industry 4.0.

Research in the area of Industry 4.0 readiness is a way that can aid companies to prepare for challenges that may appear when transforming towards the new revolution [17]. According to Schumacher, Erol, and Sihn [18], who studied and analyzed multiple readiness and maturity models for Industry 4.0 implementation, the difference between a maturity model and readiness model is that the readiness assessment occurs before the maturing process starts. Hence, the readiness model should prepare the company and clarify whether the company is ready to initialize a transformation process for Industry 4.0 or not, while a maturity assessment aims to clarify which maturity level the company is in. [18] defines the term maturity as the state of a company being complete or ready. Mittal, Khan, Romero, and Wuest [19] define readiness assessments as "evaluation tools to analyze and determine the level of preparedness of the conditions, attitudes, and resources, at all levels of a system, needed for achieving its goal" [19, p. 199]. There is a limited amount of readiness assessments available that cover challenges and specific requirements for SMEs in Industry 4.0.

## **1.3 Research Problem and Research Questions**

Industry 4.0 is in the present; hence, it is not a matter of maturity in an organization, but rather its readiness for implementing it. According to Hofman and Rüsçh [17] "... it becomes apparent that the concept of Industry 4.0 still lacks a clear understanding and is not fully established in practice yet" [17, p. 23]. Sommer [16] states that it can be challenging for smaller companies to benefit from Industry 4.0 and it could impact them in a negative way. There exists a knowledge gap in the research about SMEs and how their transformation towards Industry 4.0 can impact them. It is important that companies understand the new industrial trends and how they can

exploit them in the best way. Readiness assessments can help to clarify for the companies how to prepare for an organizational transformation towards Industry 4.0.

The research problem in this study is that there is a limited amount of readiness assessments available that cover challenges and specific requirements for SMEs regarding Industry 4.0, but assessment is needed to demonstrate the SME’s readiness for Industry 4.0 implementation [19].

With the research problem stated, the research questions addressed by this study are (1) what opportunities and challenges Industry 4.0 poses upon SMEs, and (2) to which extent SMEs are ready to embrace Industry 4.0.

The current article is a summary of a master thesis [20]. The article is more concise than the thesis and has a stronger focus on both the readiness assessment method and the results. The article is also a more mature piece of work compared to the thesis which was, by its nature, a “work in progress”.

## 2 Methodology

This research is a literature study described by Wolfswinkel’s et al. [21] as five-stage approach: (1) define what to search for and the sources, (2) search, (3) select, (4) code and analyze the literature by grounded theory, (5) present the findings. The literature review process is outlined in Table 1.

**Table 1.** Literature review process

Stage	Task
<b>Define</b>	Inclusion criteria: year 2016–2020, academic publications and research articles, top 100 hits if available. Years prior to 2016 are regarded as the formative age of Industry 4.0 and, therefore, less relevant in the context of SMEs.
	Exclusion criteria: Newspapers, magazines, personal communications, social media streams
	Fields of research: Industry 4.0, information systems
	Appropriate sources: Google Scholar
	Specific terms: (SME OR “Small and medium enterprises”) AND “Industry 4.0” AND (readiness OR benefits OR challenges) AND Sweden (SME OR SMF OR “små och medelstora företag”) AND (“industri 4.0” OR “Industry 4.0”) AND (beredskap OR fördelar OR utmaningar) (SME OR “Small and medium enterprise”
<b>Search</b>	100 top links on Google Scholar were looked at to gather a sufficient amount of information. The search term in Swedish only generated 50 hits. The searches were documented in a Google sheet with a new sheet for each search term. All duplicates and irrelevant literature were discarded at this stage.
<b>Select</b>	The sample was refined by firstly reading the headings and checked if it contained key words like Industry 4.0, SME and readiness. If the abstract contained two out of these three words it was selected. Secondly, the abstracts were read and those which contained at least two of the search terms were selected. The selected literature was then downloaded in the Google sheet file for further reading.
<b>Analyze</b>	<i>Open coding</i> : all selected articles were reread and categories identified. The categories were documented in the Google sheet file including some highlights from the text.
	<i>Axial coding</i> : two columns were added in Google sheet named “subcategories” and “axial codes” which represented interrelations between the subcategories and the axial codes. Highlighted words and sentences were added which supported the categories.
	<i>Selective coding</i> : all documented main categories and subcategories were looked on again and then were refined to adapt to the research topic.
<b>Present</b>	The whole literature review is represented in Appendix A. The findings are discussed in Section 4.
	The literature review was structured in a Google sheet with the columns; article name, main category which is related to subcategory, highlights and notes.

Analysis by grounded theory prescribes three kinds of literature coding: open, axial, and selective coding. Our interpretation of the coding is described in Table 1. In Appendix A, the reader can find how the axial codes were grouped into sub- and main categories, where both

categories correspond to selective codes of high and higher levels. In order to illustrate each subcategory, representative quotes from the literature were selected, where a selected quote stood for a number of similar ones. A quote is not an open code; the quotes were extracted after the open coding was finished and the authors were familiar with the content of the publications. In total, 48 quotes were selected. The quotes were further used in assessment of the readiness of SMEs for Industry 4.0.

An alternative to a literature review would be case studies exploring real-life SMEs. The downside of such case studies is that we can consider only a limited number of companies, most probably in a limited geographical area. A literature review has broader coverage, although it does not generate new empirical data.

There exist several Industry 4.0 readiness and maturity assessment models [15]; we chose IMPULS [22]. Because IMPULS was originally created for assessing individual companies, we modified it in order to adapt it for assessing SMEs in general through literature findings. Both the original IMPULS model and the modifications are described in the Section 3.

### 3 Readiness Assessment

IMPULS [22] assesses readiness of a company for Industry 4.0 by 6 dimensions and a number of fields [23] and readiness levels for each field described in Section 3.2. According to Sony and Naik [24], IMPULS is a suitable model for several types of industries. Therefore, it was chosen for this study.

#### 3.1 Dimensions and Associated Fields

**Dimension “Smart Factory”.** Smart factory is one of the key concepts of Industry 4.0 where an intelligent and interconnected factory produces products through smart operations by using smart products. In other words, the factory should be self-regulated when it comes to all business processes, especially, production. This dimension includes the fields: Digital modeling, Equipment infrastructure, Data usage, IT systems. According to [22, p. 13],

- *Digital modeling* involves “smart gathering, storage, and processing of data”,
- *Equipment infrastructure* means that “the smart factory relies on cyber-physical systems (CPS), which link the physical and virtual worlds by communicating through an IT infrastructure, the Internet of Things”,
- *Data usage* mean that “integrated systems produce huge amounts of data that are processed, analyzed, and integrated into decision-making models”,
- *IT systems* “require real-time, cross-enterprise collaboration between production systems, information systems, and people”.

**Dimension “Smart Operations”.** Smart operations mean that components and systems are all integrated both horizontally and vertically. This results in a cross-enterprise network which enhances the planning and control of the product’s lifecycle. This dimension includes the fields: Cloud usage, IT security, Autonomous processes, Information sharing. According to [22, p. 13],

- *Cloud usage* means that cloud services are used in the business,
- *IT security* indicates that measures towards IT security are taken,
- *Autonomous processes* are “technical requirements in production and production planning necessary to realize the self-controlling workpiece”,
- *Information sharing* is “the enterprise-wide and cross-enterprise integration of the physical and virtual worlds”.

**Dimension “Smart Products”.** Smart products can be described as physical objects that use information communication technologies (ICTs). In Industry 4.0, the products should be able to carry out their own work. This means that they should have a unique identification so that they

can interact with their environment and do recordings of it through sensors. For instance, a physical object should be self-guided and communicate to other machines which work steps need to be done. This dimension includes the fields: ICT add-on functionalities and Data analytics in usage phase. According to [22, p. 13],

- *ICT add-ons*: “Physical products are equipped with ICT components (sensors, RFID, communications interface, etc.) to collect data on their environment and their own status”,
- *Data analytics in usage phase* is when it is “possible to monitor and optimize the status of the individual products”.

**Dimension “Data-Driven Services”.** Data collection and analysis can provide valuable information to produce new business models that enhance benefits to the customers. With the help from new data-driven services, companies can digitize their old conventional business models and develop new ones. By combining the company’s products and services the added value increases to the customer. This dimension includes the fields: Data-driven services, Share of revenues, Share of data used. These fields imply that “the after-sales and services business will be based more and more on the evaluation and analysis of collected data and rely on enterprise-wide integration” [22, p. 13].

**Dimension “Employees”.** Employees play a key role in organizational changes and are the ones affected most by the changes in the work environment. Requirements for new skills and qualifications will arise. In this dimension it becomes important to evaluate the readiness of not only employees’ skills but also their willingness to learn and take actions. This dimension includes the fields: Employee skill sets and Skill acquisition. The two fields: “Their direct working environment is altered, requiring them to acquire new skills and qualifications. This makes it more and more critical that companies prepare their employees for these changes through appropriate training and continuing education” [22, p. 52].

**Dimension “Strategies and Organizations”.** This dimension covers the strategies needed for companies to develop new business models that will support the Industry 4.0 implementation. It is important for companies to know how to go about when, for instance, investing in new technologies that will change their business processes. Hence, without a proper strategy for implementation, the invested technologies become difficult to grasp. In other words, having new strategies is of great importance in order to kick-start the organizational transformation towards Industry 4.0. This dimension includes the fields: Strategy, Investments and innovation management. According to [22, p. 29],

- *Strategy* “offers the opportunity to develop entirely new business models”,
- *Investment and innovation management* is about where the business allocates its economic resources and how much effort is put into innovation.

### 3.2 Readiness Levels

In IMPULS there are six levels, numbered 0 to 5, for assessing readiness of companies for Industry 4.0. The levels are divided into three groups: newcomers (0-1), learners (2), and leaders (3-5) [22].

- *Level 0, Outsider*, indicates that a company either does not know of Industry 4.0, thinks it is irrelevant or has not taken any steps towards an implementation.
- *Level 1, Beginner*, involves some steps taken towards Industry 4.0, such as doing pilot studies and having some system compatibility for Industry 4.0, along with very little competence in the organization and only planned IT security.
- *Level 2, Intermediate*, companies have implemented Industry 4.0 to some extent into their strategies, some investments are being made, the infrastructure is to some extent using

Industry 4.0, there is in-house sharing of information, there are competencies and sufficient IT security in the company.

- *Level 3, Experienced*, is assigned to companies that have an Industry 4.0 strategy, make investments in more than a few areas, promote Industry 4.0 via the innovation department, have information sharing in-house and partly external, and have connected infrastructure with future expansion in mind that collects data automatically. Also, necessary IT security is implemented, cloud is used for future expansions, and major steps are taken to make sure that competencies for all this already exist in the company or efforts are marked to achieve them.
- *Level 4, Expert*, is for companies already using and monitoring Industry 4.0, making investments in almost all areas, supported by interdepartmental innovation, IT-systems support almost all production and collect vast amounts of data also used for optimization. Here, future expansions can easily be made due to already supporting systems, information sharing is on both internal and business levels, IT security is applied and scalability is not a problem, data-driven services are used and the company has all necessary skills in-house.
- *Level 5, Top performer*, is for companies that have already implemented their Industry 4.0 strategy and monitor implementations of other projects in the company, which is supported by investments across the company. The innovation department is covering the entire company; IT systems are fully implemented along with autonomous processes, collecting vast amounts of relevant data. The infrastructure fulfills all needs for integration across the company's systems for internal and business information sharing. The IT-architecture is flexible, IT security is at a comprehensive level, and the competencies within the company provide all the expertise they need.

### 3.3 The Original Process of IMPULS

The IMPULS model process [22] was conducted by assessing the readiness level of a company by using the dimensions and fields. Each dimension and its associated fields are assessed and a level for each field is determined.

The first step is to look at the six dimensions and identify which dimensions are applicable. These could be all the dimensions or just a few, depending on the company. The input for this step is the information about the company, which could be retrieved in several ways such as questionnaires or literature reviews. The output is the identified dimensions for the company.

The next step is to determine the fields for each dimension which will be used for measuring Industry 4.0 readiness level for the company. The fields are analyzed in a similar manner as dimensions, with the purpose to find applicable fields in the identified dimension. The input is derived from the previous step and the output is the suitable fields.

After this, the assessment of levels starts by utilizing the levels 0-5 which need to meet specific minimum requirements. Minimum requirements are described by IMPULS for each field in each dimension. These requirements are related to the levels and must be fully met in order to complete a level. For instance, in the dimension "Employees" and in the field "Employee skill set", level 2 can be achieved only by meeting the minimum requirement of "Employees have low skill levels in one relevant area". Once the level is determined for each field, the lowest level in the fields determines the overall level for the dimension. This means that a dimension with level 5 in one field and level 1 in another field will get the overall level of 1.

Each dimension has a different weight of importance depending on the organization and situation. For instance, for some industries the dimension "Smart operations" could be more important than "Smart products". The dimensions are weighted by allocating a total of 100 importance points. The purpose of the importance points is to see which dimensions are more important to a company for Industry 4.0 implementation and which dimensions need more attention. The decision of how many points each dimension receives is determined by a survey

or a similar activity where top managers or business experts are asked to answer questions about Industry 4.0 in the context of the company.

The importance points are used to calculate the readiness score for a company. The difference between levels and importance points is that the level is a measurement of readiness, meaning how well a company meets a minimum requirement for a dimension; whereas the importance points are a measurement of how important that specific dimension is to a company.

The readiness score within a particular IMPULS dimension has two constituents: (1) the lowest readiness level that the company has achieved within the dimension, and (2) the importance points of the dimension. Let us say that the company has reached level 2 within the dimension “Smart products”, and the dimension has been assigned 25 importance points. In such a case the company’s readiness score within the dimension “Smart products” is  $25/100*2=0.5$ .

The final step is to summarize the results and present them in a comprehensible manner. This can be done by creating tables for each dimension and its fields with determined levels and scores. The score represents the overall readiness for each dimension.

### 3.4 Modification of IMPULS Model

The original IMPULS model was created for assessing individual companies [22]; in this article, we assess SMEs in general through literature research. During our work we discovered that the original IMPULS model did not exactly fit our needs, therefore we modified it. This section describes the changes in the original IMPULS model.

#### 3.4.1 Chosen Dimensions and Fields

The findings of our literature study did not support one existing IMPULS dimension and several fields, as well as required a new dimension with new fields. The list below shows which dimension and fields were removed (crossed out) and which added (italic) for this study.

- Smart factory
  - ~~— Digital modeling~~
  - Equipment infrastructure
  - Data usage
  - IT systems
- Smart operations
  - Cloud usage
  - IT security
  - Autonomous processes
  - ~~— Information sharing~~
- ~~• Smart products~~
  - ~~— Data analytics in usage phase~~
  - ~~— ICT add-on functionalities~~
- Data-driven services
  - Data-driven services
  - ~~— Share of revenues~~
  - Share of data used
- Employees
  - Employee skill set
  - Skill acquisition
- Strategy and organization
  - Strategy
  - ~~— Investments~~



- Innovation management
- *Cost*
  - *Financial aid*
  - *Financial resources*
  - *Funding strategy*

The dimension “Smart products” was discarded because related to it literature findings were placed into “Smart factory” and “Smart operations”; the dimension “Smart products” was overlapping with the other two dimensions. The literature did not show sufficiently explicit information about the use of Industry 4.0 physical technologies to keep the dimension.

The field “Information sharing” was discarded because the literature did not show enough details regarding specific systems that are integrated and share information. “Digital modeling” and “Share of revenues” were left out because we did not find any information about adoption of Industry 4.0 by SMEs relevant to these fields.

An added dimension to the model is “Cost”. It was added because in the literature it was evident that economic factors play an important role for SMEs’ readiness to invest in Industry 4.0. The three fields for “Cost” are:

- *Financial aid* that means any subsidies or financial support from governmental organizations or other corporate projects that are aimed to help, among others, SMEs to move towards Industry 4.0;
- *Financial resources* that mean the available economic resources that a company can allocate in the business towards Industry 4.0;
- *Funding strategy* that means the company’s economic strategy to invest into Industry 4.0 concepts.

### 3.4.2 Minimum Requirements

In Table 2, all minimum requirements for all dimensions, fields and levels are stated. The majority of the requirements are taken from the original IMPULS model [22]. The model does not provide a description of the process how to create minimum requirements, therefore the reasoning for creating new minimum requirements has been based on the literature study findings applying the logic of the existing minimum requirements. The grey areas indicate requirements that have been created by the authors due to either being them absent from the IMPULS model (this was the case for the fields “Skill acquisition”) or being a new dimension created by the authors (the “Cost” dimension).

### 3.4.3 Assessing Readiness Levels

Appendix C shows 48 quotes that were extracted from the literature in order to illustrate particular features of the relationships between SMEs and Industry 4.0. We placed the quotes into appropriate readiness levels of each IMPULS field. The criteria for placing the quotes were: (1) the top-down approach from the highest minimum requirement to the lowest minimum requirement was applied when matching the message conveyed by the quote to the readiness levels, (2) the concepts in a quote were compared to the concepts in the minimum requirements of a readiness level, (3) two authors of this article agreed upon the placement of a quote, (4) a quote appears in only one field, meaning no cross-use of the quotes between the fields.

When all the fields in a dimension have their readiness level set, the lowest field level is assigned as the readiness level for the entire dimension. We call this level assignment approach AP1.

AP1 resulted in mostly 0 readiness levels for the dimensions, therefore, we designed another approach, AP2, with the aim to obtain more varied readiness levels. In AP2, we were looking for a field-level with the largest number of quotes, and assigned that field-level as the readiness level for the entire dimension.

**Table 2.** Minimum requirements

Fields	Level 0	Level 1	Level 2	Level 3	Level 4	Level 5
<b>Smart factory</b>						
Equipment infrastructure	Machine and system infrastructure cannot be controlled through IT, no integration (M2M)	Some machines can be controlled through IT, are interoperable, or have M2M capability	Machine and system infrastructure can be controlled to some extent through IT, is interoperable or integrated	Machine and system infrastructure can be controlled through IT and is partially integrated	Machinery can be controlled completely through IT, is partially integrated (M2M) or interoperable	Machines and systems can be controlled almost completely through IT and are fully integrated (M2M)
Data usage	No data available for further use	No data available for further use	Data is used for a few selected purposes (greater transparency, etc.)	Some data used to optimize processes (predictive maintenance, etc.)	Data used in several areas for optimization	Data used for comprehensive process optimization
IT systems	No support through IT systems	Main business process supported by IT systems	Some areas of the business are supported by IT systems and are integrated	Some areas of the business are supported by IT systems and are integrated one with another	Complete IT support of processes, full integration	IT systems support all company processes and are integrated
<b>Smart operations</b>						
Cloud usage	Cloud solutions not in use	Cloud solutions not in use	Cloud solutions not in use	Initial solutions planned for cloud-based software, data storage, and data analysis	Initial solutions implemented	Multiple solutions implemented
IT security	No IT security solutions in development or implemented	Initial IT security solutions planned	Multiple IT security solutions are planned or initial solutions are in development	IT security solutions have been partially implemented	Comprehensive IT security solutions have been implemented, existing gaps are being closed	IT security solutions have been implemented for all relevant areas
Autonomous processes	Autonomously guided workpieces not in use. Self-reacting processes not in use	Autonomously guided workpieces not in use. Self-reacting processes not in use	Autonomously guided workpieces not in use. Self-reacting processes not in use	Autonomously guided workpieces not in use. Self-reacting processes not in use	Experiments in test and pilot phase	Use in selected areas or even cross-enterprise

<b>Data-driven services</b>						
Data-driven services	No data-driven services offered	Data-driven services are offered, but without customer integration	Data-driven services are offered, but without customer integration	Data-driven services are offered, but without customer integration	Data-driven services are offered with customer integration	Data-driven services are fully integrated into the business model (integration with the customers)
Share of data used	Data not used	Data not used	0–20% of collected data is used	20–50% of collected data is used	20–50% of collected data is used	More than 50% of collected data is used
<b>Employees</b>						
Employee skill set	No skills	Employees have at least low skill levels in one relevant area	Employees have at least low skill levels in a few relevant areas	Employees have adequate skill levels in some relevant areas	Employees have adequate skill levels in several relevant areas	Employees possess all necessary skills in several relevant areas
Skill acquisition	No plans to hire new competent employees nor train current employees	Investigation regarding hiring new competent employees or training current employees	Some plans to hire new competent employees or train current employees	Some new competent employees hired or trained current employees	Multiple new competent employees hired or training of current employees in progress	Sufficient competent employees hired or continuous training of current employees
<b>Strategy and organization</b>						
Strategy	Industry 4.0 is not part of the strategic process	Industry 4.0 is an issue at the departmental level but is not integrated into the strategy	Industry 4.0 is part of the strategic process, and a strategy is being developed	An Industry 4.0 strategy has been defined	An Industry 4.0 strategy is in implementation	An Industry 4.0 strategy has been implemented enterprise wide
Innovation management	No innovation management	No innovation management	No innovation management	Innovation management in isolated areas	Innovation management implemented in several departments	Uniform, inter-departmental innovation management has been established
<b>Cost</b>						
Financial aid	No aid	No aid	No aid	Some aid	Some aid	Multiple aids
Financial resources	No sufficient resources	No sufficient resources	Some resources	Some resources	Sufficient resources	Resources not an issue
Funding strategy	No funding strategy	No funding strategy	Some strategy towards investing in Industry 4.0	Some strategy towards investing in Industry 4.0	Good strategy towards investing in Industry 4.0	Well established strategy towards investing in Industry 4.0

### 3.4.4 Assessing Readiness Scores

In the original IMPULS process (Section 3.3), each dimension gets *importance points* as a subjectively assigned weight, where the sum of the weights across all the dimensions is 100. We calculated importance points of a dimension as the percentage of the quotes that were assigned to the dimension during the assessment of the readiness level in the previous subsection. For instance, if a dimension has 8 quotes, and there are 48 quotes in total, then the importance points of the dimension are  $(8/48) \cdot 100 \approx 16.67$ .

The *readiness score* of a dimension is calculated as the importance points of the dimension multiplied by the readiness level of the dimension. AP1 and AP2 generate different readiness levels of the dimension and, hereby, different readiness scores.

## 4 Results

The results of the literature study are two-fold. First, we present challenges, opportunities, and preparedness of SMEs for Industry 4.0 according to the literature study (Section 4.1). Then we assess readiness of SMEs for Industry 4.0 by applying the modified IMPULS model (Section 4.2).

Although the geographic scope of our survey was global, the research on Industry 4.0 proved geographically biased. Figure 1 gives an estimation of the countries and parts of the world mentioned in our literature review, and suggests that our literature study leans towards a more western perspective.

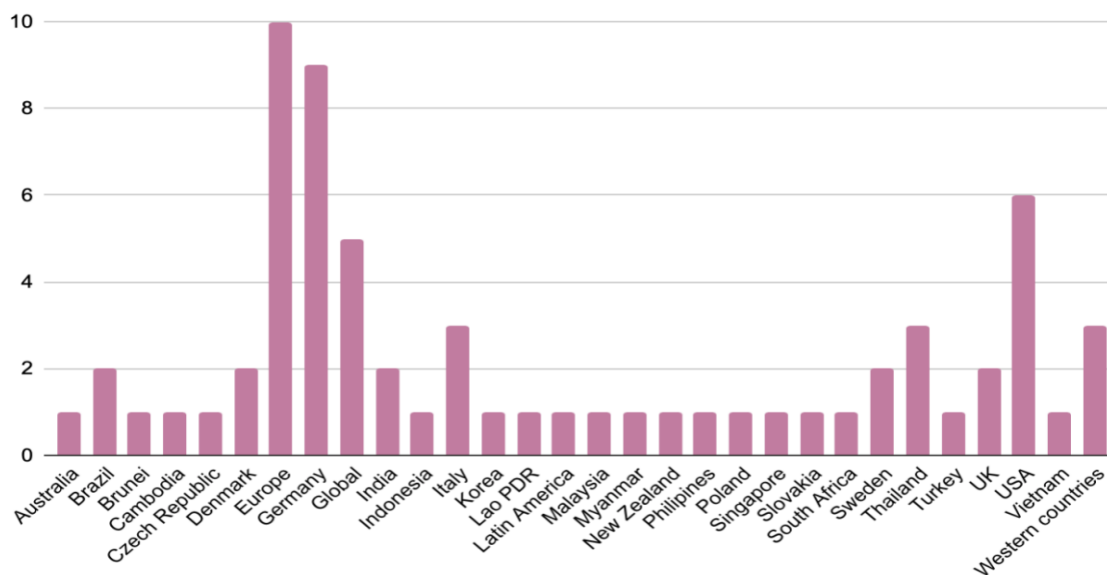


Figure 1. Geographical spread

### 4.1 Challenges, Opportunities, and Preparedness of SMEs for Industry 4.0

Table 3 summarizes the literature review findings detailed in Appendix A. The selective codes from our literature analysis by grounded theory (see Section 2) represent the main categories and subcategories. The quotes from the literature support their respective subcategories. A full list of articles used in the literature review can be found in Appendix B. The quotes are listed in Appendix C.

**Table 3.** Literature review findings concerning challenger opportunities and preparedness

Main categories	Subcategories	Quotes
Challenges	Cost	Q6, Q5, Q7, Q3, Q4
	Lack of competencies	Q30, Q26, Q22, Q23, Q29, Q27, Q28
	Technological issues	Q14, Q10, Q13, Q12, Q15, Q48
	Organizational issues	Q31, Q33, Q41, Q42, Q32, Q37
Opportunities	Corporate collaboration	Q11, Q24, Q25, Q2, Q20
	Good preconditions	Q43, Q45, Q44, Q39
	Mass customization	Q46, Q40, Q16, Q47, Q17, Q18, Q19, Q8
Preparedness	Governmental influence	Q9, Q1, Q38
	Knowledge level	Q34, Q21
	SME requirement specification	Q36, Q35

#### 4.1.1 Challenges

The main category “Challenges” has subcategories *Cost*, *Lack of competencies*, *Technological issues* and *Organizational issues*. *Cost* turned out to be a challenge which involves economic aspects for SMEs in terms of affording an implementation of Industry 4.0. Examples of such *Costs* are not sufficient funds for the latest technology (Q4) and fewer resources in terms of budget and qualified work forces (Q5). *Lack of competencies* is about employees’ skills already at hand and skills required for using Industry 4.0 technologies within the organization. Examples of *Lack of competencies* are lack of knowledge or expertise when it comes to technologies and its applications (Q29), the challenge of having many and new IT areas (Q26), and the high cost and competition of the staff (Q27). *Technological issues* cover the challenges SMEs face with integration and configuration of various Industry 4.0 technologies in the business. Examples of *Technological issues* are the challenge of having new concepts that are not so simple for SMEs to adapt (Q12) and also the issues regarding data security (Q10). Lastly, the *Organizational issues* cover the challenges for SMEs like the size and complexity of the business and finding a suitable implementation strategy (Q37).

#### 4.1.2 Opportunities

The main category “Opportunities” has three related subcategories. *Corporate collaboration* means collaborations or formed partnerships, for instance, between SMEs and governments. Examples of *Corporate collaboration* are multiple governmental initiatives ongoing in Europe (Q1) as well as globally (Q20, Q22) and could also be collaborations between established enterprises and small companies. *Good preconditions* mean strengths SMEs hold for an organizational transformation like Industry 4.0 implementation, by simply being a SME. SMEs typically are smaller in size, thus more flexible, have less complexity and have an advantage when it comes to changes due to these characteristics (Q43). *Mass customization* is a combination of flexibility and personalization which Industry 4.0 supports by using a combination of smart technologies and big data analysis. This is an important opportunity for SMEs to optimize their business offers to customers and stay competitive (Q8, Q40).

#### 4.1.3 Preparedness

The last main category, “Preparedness”, relates to the company’s current preparedness and maturity level for a digital transformation such as Industry 4.0 implementation, according to the literature. Preparedness is categorized into three subcategories. *Governmental influence* on a national level, such as organizational initiatives or governmental projects, affects SMEs’ approach for Industry 4.0 implementation. It is evident that developed countries and developing countries have different approaches to implementing Industry 4.0 depending on the type of government (Q38). *Knowledge level* for a SME could be the awareness of some areas required for implementation of Industry 4.0. SMEs need to have a certain knowledge level to be sure when and how they should implement Industry 4.0 (Q34). Hence, it affects the drive for an SME to initiate an implementation process. A *SME requirement specification* is a kind of requirement evaluation needed to define the vision, aims, goals, available resources and standards in order to

start preparing and adapt to an implementation of Industry 4.0. SMEs can use requirement specifications to structure the business needs, however, it is a very difficult task for SMEs to do and they struggle with that task (Q35). SMEs are in need to do these activities, but are currently not able to (Q36).

## 4.2 Readiness of SMEs for Industry 4.0

The SMEs' readiness levels for Industry 4.0 by IMPULS (the process described in Sections 3.4.3) are presented in Table 4. The quotes used in the assessment are listed in Appendix C. In order to assess the readiness level for a dimension, two approaches, AP1 and AP2, have been used.

### 4.2.1 Level 0: Outsider

**According to AP1**, SMEs have the readiness level 0 in the dimensions “Smart operations”, “Employees” and “Strategy and organization”. This means that SMEs are generally outsiders in these business areas related to Industry 4.0, meaning they have no knowledge about Industry 4.0 or have not yet done anything to move towards it. **According to AP2**, there are two dimensions with the level 0, namely “Smart operations” and “Employees”. This indicates that SMEs are considered outsiders for these two dimensions as well.

What can be determined in the results of the two approaches is that “Smart Operations” and “Employees” are definitely on level 0. “Strategy and organization” differs in both approaches, AP2 results in a higher level than AP1. The low level for “Smart operations” according to AP1 is supported by the subcategory *Technological issues*, which is about SMEs' challenge to integrate and configure technologies that would lead to autonomous processes, which is one pillar of Industry 4.0.

Q13: “... the degree of automation in SMEs is on average currently rather low, which results in a high dependency on employees' expertise, which has grown over the years and cannot easily be externalized and transferred into program code.”

Why dimension “Employees” has such a low level can be understood through the challenge *Lack of competencies* which the quote Q29 describes as:

Q29: “[...] the lack of knowledge or expertise regarding the possibility and potential of using the current technology and its applications. This has been a major problem with SMEs where more than 50% of the companies having faced difficulties to fill vacancies for IT specialists in 2016 and about 30% of companies working without their own websites.”

“Strategy and organization” according to AP1 is lower than to AP2; but both approaches do not have a big difference since they both result in relatively low levels 0 and 1. The reason for level 0 can be argued by *Organizational issues*, meaning SMEs' challenges to form a comprehensive strategy for Industry 4.0 and this may be due to their small size. This is confirmed by:

Q37: “[...] many leaders of SMEs do not have a comprehensive strategy regarding Industry 4.0 to gain an appropriate maturity level. The smaller the company size, the more likely this is to be the case.”

### 4.2.2 Level 1: Beginner

When it comes to the dimensions “Cost”, “Smart factory” and “Data-driven services” for **AP1**, the level is 1. This means that SMEs are on the beginner level where they have taken some actions towards Industry 4.0, for instance, pilot studies, and having system compatibility to Industry 4.0 with some planned IT security. The results of **AP2** show that “Smart operations” and “Strategy and organization” are also on the beginner level. It is interesting to note that “Smart operations” and “Strategy and organization” have a higher level here than in AP1.

Why the dimension “Cost” is on level 1 and not higher could be because the majority of SMEs simply cannot afford latest technologies.

Q4: “Generally, all over the world, small and medium-sized enterprises often do not have sufficient funds to invest in the latest technologies and must allocate capital very effectively and carefully.”

**Table 4.** Readiness assessment results

Dimension and fields		Level 0	Level 1	Level 2	Level 3	Level	Overall level AP1	Overall level AP2
Cost	Financial aid			Q2	Q1	2	1	2
	Financial resources		Q4	Q3, Q5		1		
	Funding strategy		Q7	Q6	Q8	1		
Dimension and fields		Level 0	Level 1	Level 2	Level 3	Level	Overall level AP1	Overall level AP2
Smart operations	Cloud usage				Q9	3	0	0/1
	IT security		Q10, Q11			1		
	Autonomous process	Q12, Q13				0		
Dimension and fields		Level 0	Level 1	Level 2	Level 3	Level	Overall level AP1	Overall level AP2
Smart factory	Equipment infrastructure			Q14, Q15		2	1	2
	Data usage			Q16, Q17, Q18		2		
	IT systems		Q20, Q21	Q19		1		
Dimension and fields		Level 0	Level 1	Level 2	Level 3	Level	Overall level AP1	Overall level AP2
Employees	Employee skill set	Q23, Q25	Q22, Q24			0	0	0
	Skill acquisition	Q27, Q28, Q29	Q26, Q30			0		
Dimension and fields		Level 0	Level 1	Level 2	Level 3	Level	Overall level AP1	Overall level AP2
Strategy and organization	Strategy	Q32, Q34	Q21, Q33, Q35, Q36, Q37, Q38			0	0	1
	Innovation management		Q42	Q41	Q39, Q40, Q43, Q44, Q45	1		
Dimension and fields		Level 0	Level 1	Level 2	Level 3	Level	Overall level AP1	Overall level AP2
Data-driven services	Data-driven services		Q46			1	1	2
	Share of data used			Q47, Q48		2		

However, since the dimension “Cost” is not on the lowest level but on the beginner one, it means there is some progress being made in this dimension in terms of the readiness. Looking at the subcategory *Corporate collaboration*, SMEs have possibilities to create partnerships with other established companies and work with several governmental initiatives that aim to support SMEs’ shift to Industry 4.0 in the future. Furthermore, looking at the subcategory *Governmental influence*, it is supported again by another quote where it is stated that there are already many initiatives established for SMEs.

Q2: “The European Commission has presented the Digital Europe programme for the next EU financial period 2021–2027, which plans to invest in five main areas: supercomputers, Artificial Intelligence (AI), cybersecurity and trust, digital skills and ensuring a wide use of technologies across the economy and the society.”

Q1: “An overview of the European Commission shows that there are more than 30 national and regional initiatives at European level: e.g., Plattform Industrie 4.0 in Germany, Catapult in UK, Fabbrica Digitale in Italy, Made Different in Belgium, Industry du Futur in France, Produktion 2030 in Sweden, Made in Denmark, Smart Industry in Netherlands, Produtech in Portugal, Industria Conectada 4.0 in Spain, Production of the Future in Austria, Průmysl 4.0 in Czech Republic, Smart Industry SK in Slovakia and many others.”

Q40: “Innovative and agile start-ups and SMEs with no need to defend legacy business are widely entering the circular economy and Industry 4.0 field by providing new digital platforms and disruptive service solutions to maximize the value of products and materials. Partnerships between established and small companies hold great promise for disruptive new solutions.”

The dimension “Smart factory” receives, according to AP1, level 1 which indicates SMEs are beginners in this dimension. According to AP2, the dimension receives a higher level. Why level 1 is met in AP1 could be supported by the subcategory *Knowledge level* where it is found that SMEs possibly only follow trends and are not quite ready to implement Industry 4.0.

Q21: “[...] more than 50% of companies do not have well defined goals when adopting Industries 4.0 technologies, and just follow trends or what competitors are doing, and in doing so, adopt technologies that are not appropriate to its need.”

“Data-driven services” receives level 1 in AP1 and level 2 in AP2. Why it received level 1 can be justified as previous studies show that Industry 4.0 can be helpful to solve problems faster by enabling autonomous processes. Hence, SMEs are beginning to see the benefits of Industry 4.0 rather than just the challenges of it.

Q47: “I 4.0 help firms to identify the problem in realistic approach known as digital lean. By reducing the waste through eliminating non-value added activities using sensors, robots, data analytics and automation ...”

When following AP2, “Smart operations” and “Strategy and organization” receive level 1 instead of level 0. Here it is difficult to tell which level is appropriate for “Smart operations” since it is divided between the two levels. A possible argument for why this dimension is on level 1 could be that governments have already begun to help SMEs to adopt digital transformation.

Q20: “Digital transformation has been for a long time on the EU agenda and the initiatives adopted at European level facilitate the access to finance, technologies, knowledges for enterprises, notably for SMEs.”

For “Strategy and organization”, the higher level according to AP2 could be supported with the quote Q36 below, stating that investments are being made, but are often evaded. Also, the quote is placed in the subcategory *SME requirement specification*, indicating that potentially the requirement specification process is lacking.

Q36: “Moreover, SMEs tend to avoid technologies with uncertain results, so investments as early adopters are often evaded, due to the risk of investing in the wrong technologies. This conservative investment strategy has shortcomings, as researchers highlight the importance of identifying new technological trends early and of promptly responding to them.”

The subcategory *Good preconditions* perhaps shows that SMEs are opportunistic when it comes to strategy and organization. As quote Q45 below implies, a good precondition SMEs have is their ability to implement digital transformation much faster than larger companies can. This might be because of SMEs’ flexibility and small size.

Q45: “SMEs are most likely to be the big winners from the shift; they are often able to implement the digital transformation more rapidly than large enterprises, because they can develop and implement new IT structures from scratch more easily. Many small- and medium-sized companies are already focusing on digitized products in order to stand out in the market.



The integration of information and communication technology (ICT) and modern Industry 4.0 technologies would transform today’s SME factories into smart factories with significant economic potential.”

#### 4.2.3 Level 2: Intermediate

According to **AP1**, no dimension receives level 2, while according to **AP2** the dimensions “Cost”, “Smart factory” and “Data-driven services” receive level 2. The intermediate level indicates that SMEs have implemented a strategy for Industry 4.0 and initiated investments, infrastructure, in-house information sharing and some skills exist to some extent and also have sufficient IT security. It is interesting to note that if AP1 solely was used, SMEs would not have reached a higher level than 1.

The reason why dimension “Cost” has received level 2 in AP2 can be that SMEs are at the learning stage when it comes to *Mass customization*. The studies have been made on the main advantages of mass customization, which is supported by implementing Industry 4.0.

Q8: “Main advantages of mass customization: ...Lower cost of material waste and inventory – it is a contract production, it is not necessary for the company to have a stock of finished products; ... Faster cash flow: quick production – quick turnaround; ... The manufacturer's ability to offer a wide range of products with low production costs – various product types with the same basic components but different final design will allow manufacturers to offer a whole range of products to satisfy every customer.”

Since dimension “Smart factory” is one of the key concepts of Industry 4.0, it might not be surprising it is on level 2 in AP2. An argument for this could be the rise of technologies such as machine learning. It can be an opportunity for SMEs, which supports *Mass customization* where the quote below states opportunities with machine learning.

Q18: “The most innovative element of Industry 4.0 is the capacity of machines to solve a problem faster than before, due to the increasing information captured by the system: the so-called machine learning.”

For the dimension “Data-driven services” the level 2 is reached since SMEs seem to be gathering information, but face some challenges in putting the information to use. In the subcategory *Technological issues* the quote Q48 states that investments in information gathering are made, but difficulties appear when trying to do something with the gathered data.

Q48: “[...] value creation challenges can develop into value offer challenges. This is reflected by companies, which invest in gathering information through Industry 4.0 technologies, while facing challenges in putting the information to commercial use.”

#### 4.2.4 Readiness Scores

The importance points and readiness scores are calculated as described in Section 3.4.4. Our calculated values are presented in Table 5. “Smart operations” have been given level 1 out of 0/1 in AP2 because no significant difference implies due to not being the most ready dimension in either case.

**Table 5.** Scores for each dimension

Dimensions	Importance Points	Overall level AP1	Readiness score AP1	Overall level AP2	Readiness score AP2
Cost	16.67	1	16.67	2	32.5
Smart operations	10.4	0	0	1	10.4
Smart factory	16.67	1	16.67	2	32.5
Employees	18.75	0	0	0	0
Strategy and organization	31.25	0	0	1	31.25
Data-driven services	6.25	1	6.25	2	12.5

For both AP1 and AP2, the most ready dimension is a tie between two dimensions, “Cost” and “Smart factory”. This could possibly tell that SMEs are focusing most on these two areas when implementing Industry 4.0.

The importance score is interesting because it suggests how popular a dimension is among scholars. It is easy to notice that the organizational dimensions (“Strategy and organization”, “Employees”) are more important than the technical ones (“Smart operations”, “Data driven services”). Arguably the sentiment among scholars is that, once the organization gets going, the technology is merely a matter of existence and implementation cost.

“Strategy and organization” is important: it does not matter how much money, technology, and competence a company has, the decision makers still need to know why, when and how these assets should be used to move towards Industry 4.0.

Technology is a human-resource problem more for SMEs than it is for large companies, and so is implementing new business models. The demand for highly skilled employees seems higher than availability of such employees, and large companies can afford paying higher salaries; this causes hiring difficulties for SMEs. All these challenges make “Employees” the second most important dimension, although lagging far behind the strategies.

## 5 Conclusions

This literature study explores adoption of Industry 4.0 by SMEs. By applying grounded theory, we have identified three main categories – challenges, opportunities, preparedness – and ten subcategories that designate the state of the art of the adoption (Table 3).

In order to assess the readiness of SMEs for Industry 4.0, we have applied the modified IMPULS model (Section 3.4) and mapped our literature findings into the readiness fields and dimensions of the model (Table 4). An assessment of relative importance of the dimensions (Table 5) shows that the organizational dimensions – strategies and human resources – are more important for successful adoption of Industry 4.0 than the technical ones. The main takeaways from our literature study are following.

1. SMEs need help with developing individual, company-specific strategies for adoption of Industry 4.0 – why, when, and how Industry 4.0 should be implemented at the company.
2. SMEs need better access to skilled employees who would implement the technology and business models of Industry 4.0. Solving these two needs would be a major break-through on the SMEs’ journey towards Industry 4.0.
3. The opportunities that help SMEs adopt Industry 4.0 are flexibility and ability to embrace innovation, cloud computing; and public investments into science, technology, as well as into adoption of Industry 4.0 by companies.

The answer to the research question “to which extent SMEs are ready to embrace Industry 4.0” is “not much”. The readiness level according to the IMPULS model is no higher than the level “Intermediate” (Table 4); SMEs are still learners of Industry 4.0.

### 5.1 Societal Consequences

The societal consequences of the research contribute to the research field Industry 4.0 by showing the current status of SMEs. This is important because SMEs play a big role in the global economy and Industry 4.0 being the fourth revolution already present. Below is a list of societal consequences and its related stakeholders.

#### For researchers targeting SMEs

- *Readiness assessment*: This study contributes to the research field Industry 4.0 by presenting a readiness assessment of SMEs from a global perspective. The results show that the readiness level of SMEs is rather low, but they start to learn more about this new concept.

- *Choice of readiness model*: The readiness assessment is based on IMPULS, with minor changes. The results may have had a different outcome if another model was chosen. This study proves that IMPULS can be applicable to SMEs.

### **For business people working at or evolving a SME**

- *Two important dimensions*: The two important dimensions SMEs should start to look at are “Cost” and “Smart factory”. Cost implies that the company should set up a financial strategy, use available financial aid and establish the financial resources. Smart factory means that the company should define the needed IT systems (Industry 4.0 technologies), set up the equipment infrastructure and ensure all valuable data is used.
- *Main Industry 4.0 related challenges and benefits*: This study shows the main challenges and benefits SMEs have from a global perspective. Also, it presents which are the most important ones and how they are linked to each other showing what challenges need to be tackled in order to embrace the benefits.

## **5.2 Future Research**

This study has defined SMEs readiness level for Industry 4.0 from a global perspective (with a leaning towards a western perspective) based on a literature review. Future research can be made where this study’s readiness assessment can be used in practice for specific SMEs in different industries and different countries. Other future studies can focus on identifying strategies to depict how SMEs can approach Industry 4.0 in the best way, to optimize SMEs’ benefits and limit their challenges.

Regarding the list of societal consequences, future research can be made in each point of the list. For *readiness assessment*, future research can investigate different readiness assessments on national level instead of a global perspective to gather more in-depth details. A suggestion is to base the readiness assessment on national level by using case study as a method. Concerning *choice of readiness model*, future research can be made on developing a new model that is customized for a specific SME. A case study or survey approach could be utilized for gathering data for the new model. Concerning *two important dimensions*, future research, possibly in combination with developing a new model, could result in other important dimensions, which would be interesting to look further into.

Regarding the main Industry 4.0 related challenges and benefits for SMEs, future research could focus on these lessons learned to investigate in more detail on how to best prepare for Industry 4.0

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## Appendix A – Mapping Process Details

In the table below, the mapping of the chosen IMPULS dimensions can be seen in the 5th column. Column 1 and 2 represents the selective codes, which are defined as main categories found in the literature review process along with the subcategories. The categories were used to compare with the content in IMPULS. The axial codes are supported with quotes and mapped into fields that could be mapped into suitable dimensions (column 3–5).

Column 1	Column 2	Column 3		Column 4	Column 5
Main categories	Subcategories	Axial codes	Quotes	IMPULS fields and new fields	IMPULS dimensions and new dimensions
Challenges	Cost	Costs, Costs, Adaptability of CPS and Rollout Strategies, Cost, Cost	Q6, Q5, Q7, Q3, Q4	Funding strategy, Financial resources, Funding strategy, Financial resources, Financial resources	COST (New dimension, not original from IMPULS)
	Lack of competencies	Lack of competencies, Lack of competencies, Job losses, Job losses, Lack of competencies, Hiring, Hiring	Q30, Q26, Q22, Q23, Q29, Q27, Q28	Skill acquisition, Skill acquisition, Employee skill set, Employee skill set, Skill acquisition, Skill acquisition, Skill acquisition	EMPLOYEE
	Technological issues	Small amount of IT systems, IT security issues, Adaptability of CPS and Rollout Strategies, Adaptability of CPS and Rollout Strategies, Lessons learned, Data issues	Q14, Q10, Q13, Q12, Q15, Q48	Equipment infrastructure, IT security, Autonomous processes, Autonomous processes, Equipment infrastructure, Share of data used	Smart factory / Smart operations
	Organizational issues	Size matters, Lacking structure, Lacking structure, Lacking structure, Strategy issues, Adaptability of CPS and Rollout Strategies	Q31, Q33, Q41, Q42, Q32, Q37	Strategy, Innovation management, Innovation management, Strategy, Strategy	STRATEGY AND ORGANIZATION

Opportunities	Corporate collaboration	Collaboration with large companies, Collaboration with large companies, Collaboration with large companies, EU financial programme, Digital transformation	Q11, Q24, Q25, Q2, Q20	IT security, Employee skill set, Employee skill set, Financial aid, IT systems	Employee / Smart factory / Smart operations / Cost
	Good preconditions	Flexibility, Flexibility, Flexibility, Capture new opportunities	Q43, Q45, Q44, Q39	Innovation management, Innovation management, Innovation management, Innovation management	STRATEGY AND ORGANIZATION
	Mass customization	Servitization, Innovative SMEs, Data analysis, Lean data approach, Supply chain, Machine learning, AI, Mass customization	Q46, Q40, Q16, Q47, Q17, Q18, Q19, Q8	Data-driven services, Innovation management, Data usage, Share of data used, Data usage, Data usage, IT security, Funding strategy	Data-driven services / Smart operations
Preparedness	Governmental influence	Use of Cloud services, Aiding project, Policies	Q9, Q1, Q38	Cloud usage, Financial aid, Strategy	Smart factory / Cost / Strategy and organization
	Knowledge level	Low preparedness, Keeping up with trends	Q34, Q21	Strategy, IT systems	Strategy and organization / Smart operations
	SME requirement specification	Identify requirements, Identify requirements	Q36, Q35	Strategy, Strategy	STRATEGY AND ORGANIZATION

## Appendix B – Literature Review References

Below is a list of the literature included in the literature review.

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## Appendix C – Quotes and Fields

Fields	Quote list	Quote number	Reference
Financial aid	page 10: “An overview of the European Commission shows that there are more than 30 national and regional initiatives at European level: e.g., Plattform Industrie 4.0 in Germany Catapult in UK, Fabbrica Digitale in Italy, Made Different in Belgium, Industry du Futur in France, Produktion 2030 in Sweden, Made in Denmark, Smart Industry in Netherlands, Produtech in Portugal, Industria Conectada 4.0 in Spain, Production of the Future in Austria, Průmysl 4.0 in Czech Republic, Smart Industry SK in Slovakia and many others.”	Q1	D. T. Matt and E. Rauch, “SME 4.0: The Role of Small-and Medium-Sized Enterprises in the Digital Transformation,” <i>Industry 4.0 for SMEs</i> , Palgrave Macmillan, pp. 3–36, 2020. Available: <a href="https://doi.org/10.1007/978-3-030-25425-4_1">https://doi.org/10.1007/978-3-030-25425-4_1</a>
Financial aid	page 2: “The European Commission has presented the Digital Europe programme for the next EU financial period 2021-2027, which plans to invest in five main areas: supercomputers, Artificial Intelligence (AI), cybersecurity and trust, digital skills and ensuring a wide use of technologies across the economy and the society”	Q2	C. Ristuccia, “Industry 4.0: SMEs Challenges and Opportunities in the Era of Digitalization,” <i>ZEI Discussion Paper</i> , C 252/2019, pp. 1–25, 2019.
Financial resources	page 4551: “Moreover, several i4.0 technologies are still under development and it is challenging for small and medium-sized enterprises to dedicate resources for these technologies. They would in several cases prefer to use these technologies as off-the-shelf products (instead of developing in-house) to achieve product innovation.”	Q3	M. Andulkar, D. T. Le, and U. Berger, “A multi-case study on Industry 4.0 for SME’s in Brandenburg, Germany,” <i>Proceedings of the 51st Hawaii International Conference on System Sciences</i> , pp. 4544–4553, 2018. Available: <a href="https://doi.org/10.24251/HICSS.2018.574">https://doi.org/10.24251/HICSS.2018.574</a>
Financial resources	page 4: “Generally, all over the world, small and medium-sized enterprises often do not have sufficient funds to invest in the latest technologies and must allocate capital very effectively and carefully.”	Q4	M. Ingaldi and R. Ulewicz, “Problems with the Implementation of Industry 4.0 in Enterprises from the SME Sector,” <i>Sustainability, MDPI, Open Access Journal</i> , vol. 12, no. 1, pp. 1–18, 2019. Available: <a href="https://doi.org/10.3390/su12010217">https://doi.org/10.3390/su12010217</a>
Financial resources	page 150: “Compared to bigger companies, SMEs have at their disposal fewer resources in terms of budget and qualified workforces for doing research and innovation actions.”	Q5	P. Dallasega, M. Woschank, H. Zsifkovits, K. Tippayawong, and C. A. Brown, “Requirement Analysis for the Design of Smart Logistics in SMEs,” <i>Industry 4.0 for SMEs</i> , Palgrave Macmillan, pp. 147–162, 2020. Available: <a href="https://doi.org/10.1007/978-3-030-25425-4_5">https://doi.org/10.1007/978-3-030-25425-4_5</a>
Funding strategy	page 85: “Although there are some efforts of providers to adapt their offerings to the needs of small- and medium-sized enterprises (SMEs), usually their primary customers are large organizations able to afford such costs.”	Q6	R. A. Rojas and M. A. R. Garcia, “Implementation of Industrial Internet of Things and Cyber-Physical Systems in SMEs for Distributed and Service-Oriented Control,” <i>Industry 4.0 for SMEs</i> , Palgrave Macmillan, pp. 73–103, 2020. Available: <a href="https://doi.org/10.1007/978-3-030-25425-4_3">https://doi.org/10.1007/978-3-030-25425-4_3</a>

Funding strategy	page 5: “SMEs doubt that the investment in CPPS and Industry-4.0 technologies will amortize within an economically acceptable time span”	Q7	T. Ludwig, C. Kotthaus, M. Stein, V. Pipek, and V. Wulf, “Revive old discussions! Socio-technical challenges for small and medium enterprises within Industry 4.0,” <i>Proceedings of 16th European Conference on Computer-Supported Cooperative Work-Exploratory Papers. European Society for Socially Embedded Technologies (EUSSET)</i> , 2018. Available: <a href="https://doi.org/10.18420/ecscw2018_15">https://doi.org/10.18420/ecscw2018_15</a>
Funding strategy	page 628: “Main advantages of mass customization: ...o Lower cost of material waste and inventory - it is a contract production, it is not necessary for the company to have a stock of finished products; ... o Faster cash flow: quick production - quick turnaround; ... o The manufacturer's ability to offer a wide range of products with low production costs - various product types with the same basic components but different final design will allow manufacturers to offer a whole range of products to satisfy every customer.”	Q8	L. Safar, J. Sopko, S. Bednar, and R. Poklemba, “Concept of SME business model for Industry 4.0 environment,” <i>TEM Journal</i> , vol. 7, no. 3, pp. 626–637, 2018. Available: <a href="https://doi.org/10.18421/TEM73-20">https://doi.org/10.18421/TEM73-20</a>
Cloud usage	page 8: “[...] clouds assist in the outsourcing of data storage and data sharing with partners. In order to receive widespread acceptance in SMEs, such platforms need to be easily accessible, secure, and efficient in usage.”	Q9	J. M. Müller, O. Buliga, and K. I. Voigt, “Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0,” <i>Technological Forecasting and Social Change</i> , vol. 132, pp. 2–17, 2018. Available: <a href="https://doi.org/10.1016/j.techfore.2017.12.019">https://doi.org/10.1016/j.techfore.2017.12.019</a>
IT security	page 252: “At the same time, this industrial revolution brings some challenges regarding data security, finding the needed capital, developing a strategy for implementing it and finding qualified employees.”	Q10	G. Orzes, R. Poklemba, and W. T. Towner, “Implementing Industry 4.0 in SMEs: A Focus Group Study on Organizational Requirements,” <i>Industry 4.0 for SMEs</i> , Palgrave Macmillan, pp. 251–277, 2020. Available: <a href="https://doi.org/10.1007/978-3-030-25425-4_9">https://doi.org/10.1007/978-3-030-25425-4_9</a>
IT security	page 4: “This enables a much higher degree of transparency and efficiency in transactions compared to the third Industrial Revolution and brings new questions in the already established debate on cyber security”	Q11	J. M. Müller, O. Buliga, and K. I. Voigt, “Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0,” <i>Technological Forecasting and Social Change</i> , vol. 132, pp. 2–17, 2018. Available: <a href="https://doi.org/10.1016/j.techfore.2017.12.019">https://doi.org/10.1016/j.techfore.2017.12.019</a>
Autonomous processes	page 5: “Current Industry 4.0 concepts and technologies, such as cyber-physical production systems, focus on large-scale production with autonomous modifications of the internal and external supply chain. These concepts cannot simply be adapted by SME, as they operate in niche markets and often create individual pieces in accordance with special customer requirements.”	Q12	T. Ludwig, C. Kotthaus, M. Stein, V. Pipek, and V. Wulf, “Revive old discussions! Socio-technical challenges for small and medium enterprises within Industry 4.0,” <i>Proceedings of 16th European Conference on Computer-Supported Cooperative Work-Exploratory Papers. European Society for Socially Embedded Technologies (EUSSET)</i> , 2018. Available: <a href="https://doi.org/10.18420/ecscw2018_15">https://doi.org/10.18420/ecscw2018_15</a>

Autonomous processes	page 5: "... the degree of automation in SMEs is on average currently rather low, which results in a high dependency of employees' expertise, which has grown over the years and cannot easily be externalized and transferred into program code."	Q13	T. Ludwig, C. Kotthaus, M. Stein, V. Pipek, and V. Wulf, "Revive old discussions! Socio-technical challenges for small and medium enterprises within Industry 4.0," <i>Proceedings of 16th European Conference on Computer-Supported Cooperative Work-Exploratory Papers. European Society for Socially Embedded Technologies (EUSSET)</i> , 2018. Available: <a href="https://doi.org/10.18420/ecscw2018_15">https://doi.org/10.18420/ecscw2018_15</a>
Equipment infrastructure	page 85: "... we suggest that OSS and open standards are also key enablers of IIoT in SME. To support this statement, we observe that SMEs have a relatively small amount of digital systems and processes to be integrated, thus they may be able to afford to develop in-house software applications. Moreover, thanks to the source code availability, OSS gives SMEs the possibility of developing highly customized and lean solutions based on their know-how."	Q14	R. A. Rojas and M. A. R. Garcia, "Implementation of Industrial Internet of Things and Cyber-Physical Systems in SMEs for Distributed and Service-Oriented Control," <i>Industry 4.0 for SMEs</i> , Palgrave Macmillan, pp. 73–103, 2020. Available: <a href="https://doi.org/10.1007/978-3-030-25425-4_3">https://doi.org/10.1007/978-3-030-25425-4_3</a>
Equipment infrastructure	page 1165: "• SME's must work strategically with production that makes more long-term planning possible and consistent. • The planning and control systems must be simple and efficient solutions to support personal at the shop floor, to make right decisions. • Focus at Lean tools to reduce waste and create flow, to prepare for automation. • SME's must think smart in simple Lean Automation solutions, that may be specific to the individual companies, but still there are some general learnings and benchmarking between companies."	Q15	D. Grube, A. A. Malik, and A. Bilberg, "Generic Challenges and Automation Solutions in Manufacturing SMEs," <i>Annals of DAAAM &amp; Proceedings</i> , pp. 1161–1169, 2017. Available: <a href="https://doi.org/10.2507/28th.daaam.proceedings.161">https://doi.org/10.2507/28th.daaam.proceedings.161</a>
Data usage	page 137: "The key areas where data analysis helps I 4.0 are predicting machine health, transparent supply chain, reduction labor cost, better working environment, energy saving and maintenance schedule."	Q16	C. Ristuccia, "Industry 4.0: SMEs Challenges and Opportunities in the Era of Digitalization," <i>ZEI Discussion Paper, C 252/2019</i> , pp. 1–25, 2019.
Data usage	page 6: "The availability of such data generates an added value in terms of range of services and efficiency in managing supply chains. Furthermore, businesses can define customer needs in real time and respond to specific trends."	Q17	C. Ristuccia, "Industry 4.0: SMEs Challenges and Opportunities in the Era of Digitalization," <i>ZEI Discussion Paper, C 252/2019</i> , pp. 1–25, 2019.
Data usage	page 6: "The most innovative element of Industry 4.0 is the capacity of machines to solve a problem faster than before, due to the increasing information captured by the system: the so-called machine learning."	Q18	C. Ristuccia, "Industry 4.0: SMEs Challenges and Opportunities in the Era of Digitalization," <i>ZEI Discussion Paper, C 252/2019</i> , pp. 1–25, 2019.
IT systems	page 7: "AI could be an important tool to address socio-economic	Q19	C. Ristuccia, "Industry 4.0: SMEs Challenges and Opportunities in the Era of

	challenges and to pursue the human development, which raises new ethical, legal and even democratic issues. This technology will make machines and robots able to interact with each other and above all will enable them to learn from the various situations. Automotive, aerospace, energy, pharmaceutical are the main sectors in which AI has been already applied.”		Digitalization,” <i>ZEI Discussion Paper, C 252/2019</i> , pp. 1–25, 2019.
IT systems	page 13: “Digital transformation has been for a long time on the EU agenda and the initiatives adopted at European level facilitate the access to finance, technologies, knowledges for enterprises, notably for SMEs.”	Q20	C. Ristuccia, “Industry 4.0: SMEs Challenges and Opportunities in the Era of Digitalization,” <i>ZEI Discussion Paper, C 252/2019</i> , pp. 1–25, 2019.
IT systems	page 47: “[...] more than 50% of companies do not have well-defined goals when adopting Industries 4.0 technologies, and just follow trends or what competitors are doing, and in doing so, adopt technologies that are not appropriate to its need.”	Q21	T. B. de Sousa, F. M. Guerrini, and M. Coghi, “Main objectives and barriers of the enterprise adaptation project to Industry 4.0: a case study in a technologies supplier company,” <i>2nd International Symposium on Supply Chain 4.0</i> , pp. 43–48, 2018.
Employee skill set	page 20: “Industry 4.0 technologies are also rapidly increasing jobs that can be performed better and faster by machines rather than by people. While these may reduce costs and raise productivity, they will also threaten jobs, and some members of ASEAN will be more affected than others. The immediate threats are to low-skilled, repetitive jobs such as those by assembly line workers.”	Q22	V. Anbumozhi and F. Kimura, “Industry 4.0: What Does it Mean for the Circular Economy in ASEAN?” <i>Industry</i> , vol. 4, pp. 1–35, 2018.
Employee skill set	page 193: “Loss of many jobs to automatic processes and IT-controlled processes, especially for lower educated parts of society.”	Q23	M. Jones, L. Zarzycki, and G. Murray, “Does Industry 4.0 Pose a Challenge for the SME Machine Builder? A Case Study and Reflection of Readiness for a UK SME,” <i>International Precision Assembly Seminar</i> , Springer, pp. 183–197, 2018. Available: <a href="https://doi.org/10.1007/978-3-030-05931-6_17">https://doi.org/10.1007/978-3-030-05931-6_17</a>
Employee skill set	page 8: “the results show that while most companies in the sample lack expertise in implementing Industry 4.0, this deficiency can open new doors for cooperation and value creation innovation with partnering companies and institutions”	Q24	J. M. Müller, O. Buliga, and K. I. Voigt, “Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0,” <i>Technological Forecasting and Social Change</i> , vol. 132, pp. 2–17, 2018. Available: <a href="https://doi.org/10.1016/j.techfore.2017.12.019">https://doi.org/10.1016/j.techfore.2017.12.019</a>
Employee skill set	page 6: “The SMEs revealed their lack of expertise for mastering such challenges as well as their derived need for external assistance, which can be provided by governmental institutions and by work groups of the trade community.”	Q25	J. M. Müller, O. Buliga, and K. I. Voigt, “Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0,” <i>Technological Forecasting and Social Change</i> , vol. 132, pp. 2–17, 2018. Available: <a href="https://doi.org/10.1016/j.techfore.2017.12.019">https://doi.org/10.1016/j.techfore.2017.12.019</a>
Skill acquisition	page 19: “Utmaningen för dessa företag består i att de måste hantera ett stort antal teknikområden som i	Q26	H. Bossen and J. Ingemansson, “Digitalisering av svensk industri- kartläggning av svenska styrkor och

	många fall dessutom är nya för dem.”		utmaningar.” Roland Berger AB på uppdrag av Vinnova, Stockholm, 2016 (in Swedish).
Skill acquisition	page 4: “Other problems are difficulties in hiring staff, the high cost of staff and big competition.”	Q27	M. Ingaldi and R. Ulewicz, “Problems with the Implementation of Industry 4.0 in Enterprises from the SME Sector,” <i>Sustainability, MDPI, Open Access Journal</i> , vol. 12, no. 1, pp. 1–18, 2019. Available: <a href="https://doi.org/10.3390/su12010217">https://doi.org/10.3390/su12010217</a>
Skill acquisition	page 4: “... lack of employees.”	Q28	M. Ingaldi and R. Ulewicz, “Problems with the Implementation of Industry 4.0 in Enterprises from the SME Sector,” <i>Sustainability, MDPI, Open Access Journal</i> , vol. 12, no. 1, pp. 1–18, 2019. Available: <a href="https://doi.org/10.3390/su12010217">https://doi.org/10.3390/su12010217</a>
Skill acquisition	page 4552: “Another factor is about the lack of knowledge or expertise regarding the possibility and potential of using the current technology and its applications. This has been a major problem with SMEs where more than 50% of the companies having faced difficulties to fill vacancies for IT specialists in 2016 and about 30% of companies working without their own websites.”	Q29	M. Andulkar, D. T. Le, and U. Berger, “A multi-case study on Industry 4.0 for SME’s in Brandenburg, Germany,” <i>Proceedings of the 51st Hawaii International Conference on System Sciences</i> , pp. 4544–4553, 2018. Available: <a href="https://doi.org/10.24251/HICSS.2018.574">https://doi.org/10.24251/HICSS.2018.574</a>
Skill acquisition	page 150: “... the results showed that education and qualification of employees is one of the main requirements for the implementation of Industry 4.0.”	Q30	P. Dallasega, M. Woschank, H. Zsifkovits, K. Tippayawong, and C. A. Brown, “Requirement Analysis for the Design of Smart Logistics in SMEs,” <i>Industry 4.0 for SMEs</i> , Palgrave Macmillan, pp. 147–162, 2020. Available: <a href="https://doi.org/10.1007/978-3-030-25425-4_5">https://doi.org/10.1007/978-3-030-25425-4_5</a>
Strategy	page 5: “The smaller SMEs are, the higher the risk that they will not be able to benefit from this revolution.”	Q31	D. T. Matt and E. Rauch, “SME 4.0: The Role of Small-and Medium-Sized Enterprises in the Digital Transformation,” <i>Industry 4.0 for SMEs</i> , Palgrave Macmillan, pp. 3–36, 2020. Available: <a href="https://doi.org/10.1007/978-3-030-25425-4_1">https://doi.org/10.1007/978-3-030-25425-4_1</a>
Strategy	page 288: “... It is obviously difficult to apply all Industry 4.0 concepts to SMEs due to the limitation of human resources, technology, and financial potential. Thus, SMEs should start their implementation of SMEs 4.0 concept with prioritized and appropriate measures.”	Q32	A. Sopadang, N. Chonsawat, and S. Ramingwong, “Smart SME 4.0 Implementation Toolkit,” <i>Industry 4.0 for SMEs</i> , Palgrave Macmillan, pp. 279–302, 2020. Available: <a href="https://doi.org/10.1007/978-3-030-25425-4_10">https://doi.org/10.1007/978-3-030-25425-4_10</a>
Strategy	page 150: “They emphasized specific barriers to Industry 4.0 implementation such as missing standardization and an inappropriate company strategy.”	Q33	P. Dallasega, M. Woschank, H. Zsifkovits, K. Tippayawong, and C. A. Brown, “Requirement Analysis for the Design of Smart Logistics in SMEs,” <i>Industry 4.0 for SMEs</i> , Palgrave Macmillan, pp. 147–162, 2020. Available: <a href="https://doi.org/10.1007/978-3-030-25425-4_5">https://doi.org/10.1007/978-3-030-25425-4_5</a>

Strategy	page 17: "...analyzes the readiness of Danish SMEs from the metal processing sector for Industry 4.0 using case study research. Up to this point, there was no maturity or readiness model available and thus the analysis was conducted basically on a qualitative level. The basic outcome is that SMEs at this time were not sure if, when and how they should start to introduce Industry 4.0 in their firms."	Q34	D. T. Matt and E. Rauch, "SME 4.0: The Role of Small-and Medium-Sized Enterprises in the Digital Transformation," <i>Industry 4.0 for SMEs</i> , Palgrave Macmillan, pp. 3–36, 2020. Available: <a href="https://doi.org/10.1007/978-3-030-25425-4_1">https://doi.org/10.1007/978-3-030-25425-4_1</a>
Strategy	page 6: "While many of those companies aim to establish an IT-facilitated, automated interconnection with suppliers and customers, they struggle with the resulting uncertainties and complexities, for instance in case of disturbances."	Q35	J. M. Müller, O. Buliga, and K. I. Voigt, "Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0," <i>Technological Forecasting and Social Change</i> , vol. 132, pp. 2–17, 2018. Available: <a href="https://doi.org/10.1016/j.techfore.2017.12.019">https://doi.org/10.1016/j.techfore.2017.12.019</a>
Strategy	page 8: "Moreover, SMEs tend to avoid technologies with uncertain results, so investments as early adopters are often evaded, due to the risk of investing in the wrong technologies. This conservative investment strategy has shortcomings, as researchers highlight the importance of identifying new technological trends early and of promptly responding to them"	Q36	J. M. Müller, O. Buliga, and K. I. Voigt, "Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0," <i>Technological Forecasting and Social Change</i> , vol. 132, pp. 2–17, 2018. Available: <a href="https://doi.org/10.1016/j.techfore.2017.12.019">https://doi.org/10.1016/j.techfore.2017.12.019</a>
Strategy	page 5: "[...] many leaders of SMEs do not have a comprehensive strategy regarding Industry 4.0 to gain an appropriate maturity level. The smaller the company size, the more likely this is to be the case."	Q37	T. Ludwig, C. Kotthaus, M. Stein, V. Pipek, and V. Wulf, "Revive old discussions! Socio-technical challenges for small and medium enterprises within Industry 4.0," <i>Proceedings of 16th European Conference on Computer-Supported Cooperative Work-Exploratory Papers. European Society for Socially Embedded Technologies (EUSSET)</i> , 2018. Available: <a href="https://doi.org/10.18420/ecscw2018_15">https://doi.org/10.18420/ecscw2018_15</a>
Strategy	page 15: "[...] developed countries have formulated national strategies and policies for incentivizing Industry 4.0 technologies, whereas developing countries have adopted Industry 4.0 technologies on a corporate level, relying on individual corporate initiatives rather than national and coordinated policies. The influencing barriers in developed and developing countries differ due to divergent policies for the advancement of Industry 4.0."	Q38	A. Raj, G. Dwivedi, A. Sharma, A. B. L. de Sousa Jabbour, and S. Rajak, "Barriers to the adoption of Industry 4.0 technologies in the manufacturing sector: An inter-country comparative perspective," <i>International Journal of Production Economics</i> , vol. 224, 2020. Available: <a href="https://doi.org/10.1016/j.ijpe.2019.107546">https://doi.org/10.1016/j.ijpe.2019.107546</a>
Innovation management	page 25: "Innovative SMEs and start-ups will be critical in capturing new opportunities offered by Industry 4.0. Many ASEAN countries already have innovation hubs and incubators at national level. To be competitive, however, new	Q39	V. Anbumozhi and F. Kimura, "Industry 4.0: What Does it Mean for the Circular Economy in ASEAN?" <i>Industry</i> , vol. 4, pp. 1–35, 2018.

	businesses will need to operate at scale and reach it rapidly.”		
Innovation management	page 19: “Innovative and agile start-ups and SMEs with no need to defend legacy business are widely entering the circular economy and Industry 4.0 field by providing new digital platforms and disruptive service solutions to maximise the value of products and materials. Partnerships between established and small companies hold great promise for disruptive new solutions.”	Q40	V. Anbumozhi and F. Kimura, “Industry 4.0: What Does it Mean for the Circular Economy in ASEAN?” <i>Industry</i> , vol. 4, pp. 1–35, 2018.
Innovation management	page 225: “... it can be stated that larger companies can follow the higher maturity levels in the technological domain for this concept more quickly than SMEs.”	Q41	V. Modrák and Z. Šoltysová, Z. “Development of an Organizational Maturity Model in Terms of Mass Customization,” <i>Industry 4.0 for SMEs</i> , Palgrave Macmillan, pp. 215–250, 2020. Available: <a href="https://doi.org/10.1007/978-3-030-25425-4_8">https://doi.org/10.1007/978-3-030-25425-4_8</a>
Innovation management	page 216: “Although there is high potential from Industry 4.0 in SMEs, the main limit lies in a lack of methodological frameworks for its introduction and wide implementation.”	Q42	V. Modrák and Z. Šoltysová, Z. “Development of an Organizational Maturity Model in Terms of Mass Customization,” <i>Industry 4.0 for SMEs</i> , Palgrave Macmillan, pp. 215–250, 2020. Available: <a href="https://doi.org/10.1007/978-3-030-25425-4_8">https://doi.org/10.1007/978-3-030-25425-4_8</a>
Innovation management	page 5: “Due to their flexibility, the entrepreneurial spirit, and the innovation capabilities, SMEs have proved to be more robust than large and multinational enterprises, as the previous financial and economic crisis showed.”	Q43	T. Ludwig, C. Kotthaus, M. Stein, V. Pipek, and V. Wulf, “Revive old discussions! Socio-technical challenges for small and medium enterprises within Industry 4.0,” <i>Proceedings of 16th European Conference on Computer-Supported Cooperative Work-Exploratory Papers. European Society for Socially Embedded Technologies (EUSSET)</i> , 2018. Available: <a href="https://doi.org/10.18420/ecscw2018_15">https://doi.org/10.18420/ecscw2018_15</a>
Innovation management	page 5: “SMEs are not only adaptive and innovative in terms of their products, but also in terms of their manufacturing practices.”	Q44	T. Ludwig, C. Kotthaus, M. Stein, V. Pipek, and V. Wulf, “Revive old discussions! Socio-technical challenges for small and medium enterprises within Industry 4.0,” <i>Proceedings of 16th European Conference on Computer-Supported Cooperative Work-Exploratory Papers. European Society for Socially Embedded Technologies (EUSSET)</i> , 2018. Available: <a href="https://doi.org/10.18420/ecscw2018_15">https://doi.org/10.18420/ecscw2018_15</a>
Innovation management	page 5: “SMEs are most likely to be the big winners from the shift; they are often able to implement the digital transformation more rapidly than large enterprises, because they can develop and implement new IT structures from scratch more easily. Many small- and medium-sized companies are already focusing on digitized products in order to stand out in the market. The integration of information and communication technology (ICT) and modern Industry 4.0 technologies would	Q45	T. Ludwig, C. Kotthaus, M. Stein, V. Pipek, and V. Wulf, “Revive old discussions! Socio-technical challenges for small and medium enterprises within Industry 4.0,” <i>Proceedings of 16th European Conference on Computer-Supported Cooperative Work-Exploratory Papers. European Society for Socially Embedded Technologies (EUSSET)</i> , 2018. Available: <a href="https://doi.org/10.18420/ecscw2018_15">https://doi.org/10.18420/ecscw2018_15</a>



	transform today's SME factories into smart factories with significant economic potential.”		
Data-driven services	page 9: “[...] the present paper shows that servitization is a worthy pursuit for SMEs, leading to innovative business models, beginning with repair and maintenance, followed by technological trainings and consulting as well as CPS-related services, such as digitization of processes, real-time product co-development or data processing and analysis.”	Q46	J. M. Müller, O. Buliga, and K. I. Voigt, “Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0,” <i>Technological Forecasting and Social Change</i> , vol. 132, pp. 2–17, 2018. Available: <a href="https://doi.org/10.1016/j.techfore.2017.12.019">https://doi.org/10.1016/j.techfore.2017.12.019</a>
Share of data used	page 137: “I 4.0 help firms to identify the problem in realistic approach known as digital lean. By reducing the waste through eliminating non-value added activities using sensors, robots, data analytics and automation ...”	Q47	N. Suresh, K. Hemamala, and N. Ashok, “Challenges in implementing industry revolution 4.0 in INDIAN manufacturing SMES: insights from five case studies,” <i>International Journal of Engineering &amp; Technology</i> , vol. 7, no. 2.4, pp. 136–139, 2018. Available: <a href="https://doi.org/10.14419/ijet.v7i2.4.13024">https://doi.org/10.14419/ijet.v7i2.4.13024</a>
Share of data used	page 6: “[...] value creation challenges can develop into value offer challenges. This is reflected by companies, which invest in gathering information through Industry 4.0 technologies, while facing challenges in putting the information to commercial use.”	Q48	J. M. Müller, O. Buliga, and K. I. Voigt, “Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0,” <i>Technological Forecasting and Social Change</i> , vol. 132, pp. 2–17, 2018. Available: <a href="https://doi.org/10.1016/j.techfore.2017.12.019">https://doi.org/10.1016/j.techfore.2017.12.019</a>