acatech STUDY

Industrie 4.0 in a Global Context

Strategies for Cooperating with International Partners

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German Research Center for Artificial Intelligence
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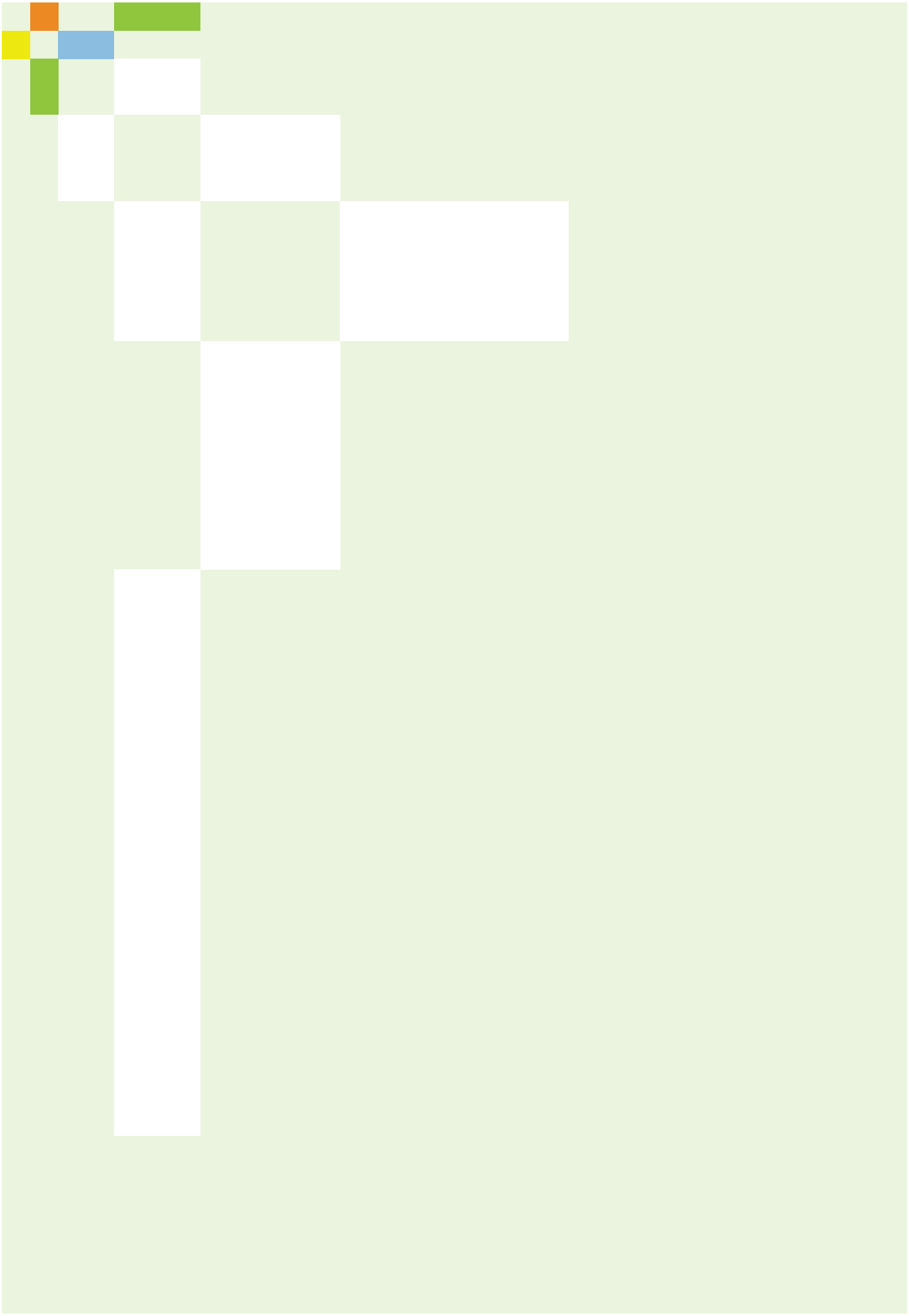
acatech NATIONAL ACADEMY OF SCIENCE AND ENGINEERING



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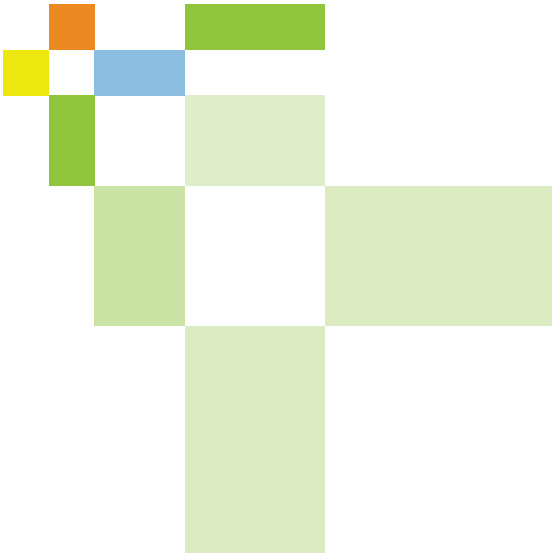

Foreword

Industrie 4.0 denotes the transformation of "traditional" industries by the Internet of Things, Data and Services. The term has been used to encapsulate a paradigm shift in the economy ever since the report of the Industry-Science Research Alliance Working Group was presented to the German Chancellor and the Plattform Industrie 4.0 was launched at the 2013 Hannover Messe. The real-time networking of products, processes and infrastructure is ushering in the fourth industrial revolution where supply, manufacturing, maintenance, delivery and customer service are all connected via the Internet. Rigid value chains are being transformed into highly flexible value networks.

The Plattform Industrie 4.0 steering committee and the Industry-Science Research Alliance/acatech have made a major contribution to developing a common understanding of "Industrie 4.0" in Germany.[1] The term describes a new stage in the organisation and management of the entire value chain throughout a product's lifecycle. The product lifecycle is geared towards customers' increasing desire for customisation and encompasses everything from the original concept to ordering, development, manufacture, delivery to the end customer and recycling, as well as all the associated services.

What makes this possible is the availability of all the relevant information in real time thanks to the networking of all the entities involved in the value creation process, together with the ability to use this data to determine the optimal value stream at any given point in time. Connecting people, objects and systems leads to the emergence of dynamic, real-time optimised and self-organising cross-company value networks that can be optimised on the basis of different criteria such as cost, availability and resource consumption.[2]

Germany's innovative and successful manufacturing industry, its strengths in the field of business IT and its know-how in the relevant key technologies mean that it is well placed to build a leading market and position itself as a leading supplier of innovative Industrie 4.0 solutions. Accordingly, Industrie 4.0 promises to deliver high-quality jobs and stable economic growth. It also offers new opportunities with regard to demographic change and sustainable, resource-efficient business.

Nevertheless, it also poses a number of major challenges for businesses. Existing manufacturing systems need to be horizontally integrated into value networks and vertically connected with companies' internal business processes. It is therefore necessary to engineer the end-to-end digitalisation of the entire value chain.

Government, business and the general public have yet to fully appreciate the dramatic extent of the digital transformation sweeping through our economy and society. Germany is in danger of falling behind its global competitors with regard to the development of the necessary infrastructure, the integration of digital technologies, the race to establish norms and standards and the creation and development of business models. However, this threat is going almost unnoticed due to current strength of the German economy.

This is the background to the present study which was funded by the Federal Ministry for Economic Affairs and Energy (BMWi). Based on the findings of an empirical survey of experts from six industrialised nations, it analyses both the opportunities and challenges for international cooperation in the field of Industrie 4.0 and the issues relating to the development of common norms and standards. The study thus provides businesses, organisations and policymakers with a sound basis for the numerous decisions that will have to be taken if the digital transformation of our economy and society is to be completed successfully.

Prof. Dr. Dr.-Ing. E. h. Henning Kagermann
President acatech

1 | See Forschungsunion/acatech 2013.
2 | See Plattform Industrie 4.0 2016.

Executive Summary

The transformation of the economy being brought about by Industrie 4.0 means that, in the future, business processes such as supply, manufacturing, maintenance, delivery and customer service will all be connected via the Internet. The resulting highly flexible value networks will require new forms of cooperation between companies, both nationally and globally. There is still considerable uncertainty regarding the areas in which German businesses should engage in this kind of cooperation – despite the potential synergies and competitive advantages there is also concern about the possible loss of know-how and value-added.

This study analyses the opportunities and challenges of international cooperation in the field of Industrie 4.0. It is based on more than 150 interviews and discussions with experts from Germany, China, Japan, South Korea, the UK and the US. The latter five countries are set to become important future suppliers of Industrie 4.0 solutions and are therefore potentially attractive cooperation partners for Germany.

Opportunities and threats of Industrie 4.0

The experts interviewed in the study considered the **holistic conceptual basis** of the term Industrie 4.0 to be its key strength. It serves as an important model to global operating companies for the vertical integration of smart machines, products and production resources into flexible manufacturing systems and their horizontal integration into cross-industry value networks. Accordingly, all the countries included networking and digitalisation as the priority themes for Industrie 4.0.

Against this background, the six countries all agreed that the greatest economic opportunities of Industrie 4.0 lie in **production optimisation**. The experts from all the focus countries expect the resulting productivity gains to significantly increase their **global competitiveness** and strengthen manufacturing industry in their respective nations.

However, there are differences in terms of how they rate the other opportunities associated with Industrie 4.0. In Germany in particular, the focus is on integrating information, communication and manufacturing technologies in smart, self-organising factories. In the US and increasingly also China, on the other hand, Industrie 4.0 is strongly associated with smart products, Internet platforms and the **new business models** that are based on them.

In the US, Silicon Valley Internet companies, innovative start-ups and financially strong, globally networked venture capital providers have all understood the significant business opportunities provided by the emerging **platform economies**. They are making targeted inroads into the global markets for Industrie 4.0 solutions and are shaping the future of these markets. In China, the government initiatives *Made in China 2025* and *InternetPlus* establish a contextual link between networking, integration and the accompanying new business models. The size of China's domestic market and the fact that it is relatively closed to the outside world provides Chinese platform operators with a favourable environment to rapidly grow their domestic market in order to generate the critical mass of customers and complementary products needed to fuel a subsequent global expansion.

As a result, German companies are encountering emerging **digital ecosystems** around Industrie 4.0 platforms, as well as **network and lock-in effects**. These are some of the key challenges facing Germany as it strives to secure a long-term position as one of the leading global players in the emerging Industrie 4.0 platform economies. Furthermore, the strong competition from the US and increasingly also China is focusing attention on the **size of Germany's domestic market** as an institutional influence on the ability of platform operators to expand globally.

At the same time, the experts from Germany and the US – the two countries that are currently the leading suppliers of Industrie 4.0 solutions – highlighted the **risk of developing products that lack market relevance**. In addition, all the countries in the survey were concerned about **data security** and **data sovereignty**. If Germany wishes both to lead the way in actively shaping the future of Industrie 4.0 and to enable early adoption in businesses, it will need to work internationally to promote norms and standardisation so that a common international infrastructure can be created.

Why are platform economies important in Industrie 4.0?

In markets where the benefits of a digital good increase in proportion to the number of users, global market leadership can only be achieved through rapid and widespread global expansion. Platform-based software markets in particular are frequently characterised by network effects. Direct network effects occur in these "winner takes all" markets when the benefits to existing users increase as the number of new users grows. Indirect network effects are generated through the growing number of complementary products based on the central platform provider's de facto standard. In view of the emergence of platform-based ecosystems in the field of Industrie 4.0 – along the same lines as traditional Internet platforms – the combination of strong network effects and significant economies of scale often means that it is essential to establish an early global presence in order to achieve the critical mass of users needed to create de facto standards.[3]

The benefits of standardisation

The standardisation of architectures, data exchange formats, semantics, vocabularies, taxonomies, ontologies and interfaces is key to creating interoperability between the different technologies involved in a complex and extremely heterogeneous field like Industrie 4.0. The experts who took part in the study did not focus on any one particular standard. What matters is for whichever standards are settled on to be adopted on a widespread basis in order to enable the creation of **interoperable systems that can be flexibly integrated**.

The experts from all the countries in the survey agreed that because it is such a complex field **there will not be one single Industrie 4.0 standard**. Instead, the next few years will see the emergence of numerous standards, some of them highly specialised, enabling interoperability in and between all manner of different systems.

One focus of German and international standardisation initiatives should therefore be on semantic interoperability and standard data formats, as well as metadata, vocabularies and domain models. The experts from Germany and Japan also considered reference models to be important, whereas the Chinese experts regarded the introduction of a standard Industrie 4.0 vocabulary as a top priority.

In this context, two of the key issues that need to be addressed by standardisation are **interoperable interfaces** between solutions from different manufacturers and the establishment of **open standards**. The experts felt that these are essential for the emergence of open, flexible and successful ecosystems spanning not only different manufacturers but also different countries and continents.

According to the experts, if the appropriate solutions are not developed there is a danger that isolated, proprietary standalone or silo solutions could emerge. This would expose purchasers of Industrie 4.0 solutions to the **risk of technological lock-in**, resulting in technological dependence and high costs if they wished to switch to a different solution. For small and medium-sized Industrie 4.0 suppliers that do not control the market, open standards increase its potential both in terms of the number of customers for their products and the demand for complementary products. Open systems are thus of particular importance to **small and medium-sized enterprises** whose relatively limited influence makes them more reliant on the existence of interoperable systems for accessing what is potentially a very large market.

These standards are developed by organisations that work closely with industry in order to efficiently address and close the technology gaps and requirements that it identifies. German standardisation organisations should engage more closely with the **international consortia** that play a key role in this area. The Industrial Internet Consortium (IIC) and the associated Object Management Group (OMG) occupy a prominent global position in the dynamic and diverse international standardisation organisation landscape. Germany has an excellent international reputation thanks to the developments and initiatives that it has already undertaken in the field of Industrie 4.0, such as Bitkom, DIN, DKE/VDE, VDMA and ZVEI. It is thus very well placed to engage in further international cooperation in the area of standardisation.

In view of the race that is currently underway to establish international norms and standards as quickly as possible, many of the experts in the survey – particularly those from Germany and South Korea – believed that standardisation work is currently

3 | See Buxmann et al. 2011.

progressing too slowly. However, they also stressed the fact that the highly complex nature of Industrie 4.0 and the need for extensive committee work have a strong impact on the **speed at which standardisation progresses**. The experts felt that closer international cooperation between companies, associations and policymakers is required in order to give current standardisation activities greater impetus.

The conflicting factors affecting Industrie 4.0 standardisation

Standardisation is an essential requirement for combining different systems. Different components can only work together (interoperability) or be used on other systems (portability) if cross-manufacturer standards are established for the design of technical IT infrastructures. The key factors that influence the standardisation process include the stakeholders' general interest in establishing standards and their preference for one particular standard or another. Closed standards can be more precisely controlled as the technology continues to develop and promise higher returns for the suppliers of technology products. Open standards can be more rapidly and widely established, although it is harder to use them for commercial gain. In the highly complex field of Industrie 4.0 with its vast array of stakeholders, suppliers of Industrie 4.0 solutions need to make their own individual assessment of the opportunities and risks of widespread market penetration versus relative market power.[4]

The meaning of cooperation in Industrie 4.0

The international competition with regard to the establishment of norms and standards for Industrie 4.0 means that close cooperation is required between businesses and institutions. The experts from all the countries in the survey identified networking and digitalisation as the key technology areas where a need for cooperation exists. They attached particular importance to data acquisition/transmission, networking, data processing/analysis and interfaces. The experts identified different ways of cooperating in order to drive norms and standardisation and develop innovative Industrie 4.0 solutions in these areas: industry-specific and cross-industry cooperation, cooperation with suppliers and with competitors and cooperation with global corporations and innovative start-ups.

The experts considered the most effective instruments to be **testbeds** for the development of prototypes and the pragmatic implementation of new solutions, together with industry-specific integration platforms for facilitating the widespread adoption of solutions. Both Germany and in particular the US place greater emphasis on testbeds, while China, Japan and South Korea additionally focus on industry-specific integration platforms.

However, the main difference in focus is not so much between individual countries as between large, global **corporations and SMEs**. Because of the extensive resources at their disposal, large corporations are able to participate in a variety of international standardisation organisations and networks. Testbeds are thus a good way for them to cooperate with other large corporations, SMEs and start-ups. They allow Industrie 4.0 innovations to be **rapidly and pragmatically** transformed into commercially viable solutions. The corporations then disseminate the technical standards established in the testbeds across their extensive networks of suppliers and customers. Consequently, it is important to ensure that German corporations engage in the latest international standardisation debates from an early stage.

As well as testbeds, industry-specific platform solutions can help SMEs in particular to reduce **investment risks**, benefit from synergies in the establishment of standards and successfully communicate standards to their customers. Academic organisations and the relevant associations can play a valuable role in orchestrating cooperation on industry-specific integration platforms.

Overall, the experts who took part in the survey expected cooperation to **enhance know-how**, especially with regard to data security and business models, reduce development times and prevent redundant solutions. Germany and Japan were particularly keen on the idea of an international dialogue on data-based business models, not least because of the threat of US and Chinese platform providers dominating the market in the medium term. China, South Korea and Japan also identified a need for cooperation in the areas of R&D and training and professional development. On the whole, the respondents from the US and the UK rated government cooperation initiatives as less important.

4 | See Shapiro/Varian 1999; Picot et al. 2003.

The experts cited **data security** and a potential loss of know-how as the greatest threats to the establishment of integrated systems. On the whole, however, the potential risks are not enough to prevent most companies from engaging in cooperation. In particular, cooperation is seen as an important way of preventing Internet companies from stealing a march on traditional manufacturing industry in the Industrie 4.0 transformation.

In order to stay abreast of the dynamic developments in this area, many companies – especially large corporations – are currently actively involved in a variety of Industrie 4.0 organisations and initiatives. The main benefits that they hope to achieve through this involvement relate to **interoperability** and **innovation**.

According to the experts, the most important requirements for engaging in cooperation are **contracts** and the formulation of **ground rules**. Moreover, they believe that cooperation should take place in simple, international company networks. Academic institutions and the relevant associations should also be included so that they can contribute their expertise and views. A well-coordinated approach with separate responsibilities for each partner is seen as important for building trust among the different companies and countries whilst at the same time providing them with the freedom to decide how they go about addressing the technical, business and organisational challenges of a highly dynamic field like Industrie 4.0.

What are the investment risks for SMEs?

The penguin effect refers to a phenomenon whereby the smaller the number of users, the less useful a given application is. The metaphor relates to the behaviour of hungry penguins. Fear of predators causes all the penguins to remain on the shore until the first one decides to take its chances and jump into the water. Watching what happens gives the other penguins a better idea of their own chances of survival if they follow suit. In the same way, despite being very interested in Industrie 4.0 solutions, potential users – especially SMEs – are reluctant to invest. This is because as long as there are no international standards or universal solutions providing interoperability between different systems, individual companies run the risk of technological lock-in. If they acquire proprietary standalone or silo solutions there is a danger that, in the medium term, they could become dependent on the technology of one particular supplier. In the dynamic Industrie 4.0 market with its huge number of actors, the investment risks are particularly high for cash-strapped SMEs.[5]

Status quo of Industrie 4.0 in different countries

Germany

In Germany, the term Industrie 4.0 describes a strong, technology-based vision of the future. The focus is on optimising production processes in terms of quality, price and flexibility and delivering better financial returns overall. The strategic goal is to maintain Germany's traditionally strong position in manufacturing and mechanical engineering throughout the digital transformation. The development of new business models and smart products is considered to be less important.

Because of its strength in the fields of automation and factory equipment, German industry has taken on a key role in the development of Industrie 4.0 – not only through its large corporations, but particularly through its globally successful SMEs. Germany's excellent international reputation in this field means that it is well placed to engage in ongoing international cooperation initiatives, several of which are already up and running. In general, it is recommended that cooperation should focus on Japanese and US firms from the information and communication (ICT) industry with particular expertise in Internet technologies. Meanwhile, South Korea and China are both promising markets for German products owing to their high demand for manufacturing technology.

A top-down approach to standardisation predominates in Germany, led by government, pioneering companies and academia. Companies collaborate closely with the research community and their activities are coordinated by organisations such as the Plattform Industrie 4.0 with the aim of achieving a dialogue-based consensus. However, if this process takes too long, there is a danger that Germany could fall behind its global competitors over the medium term. Overall, the speed of standardisation is rated much more negatively in Germany than in

5 | See Zerdick et al. 2002.

other countries, while the expectations regarding reference architectures and standard programming interfaces (APIs) are significantly higher.[6]

General dos & don'ts

- **Build on the strong Industrie 4.0 brand:** Continue to strengthen the international dimension of German Industrie 4.0 activities in order to benefit more from the high interest shown by countries around the world in German-made Industrie 4.0 solutions.
- **Use international standardisation as a catalyst for cooperation:** German industry should become more involved in the leading international standardisation organisations and seek to take on an active leadership role.
- **Create stronger links between innovation centres:** Promote collaboration between innovation centres in order to facilitate cooperation between businesses and researchers from different countries.
- **Make sure that the benefits of Industrie 4.0 do not seem too abstract:** Pursue a dual approach that pushes ahead with the development of an integrated Industrie 4.0 strategy whilst at the same time developing pragmatic, high-profile solutions.

China

The Chinese manufacturing landscape currently is extremely heterogeneous in nature. On the one hand, there are a handful of major global corporations (e.g. Huawei, Sany and Haier) that possess advanced and in some cases highly automated factories. On the other hand, there are large numbers of SMEs in which almost no automation or digitalisation has occurred – indeed, many of them are still only just starting to introduce computer-integrated manufacturing. The Chinese government recently adopted the *Made in China 2025* strategy with the aim of fully modernising the country's manufacturing industry. Industrie 4.0 is seen as a key enabler of these efforts to catch up with other nations. Industrie 4.0 is therefore being heavily promoted and China has explicitly expressed its desire to engage in cooperation, particularly with Germany.

There are numerous opportunities for Germany in the short to medium term. China is a promising market for upgrade technologies such as industry software and automation technology. Moreover, the Chinese market's high implementation speed can be used by German organisations to develop their own Industrie 4.0 solutions and promote the widespread adoption of the associated norms and standards. Over the longer term, however, the planned transformation of the Chinese economy is also set to turn China into a serious competitor.

Dos & don'ts for China

- **Use China as a multiplier for German standards:** Implement German beta standards in Sino-German cooperation initiatives in order to improve their chances of being adopted worldwide.
- **Supply China with automation equipment:** Take advantage of the opportunities to sell Industrie 4.0 solutions to the Chinese market.
- **Make the most of the opportunities in the sustainable technologies market:** Promote environmentally sustainable Industrie 4.0 solutions in order to make the most of the Chinese government's green manufacturing initiative.
- **Approach Beijing via the provinces:** Take account of the high regional diversity and extensive political powers of the provincial governments and seek to enter the Chinese market via selected provinces.
- **Enter with strong partners:** SMEs should enter the market in partnership with established companies and take advantage of their local infrastructure.
- **Weigh up the investment risks:** Be aware of the fragile regulatory framework and ensure that investment decisions are accompanied by an exit strategy.

6 | The conclusions were formulated from a German perspective.

Japan

Industrie 4.0 is already very advanced in Japan. As in Germany, manufacturing industry has a long-standing tradition in the Japanese economy. Industrie 4.0 is thus both an opportunity for Japan and a challenge in terms of how the digitalisation of industry is managed. A modular technology stack[7] and the relevant standardisation of Internet technologies are regarded as important, particularly for new business models. As far as existing business models are concerned, standardisation is explicitly ruled out in some areas. The Japanese government and various private business initiatives are driving standardisation in the field of Industrie 4.0, even though they have different views on these aspects.

Dos & don'ts for Japan

- **Develop integration solutions for the Japanese market:** Gain an overview of the system landscape at the different levels of the value-added process and discuss integration solutions down to the sub-supplier level.
- **Integrate robotics with human factors and ergonomics:** Promote cooperation in the fields of robotics and human factors and ergonomics and take advantage of Japanese expertise in data-focused technologies.
- **Drive cooperation on data-based process optimisation:** Engage in pilot projects with relevant partners in order to take advantage of Japanese expertise in the field of process optimisation.
- **Cooperate flexibly in initiatives:** Bearing in mind the complex Industrie 4.0 landscape in Japan, avoid creating bottlenecks and ensure that cooperation initiatives with Germany are decentralised.
- **Implement the sensei principle in technology solutions:** Develop a thorough understanding of the role of the sensei (teacher/master) and integrate this approach into the German Teaching & Learning Factory concept.

South Korea

South Korea's economy is characterised by global, hierarchically structured conglomerates ("chaebols") in the high-tech and mechanical engineering sectors (e.g. Samsung, Hyundai and LG). Many SMEs are highly dependent on these conglomerates. The benefits of Industrie 4.0 are widely recognised in South Korea. The government has launched a nationwide project primarily aimed at helping SMEs to boost their production capacity through the use of smart factory technologies. The goal is to establish up to 10,000 more productive factories by 2020 through partnerships between business, the relevant organisations and government. These measures are a response to the growing pressure on the South Korean economy due to the improving quality of Chinese manufacturing.

As well as productivity gains, South Korea also believes that Industrie 4.0 can deliver economic benefits through new, data-driven business models, e.g. in the field of smart cities where it is already a global leader. As far as standardisation is concerned, the government is keen to engage in international cooperation and to involve the private sector. South Korean industry is calling for rapid standardisation solutions to enable interoperability. The pronounced focus on increasing productivity and the established tradition of cooperation with Germany mean that there is an opportunity for German businesses to target South Korea more strongly as a market for their Industrie 4.0 solutions. Cooperation with the large conglomerates should facilitate access to South Korean SMEs, enabling the widespread establishment of standards across several different industries.

Dos & don'ts for South Korea

- **Use the chaebols as a route into the market:** Seek to cooperate with global conglomerates that bring together several value chains and suppliers under one roof.
- **Recognise SMEs as an important target market:** Identify relevant SME customers that are investing

7 | In this context, "technology stack" refers to a group of technologies that, while separate from each other, are nonetheless developed in close coordination. One example is the web technology stack that incorporates e.g. coordinated protocols for exchanging (HTTP) and representing (HTML) information.

heavily in Industrie 4.0 solutions under the government's *Smart Factory Initiative*.

- **Transfer know-how from the consumer sector:** Take advantage of South Korean companies' strengths in data-driven business models and establish joint cooperation projects on smart services.
- **Establish cooperation structures for German and South Korean start-ups:** Use South Korea's highly developed innovation centres as a point of contact for accessing the local start-up scene network.
- **Recognise the opportunity for IT security projects provided by South Korea's foreign policy environment:** Draw on the established tradition of cooperation between Germany and South Korea to develop Industrie 4.0 security solutions in conjunction with partner companies.

United States

In the US, Industrie 4.0 is generally included under terms such as the Internet of Things, smart production or the Industrial Internet. Consequently, it is understood to have a much wider meaning than in Germany, encompassing not only the technological dimension but also the development of the new business models (smart services) that are coming about as a result of Industrie 4.0 (e.g. in the field of big data analytics). Silicon Valley firms in particular are hopeful that the transition to a network economy will provide export opportunities for sensor and wireless technologies. Overall, the US rates the opportunities associated with Industrie 4.0 as far more significant than the possible risks.

Industrie 4.0 is being driven by private sector consortia, chief among them the Industrial Internet Consortium (IIC) founded by General Electric (GE). The IIC coordinates initiatives to create ecosystems connecting physical objects with people, processes and data. It aims to guarantee interoperability through reference architectures, frameworks and open standards. Rather than regarding each other as competitors, the various consortia that exist in the US see Industrie 4.0 as a collective endeavour. Companies domiciled outside of the US already account for the majority of their members. The risk for Germany is that these US consortia could rapidly establish "quasi-standards" and steal a march on German companies in the field of standardisation. Germany has an excellent reputation in the US as a potential cooperation partner.

Dos & Don'ts for the US

- **Continue to strengthen trade relations in the field of Industrie 4.0:** Make the most of the traditionally strong trade relations between Germany and the US and capitalise on the reindustrialisation of the American economy.
- **Don't lose control over Industrie 4.0 business models:** Ensure that future business models form an integral part of long-term corporate strategies and that control over them is not lost when cooperating with software firms.
- **Focus on Industrie 4.0 platforms:** Create a level playing field for cooperation with the large US Internet companies by establishing industry-specific platforms for SMEs.
- **Actively manage ideas and talent:** Engage in active ideas and talent management through strategic partnerships with US companies and applied research institutions.

United Kingdom

British companies recognise the potential of Industrie 4.0. The government is promoting reindustrialisation in order to rebalance the British economy and reduce its dependence on volatile financial markets. Although there is still no coherent national innovation plan, individual programmes are already up and running. The current strategy is centred on innovation centres in a variety of different fields, known as "Catapults". The Catapults provide a dedicated environment where businesses and researchers can work together to develop innovative commercial Industrie 4.0 solutions.

Dos & Don'ts for the UK

- **Get involved with innovation centres (Catapults):** Use the Catapults as testbeds for innovative Industrie 4.0 solutions and for cooperating with other businesses and research institutions in the UK.
- **Observe non-manufacturing sectors with a view to know-how transfer:** Identify technologies and business models in highly-developed British sectors such as smart education and smart infrastructure in order to benefit from know-how transfer.
- **Use British services expertise to develop smart services:** Take advantage of the UK's large service sector and British e-commerce expertise by cooperating with companies and research organisations to develop smart services.

Outlook for Industrie 4.0

The vision of Industrie 4.0 has had a dynamic impact on innovation policy both in Germany and in other countries around the world. Close cooperation between businesses, the trade unions, the relevant associations, academia and government has increasingly allowed the vision to be conceptualised, refined and implemented. In the past few years, several companies in Germany have established new factories and a competence centre network modelled on Industrie 4.0 projects such as the smart factory and learning factory. As a result, Germany is currently around two to three years ahead of other countries in the field of Industrie 4.0. Assuming that the relevant actors work together, it should be possible to achieve the targets for 2030 set out in the *INBENZHAP* project[8] which describes the probable scenario of an Industrie 4.0 economy that strikes the right balance between people and technology and in which government engages effectively. Thanks to its good digital infrastructure, its know-how in the key technology areas and its holistic understanding of value creation, Germany is a leading global player in this field. However, companies from other countries around the world are taking rapid action to close the gap. Consequently, specific measures are required to ensure the long-term success of Industrie 4.0 in Germany:

- Large, predominantly multinational **corporations** should resist the temptation to promote silo solutions for Industrie 4.0. The financial returns of universal products such as analytics tools for the large volumes of data generated in industrial processes can be increased if these products provide open interfaces that allow integration with solutions from different providers. Corporations would therefore do better to focus on interoperability and on actively supporting international standardisation efforts.

- This approach also makes it easier for **SMEs** to enter the market – universal modular products with open interfaces allow them to integrate their own solutions. This benefits both the large corporations by providing them with a wide user base and the SMEs by allowing them to market specialised modules in specific areas. When developing new technologies, it is important to ensure right from the outset that the relevant business models are developed in tandem, as well as to facilitate global expansion through the targeted development of strategic networks.

- **Associations** play an important role in technology development – both large corporations and SMEs need to be more active on this front. It is important to clearly define which technology areas should be standardised and which are explicitly regarded as proprietary intellectual property by the companies involved. Furthermore, close, long-term and agile cooperation between **business, academia, government and the relevant associations** is essential – both nationally and globally – in order to keep up with the rapid pace of developments in the field of Industrie 4.0. Organisations, trade unions and the relevant associations can also employ showrooms and use cases to provide a targeted demonstration of the technological, organisational and commercial implications of Industrie 4.0 for SMEs. Moreover, cross-industry dialogue formats can be used to enable closer networking across different industries.

- **Government** has a vital role in implementing the recommendations described above. It should use structures such as the Plattform Industrie 4.0 to try and prevent buyer lock-in and encourage these organisations to participate in national and international standardisation activities. Government should also facilitate networking between the relevant associations and promote targeted initiatives involving multiple associations. In addition, it must drive the nationwide expansion of high-performance, high-speed networks (e.g. G5), the expansion of smart networks and the digitalisation of analogue

8 | See Gausemeier/Klocke 2016.

infrastructure. Government also needs to create a binding legal framework that takes account of the right to information and data sovereignty whilst at the same time providing the necessary freedom for the commercial implementation of data-driven business models.

If Germany manages to actively address these challenges and implement the relevant policy measures, it will be able to extend its current lead over other countries and ensure that Industrie 4.0 becomes a lasting success for the German economy and society as a whole.

Project

Project management

- Prof. Dr. Dr.-Ing. E. h. Henning Kagermann/acatech President

Project group

- Prof. Dr.-Ing. Reiner Anderl, Department of Computer Integrated Design, Technische Universität Darmstadt/acatech
- Prof. Dr.-Ing. Jürgen Gausemeier, Heinz Nixdorf Institute, University of Paderborn/acatech Executive Board member
- Prof. Dr.-Ing. Günther Schuh, RWTH Aachen University/acatech Executive Board member
- Prof. Dr. Dr. h.c. mult. Wolfgang Wahlster, German Research Center for Artificial Intelligence (DFKI)/acatech

Consortium partners/project team

- Sebastian Haag, Technische Universität Darmstadt
- Christian Dülme, Heinz Nixdorf Institute, University of Paderborn
- Julian Echterfeld, Heinz Nixdorf Institute, University of Paderborn
- Daniel Eckelt, Heinz Nixdorf Institute, University of Paderborn
- Bastian Fränken, RWTH Aachen University
- Dr. Christina Reuter, RWTH Aachen University
- Dr. Tilman Becker, German Research Center for Artificial Intelligence (DFKI)
- Dr.-Ing. Christiane Plociennik, German Research Center for Artificial Intelligence (DFKI)
- Dr. Georg Rehm, German Research Center for Artificial Intelligence (DFKI)
- Dr. Felix Sasaki, German Research Center for Artificial Intelligence (DFKI)

Project coordination

- Dr. Alexander Werbik, acatech Office
- Dr. Johannes Winter, acatech Office

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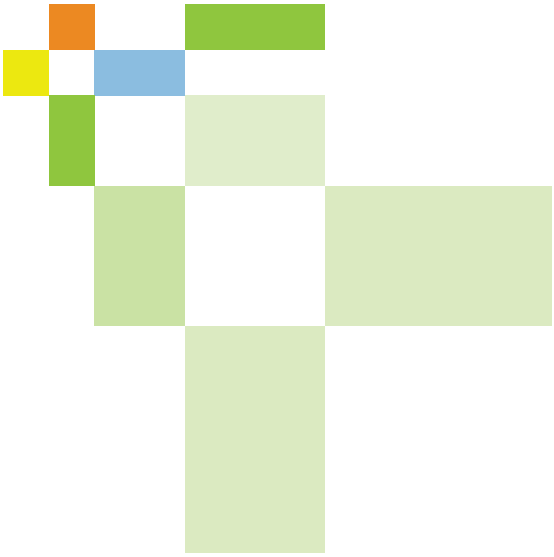

1 Introduction

A radical transformation is occurring in our economy. Following on from industrialisation, mass production and automation, the fourth industrial revolution is now underway. Known in Germany as Industrie 4.0, this phenomenon involves the real-time networking of products, processes and infrastructure. Just like the previous technological milestones in our economic history, Industrie 4.0 will have profound global impacts on manufacturing processes, business models, technologies, the workplace and people's everyday lives. It is too early to predict exactly what the factories of the future will look like. What we do know, however, is that networking and cooperation will play a key role in them.

At its core, Industrie 4.0 involves the technical integration of Cyber-Physical Systems (CPS) in the realms of production and logistics. Supply, manufacturing, maintenance, delivery and customer service are all connected via the Internet. Smart machines, warehousing systems and production resources are capable of independently exchanging information, triggering actions and autonomously controlling each other. This makes it possible to achieve a fundamental improvement in industrial processes: rigid value chains are being transformed into highly flexible value networks.[9]

With its innovative and internationally successful manufacturing industry, modern software solutions for corporate customers and established know-how in the relevant key technologies, Germany is well placed to become a leading market and leading supplier of innovative Industrie 4.0 solutions. This in turn has the potential to deliver high-quality jobs and stable economic growth. Industrie 4.0 also opens up new opportunities in the areas of demographic change and sustainable, resource-efficient business.

At present, German companies are concentrating on their strengths in the development and production of high-quality manufacturing technologies for industrial (B2B) customers. They are also globally renowned for their expertise in the field of data analysis and for their highly-skilled workforce. On the other hand, Germany's weaknesses include the slow rate at which innovations are developed into products and the fact that German entrepreneurs tend to be less adventurous than in other countries. These problems are accompanied by serious shortcomings in Germany's digital infrastructure which is far less developed than in South Korea and the US, for example. In order for Germany to play its part in actively shaping the future of Industrie 4.0, these obstacles will need to be proactively addressed.[10]

Based on the findings of the *INBENZHAP* project, another important requirement is the development of international standards.[11] A series of standard protocols will be required to allow factories, machines and products all over the world to communicate and interact with each other and to make sure that solutions can be used in any country. Indeed, these standards are necessary for international technical cooperation to be possible in the first place. The full integration of digitalisation, networking and new ways of collaborating in manufacturing industry is therefore a global challenge. The Plattform Industrie 4.0 is leading the way on this issue in Germany. Similar initiatives exist in many leading industrialised nations, for instance Smart Industry in the Netherlands, *Produktion 2030* in Sweden, *Nouvelle France Industrielle* in France, *Industria Conectada* in Spain, *Průmysl 4.0* in the Czech Republic and *Fabbrica Intelligente* in Italy.[12] In order to ensure a strong voice internationally, cooperation should be strengthened at national, European and global level between businesses and the institutions that coordinate these government and private sector initiatives.[13]

This is an extremely challenging area, since norms and standards must be applied not only across different countries but also across different systems. Moreover, the highly dynamic nature of the technology requires them to be highly flexible and adaptable. Ideally, standards or norms should be established for national or corporate solutions in order to create a secure investment environment and build trust.[14]

Standards are especially important to companies that are currently adopting a wait-and-see approach towards Industrie 4.0. One of this study's main aims was to investigate the developments and expectations in different industrialised nations. In order to carry out this international evaluation of the importance of cooperation in the field of Industrie 4.0, representatives of businesses and organisations from the largest industrialised nations were asked about what Industrie 4.0 means to them, where they think cooperation is needed and how this cooperation should be approached.

9 | See Forschungsunion/acatech 2013.
10 | See Gausemeier/Klocke 2016.
11 | Ibid.
12 | See Europäische Kommission 2015.
13 | See Scheer 2013.
14 | See DIN e.V./DKE 2015.

2 Methodology

The project *Industrie 4.0 in a Global Context: Strategies for Cooperating with International Partners* was funded by the Federal Ministry for Economic Affairs and Energy (BMWi). It analyses the prospects for international cooperation in digital, connected industry.[15]

The study is based on over 150 interviews and conversations with experts from Germany, China, Japan, South Korea, the UK and the US conducted between September 2015 and June 2016.[16] One of the main focuses was the extent to which German businesses should cooperate with global partners in the field of norms and standards in order to generate synergies and obtain competitive advantages. Another priority was to identify the challenges of international cooperation with regard to Industrie 4.0. This included discussion of whether German businesses also need to cooperate from an early stage with partners from outside of Europe in order to set global standards.

Data was collected through exploratory, semi-structured guided interviews based on existing studies, publications and projects concerning the relevant Industrie 4.0 technology areas. The flexible interview guidelines contained prompts and key questions for guiding the conversations, together with quantitative elements. The content addressed the technical, financial and business aspects of standardisation and cooperation in the field of Industrie 4.0. The respondents' expert knowledge influenced the direction taken by the interviews. The results of the personal interviews were complemented by an online questionnaire. The analysis included data provided by representatives of business, academic institutions and other relevant organisations.[17]

The experts were interviewed on a country-by-country basis, with interviews being conducted in Germany and in the focus countries of the UK, China, Japan, South Korea and the US. The results were presented to representatives of government, business, academia and other organisations at a technical workshop where the key outputs of the interviews were communicated and discussed in depth. The workshop participants also assessed the opportunities and threats of Industrie 4.0 for German industry and drew a number of preliminary conclusions.[18]

In parallel with the interviews, current government and private sector initiatives and the opinions of academia and standardisation organisations were studied in order to identify priorities, commonalities and differences across the different countries. Detailed profiles were drawn up for the focus countries of China, Japan, South Korea, the US and the UK, highlighting their respective background situations, specificities and progress with regard to Industrie 4.0. These provide an important basis for the recommendations regarding cooperation between German actors and global partners that are presented in the final part of this report.

15 | The study's focus is based on the results of the project *Industrie 4.0 – International Benchmark, Future Options and Recommendations for Production Research (INBENZHAP)*, which was also funded by the BMWi. Among other things, this project recommended that German businesses should cooperate with international partners and that Germany should play a leading role in the field of standardisation.

16 | The names of the interviewees have not been published in order to protect their confidentiality.

17 | See Hildebrandt et al. 2015.

18 | The acatech workshop held on 3 February 2016 in Berlin was attended by more than 30 participants.

3 Results

3.1 Understanding of Industrie 4.0

Industrie 4.0 is a broad term that encompasses different perspectives, industries, corporate functions, technologies and fields. The experts interviewed in the study considered its holistic conceptual basis to be one of its key strengths. As a rule, the concept was understood and had been successfully exported across the globe. Industrie 4.0 serves as an important model to companies around the world for the vertical integration of smart machines, products and production resources into flexible manufacturing systems and their horizontal integration into cross-industry value networks that can be optimised on the basis of different criteria such as cost, availability and resource consumption. At the same time, the focus and understanding of Industrie 4.0 are constantly evolving due to the high level of activity and continual development of new approaches, concepts and solutions on the part of businesses and research institutions, as well as the associated debate in the media, in government and throughout society as a whole. Nevertheless, for efficient cooperation and standardisation to be possible in an international context, it is necessary to identify and openly discuss the commonalities and differences with regard to the understanding and focus of Industrie 4.0 in different countries.

A focus on networking and integration

The results of the survey show that many countries share a very similar understanding of Industrie 4.0, despite differences in their specific focus. The term Industrie 4.0 has also become established as a global brand. The experts from all of the countries in the study primarily associated Industrie 4.0 with networking and digitalisation (see Figure 1). Other themes associated with the term included smart products, production optimisation, automation and new business models.

Businesses in particular are not simply introducing and adapting to Industrie 4.0 for the sake of it – they are doing so because of the economic opportunities that it provides. The experts from all of the countries saw production optimisation as one of the main economic benefits (see Figure 2). This was by far the most frequently cited benefit in Germany, South Korea and the UK, reflecting the strong manufacturing focus of Industrie 4.0 in these countries. Automation is also regarded as extremely important. The experts

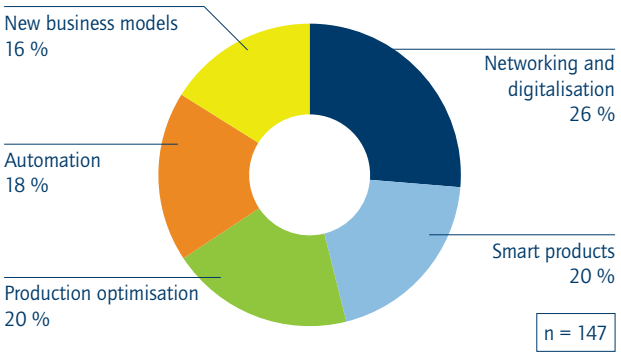

Figure 1: Understanding of Industrie 4.0

from all the focus countries expected the resulting productivity gains to significantly increase their global competitiveness and strengthen manufacturing industry in their respective nations.

However, there were differences in how they rated the other economic opportunities of Industrie 4.0. In Germany in particular, there is a focus on combining information, communication and manufacturing technologies in smart, self-organising factories. In the US and China, meanwhile, there is also a strong emphasis on smart products. While the significant potential for new business models was most frequently cited by interviewees from the US, it is also recognised in Germany, Japan and increasingly China. The experts from the US also hope that Industrie 4.0 will lead to better customer service, whereas in China they expect it to expand their product and service portfolio. Overall, the experts who took part in the survey considered one of the main strengths of the term Industrie 4.0 to be its holistic conceptual basis.

Opportunities in production optimisation and data-driven business models

The experts from the US were particularly conscious of the economic opportunities in the field of platform economies and emerging ecosystems. Financially strong, globally networked venture capital providers, innovative Silicon Valley start-ups and established software and Internet firms are all increasing their strategic focus on the market for Industrie 4.0 solutions. In China, the government initiatives *Made in China 2025* and *InternetPlus* establish a contextual link between networking, integration and new, platform-based business models. The size of both the US and Chinese markets provides these countries with an advantage insofar as it enables local companies to rapidly

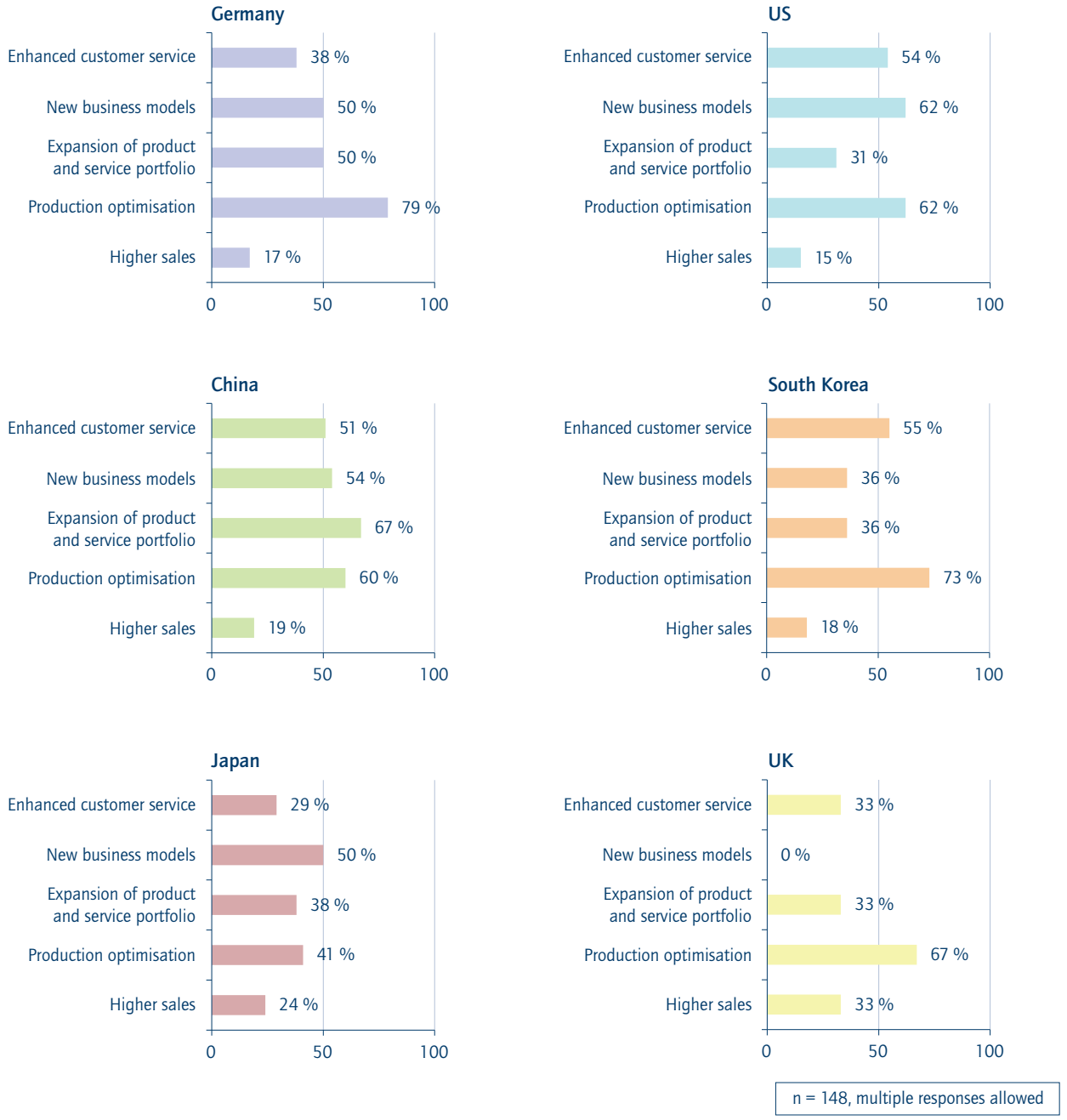

Figure 2: The most significant economic opportunities of Industrie 4.0

grow their domestic market in order to generate the critical mass of customers and complementary products needed to take full advantage of future opportunities for global growth.

In order to accomplish the goal of becoming a leading global supplier of Industrie 4.0 solutions, strategic action is required by German SMEs regarding the makeup of the ecosystems emerging around Industrie 4.0 platforms. Among the key challenges facing Germany are its medium-sized market and the sometimes limited availability of capital for investment in risky expansion strategies in markets with strong network effects.

The challenge of data security and data sovereignty

Industrie 4.0 entails risks as well as opportunities. The experts from Germany and the US, the two leading suppliers of Industrie 4.0 solutions, believed that there is a risk of developing solutions that lack market relevance. Alongside this, the most frequent concern expressed by all the countries in the survey relates to data security and data sovereignty (see Figure 3). The interviewees highlighted concerns about their core competencies either being lost or entering the public domain. Small and medium-sized enterprises in particular lack the know-how and financial resources to ensure adequate data security. Larger companies, on the other hand, are often used to working globally and are therefore familiar with the issues from their own experience. As well as data security, standardisation is another aspect of Industrie 4.0 where action is required. The majority of the companies in the survey would prefer to see the current shortcomings addressed through open, global standards. Other risks identified by the respondents included adoption, acceptance and migration problems, as well as low profitability if the hoped-for economic benefits of Industrie 4.0 fail to materialise and organisations are unable to refinance their investments.

On the whole, the experts from all of the countries in the survey recognised the relevance of Industrie 4.0, both in general terms and to their own business. Most of them had incorporated Industrie 4.0 into their strategy and were pursuing the strategic goal of actively shaping the digital transformation (see Figure 4).

Whilst the drive to do so is particularly strong in the US, it also apparent in Germany, South Korea and Japan. In China, on the other hand, although there is a lot of interest in Industrie 4.0

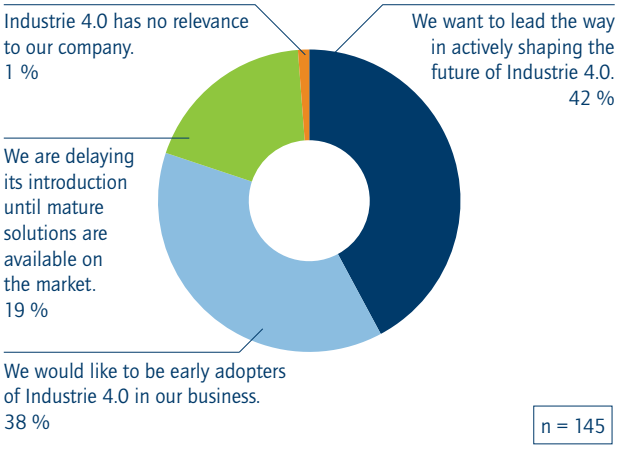

Figure 3: The fundamental significance of Industrie 4.0 to your own business

and Chinese companies are even prepared to be early adopters, they did not identify themselves as wishing to lead the way in shaping Industrie 4.0 – at least not in the immediate future. A quarter of the Chinese interviewees intended to delay the introduction of Industrie 4.0 until mature solutions become available and common standards enable more reliable planning. Nevertheless, over the medium to long term, China too is very keen to become a leading supplier and to play an active role in shaping Industrie 4.0.

In order to achieve a faster and more widespread breakthrough for Industrie 4.0, the overall feeling among the experts was that international efforts with regard to norms and standardisation must be stepped up with a view to creating interoperability between the large number of different systems in existence.

Expert quotes

- "To maintain its leading role in many industries such as machinery or automotive, Germany needs to take a leading role in Industry 4.0."
- "The more data we can use, the more business chances we can get."

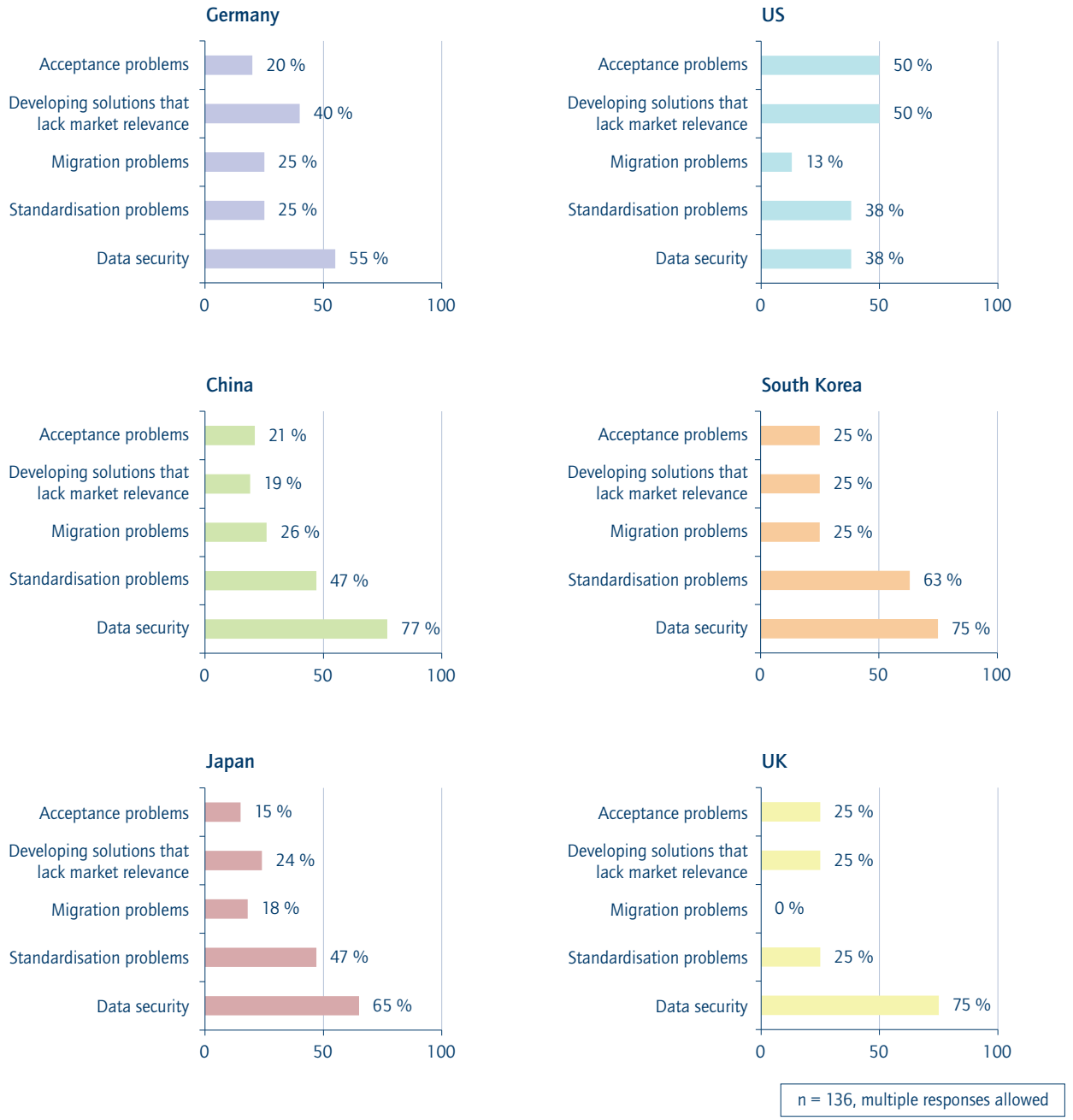

Figure 4: The most significant economic risks of Industrie 4.0

3.2 Standardisation

The standardisation of architectures, data exchange formats, semantics, vocabularies, taxonomies, ontologies and interfaces is key to creating interoperability between the different technologies involved in a complex and extremely heterogeneous field like Industrie 4.0. The experts believed that one important requirement for the success of Industrie 4.0 is that individual modules, components, devices, production lines, robots, machines, sensors, catalogues, directories, systems, databases and applications should have common standards both for the connections between them and the overall semantics. This would, for instance, make it possible to flexibly build a production facility from components made by different manufacturers.

A scenario where common standards do not exist or where suppliers choose not to adopt Industrie 4.0 solutions would lead to the emergence of isolated, proprietary standalone or silo solutions. Potential buyers would be faced with the risk of technological lock-in – whenever you purchase a proprietary solution, there is always a risk that, in the medium term, you will be forced to accept your supplier's arbitrary decisions, unilateral price rises and fixed-term maintenance contracts.

Ultimately, the only way out is to switch to a solution that is based on international standards and therefore provides greater flexibility and modularity, not least in terms of the extra freedom to choose between functionally identical systems from different suppliers.

Solutions that connect legacy systems with new technologies are especially useful. Modular mapping techniques (e.g. ontologies, taxonomies or other semantic techniques) enable efficient translation between older and newer systems, allowing older standards to be pragmatically integrated with newer solutions.

International standards are also essential for the emergence of open, flexible and successful ecosystems spanning not only different manufacturers but also different countries and continents. Moreover, established standards are a key research enabler, since research laboratories need standard interfaces, for example to develop much more efficient replacements for existing systems.

More than a hundred standardisation organisations worldwide

The high complexity of Industrie 4.0 means that, in the medium term, there will not be one single Industrie 4.0 standard. Instead, the next few years will see the emergence of numerous standards – some of them highly specialised and some more general in nature – providing interoperability in and between all manner of different systems and at various different levels. This approach has, for example, been adopted by the World Wide Web Consortium (W3C) under the heading of the Web of Things (WoT). The WoT aims to provide a basis for cross-domain interoperability using basic web technology principles: client-server architecture, "loose coupling" of components (i.e. minimising component interdependence) and the definition of lightweight data formats and interfaces. In recent years, these principles have led to new, globally successful business models on the Web. History teaches us that a consistently international approach to standardisation is essential in order to avoid solutions that are limited e.g. to a particular country, continent or specific application. International standards allow technologies from different countries (e.g. a German and an American technology) to be used together without requiring any additional integration measures or modifications.

Many different standardisation initiatives currently exist for the Internet of Things and Industrie 4.0. Figure 5 was produced by the EU's Alliance for Internet of Things Innovation (AIOTI). It shows some of the Standards Developing Organisations (SDOs) that are currently active. In total, more than a hundred standardisation organisations of varying importance are now working in this extremely wide field. It is not easy to say which of them are relevant to Industrie 4.0, since the landscape is constantly changing and important standardisation organisations are emerging concurrently in certain areas. Accordingly, it is important to carefully and continually monitor the individual areas, technology themes and sub-domains and to continuously identify and update the standardisation organisations that are relevant to them.

This study is unable to address such a complex challenge in the necessary breadth and depth. Nevertheless, it is possible to draw some preliminary conclusions. The Industrial Internet Consortium (IIC) is currently a key player and will continue to be so over the next few years, not only in the US but also in Europe and especially in Germany. Although the IIC does not explicitly regard itself as a standardisation organisation, it does collaborate

Figure 5: Standardisation organisations for the Internet of Things (source: AIOTI WG3)

very closely with the Object Management Group (OMG). One manifestation of this cooperation is that the same person currently occupies the role of Executive Director in both organisations. The IIC has already entered into several cooperation agreements with German actors, including the Plattform Industrie 4.0 and the German Institute for Standardization (DIN).

The W3C's Web of Things initiative is geared towards the establishment of a cross-domain technology stack.[19] Its goal is to describe "connected things" using "thing descriptions" and enable them to be addressed interoperably via standard protocols. More and more W3C members are joining this Siemens-led initiative. A number of cooperation agreements have now been signed with various organisations such as the IIC and there have also been agreements in the field of semantics with the Plattform Industrie 4.0, the OPC Foundation, oneM2M, AIOTI and IETF/IRTF.

The need for international coordination of national initiatives

At the 2016 Hannover Messe, German industry launched the Standardisation Council I4.0. This initiative of Bitkom, DIN, DKE/VDE, VDMA and ZVEI aims to "initiate digital manufacturing standards and coordinate them both nationally and internationally".[20] The Standardisation Council's role is to facilitate coordination between industry and standardisation organisations, i.e. to act as an intermediary between the members of the Plattform Industrie 4.0 and the various standardisation organisations and to feed the identified norm and standardisation requirements into the Industrie 4.0 Roadmap.

As far as the required standardisation activities are concerned, it is important to bear in mind that traditional industries have been actively involved in national or international standardisation organisations such as DIN or ISO for several decades. Similar initiatives also exist in other countries, such as the Japanese Industrial Standards (JIS) in Japan. Although traditional industries have in some specific instances attempted to establish links with the IT industry (e.g. ISO/IEC JTC1), in general there is still a wide gulf between IT companies and traditional industry. IT companies tend to approach standardisation through international industry-based organisations such as W3C.

These consortia frequently have very agile decision-making structures that are not based on particular countries or regions, giving the IT industry's typically global companies greater flexibility when it comes to driving new technologies. The gulf between IT and traditional industry can also be observed within many large enterprises where the IT departments work with

19 | In this context, "technology stack" refers to a group of technologies that, while separate from each other, are nonetheless developed in close coordination. One example is the web technology stack that incorporates e.g. coordinated protocols for exchanging (HTTP) and representing (HTML) information.

20 | See Plattform Industrie 4.0 2016 (own translation).

different standardisation organisations to the departments that are involved in conventional forms of production. Slow and poorly coordinated technology transfer between IT and production could constitute a significant problem for Industrie 4.0 both in Germany and in other countries. Innovative IT companies or companies working in IT-related industries have an opportunity to gain an almost unassailable competitive advantage before the rest of the market starts to develop innovations in this area. Another key factor is that industry-based consortia often work more quickly than traditionally structured standardisation organisations.

As well as regarding the establishment of one single Industrie 4.0 standard as unlikely, the experts who took part in the survey also felt that it was unrealistic to expect all the relevant development and standardisation activities to be brought together under the auspices of a single organisation. Instead, they considered the likeliest scenario to be the emergence of a system of standardisation organisations that cooperate closely with each other in order to efficiently address the technology gaps and requirements identified by industry. Bodies such as the Standardisation Council can play an important coordinating role in this regard. The main aspects and principles that should form the basis of these standardisation processes are outlined below.

The standardisation activities currently taking place in the field of Industrie 4.0 are extremely dynamic. This makes it impossible to systematically identify and list the relevant standards or standardisation areas. Many actors have recognised this problem and consequently place great importance on cooperation between standardisation organisations and on the continuous collation of all the relevant standards.[21] According to the German Standardization Roadmap Industrie 4.0 (version 2.0), the most frequently cited areas requiring standardisation are reference models, communication, manufacturing technology, human beings in Industrie 4.0 and non-functional properties. The standardisation of cross-domain terminology is extremely important in this context.

Demand for interoperable systems that can be flexibly integrated

The experts who participated in the interviews considered networking, integration, data acquisition and processing to the most important areas for standardisation in Industrie 4.0. Regardless of their country, they all agreed that the principal focus when developing standards and norms should be on standard data formats and (semantic) interoperability, while metadata, vocabularies and domain models were also considered to be significant (see Figure 6).

In other areas, however, differences between countries were evident. Whereas reference models were important to the interviewees from Germany and Japan, they were relatively unimportant (18 percent) in the US. In China, meanwhile, one of the priorities is the introduction of a standard Industrie 4.0 vocabulary. The interviewees felt that it was crucial for companies in all countries to identify the areas where there is a need for standards and feed this information into the corresponding international initiatives of the relevant standardisation organisations.

The vast majority of the experts who were interviewed regarded open standards as an important requirement for flexible interoperability between different manufacturers' solutions: 35 percent rated open standards as very important, while 37 percent said they were extremely important (see Figure 7). Open standards help to create affordable solutions for a broad user layer. The experts felt that spreading the design and standardisation work across all the organisations involved in the process helps to cut development costs and reduce the investment risks, particularly for small and medium-sized enterprises.

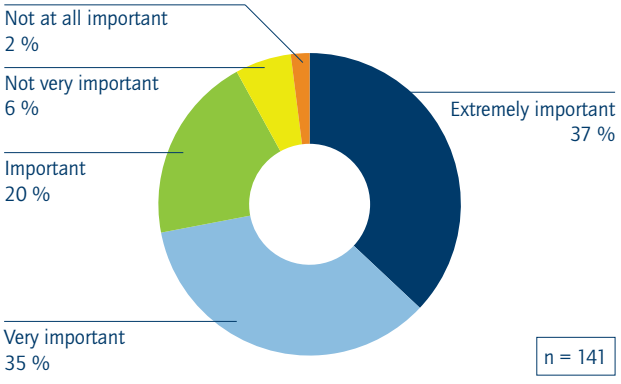

Figure 7: Importance of open standards

The challenges posed by platforms and digital ecosystems

The experts who took part in the interviews were unsure about whether individual industrial companies will in future develop their own closed silo solutions (walled gardens) as is currently the case in the IT sector. 53 percent chose "don't know" in

21 | See the DKE's standardisation roadmap.

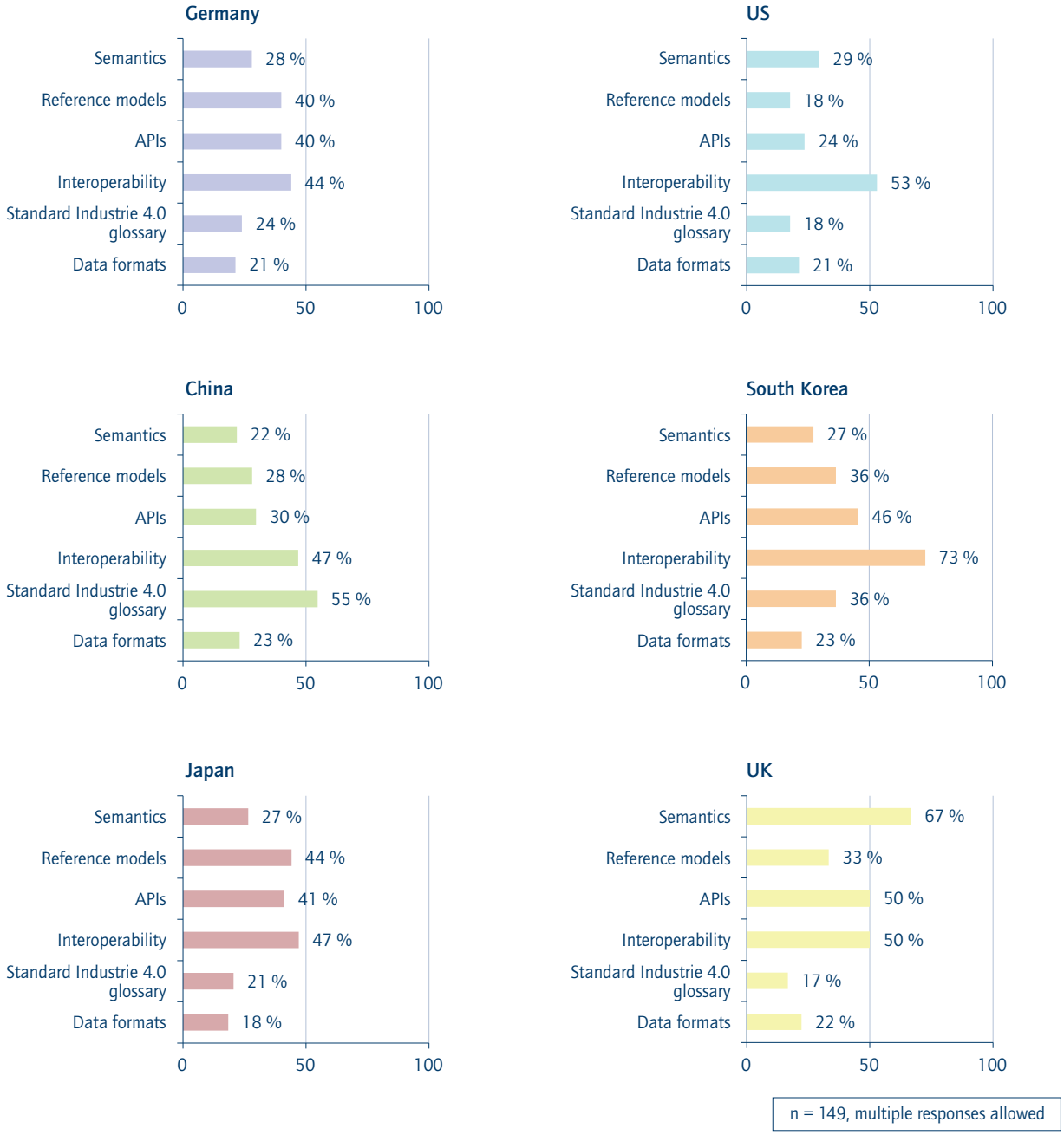

Figure 6: Areas where there will be a high requirement for specific norms and standards in the future

response to this question (see Figure 8). However, the majority of the interviewees thought that modular, interoperable solutions must be created for Industrie 4.0 to succeed. The experts also highlighted the danger of large US companies with established platforms and digital ecosystems being able to directly dominate the fledgling digital market in Europe. It should be stressed that most of the interviewees did not insist that the standardisation processes should result in the adoption of any one particular standard. What matters is for whichever standards are settled on to be adopted on a widespread basis in order to enable the creation of interoperable systems that can be flexibly integrated.

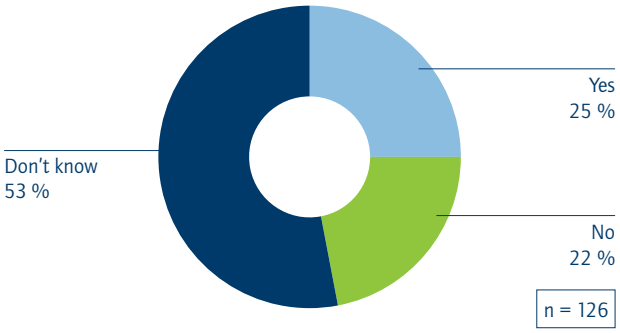

Figure 8: Likelihood of closed ecosystems also in industry

Establishment of de facto standards by corporations

It was felt that the establishment of norms and standards should be driven by industry. The experts highlighted the danger of standardisation organisations, government or organisations with close links to government decreeing which themes require standardisation. This could result in the standardisation processes and the resulting standards neglecting the needs of businesses. In practice, large corporations in particular are leading the way with regard to the establishment of de facto Industrie 4.0 standards, whereas SMEs are more likely to adopt a wait-and-see approach. However, the experts thought that security-related issues should not be driven solely by (large) individual companies and that a wide range of actors from industry, academia and other relevant organisations should be consulted.

The chief obstacles to the establishment of norms and standards cited in the interviews were divergent (commercial) interests, concern about loss of know-how and a lack of trust on security-related issues. The experts also felt that there are a number of themes that should be explicitly excluded from standardisation, for instance technology areas that are simply developing too quickly, lack the necessary degree of convergence or maturity, or involve company-specific intellectual property. The development of the regulatory framework in this area will need to address various challenges in order to provide the stakeholders with greater legal certainty.

In view of the race that is currently underway to establish international norms and standards as quickly as possible, many of the companies in the survey believed that standardisation work is currently progressing too slowly. However, the experts also stressed the fact that the highly complex nature of Industrie 4.0 and the need for extensive committee work mean that standardisation processes are more complex and take longer. Once again, there were differences between countries on this issue (see Figure 9). While 78 percent of respondents from Germany thought that standardisation is progressing too slowly, the respondents from China, Japan and the US were likelier to be satisfied with the current rate of progress.

The controversy regarding the speed of standardisation activities was also evident in the opinions of those experts who believe that standards are an essential requirement for interoperable, modular solutions but also argue that if standardisation is rushed, the standards may fail to cover key areas adequately or indeed at all. However, the experts did think that there was potential for standardisation organisations to carry out their work more quickly. The interviewees believed that they should also be actively supported and funded by government. Closer coordination could generate numerous synergies (e.g. the avoidance of two different standards for the same thing) between formerly separate standardisation activities. In addition to technology leadership this could also provide a head start in terms of time. There is currently little point in carrying out extensive standardisation work in some Industrie 4.0 areas that are still at the experimental stage, for example assistance systems. Nevertheless, preliminary basic strategies and standards should still be established in order to create a stable investment environment and foster innovation. The experts pointed out that Industrie 4.0 solutions are already working and in operational use in certain sectors. The opportunity to actively contribute to the standardisation process from an early stage should not be wasted because of an over-cautious and tentative attitude.

Figure 9: Opinion about the rate of progress on standardisation

Expert quotes

- "In strong sectors, where you could find the global players, the standardisation should come from companies, in small business sectors from organisations."
- "Cooperation slows the process down. But because it's such a complex topic, everyone needs to be singing from the same hymn sheet."[22]
- "The language that machines use to talk to each other must be based on an open, licence-free standard. Otherwise we could see a repeat of what happened with Google, Facebook and Amazon, where individual companies become so powerful that there comes a point where we can no longer do anything without them.[23]
- "Speeding up implementation through flexible, industry-driven testbed solutions."[24]

3.3 Cooperation

Cooperation right across the value chain will acquire new significance as a result of Industrie 4.0. New forms of cooperation and collaboration could emerge if industrial service providers, plant operators, machinery manufacturers and the operators of the underlying platforms come together to form digital ecosystems. In the future, networks of companies will be formed more frequently and above all more rapidly. "Ad hoc networking" in value networks will not be confined to production but will also have a growing impact on other areas of companies' activities such as research and development and administrative functions.

Cooperation as an essential requirement for Industrie 4.0

Against this backdrop, the majority of the companies, research institutions and associations interviewed regarded cooperation as an essential requirement for the successful implementation of Industrie 4.0. Among other things, cooperation was seen as desirable in order to enhance know-how (e.g. with regard to data security or business models), reduce development times and prevent redundant solutions. The priority themes for cooperation were data acquisition/transmission, networking, data processing/analysis and interfaces (see Figure 10).

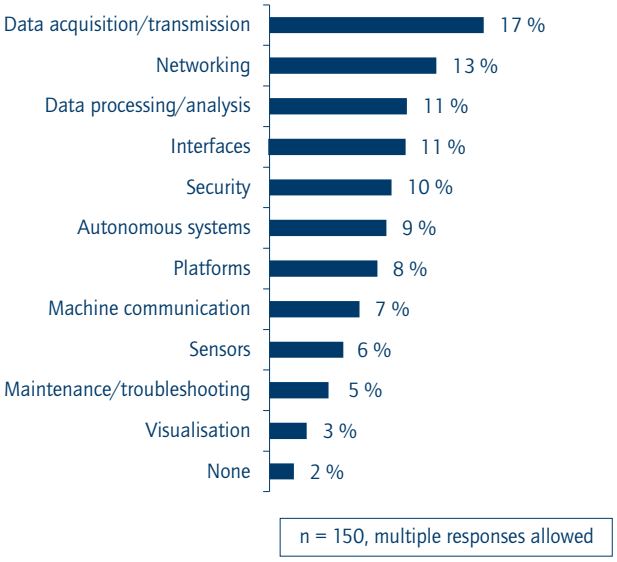

Figure 10: Technology areas with the greatest need for cooperation

Different issues were prioritised by different countries in the survey. The German experts emphasised the need for cooperation in the technology areas of data acquisition/transmission and networking, whereas autonomous systems were rated as less important. Data acquisition/transmission is also seen as the technology area with the greatest need for cooperation in China, followed by interfaces and security. South Korea and the UK regard data acquisition/transmission, data processing/analysis, networking and autonomous systems as the main priorities. Meanwhile, the experts from Japan identified platforms as the technology area with the greatest need for cooperation.

Overall, the findings reveal that countries all over the world are very keen to cooperate with German research institutions. However, Germany can also learn from other countries, particularly in the field of IT security. The interviewees also stressed the need to promote proactive platform building with key actors whilst avoiding silo thinking and behaviour. Technologies should be discussed across the board and holistic, interdisciplinary approaches should be developed.

22 | Own translation.
23 | Own translation.
24 | Own translation.

There are partners from all over the world who are interested in cooperating with German businesses and organisations in the areas of data acquisition/transmission and data processing/analysis. When selecting partners, however, it is important to pay careful attention to the conditions governing how data are used in different countries and by potential partners. Other countries expect German data processing solutions to have high security and data protection standards. Solutions with similarly high data protection standards are urgently needed in other parts of the world, too.

The results also indicate that networking is regarded as an important technology area, especially in Europe. This is because the European understanding of Industrie 4.0 focuses on the ad-hoc networking via the Internet of smart machines, production resources, products/workpieces and warehousing and transport systems in order to create efficient value networks. German organisations such as the Plattform Industrie 4.0 should work to promote this interpretation of Industrie 4.0 in the rest of the world.

In addition to the technology areas, the interviewees also identified a need for cooperation in allied Industrie 4.0 fields such as training and professional development, research and development (R&D), business models, access to venture capital and access to talent (see Figure 11). However, the focus varied from one country to another. Half of the experts from Germany said there was a need for cooperation on business models, while R&D was rated as the next most important area. There was less interest in international cooperation in the fields of training and professional development and access to talent and venture capital. Overall, the US experts saw little need for international cooperation. They identified a moderate requirement in the fields of business models, training and professional development and R&D. The number one priority for cooperation in China was in the field of R&D, followed by training and professional development, access to talent and business models. South Korea and Japan also identified a need for cooperation on business models, R&D and training and professional development.

Innovative business models a challenge for SMEs

It is particularly challenging for SMEs to find suitable partner companies in the field of business models. They need partners that can support them in the development of data-driven business models without undermining the SMEs' competitive advantage through their own platform solutions. Accordingly, the experts highlighted loss of know-how as one of the dangers of cooperating with external partners. SMEs in particular run the risk of becoming nothing more than interchangeable suppliers if they fail to protect their strategic business areas from the competition. There is thus a requirement for new ways of protecting intellectual property that go far beyond traditional property rights. The experts highlighted the need for additional professional development at management level in order to enable companies to successfully engage in value-added cooperation with external partners without losing their strategic USPs.

In order to ensure a strong voice internationally, cooperation on the implementation of Industrie 4.0 should be engaged in at a national, European and global level. According to the experts, this cooperation should not be confined to companies' R&D departments but should also occur at a political and academic level, as exemplified by the partnership agreement concluded between the Plattform Industrie 4.0 and America's Industrial Internet Consortium (IIC) in February 2016[25]. The German and Chinese governments reached an agreement to cooperate closely in the field of Industrie 4.0 as long ago as July 2015.[26] This was followed by a cooperation agreement between Germany and Japan in April 2016.[27] Germany is globally regarded as a desirable and reliable partner for international cooperation. Despite this international recognition, it is still important to remember that the protection of competitive advantages in both know-how and technology is of fundamental strategic importance to the individual partners in any cooperation agreement. Consequently, the experts stressed that cooperation should always be based on reciprocity, i.e. it should be mutually beneficial to all the partners involved.

The development of international testbeds and cross-industry integration platforms

All the countries in the survey cited testbeds and industry-specific integration platforms as effective instruments for future cooperation in the field of development. Testbeds are particularly useful for cross-company prototype development and the pragmatic implementation of beta versions. Industry-specific integration platforms are a valuable tool for developing and disseminating standards within a particular industry. Advocates of this form of cooperation argue that the complexity of Industrie 4.0 means that cross-industry standards development is either impossible or would be harmful to their particular industry.

25 | See Plattform Industrie 4.0 2016.
26 | See BMWi/BMBF 2014.
27 | Ibid.

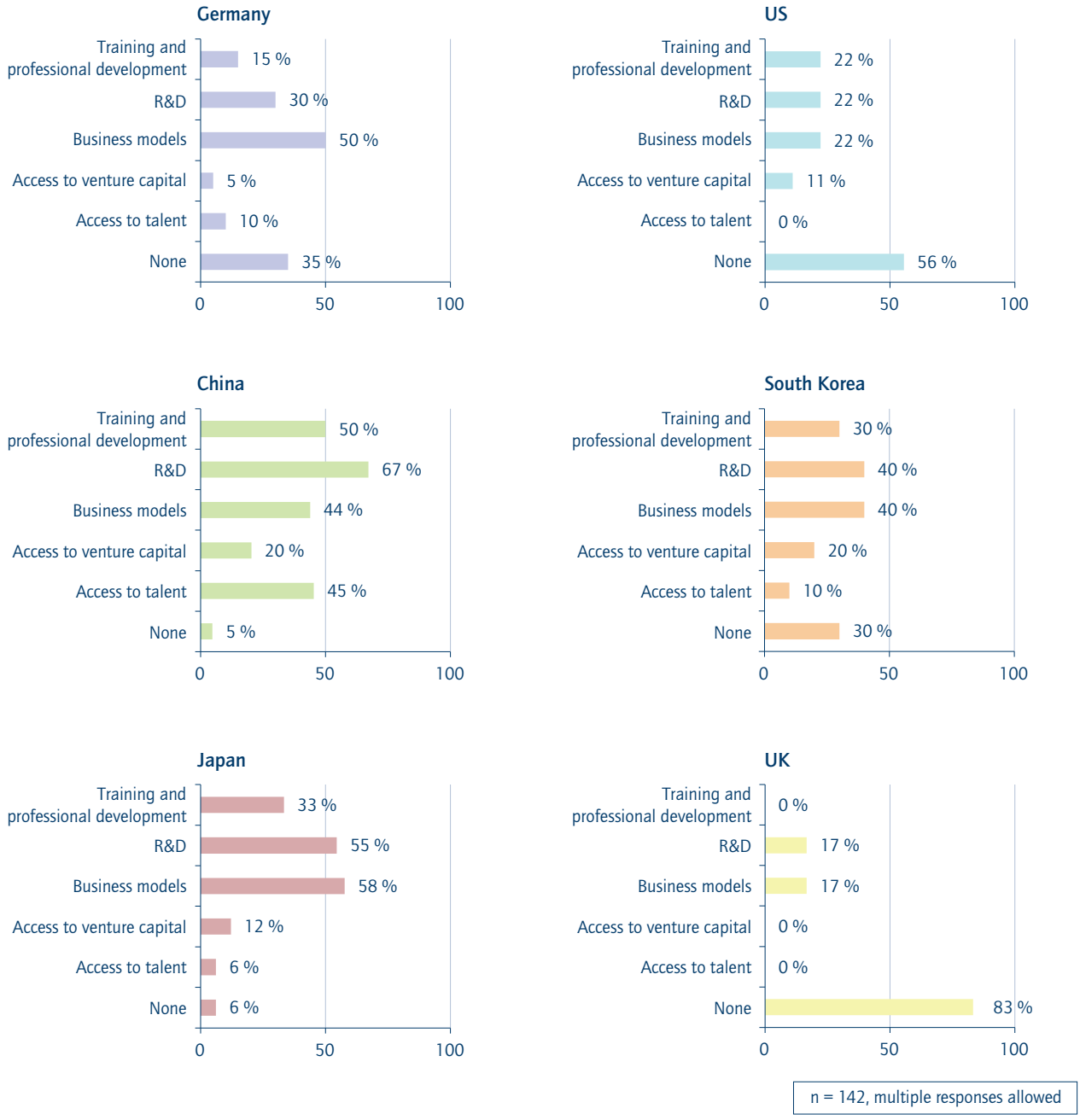

Figure 11: Allied fields where there is a need for cooperation

Figure 12: Ways of accelerating the development of norms and standards

Regardless of which country they came from, the companies in the study largely favoured testbeds, whereas academic organisations and associations preferred cooperation through industry-specific integration platforms. As far as national differences go, both Germany and in particular the US placed greater emphasis on testbeds, while there was a stronger focus on industry-specific integration platforms in China, Japan and South Korea (see Figure 12).

However, the greatest differences in focus were between large, global corporations and SMEs. Large corporations prefer to be involved in several international standardisation organisations and to develop testbeds. They can do this thanks to the extensive resources at their disposal and their well-developed global networks. The benefit of this approach is that it provides them with a pragmatic means of cooperating with other large corporations, SMEs and start-ups.

Most SMEs do not have the same resources as large corporations and therefore tend to favour cooperation within their own particular industry. This approach is endorsed by some of the experts who argue that rather than one single Industrie 4.0 standard, different industries will develop their own specific standards. This would give SMEs a stronger voice, helping them to push through their own demands. Industry-specific platform solutions also allow SMEs to reduce investment risks, benefit from synergies in the establishment of standards and successfully communicate standards to their customers. Academic organisations and the relevant associations can play a valuable role in orchestrating cooperation on industry-specific integration platforms.

The experts did not feel that there were many risks involved in using testbeds and industry-specific integration platforms to carry out joint testing of new ideas. On the other hand, they did think that pragmatic research cooperation offers excellent opportunities. The companies that took part in the survey identified several different ways of cooperating: industry-specific versus cross-industry, cooperation with suppliers versus cooperation with competitors, cooperation with global corporations versus cooperation with innovative start-ups. In order to ensure that they are well-prepared to meet the challenges posed by the dynamic development of Industrie 4.0, many companies are actively involved in a variety of organisations and initiatives. The interviewees drew a distinction between organisations with a predominantly technical focus and those that are more focused on marketing. Some companies felt that the decision-making structures of certain organisations lack transparency.

Cooperation to promote interoperability and innovation

Most companies, research institutions and associations expect the main advantages of cooperation to be interoperability and innovation and cost benefits (see Figure 13). Interviewees from Germany also cited cost benefits and synergies, while similar responses were received from both the US and the UK. Most of the respondents in the latter two countries also regarded interoperability as a key challenge. Meanwhile, the interviewees from China and Japan saw speed as one of the principal benefits of international cooperation, together with knowledge acquisition, having your finger on the pulse of the market and market access. The key themes for South Korea were interoperability, synergies, cost benefits and knowledge acquisition.

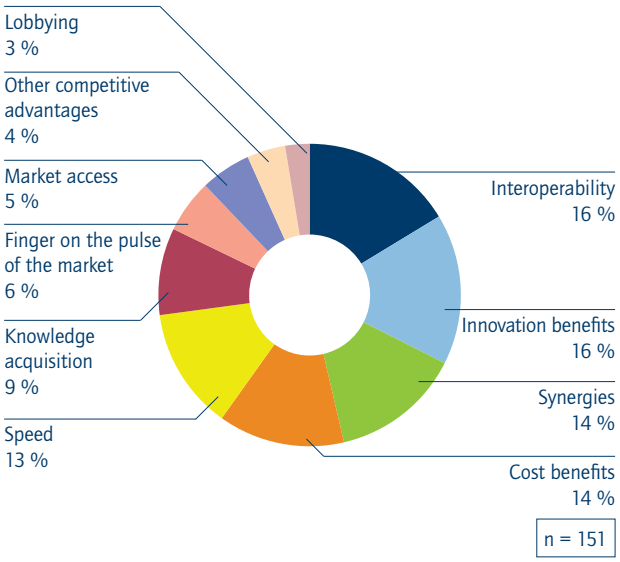

Figure 13: Benefits of cooperation

More than two thirds of all the respondents saw data protection as the main risk of cooperation (see Figure 14), while around half also cited a potential loss of know-how. This figure rose to 75 percent for Germany and 62 percent for the US. While the Japanese interviewees identified loss of control as the biggest risk, this was less important for the other countries, especially China. Product piracy was considered to be of secondary importance by all the countries.

Notwithstanding the above, the majority of the companies and organisations interviewed said that none of these risks would

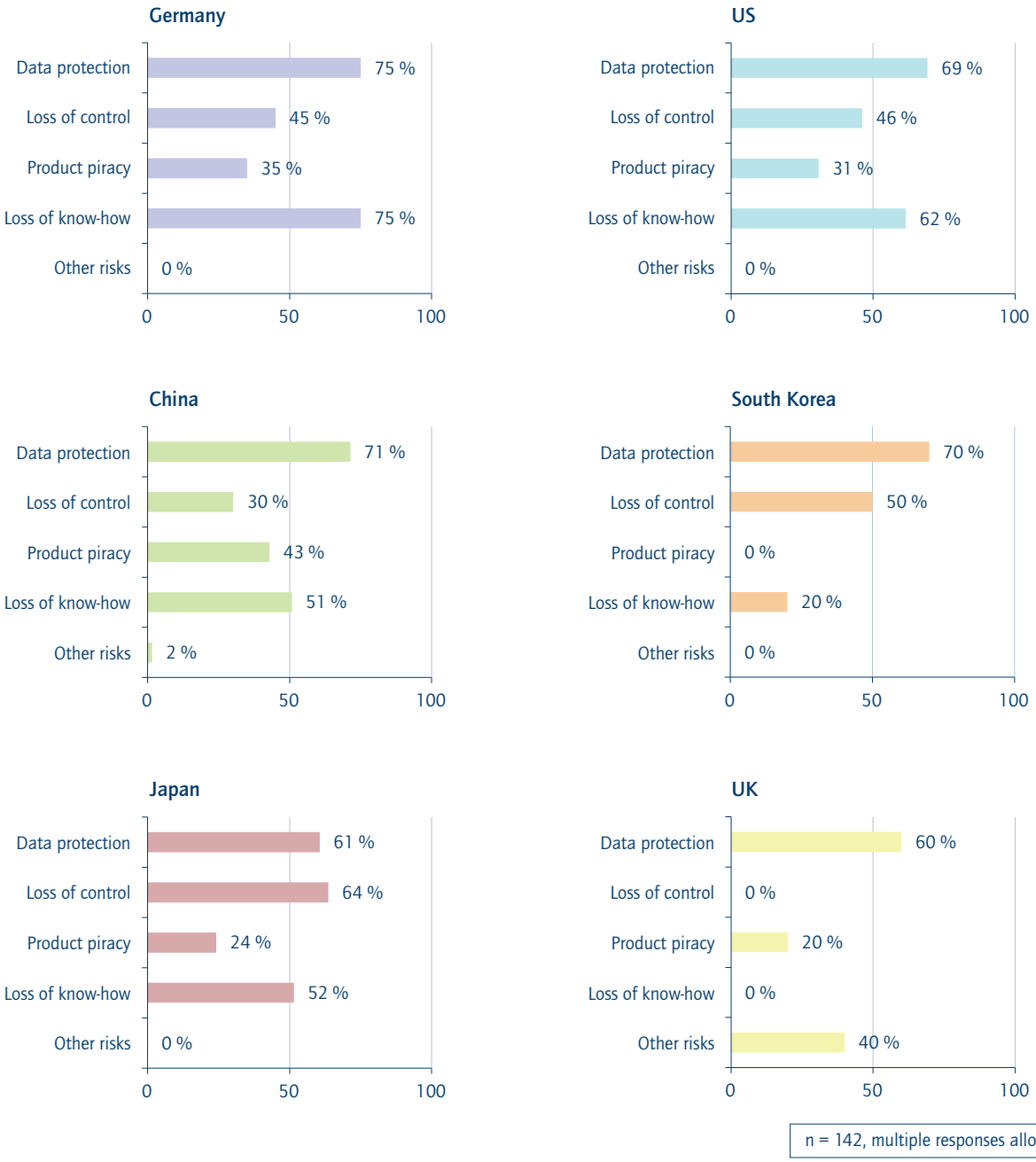

Figure 14: Risks of cooperation

deter them from engaging in cooperation. Instead, they stressed the need to manage the risks by exercising due care when selecting partners and defining the scope of the cooperation. Japan was the only country where a significant proportion of respondents felt that the risks constituted a reason not to engage in international cooperation.

In addition, some companies believe that cooperation and alliances are important in order to prevent large Internet companies from stealing a march on traditional manufacturing industry in the field of Industrie 4.0. While around half of the respondents did not think that their company's or organisation's business model was currently threatened by Internet companies, more than 20 percent did identify a threat and around a third were unsure. This uncertainty was particularly pronounced among the interviewees from the UK, South Korea, the US and Germany. In many cases, this issue has not been systematically analysed. Not enough people are thinking outside of the box and systematically trying to predict the specific impacts that the Internet giants could have on their own company. In spite of these issues, half of all the interviewees said they would still be prepared to cooperate with the large Internet companies. Japan was the only country where a significant percentage of respondents were sceptical about cooperating with them.

At this point, it is necessary to emphasise the importance of know-how and intellectual property (IP) to Germany technology companies. The global success of both large corporations and SMEs is in large part due to their competitive advantage in know-how and technology. This pre-eminence is accompanied by a risk – loss of know-how as a result of cooperation with other companies can rapidly threaten the survival of SMEs in particular, since their strength lies in their specialised knowledge.

The need for binding agreements and contractual rules

Despite this concern about the impact of cooperation with regard to core competencies/core IP, most of the companies said that in principle they would not rule out cooperation in any area. The respondents thought that agreements should primarily be governed by ground rules. These should, for example, cover the interpretation of rights of use and exploitation (intellectual property rights) for the jointly developed know-how, as well as confidentiality matters. The respondents unanimously rejected verbal agreements as a basis for successful cooperation. Most of the respondents thought that contractual rules also have a part to play (see Figure 15). Ground rules and contractual rules should address topics such as knowledge protection, ethical guidelines and frameworks for legal, commercial and personal issues. Trust was a significant issue for the respondents from China, South Korea and Japan. The interviewees stressed the fundamental importance of ensuring that contractual rules do not slow down the establishment of cooperation initiatives. Dynamic contracts can support new forms of cooperation, but it is necessary to accept that they cannot always be 100 percent watertight. New types of cooperation such as ad-hoc networks should be systematically analysed and the relevant new frameworks created. The interviewees felt that there was a particular need for dynamic, modular standard contracts.

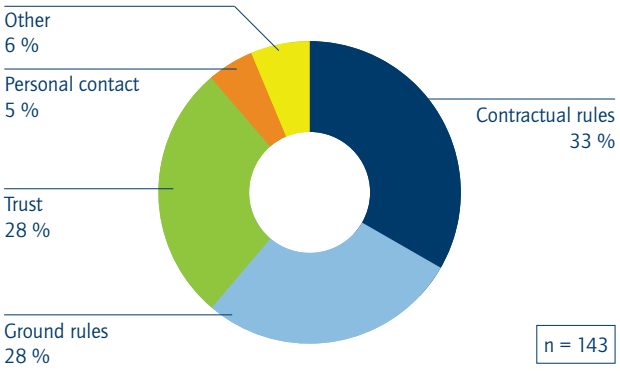

Figure 15: Requirements for engaging in cooperation

Most of the interviewees believed that in addition to the exchange of information and results, a coordinated approach with separate responsibilities for each partner is also desirable. Companies and organisations favoured cooperation with business and academia (see Figure 16). Academia was regarded as an important partner especially by Germany, South Korea and Japan. The interviewees unanimously agreed that cooperation should take place at a global level and on a regular or permanent basis.

There was less agreement as far as the desired number of partners is concerned. The respondents from Germany, the US and Japan favoured simple networks of four to ten partners. In China, the preference was for bilateral cooperation and complex networks with more than ten partners, whereas in South Korea it was for simple and complex networks. As far as the type of cooperation is concerned, the focus lies on vertical cooperation between suppliers and producers. The experts were also prepared to entertain the possibility of horizontal cooperation between direct competitors and lateral cooperation between e.g. automotive manufacturers and private banks. Japan and the UK in particular were keen on lateral cooperation as well as vertical cooperation.

Companies from all of the countries in the survey prefer to co-operate in simple networks that adopt a coordinated approach with separate responsibilities for each partner. The experts felt that simple networks provide the best opportunities and that four to ten partners should be enough to address most issues. However, it is important to recognise that e.g. platform initiatives need a larger number of partners. According to the interviewees, a coordinated approach with separate responsibilities for each partner creates the necessary sense of community and trust among the partners whilst at the same time affording individual companies more freedom to do things their own way compared to a joint organisation.

Expert quotes

- "We cannot allow the big Internet companies to steal a march on us. That is why it is so important to form alliances."
- "Cooperation cannot succeed without trust."
- "Industrie 4.0 can only succeed internationally."[28]

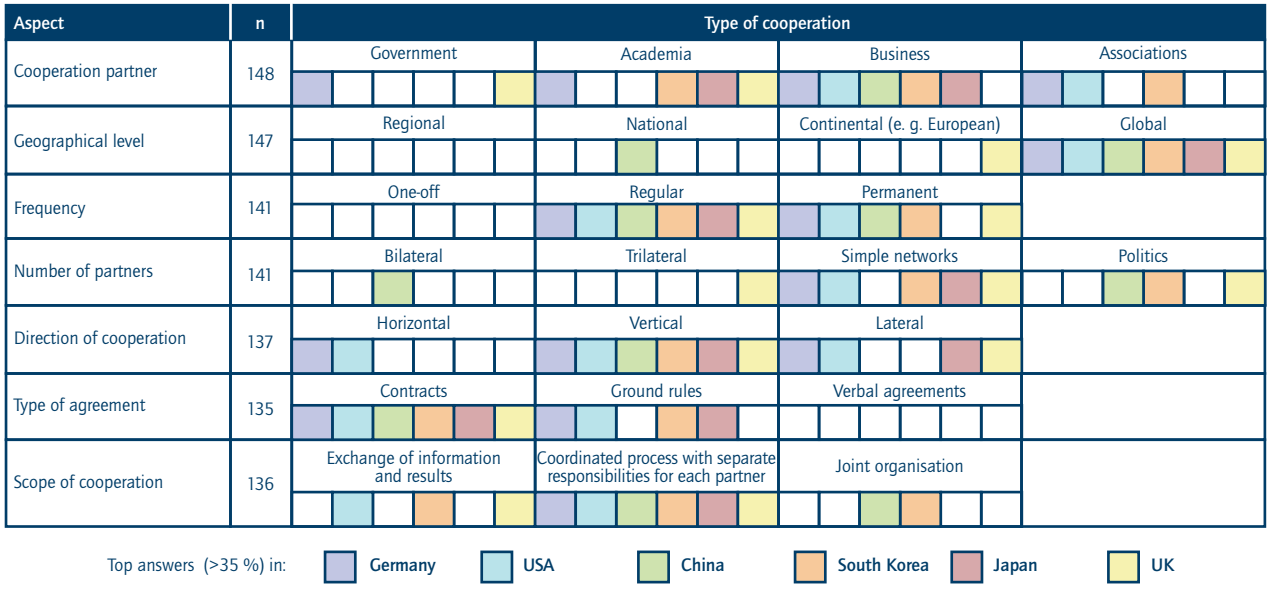

Figure 16: Cooperation preferences

28 | Own translations.

3.4 Country profiles

This section presents profiles for the countries of the experts who took part in the study, focusing on their overall economic situation, their national understanding of Industrie 4.0 and their current standardisation activities. The national initiatives and parallel developments in this field in the most important economies are also summarised with a view to formulating recommendations for representatives of government, business and the relevant associations.

The majority of the companies interviewed placed particular emphasis on global cooperation, although most of them are still at the stage where they are searching for the right partners. In order to formulate recommendations for German actors and to highlight the strengths and weaknesses of existing initiatives, we will focus on the prospects for cooperation and the potential partners in each individual country. We will begin with the situation in Germany, which will serve as the benchmark for the subsequent detailed analysis of the status quo of Industrie 4.0 in the US, the UK, China, Japan and South Korea.

3.4.1 Germany

In Germany, Industrie 4.0 is based on a strong vision of the future with a complex overall blueprint (semantics, RAMI 4.0 model, etc.).[29] The focus is on optimising production processes in terms of quality, price and flexibility and delivering better financial returns overall. The concrete goals and activities in connection with Industrie 4.0 include the creation of a reference architecture, interoperability, customised production down to a batch size of one, dismantling the automation pyramid, Plug and Produce and semantic processes and technologies for smart services and smart products.[30] The strategic goal is to maintain Germany's traditionally strong position in manufacturing and mechanical engineering throughout the digital transformation and to protect both local jobs and the investments in machinery and plant that have been made over the course of several decades. Germany's traditionally strong mechanical engineering sector includes the fields of automation and factory equipment. Accordingly, German industry has taken on a key role in the development of Industrie 4.0. This is demonstrated by the numerous individual cooperation ventures that already exist between German and international partners.

Thanks to the developments and initiatives that it has already undertaken in the field of Industrie 4.0 (see Table 1), Germany has acquired an excellent international reputation. This means that it is very well placed to cooperate with other countries around the world, for example with regard to standardisation.

Initiative	Field/Goal	Promoted by
Plattform Industrie 4.0	General recommendations coordinated by government	Government
BDEW	Energy sector	Industry association
BDI	Manufacturing, cross-sectoral	Industry association
Bitkom	ICT companies	Industry association
VDA	Automotive industry	Industry association
VDMA	Machinery and plant engineering	Industry association
ZVEI	Electrical and electrical engineering industry	Industry association

Table 1: Key Industrie 4.0 initiatives in Germany

The fact that Industrie 4.0 is already very advanced in Germany is demonstrated by the country's willingness to take on a global leadership role (see Figure 17). It is also reflected in the fact that the vast majority of the companies and organisations interviewed in the study regarded the direct implementation of Industrie 4.0 through partnerships in industry as the most suitable form of implementation and something that is already technically feasible.

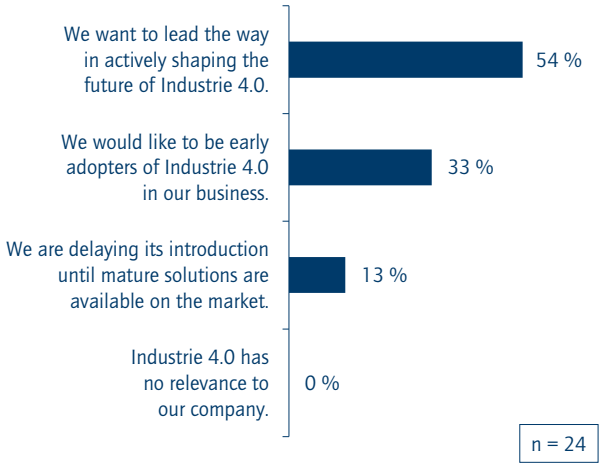

Figure 17: Relevance of Industrie 4.0 to experts from German business

29 | See VDI/VDE/ZVEI 2015.
30 | See Arbeitskreis Smart Service Welt/acatech 2015.

Like other countries around the world, Germany sees production automation and optimisation as the priority themes for Industrie 4.0. There is also a focus on the associated improvement in financial returns and the basic technology for networking and digitalisation. Compared to other countries, new business models and smart products are rated as less important by businesses.

A top-down approach to standardisation predominates in Germany. The overall direction is determined by government together with a handful of trailblazing companies and a small number of researchers and pioneering thinkers. Open standards are already seen as a key requirement for integrated Industrie 4.0 solutions by many Germany companies. Standardisation activities in Germany are coordinated by organisations including the Plattform Industrie 4.0 in close collaboration with the research community.[31] Germany predominantly employs a dialogue-based approach aimed at creating a broad consensus.

However, if it takes too long to build a consensus, there is a danger that Germany could fall behind its global competitors over the medium term, since other countries may already have taken concrete action by then. Moreover, some companies can be put off by the extremely complex nature of standardisation activities in Germany, preferring instead to turn to the Industrial Internet Consortium (IIC) which many of them perceive as likelier to provide quicker and less complicated solutions. Some leading German and international companies and organisations (e.g. Bosch, SAP, Siemens, Wittenstein and Fraunhofer) have already joined the IIC.

Overall, the speed of standardisation is rated much more negatively in Germany than in other countries. The priorities reflect the degree of technological progress that has already been achieved – as in almost all of the countries in the survey, standard data formats were rated as less important since this is seen as an issue that can already be solved. Interoperability is viewed as the main challenge by all of the countries. Unlike most other countries, however, Germany attaches much greater importance to reference architectures/models and standard APIs.

As well as large corporations, internationally successful medium-sized enterprises (hidden champions) also play a significant role in Industrie 4.0 in Germany. Smaller companies, on the other hand, often prefer to adopt a wait-and-see approach. They frequently lack both the necessary know-how regarding the technological and business implications of Industrie 4.0 and the resources to enable close involvement in standardisation bodies. It is crucial that businesses should themselves identify the standardisation requirements in Germany and feed this information into the standardisation process. Data security is regarded as the biggest financial threat, outranking even standardisation. Other potential threats such as a lack of acceptance by the market are considered to be less important.

Compared to other countries, the German approach is as a whole characterised by a strong focus on technology. New technologies and technology visions are thus at the top of the agenda, whereas less attention is often paid to commercial factors and opportunities such as new business models and smart products.

General conclusions

- **Build on the strong Industrie 4.0 brand**

While there is much international interest in current Industrie 4.0 developments in Germany, not enough is known about the concrete activities that are being undertaken. Among other things, this is due to the national focus of German consortia such as the Plattform Industrie 4.0. It is recommended that a more international outlook should be promoted among German groups by encouraging them to engage in cooperation and welcome foreign companies on board. This will serve to boost their profile and acceptance around the world. The first step is to identify those groups that are already very keen to strengthen their international focus. These groups should be marketed and promoted internationally. Sub-projects should then be created in conjunction with the international stakeholders. The specific focus of these sub-projects, e.g. as far as the role of testbeds is concerned, will depend on the technology area in question.

- **Use international standardisation as a catalyst for cooperation**

It is recommended that German companies should become more active in international standardisation bodies. This will allow them to rapidly discover which direction other industrialised nations are taking with regard to the development of technologies and business segments. This knowledge will make it easier to target them with the right Industrie 4.0

31 | See BMWi/BMBF 2014.

solutions. Engagement in international standardisation bodies also ensures consistency for decentralised cooperation. Active involvement allows R&D findings to be fed into the standardisation process, thereby consolidating technology transfer. In this context, the development of new business models can become a driver of standardisation. The key international organisations include e.g. the Industrial Internet Consortium (IIC) and its associated bodies such as the OMG, the World Wide Web Consortium (W3C) and the ISO's Strategic Advisory Group (SAG) on Industry 4.0.

- **Create stronger links between innovation centres**

Innovation centres can rapidly transform highly promising ideas into new products or services, accelerating the commercial development process and reducing innovation risks. Collaboration between innovation centres (centre-to-centre collaboration) facilitates cooperation between businesses and researchers from different countries. Once they have been drawn up, the requisite framework agreements can be used for different cooperation projects with different partner companies. Collaboration between existing and planned innovation centres should also be promoted. As and when planned innovation centres are opened, the existing innovation centres should be informed (e.g. via maps showing their distribution) and the policy frameworks for centre-to-centre collaboration created.

- **Make sure that the benefits of Industrie 4.0 do not seem too abstract**

There are clear differences in the approach taken by different countries towards the introduction of Industrie 4.0. While the focus of e.g. US consortia such as the Industrial Internet Consortium (IIC) is on rapidly and pragmatically demonstrating the value-added offered by Industrie 4.0, the German approach – which is based on government-funded initiatives – is more theoretical in nature. It aims to promote a dialogue between government, academia and business in order to create a consensus and build an integrated Industrie 4.0 strategy including reference models and standards. However, if these processes take too long, there is a danger that Germany could be left behind in the medium term because other countries will already have taken concrete action by then. Moreover, some companies can be put off by the large number of different stakeholders in Germany, preferring instead to turn to the IIC which they perceive as likelier to provide quicker and less complicated solutions.

Consequently, a dual strategy is recommended in order to establish Germany as an opinion leader for Industrie 4.0. Germany should continue to push ahead with the formulation of an integrated Industrie 4.0 strategy including the development of reference architectures, norms and standards. At the same time, however, it should also seek to develop pragmatic, high-profile solutions that demonstrate the concrete benefits of Industrie 4.0 to businesses. This would be helped by the establishment of industry-specific working groups focused on the development of marketable demonstrator solutions. Current initiatives and research projects should also place greater emphasis on showing how Industrie 4.0 can benefit businesses.

3.4.2 China

The Chinese economy is characterised by positive and dynamic growth. Over the past thirty years, China has experienced a spectacular economic boom during which its gross domestic product (GDP) has grown by an average of around ten percent a year. China's economic development has benefited greatly from the decision to open the country up to foreign companies and investors, together with the targeted establishment of special economic zones supported by the Chinese government and the ready supply of cheap labour. With a GDP of 11.4 billion US dollars (2015), China is now the second largest economy in the world after the United States. Indeed, if the purchasing power of its 1.4 billion consumers is used as a yardstick, it actually ranks as the world's number one economy.[32] In addition to its status as an attractive supplier, foreign companies are now also targeting China as a market for their own products.

The role of industrial production in China's economy is greater than in any other country in the world. Manufacturing industry accounted for around 43 percent of GDP in 2014, compared to approximately 31 percent in Germany and 21 percent in the US.[33] At present, Chinese industry is primarily focused on cheap mass production – the country is frequently described as the workshop of the world. Numerous foreign companies now have manufacturing facilities in China where they can produce goods at comparatively low cost. Exports account for a correspondingly high share of the economy – with its high current account surpluses, China has toppled Germany from its long-held position as the world's leading export nation.

Unlike highly industrialised nations such as Germany or Japan, Chinese manufacturing industry is extremely heterogeneous in nature. On the one hand, there are a handful of major global corporations (e.g. Huawei, Sany and Haier) that possess advanced and in some cases highly automated factories. These corporations are mostly located in the booming industrial and commercial cities found all the way along China's south and east coasts that emerged from the former special economic zones. On the other hand, there are large numbers of Chinese SMEs in which almost no automation or digitalisation has occurred – indeed, many of them are still only just starting to introduce computer-integrated manufacturing (Industry 3.0). For instance, just sixty percent of Chinese businesses use industry software such as Enterprise Resource Planning (ERP), Product Lifecycle Management (PLM) and Manufacturing Execution Software (MES). Thus, although much of Chinese manufacturing industry is a long way behind the leading industrialised nations, there are already a number of global leaders among its top companies.[34]

In the future, China aims to fully modernise its manufacturing industry in order to deliver efficiency and quality gains and technological advances. China has long since realised that continuing to position itself as a manufacturer of cheap, mass-produced goods is not a viable strategy for the future. One of the main reasons is the fact that wages are rising by around twenty percent a year. China's workers want to share in their country's prolonged economic boom and are increasingly turning from producers into consumers.

China sees Industrie 4.0 as an excellent opportunity to drive this transformation. Accordingly, a wide range of activities have been undertaken in this field, for example the establishment of smart cities, the *Smart Factory 1.0* initiative and the Internet of Things Center in Shanghai (see Table 2).[35] Last year, the Chinese government announced its *Made in China 2025* strategy, a national action plan that sets out the country's long-term priorities. Its aim is to transform today's mass production economy into a high-tech economy. It sets out a number of key actions and goals that are being vigorously pursued through extensive investment by government and industry, especially in research and development.[36] These include strengthening the innovativeness of state-owned manufacturing industry, greater integration of computerisation and industrialisation, the establishment of basic competencies, the development of quality brands, a comprehensive green manufacturing system, the development of services and the upgrading of manufacturing industry. In addition, breakthroughs are to be actively pursued in the following technology areas: information technology, machines and robotics, aviation and aerospace, marine equipment and vessels, rail vehicles, electric mobility, power equipment, agricultural machinery, new materials, high-end medical equipment and biopharmaceuticals.

32 | See Auswärtiges Amt: China – Wirtschaft 2016. .
33 | See Statista 2016.
34 | See Wübbeke/Conrad 2015.
35 | See GSMA 2015.
36 | See State Council of the People's Republic of China 2016.

Initiative	Field/Goal	Promoted by
Internet of Things Center Shanghai	ICT	Government
Internet Plus	ICT	Government
Made in China 2025	Manufacturing	Government
Smart Factory 1.0 Initiative	Manufacturing	Business

Table 2: Key Industrie 4.0 initiatives in China

The aim is to achieve these goals in three stages. China intends to catch up with the leading industrialised nations by 2025. In particular, it plans to make manufacturing industry more competitive by reducing existing disparities and raising manufacturing standards in those companies that are currently lagging behind. By this first deadline, the main core technologies should have been established, product quality improved and environmental standards (energy consumption, pollution, material consumption) raised. China then aims to attain an intermediate level compared to the world's leading manufacturing nations by 2035.

The automation and digitalisation of Chinese industry is seen as a key enabler of this vision for the future. Much of the inspiration for the strategy is drawn from Germany's Industrie 4.0 concept. The term is widely used and has positive connotations among both government and industry. China hopes that Industrie 4.0 will help it catch up with other nations and eventually become number one in the world. Accordingly, there is also considerable interest in developments in Germany, both in terms of theoretical approaches to Industrie 4.0 and in terms of technological innovations.

As well as being its most important trading partner in Europe, Germany is also China's partner of choice for the implementation of its *Made in China 2025* strategy. This is not only because Germany is a supplier of leading technologies in the targeted technology areas but also because China wishes to learn from Germany in order to successfully gear up its industrial sector for the future.[37] Consequently, there have recently been several meetings between representatives of both government and the private sector that have already resulted in a number of initial cooperation initiatives (see Figure 18). Examples include the third Sino-German intergovernmental consultations (October 014) and the cooperation between Germany's Federal Ministry for Economic Affairs and Energy (BMWi) and the Chinese Ministry of Industry and Information Technology (August 2015).

There are numerous technology export opportunities for German businesses, particularly in view of China's need for industry software, manufacturing technology and system integration upgrade technologies to facilitate the eventual introduction of Industrie 4.0 in its factories. The same applies to the demand for sustainability and environmental technologies. The rapid industrial growth experienced by China in recent years has all too often come at the expense of the environment. Many Chinese

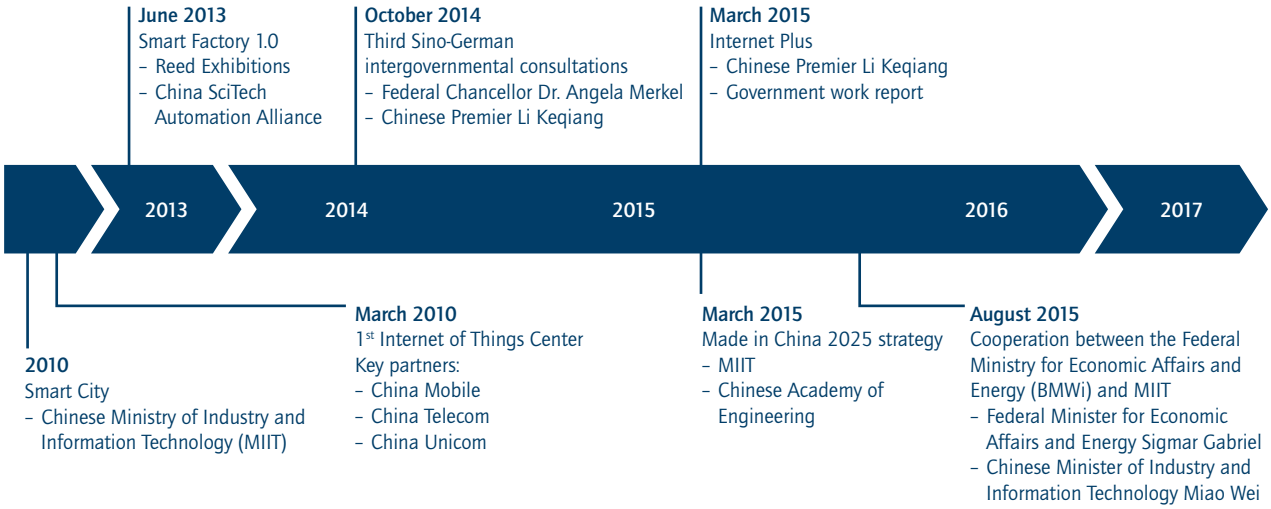

Figure 18: Milestones in the development of Industrie 4.0 in China (source: compiled by authors)

37 | Ibid. 2016.

cities suffer from severe air pollution caused mainly by emissions from the country's factories. Surface and groundwater and agricultural land are also often badly contaminated. According to a study by Berkeley Earth, 4,000 people die from air pollution in China every day. Consequently, the Chinese government is planning major investments to achieve a lasting improvement in the condition of the country's environment.

In the medium term, the planned transformation of China's economy will therefore provide German companies with significant sales opportunities in a variety of different technology areas. Over the longer term, however, it is also set to turn China into a serious competitor. This is illustrated by China's plans to reduce its foreign technology imports over the next few years. The *Made in China 2025* strategy sets out the goal of raising domestic content of core components and materials to forty percent by 2020 and seventy percent by 2025. Moreover, a look at China's patent activity reveals that it is already working concertedly to develop its own technologies, nowhere more so than in the field of Industrie 4.0 where over 2,500 Chinese patent applications were filed between 2013 and 2015. In other words, China filed significantly more applications than both the US (1,065) and Germany (441). Furthermore, a Fraunhofer IAO study found that some of these Chinese inventions are highly innovative. China is already carrying out world-leading research, especially in the fields of energy-efficient wireless sensor networks and network structures.[38]

China also possesses expertise in security solutions for integrated Industrie 4.0 solutions thanks to a variety of government initiatives, a well-developed mobile communications industry and its ample know-how in the field of information and communication technology (ICT). Chinese companies' extensive software expertise, the large number of Internet companies (such as Alibaba, Baidu and Tencent) and its huge domestic market are increasingly being accompanied by a greater focus on data-driven business models in the field of Industrie 4.0. One example of this is the government's "Internet Plus" initiative that aims to tap into the potential of new business opportunities, economic models and high value-added activities by promoting greater integration of the Internet in traditional industries.[39] In the long term, China is thus set to become a supplier of Industrie 4.0 solutions. In the short to medium term, it is likely that in particular China's major corporations will be able to successfully position themselves in the field of Industrie 4.0 with standalone solutions.

There are several areas where cooperation between Germany and China could be beneficial to both countries. For Chinese

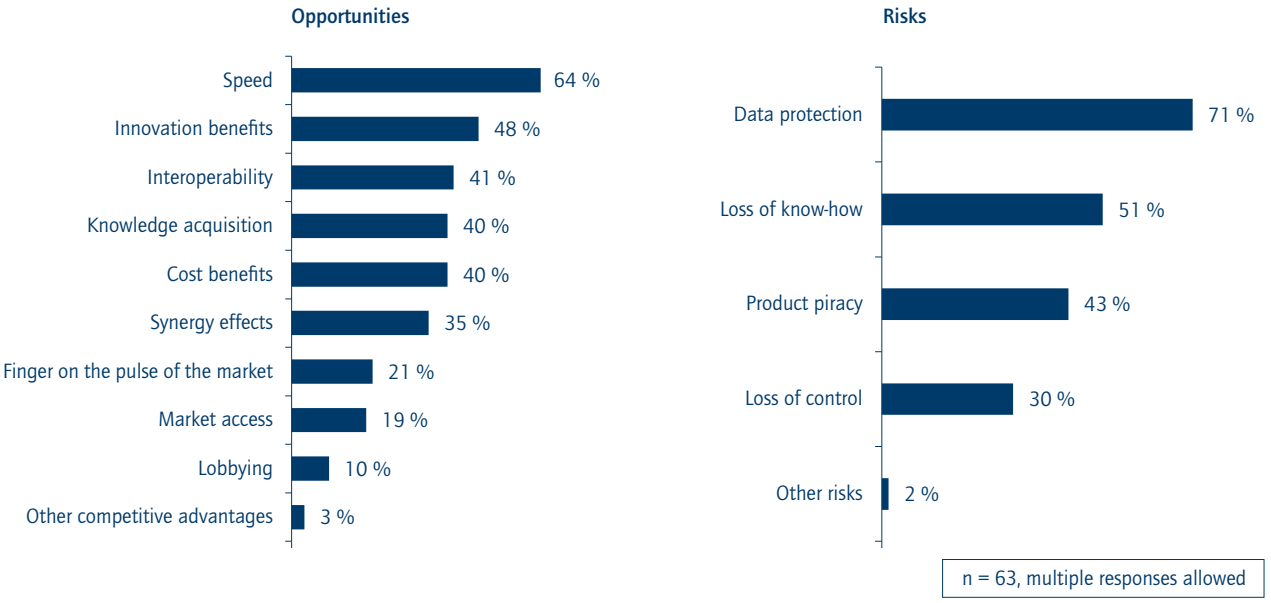

Figure 19: Opportunities and risks of cooperation from a Chinese perspective

38 | See Fraunhofer 2016.
39 | See Woetzel et al. 2014.

companies, the main potential benefits are speed (the most frequently cited advantage), innovation and cost benefits, knowledge acquisition and interoperability. German companies can take advantage of the Chinese market's speed and strength in terms of implementation to test and further develop their Industrie 4.0 solutions. Alongside these benefits, both Chinese and German companies consider data protection, loss of know-how, loss of control and product piracy to be the main risks associated with cooperation (see Figure 19).[40] In order to enable successful cooperation between the two countries, it will therefore be vital to insist on reciprocity and to ensure that any cooperation arrangements are formally signed off at a political level.

Significant potential for cooperation also exists with regard to norms and standardisation. China's activities in this area are characterised by a strongly top-down approach and are driven by government actors, although representatives of business and academia are also involved. Standardisation is regarded as an important area for cooperation with international actors. Consequently, successful cooperation initiatives (e.g. VDE/DKE and SAC) to develop common Industrie 4.0 norms and standards are being expanded. As far as China is concerned, there is a particular need for standardisation in the areas of data formats, a standard Industrie 4.0 glossary and interoperability, with great emphasis being placed on open standards. As for German companies, cooperation on norms and standardisation offers them the opportunity to promote the widespread adoption by the Chinese market of Industrie 4.0 norms and standards that they have developed themselves, thereby strengthening their position with respect to competing standards from other countries.

In summary, China is characterised by highly dynamic political, economic and social developments, together with an extremely complex system of responsibilities, a frequent lack of transparent decision-making at a political level and the fact that it can often be difficult to obtain market information. Cooperation with China thus entails challenges as well as opportunities.

Conclusions for China

- **Use China as a multiplier for German standards**

The race is now on in the field of Industrie 4.0. Whoever is first to define internationally accepted standards will have gained a long-term competitive advantage. The goal should be to use China as a multiplier to establish German Industrie 4.0 standards on the global market. The first step is to analyse the system behaviour of standardisation activities. Those activities that influence other activities particularly strongly but are themselves only weakly influenced by other activities are the drivers of Industrie 4.0 implementation. Beta standards must be rapidly agreed on for these drivers within Germany. These standards should then be implemented in Sino-German cooperation initiatives so that the Chinese market can be used to promote their establishment worldwide. However, this does not apply to standards in security-critical areas where quality always comes before speed.

- **Supply China with automation equipment**

Most companies in China are still a long way short of the manufacturing standards prevalent in the traditional industrialised nations. The Chinese government's *Made in China 2025* strategy aims to eventually close this gap, primarily by increasing the level of automation throughout the industrial sector. This opens up unique sales opportunities for German suppliers e.g. with regard to industry software, sensors and robotics. The goal should be to position Germany as a supplier of automation technology to the Chinese market and ensure that China becomes an importer of German high-tech products for many years to come. For this to be possible, it will be necessary for German SMEs to adopt a more international outlook and for economic ties with China to be further strengthened. The establishment of politically coordinated networks such as the Hessen-China Network should therefore be promoted.

- **Make the most of the opportunities in the sustainable technologies market**

As a result of its huge environmental problems, China is now investing heavily in green manufacturing. Germany's globally recognised expertise in this field makes it the partner of choice. There is thus an excellent opportunity for German companies in this sector to successfully position themselves as suppliers of clean technologies to Chinese factories in order to help them increase their resource efficiency and reduce their emissions. Exporting environmentally sustainable Industrie 4.0 solutions to China could make a significant contribution to recouping the high R&D costs. At a political level, work also needs to be carried on the implementation of the Paris Agreement.

40 | Survey of Chinese experts.

- **Approach Beijing via the provinces**

The Chinese market is highly fragmented in two separate respects. Firstly, there is a large gap in terms of development, infrastructure and prosperity between the cities and the peripheral regions and between different provinces. The second factor is the dual system of central and provincial government. After Beijing, the provinces are the most important administrative level of the Chinese state and in some respects have considerable freedom as to how they interpret and implement central government's policies. Moreover, some individual provinces, particularly those on the east coast, have very strong local economies. In order to ensure a sound basis for the decisions that they take about entering the Chinese market, companies should carry out a detailed analysis of regional differences and the opportunities and networks for accessing policymakers in the provincial governments. In consultation with central government, individual provinces should be used as a launchpad to develop expertise, networks and customer relationships on the Chinese market that can subsequently be used to progressively drive growth across the rest of the country.

- **Enter with strong partners**

In addition to large corporations, small and medium-sized enterprises play a particularly important role in Industrie 4.0 in Germany. However, as well as the many opportunities, cooperation with Chinese partners also entails risks for SMEs that are difficult to quantify. These include issues relating to know-how and technology protection, the extremely dynamic political and economic situation and the complex system of responsibilities at corporate, national and regional level. Since SMEs also generally lack international networks, the best way for them to access the market is via a "piggyback strategy", i.e. in cooperation with strong partners. Accordingly, SMEs should take targeted action to strengthen existing cooperation with German corporations and market leaders that are already established in China. Accessing these partners' infrastructure and customer networks will allow SMEs to establish a presence in China without needing to deploy large numbers of staff there. Government should support this piggyback strategy by providing stronger incentives for cooperation between German SMEs and large corporations that are already active in China.

- **Weigh up the investment risks**

For many years now, Germany and China have shared a strong and growing economic partnership that benefits both countries. Nevertheless, there is room for improvement as far as intellectual property is concerned, particularly on the Chinese side. In order to promote interest in economic cooperation among German businesses (including SMEs), the principles of such cooperation should be established at a political level. This will involve setting out how the returns of jointly created value-added can be protected from third parties and shared fairly between the respective partners. Issues to be addressed include a reform of the legal framework and regulatory instruments for protecting intellectual property and the development of mechanisms to improve data security. In order to build trust, Germany must insist on reciprocity: future cooperation with China should focus more on ensuring that the mutual benefits are maximised for both sides.

3.4.3 Japan

Japan is the world's third largest economy after the US and China and has a very diverse range of industries. Although it relies on importing large quantities of food and raw materials, it is also an exporting nation with numerous global conglomerates. These are complemented by a significant number of globally successful SMEs, especially in the mechanical engineering, automotive, electronics and chemical industries.

Weak domestic demand and demographic trends in Japan mean that international trading partners are becoming increasingly important. Consequently, it attaches great importance to the Trans-Pacific Partnership (TPP) trade agreement. It also hopes to conclude a free trade agreement with the EU by the end of 2016; Europe is Japan's largest investment partner. However, Japanese foreign investment is much higher and has a very wide geographical distribution.

Industrie 4.0 is already very advanced in the Japanese economy compared to other Asian countries. Like Germany, Japan has a strong industrial base with a long tradition. Digitalisation poses major challenges for Japanese manufacturing industry. Japan is promoting a number of themes that at the very least overlap significantly with Industrie 4.0. This can also be seen in the field of standardisation.

However, there is as yet no consistent understanding of the term Industry 4.0 in Japan. Manufacturing automation is regarded as a key element, alongside automation, network technologies and smart production. Almost all the experts who took part in the survey thought that the potential for new business models is one of the reasons why Industrie 4.0 is so important. Numerous technical challenges were identified with regard to its implementation. The most frequently cited were security, interfaces, data analysis, autonomous systems, machine-to-machine communication and visualisation.

All the participants in the survey rated the issue of standardisation as very important. The reasons cited included cost effectiveness and the ability to use the same software with different machine components. International standards are seen as a key enabler of Japan's participation in the global Industrie 4.0 market. The Industrie 4.0 technology areas cited above are also viewed as areas where international standardisation is required.

The respondents highlighted the importance of standard interfaces (APIs), reference models and the standardisation of both semantics and glossaries in order to create a standard terminology for Industrie 4.0. This indicates that there is still little consensus with regard to specific existing standards or standards that are currently under development. However, it is also clear that rather than one single, universal Industrie 4.0 standard, the experts expect to see "loose coupling", i.e. a modular technology stack that allows technological components from different manufacturers to be connected together flexibly.

The picture was less clear-cut with regard to the general conditions for standards – not all of the interviewees regarded open standards as indispensable. Some thought that non-open standards could potentially provide them with an advantage over their competitors. As for the speed of standardisation, some experts felt that it was too fast, while others believed it to be just right (see Figure 20). A number of the experts explicitly distinguished between Japan (too slow) and Germany (too fast). Suggestions to accelerate the pace of standardisation included implementation-based initiatives and testbeds, whilst the importance of government-funded R&D projects was also highlighted.

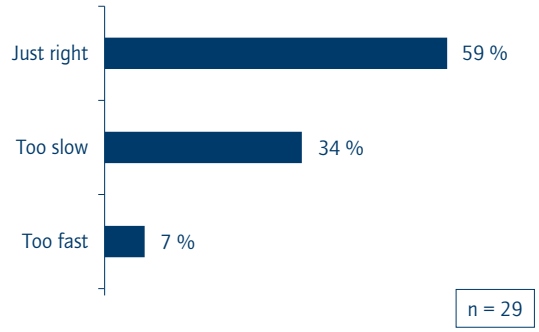

Figure 20: Opinion about the rate of progress on standardisation from a Japanese perspective

In view of the significant role played by government funding, government is included alongside industry among the key Industrie 4.0 stakeholders. Some areas are explicitly identified as being unsuitable for standardisation in Japan, either because business models already exist for them (e.g. field device integration) or because new business models are in the pipeline. Loose coupling is evidently regarded as extremely important, especially for new business models.

This emphasis on modular technology is reflected in the fact that people in Japan prefer not to tie themselves to commercial products from a single supplier. Some of the interviewees explicitly stated that silo solutions belong in the past. They do not believe that the majority of Industrie 4.0 products can be made by a single manufacturer and therefore stress the importance of an open ecosystem of solutions for the industrial sector. Many companies are reluctant to invest because of the lack of standards.

All of the technology areas included in the survey were regarded as relevant for cooperation, although there are some clear priorities such as process optimisation. While cooperation between businesses is rated as very important, some respondents said that their own companies engage in very little cooperation. Loss of know-how, product piracy and a general loss of control were identified as the main risks of cooperation. New business models, R&D projects and training were considered to be the most important areas for cooperation. Some of those interviewed thought that "challenges" similar to those employed by America's Defense Advanced Research Projects Agency (DARPA) can be a useful tool for delivering rapid progress. Faster standardisation and stronger innovation were identified as the chief potential benefits of cooperation.

In addition to cooperation between businesses, considerable importance is also attached to national and international collaboration with and between academic institutions, government ministries and the relevant associations (some of which are government-funded). There is a strong emphasis on long-term cooperation ventures built on trust. Suitable cooperation partners include buyers and sellers of Industrie 4.0 solutions (vertical cooperation) and direct competitors. Involvement in the development of standards appears to be an advantage in this respect.

As in Germany, there are a number of initiatives in Japan that for many years were only partially coordinated. These include the Industry Value Chain Initiative (IVI)[41], the Robot Revolution Initiative (RRI)[42] and the Internet of Things Acceleration Consortium founded by Hitachi and Keio University that includes Intelligent Manufacturing and the Industrial Internet among its priorities (see Table 3). There are also various proprietary solutions belonging to individual companies such as Mitsubishi Electric's e-F@ctory.[43]

Initiative	Field/Goal	Promoted by
e-F@ctory Initiative	Factory automation	Business (focus on Mitsubishi)
Industrial Value Chain Initiative (IVI)	Loose standards	Academic institutions and business
Industry 4.1J	Secure cloud-based data processing	Business (focus on NTT)
IoT Acceleration Consortium (IOTAC)	Linking IoT to big data and artificial intelligence	Government and business
Robot Revolution Initiative (RRI)	Industrial and applied robotics	Government and business

Table 3: Key Industrie 4.0 initiatives in Japan

However, things are changing fast. This is in part thanks to international cooperation at government level such as the initiative between Germany's Plattform Industrie 4.0 and the RRI which is an attractive cooperation partner because of its focus on production automation. The Ministry of Economy, Trade and Industry represents the Japanese government in this project.

The question for Germany is which initiatives it should cooperate with and what form this cooperation should take. The e-F@ctory and Industry 4.1J initiatives are best suited to one-off cooperation ventures with specific goals. However, government support is key to longer-term cooperation geared towards strengthening economic ties between the two countries. The IVI, IOTAC and RRI initiatives are better suited to this type of cooperation.

An article published in April 2016 compares the goals of America's IIC, the Plattform Industrie 4.0 and the IVI initiative.[44] The IIC focuses on new business models involving big data processing, whereas the Plattform Industrie 4.0 concentrates on more efficient, customised production. The fact that this latter priority is shared by Japan is explained by the importance of the manufacturing sector in both countries.

As in Germany, government and business in Japan cite productivity gains and better financial returns as benefits of Industrie 4.0. Nevertheless, Japan's Industrie 4.0 initiatives also focus on new business models, albeit not to the same extent as in the US. There is thus a wide range of Industrie 4.0 initiatives

41 | See Industrial Value Chain Initiative 2016.
42 | See Robot Revolution Initiative 2016.
43 | See e-F@ctory Alliance 2016.
44 | See Japan Industry News 2016.

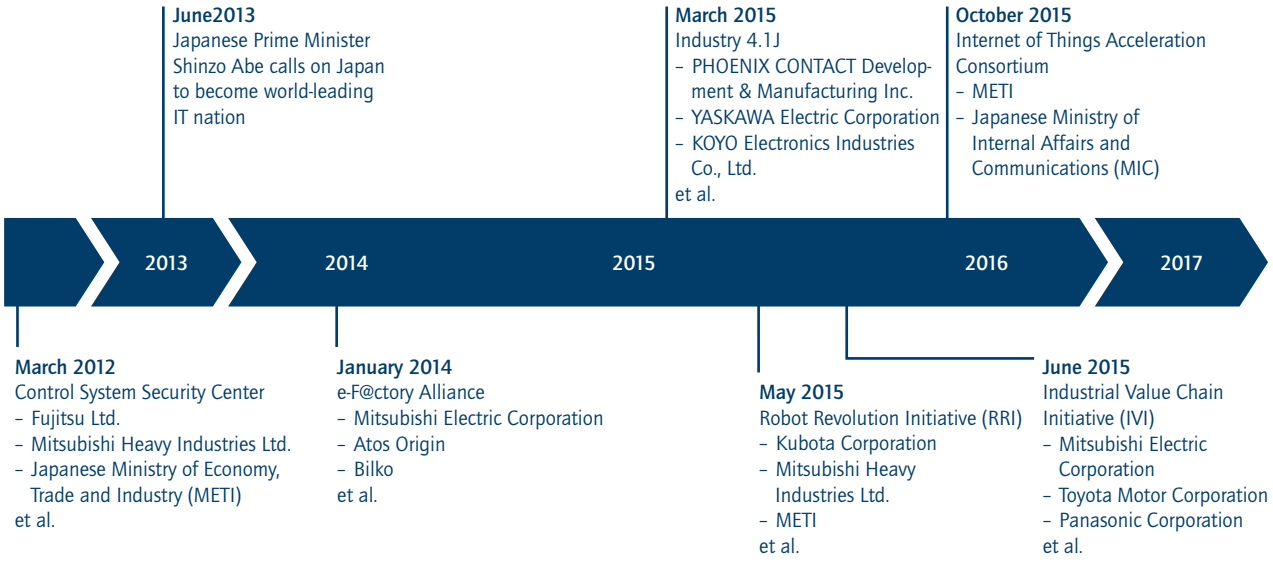

Figure 21: Milestones in the development of Industrie 4.0 in Japan (source: compiled by authors)

with different goals and varying levels of support from business, government and research institutions. Some initiatives are centred on TCP/IP-based technologies and smart applications (IoT Acceleration Consortium), while others are devoted to technologies that are also well-established in Germany (e.g. OPC UA in Industry 4.1J).[45]

The Japanese do not draw a terminological distinction between standards and norms – both are covered by the term "hyoujun". As in Germany, there is a split between IT and traditional industry within Japan's major corporations and this affects how they engage in standardisation activities. The results of the expert survey indicate that some departments within large companies focus on traditional standardisation, working with the Japanese equivalent to DIN (the JIS) and having little involvement in IT standardisation and international consortia. At the same time, however, other departments are engaging primarily in international consortia and contributing to the development of IT standards.

Thanks to the long-standing regional focus in traditional industries that characterises both Japan and Germany, there are numerous opportunities to cooperate by building on the competitive advantage of these traditional, regional industries in the two countries and engaging in IT standardisation in order to secure and enhance their global competitiveness. Like Germany, Japan's standardisation strategy is largely based on a top-down approach where the overall direction is determined by government together with a handful of researchers and pioneering thinkers. However, there are also some initiatives (e.g. IVI, e-F@ctory and Industry 4.1J) that adopt a bottom-up approach and concentrate on the concerns of the research community or industry. IVI attaches particular importance to the concept of loose coupling, promoting a modular approach instead of a single Industrie 4.0 standard.

The wide spread of areas receiving government support and the large number of initiatives in Japan can be seen as both an opportunity and a threat. One challenge is the danger of multiple uncoordinated technological developments and standardisation activities. The complex nature of Japan's Industrie 4.0 initiatives could act as a brake on innovation, especially given the highly dynamic nature of the global markets for Industrie 4.0 products. On the other hand, Japan places a lot of emphasis on technological developments, standardisation and the development of new business models. Thus, although setting up initiatives may at first be very complex, doing so can provide a basis for successful long-term cooperation.

45 | See IoT Acceleration Consortium 2016.

Conclusions for Japan

- **Develop integration solutions for the Japanese market**

Japanese industry is already very advanced as far as process automation is concerned. The challenge is to integrate the highly customised IT solutions of the different value chain partners in order to create value networks. To ensure that Industrie 4.0 lives up to expectations, these integration solutions should be discussed with Japanese companies down to the sub-supplier level. To this end, it will be necessary to gain an overview of the system landscape at the different levels of the value-added process, define interfaces and develop integration solutions.

- **Integrate robotics with human factors and ergonomics**

Japan is successfully pursuing a multifaceted approach to Industrie 4.0. This involves the promotion of selected industries (robotics) together with the Web-based development of smart, data-focused technologies and the associated new business models. To make sure that they are included in the emerging new business relationships, German companies and Industrie 4.0 initiatives should seek to build close, long-term ties with the relevant Japanese stakeholders. The goal should be to coordinate the development of new technologies and business areas and keep a close eye on developments in Japan.

One area that cooperation should focus on is robotics, human factors and ergonomics. The robotics market has enormous potential, since the use of robots enjoys high levels of acceptance among both businesses and the general public in Japan. One important area of application could be to help address the shortage of nurses and carers that has arisen as a consequence of demographic change. Germany boasts an excellent research landscape in human factors and ergonomics, especially in ergonomics and workplace design. Outputs from this field can make a valuable contribution to the development of robots.

- **Drive cooperation on data-based process optimisation**

Both Germany and Japan possess extensive expertise in the field of process optimisation. Japan in particular is famous for many of its process management methods such as kaizen and the Toyota Production System. The two countries should cooperate in this field in order to leverage the potential of data-based process optimisation. It will be necessary to identify the relevant partners, launch pilot projects and formulate guidelines for businesses, e.g. in the field of IT security. Particular emphasis should be placed on developing a shared understanding of security.

- **Cooperate flexibly in initiatives**

A whole host of Industrie 4.0 initiatives have been launched in Japan in recent years. It is still too early to say which initiatives will be relevant to which aspects of Industrie 4.0 over the longer term. Developments should therefore be monitored on an ongoing basis. For the time being, it is recommended that Germany should cooperate with the e F@ctory Alliance, Industrial Value Chain Initiative (IVI), Industry 4.1J, IoT Acceleration Consortium (IOTAC) and Robot Revolution Initiative (RRI). The shape taken by this cooperation could involve anything from regular exchanges of information to closer collaboration in the form of joint testbed development.

In view of the complex Industrie 4.0 landscape in Japan, cooperation with Germany should be decentralised in order to avoid bottlenecks. Germany's Plattform Industrie 4.0 can play an important role in terms of monitoring (to prevent contradictory strategies in different cooperation ventures) and information exchange (to avoid reinventing the wheel).

- **Implement the sensei principle in technology solutions**

In Japanese industrial culture, the sensei (teacher/master) plays a particularly important role in technical skills training. The relationship between sensei and apprentice is characterised by a respect and trust that goes far beyond the typical relationships between employees of the same company. It also requires a lot of time and resources. Germany should aim to develop technological solutions that implement the sensei principle for the Japanese market. It will be necessary to gain a thorough understanding of the sensei's role and to integrate this approach into the Teaching & Learning Factory concept. Moreover, action will need to be taken to ensure that the technological solution is accepted by all levels of the workforce.

3.4.4 South Korea

While there are parallels between modern-day South Korea and Germany's past in terms of the political tensions that characterise a divided nation, there are also many other similarities, including demographic factors, East Asian competitors (especially China), the US-dominated IT sector and the strongly export-oriented economy. Despite South Korea's relatively small population (approximately 51.5 million), a combination of economic policy measures and overseas aid (particularly from the United States) during the 1960s created a highly specialised economy that resulted in the rapid growth of several large Korean family businesses. Following decades of strong economic growth, South Korea became the 29th member of the OECD in 1996.

Today, South Korea's economy is characterised by a mix of global conglomerates (chaebols) in the high-tech and mechanical engineering sectors (e.g. Samsung, Hyundai, LG, SK Telecom and Posco) and around three million small and medium-sized enterprises (SMEs). The latter include many suppliers who are heavily dependent on the large conglomerates and have little independence compared to their German counterparts. Consequently, one of the goals of the new South Korean government under Park Geun-hye is to promote and enhance the competitiveness and export orientation of the country's SMEs by encouraging them to cooperate and exchange experiences, particularly with German SMEs.[46]

A number of highly innovative production methods and global trailblazers in the field of Industrie 4.0 can be found among South Korea's large conglomerates. In addition, the country's semiconductor production capability, Internet companies and digital end products mean that it is well placed to become a leading digital economy. The full extent of the large conglomerates' influence became apparent during the Asian financial crisis, when the prospect that some of the chaebols might fail pushed the South Korean economy to the brink of disaster. Together with ongoing government support, the lessons learned from this experience – including strict debt rules and the disposal of non-core business units – enabled South Korea to achieve modest growth during the global financial crisis of 2008. The chaebols are thus central to the South Korean economy, benefiting from their close ties with government and from the large number of domestic suppliers. SMEs predominantly act as suppliers to the conglomerates, focusing mainly on the application of manufacturing technology. Whilst this means that SMEs engage in less R&D of their own, it allows the chaebols to concentrate on their core business and carry out extensive innovation in these areas.

A preliminary report by the South Korean Ministry of Science, ICT and Future Planning (MSIP) describes the real-time networking of objects via the Internet of Things (IoT) as the fourth industrial revolution and provides a broad assessment of its impact on South Korea's economy and society (see Figure 22). There is widespread recognition of the benefits of Industrie 4.0 in South Korea due to the high proportion of GDP accounted for by manufacturing industry, the strong competitive pressure from neighbouring China and Japan and the resulting need to increase productivity among SMEs in the manufacturing sector.

As a result, the South Korean government's national *Manufacturing 3.0* project – the South Korean version of the Plattform Industrie 4.0 – focuses on helping SMEs to increase their production capacity through the use of smart factory technologies. Aimed at raising manufacturing standards, the MSIP's *Smart Factory Initiative* also forms part of this drive.[47] The goal is to establish up to 10,000 more productive factories by 2020 through cooperation between business and industry, large, small and medium-sized enterprises, the relevant organisations and government. This project is complemented by a number of other South Korean initiatives that are relevant to Industrie 4.0 (see Table 4).

Initiative	Field/Goal	Promoted by
Creative Economy Innovation Centers	ICT/Industrie 4.0 innovation	Business and government
Korean Smart Factory Foundation	Factory automation	Business and government
Smart City Testbed Initiative	Smart cities	Government
Smart Factory Initiative	Factory automation	Business and government

Table 4: Key Industrie 4.0 initiatives in South Korea

South Korea's lack of strong factory equipment and automation sectors means that there is currently very little focus on becoming a supplier of Industrie 4.0 solutions. Instead, South Korea believes that – as well as productivity gains – the economic benefits of Industrie 4.0 will come from new, data-driven business models (e.g. in the field of smart cities) that start-ups will also

46 | See Konrad Adenauer Stiftung 2013.
47 | See AHK 2015.

be able to take advantage of in the future. South Korea is already leading the way in this area today. Located in the Incheon Metropolitan City, the world's first smart city, Songdo, is being used to trial new smart housing and smart city technologies. Moreover, the special political and economic regulations provide an attractive environment for growing numbers of suppliers and start-ups working in this field. Covering an area of six square kilometres and with a population of 22,000 in 2012, Songdo provides a unique testbed in terms of both physical size and number of inhabitants. The government's Smart City Testbed initiative run by the National IT Promotion Agency (NIPA) and MSIP encourages people to get involved and promotes Songdo internationally.

While Songdo focuses on the interaction between man and machine, other government initiatives are aimed at achieving comprehensive interconnectivity and convergence between people, machines and products over the coming years. In addition, 17 regional competence centres have been created to support innovative start-ups in the fields of ICT and Industrie 4.0 and help them establish links with South Korean conglomerates and regional actors.[48] These Creative Economy Innovation Centers have been opened all over the country. With their in-depth expertise and uncomplicated cooperation and investment arrangements – even for foreign investors – the centres offer start-ups excellent facilities and invaluable assistance in all business areas, from product design to export.

The Innovation Centers also help SMEs to innovate. 2,000 SMEs have already joined the programme, allowing some of them to achieve significant improvements in product quality.[49] To date, public and private sector backing has enabled the centres to provide their members with support worth around US $1.8 billion in the shape of investments, guarantees and loans. 437 South Korean start-ups had already joined the platform by September 2015, just one year after it was established.[50] A global network helps them to make contacts abroad and to facilitate the entry of foreign start-ups into the South Korean market. At some companies, various sites from other parts of the world have joined the programme (e.g. KIC Europe, KIC USA, KIC Beijing, KIC Moscow) and this is complemented by close cooperation with publicly and privately funded innovation initiatives in other countries (e.g. Britain's Digital Catapults and Japan's NTT Docomo venture capitalists).

As far as standardisation is concerned, the government (MISP, MOTIE) is keen to engage in international cooperation and dialogue and to involve the private sector. The focus is on integrated solutions (e.g. RAMI 4.0), with Germany enjoying a particulary high reputation in the field of Industrie 4.0. Meanwhile, the priority for SMEs is the establishment of interoperability. This is a key factor in the decisions of South Korean businesses, particularly those that are primarily focused on the application of Industrie 4.0, since it would allow them to acquire technological solutions for boosting productivity from a variety of different international suppliers.

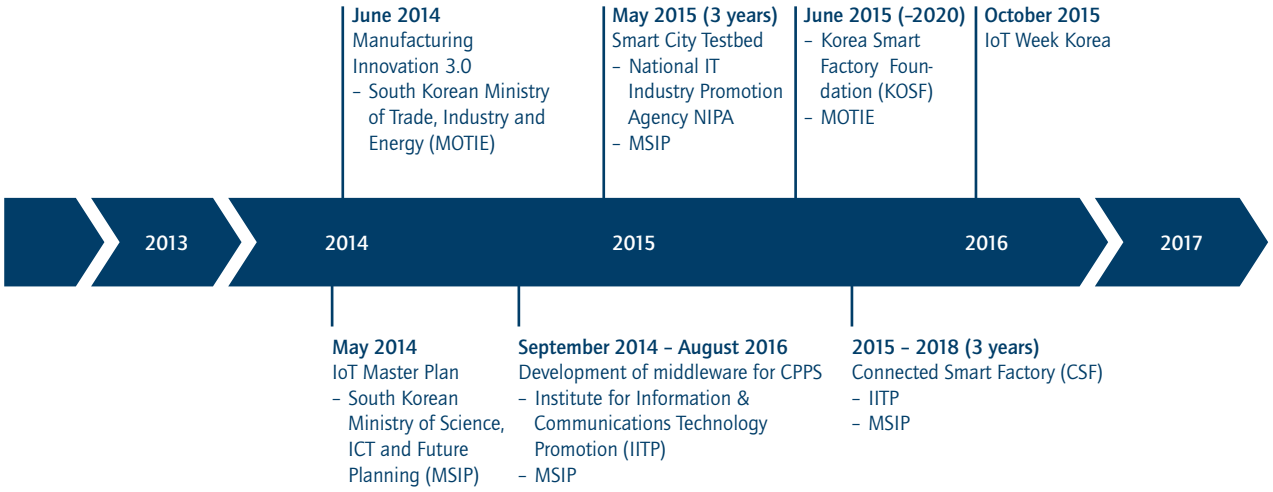

Figure 22: Milestones in the development of Industrie 4.0 in South Korea (source: compiled by authors, see MSIP 2014)

48 | See MSIP 2014.
49 | See AHK 2015.
50 | See Startup Korea 2016.

The large South Korean conglomerates are also keen to promote the rapid establishment of global standards, not least because of the growing competition from American Internet companies. As an important member of international bodies such as ISO, IEC and PASC, the South Korean standardisation agency KATS (Korean Agency for Technology and Standards) has some ability to influence global standards and is represented on almost all the relevant technical committees and sub-committees.[51] At national level, it pursues a bottom-up approach, working closely with industry to ensure that its standardisation activities mainly benefit national suppliers.

Some of the conglomerates are currently reviewing their business models with a view to making greater commercial use of smart data. The fact that the conglomerates bring together large numbers of subsidiaries under one roof makes it easier to implement an integrated digital strategy and planning system for Industrie 4.0. Moreover, their close cooperation with the standardisation agency helps to drive cross-company, national solutions. Given South Korean companies' willingness to cooperate in the field of Industrie 4.0, standardisation is vital in order to ensure seamless interdisciplinary communication. Interoperability and synergies are perceived to be the main benefits of cooperation. South Korean businesses are also keen to cooperate with foreign companies, especially German ones. They would like to see the establishment of new organisations that facilitate cooperation through prompt dialogue and standardisation measures for new solutions. The principal risks are seen as data security and loss of know-how, while trust and binding contractual agreements are felt to be key requirements for successful cooperation.

One especially important aspect is the demand for Industrie 4.0 solutions that enable South Korean businesses to enhance their manufacturing technology. Manufacturing industry in South Korea is coming under growing pressure because of its low capacity and the steadily improving quality of Chinese manufacturers. Addressing this issue will require seamless interdisciplinary communication between machines made by different companies. This is one of the main reasons why South Korea's private sector is pressing for rapid solutions in the field of standardisation.

This current focus on Industrie 4.0 solutions that boost productivity and the established tradition of cooperation with Germany could be viewed as an opportunity for German businesses to target South Korea more strongly as a market for their products. Cooperation with conglomerates that bring together several value chains under one roof also facilitates access to SMEs and creates an opportunity for the widespread establishment of standards across several different industries. At the same time, however, the hierarchical, self-contained structure of the large chaebols with their numerous specialised subsidiaries can make them less inclined to cooperate with foreign partners.

Conclusions for South Korea

- **Use the chaebols as a route into the market**

South Korea's economy is characterised by global conglomerates (chaebols) that bring together several value chains under one roof. Many SMEs are closely tied to these conglomerates and have relatively little independence. German businesses should seek to actively exploit the complementary structure of the South Korean economy. Cooperation with the chaebols is recommended in order to benefit from their IT know-how and gain access to South Korea's SMEs. Relevant partners should be identified and pilot projects launched with a view to developing integrated Industrie 4.0 solutions for the South Korean market that cover a wide range of value chains.

- **Recognise SMEs as an important target market**

South Korea's SMEs have traditionally focused mainly on manufacturing technology and have a low level of automation. Nevertheless, the benefits that Industrie 4.0 can bring them are widely recognised in view of the high proportion of GDP accounted for by manufacturing industry, the strong competitive pressure from China and Japan and the resulting need to increase productivity in the manufacturing sector. In order to attract investment from South Korean businesses in Industrie 4.0 solutions that boost productivity, German companies should concentrate on local SMEs as potential users of this technology. This will require the identification of the relevant customers and the establishment of contacts with both conglomerates and their subsidiaries. German suppliers of Industrie 4.0 manufacturing solutions should discuss ways of joining forces in order to address South Korean SMEs collectively.

- **Transfer know-how from the consumer sector**

There are many highly innovative product concepts and global pioneers of data-driven business models, especially within the large conglomerates. The major South Korean telecoms and electronics corporations are very active in the development of smart products, smart services and new, data-driven

51 | See KATS 2016.

business models. Joint Industrie 4.0 solutions could prove especially valuable to German machinery and plant manufacturers by providing them with access to this business and IT know-how in the field of data-driven business models. German SMEs in the machinery and plant engineering sector should join forces in order to establish targeted smart service cooperation projects with South Korean partners. Government can play a role in facilitating individual pilot projects.

- **Establish cooperation structures for German and South Korean start-ups in innovation centres**

Publicly and privately funded Creative Economy Innovation Centers offer South Korean entrepreneurs the opportunity to carry out efficient research and develop business models based on technological innovations. These centres benefit from a high level of investment and an excellent network. They are also keen to develop networks of international partners that provide their members with access to new markets and give foreign companies an insight into the South Korean market. German SMEs should take advantage of these networks to cooperate with South Korean start-ups and benefit from their innovativeness. Since the Creative Economy Innovation Centers count numerous South Korean SMEs among their members, they provide the ideal platform for marketing German manufacturing technologies. Contact should also be established between representatives of similar networks in Germany (e.g. the Korean Innovation Center Europe) and further accelerator programmes launched.

- **Recognise the opportunity for IT security projects provided by the foreign policy environment**

German businesses have identified IT security as one of the key themes of Industrie 4.0. The security of data and systems is also extremely important from a political perspective. Active collaboration is recommended in order to drive international progress on IT security issues, especially in the field of data protection and encryption for integrated systems. German companies should draw on the established tradition of cooperation between Germany and South Korea to jointly develop technological Industrie 4.0 security solutions with hi-tech partner companies. In order to strengthen this cooperation, corporate initiatives should be expanded to include the relevant research institutions and government security agencies.

3.4.5 United States

With a share of approximately twenty percent of annual global income, the United States is the world's largest economy. Its economic and financial system is predominantly characterised by entrepreneurship and free trade. Its relatively large service sector accounts for about 78 percent of GDP, followed by industry (approx. twenty percent) and agriculture (approx. one percent). Covering an area around 25 times the size of Germany, the success of the US economy is based on the country's good communications and abundance of natural resources, together with an attractive domestic market of 320 million or so inhabitants. The economy has made a slow recovery since the 2008 economic and financial crisis, with economic growth being strongly driven by private consumption. Neither the property market nor manufacturing industry have made a significant contribution to growth, however.

The US is the world's largest import market and its second largest exporter of goods, after China. Germany and the US share many common values and enjoy close economic ties. America is the largest market for German exports, while Germany is the United States' most important European trading partner.[52] Since 2013, the US and the EU have been negotiating a Transatlantic Trade and Investment Partnership (TTIP) aimed at promoting closer economic ties. Among other things, the TTIP would increase mutual access to markets, remove export barriers, simplify foreign investment and harmonise existing standards. These goals have been the target of severe criticism from environmental and consumer rights campaigners and the general public.[53]

In the US, Industrie 4.0 is generally included under terms such as the Internet of Things, smart production or the Industrial Internet.[54] Consequently, Industrie 4.0 is understood to have a much wider meaning than in Germany. This is illustrated by the cooperation initiative that was agreed at the beginning of 2016 between the Industrial Internet Consortium (IIC) and Germany's Plattform Industrie 4.0. While the IIC spans the fields of energy, healthcare, manufacturing, the public sector and transport and aims to promote interoperability in the Industrial Internet of Things, the Plattform Industrie 4.0's focus is on manufacturing and on developing a detailed model for the next-generation manufacturing value chain.[55]

Thus, in the US the term Industrie 4.0 is increasingly understood to relate to manufacturing companies, especially in the context of production chain optimisation and the development of technological innovations. Moreover US companies are primarily interested in the establishment of new business models and smart services for the Industrial Internet. In other words, the German approach is largely technology-driven, while the American approach is mostly market-driven. The greater market focus in the US can also be put down to different financing mechanisms that involve larger venture capital investments. Nevertheless, as well as business opportunities, the experts from the US also identified a number of potential threats. For instance, intellectual property protection is a major priority for American businesses. Overall, however, companies in the US believed that the opportunities of Industrie 4.0 far outweigh any potential threats.

In the United States, Industrie 4.0 is largely driven by private sector initiatives (see Table 5). Compared to Germany and Asia, government agencies play a relatively minor role. While Germany has been discussing and promoting Industrie 4.0 since around 2011, it was not until 2014 that a similarly large-scale initiative came about in the US with the establishment of the Industrial Internet Consortium (IIC). Founded by General Electric (GE) in conjunction with AT&T, Cisco and IBM, by mid-2016 the IIC already had more than 230 members. The IIC aims to progress the architectural frameworks and focus of the Industrial Internet and to coordinate initiatives to establish ecosystems that connect physical objects with people, processes and data via common architectures, interoperability and open standards. The IIC adopts a two-pronged approach. On the one hand, it seeks to promote innovation through the establishment of use cases and testbeds to enable rapid testing of ideas and technologies in real-world applications. On the other, it aims to drive development of the reference architectures, frameworks and open standards required for the interoperability of industrial systems. It also acts as a forum for exchanging experiences and generating ideas.[56]

52 | See Auswärtiges Amt – USA – Wirtschaft 2016; Statistisches Bundesamt 2016.
53 | See Europäische Kommission 2015.
54 | See PCAST 2014.
55 | See Plattform Industrie 4.0 2016.
56 | See Industrial Internet Consortium 2015.

Initiative	Field/Goal	Promoted by
Industrial Internet Consortium (IIC)	Overarching themes; input on standardisation; new business models	Business
Smart Manufacturing Leadership Coalition (SMLC)	Joint pre-competitive research on an open platform using e.g. testbeds	Business
AllSeen Alliance	Consumer electronics	Business
Open Connectivity Foundation (OCF)	Communication between different systems	Business
National Network for Manufacturing Innovation (NNMI)	Innovation centre, not specifically focused on Industrie 4.0 (except for the attached DMDII centre)	Government

Table 5: Key Industrie 4.0 initiatives in the US

In addition to the IIC, other private consortia such as the AllSeen Alliance and the Open Connectivity Foundation (OCF) are also promoting Industrie 4.0 in the US. The AllSeen Alliance concentrates mainly on the development of industry standards with a view to enabling interoperability between different product brands using an open source framework. It is strongly focused on the consumer electronics industry and has more than two hundred corporate members.[57] The OCF has over 150 members and is pursuing the same goal of connecting electronic devices – primarily smartphones, computers and sensors – in order to enable communication between different systems, industries and companies.[58] Both consortia are using testbeds and working with international partners to try and create flexible interoperability solutions. Many of their strategies and solutions are heavily promoted with a view to getting SMEs on board and providing them with guidance. It is possible that this approach will result in pragmatic Industrie 4.0 solutions becoming established as de facto standards in the medium term.

One feature common to many US consortia is that although they are initially started largely by US companies, they subsequently succeed in developing a strong global focus and gaining many international members. More than sixty percent of the OCF's members are domiciled outside of North America and the same applies to several members of both the IIC and the AllSeen Alliance. There is no obvious competition between the consortia and they do not go to great lengths to differentiate themselves from each other. Instead, they welcome dialogue and often enter into formal relationships with other consortia and organisations. This is due to the belief that no one initiative will be enough on its own to fully address all aspects of Industrie 4.0 and the interests of all the relevant stakeholders. Industrie 4.0 is instead perceived as a collective endeavour. In many of the consortia (including the IIC), US companies have a disproportionately large influence that derives, for example, from the special privileges enjoyed by the founding members (e.g. a permanent seat on the IIC's steering committee).

Industrie 4.0 and the related issues are a relatively low priority as far as the US government is concerned. Unlike the German government, the US administration does not regard Industrie 4.0 as key to the nation's future competitiveness. People certainly bemoan the fact that the competitiveness of US manufacturing firms has declined steadily in recent decades and products that were invented in the United States can often no longer be made there cost-effectively. However, policymakers do not see Industrie 4.0 as one of the key solutions to this problem. In 2013, the government launched the *National Network for Manufacturing Innovation* (NNMI) initiative that created a number of new innovation centres across the country. However, rather than being clearly geared towards Industrie 4.0, the centres have the much more general goal of improving the competitiveness of US manufacturers. Of the eight innovation centres established up to the end of 2015, the Digital Manufacturing and Design Innovation Institute (DMDII) is the only one with a clear focus on Industrie 4.0. The DMDII works closely with businesses in order to support them with the implementation of Industrie 4.0 strategies.[59] Consequently, many American companies are only just waking up to Industrie 4.0 and the need to create interoperability for the fundamentally new manufacturing approach and factory architecture that it requires. On the other hand, there is a much stronger focus than in Germany on the new business models associated with Industrie 4.0 (e.g. in the area of big data analytics). Silicon Valley firms in particular are hopeful that the transition to Industrie 4.0 will provide export opportunities for sensor and wireless technologies. Global software corporations and Internet of Things (IOT) start-ups are also becoming increasingly active in the market for Industrie 4.0 solutions.

Given the size of the American market and the global outlook of the private sector consortia, there is a danger that "quasi-standards" could rapidly become established, meaning that German companies would be deprived of the ability to play an

57 | See AllSeen Alliance 2016.
58 | See OCF 2016.
59 | See PCAST 2014.

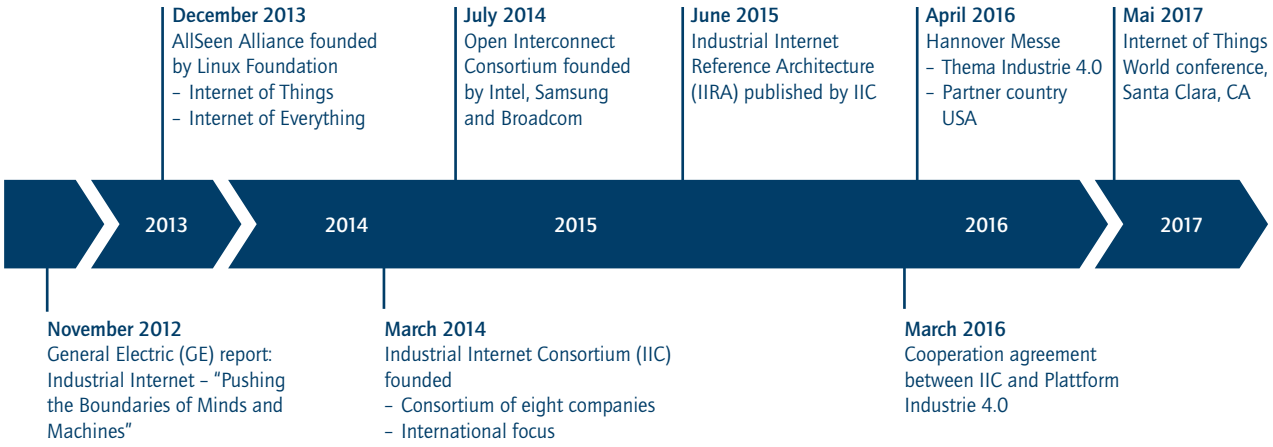

Figure 23: Milestones in the development of Industrie 4.0 in the US (source: compiled by authors)

active role in standardisation. Nevertheless, the US rates Germany highly as a potential cooperation partner. Cooperation between the two countries is based on a network of over fifty bilateral cooperation agreements between individual institutions. It is hoped that the current patchwork of user-specific, proprietary infrastructures that have been developed in parallel will eventually be replaced by compatible platforms. Germany can use its strong industrial base to complement the United States' Internet expertise, especially since companies like SAP, Bosch, Siemens, Festo and ThyssenKrupp are perceived as important stakeholders in the US and are in some cases already heavily involved in the relevant Industrie 4.0 organisations. Furthermore, despite their different approaches, the Plattform Industrie 4.0 and the IIC actually share many key goals. One of the main aims of the cooperation agreement between the two organisations is to ensure the interoperability of their two independently developed architecture models RAMI (Reference Architecture Model for Industrie 4.0) and IIRA (Industrial Internet Reference Architecture).

Conclusions for the United States

- **Continue to strengthen trade relations in the field of Industrie 4.0**

The United States is one of the largest markets for German goods in general and a particularly important export market for Germany's mechanical engineering industry. Following years of downsizing and outsourcing in the US manufacturing sector, there are signs of a change of course – it is now thought likely that manufacturers will once again make greater use of US production facilities in the future. For this to be possible, it will be essential to ensure the innovativeness and competitiveness of American industry.

Consequently, the US is a promising market for German industrial equipment suppliers. The aim should be to establish them as the leading suppliers of Industrie 4.0 solutions to the US manufacturing market. This will require further strengthening of Germany's traditionally strong trade relations with the United States, together with the adoption of a more international outlook by German SMEs. The development of government-coordinated networks should also be promoted.

- **Don't lose control over Industrie 4.0 business models**

American companies are particularly strong in the development of innovative Internet, software and service business models, whereas Germany is a high-tech supplier whose traditional strengths lie in the mechanical engineering industry. The two countries therefore complement each other in many areas. However, cooperation is not without its risks, especially for German businesses – when business models, products and services become digital, traditional companies may suddenly find themselves competing with software and Internet firms. Since data-driven business models will

account for a significant proportion of value-added in the future, German companies must make sure that they are not relegated to the role of mere hardware or technology suppliers.

The benefits of any cooperation will need to be carefully weighed up against the risks, especially as regards the sharing of sensitive corporate and usage data with large Internet and software companies. German businesses should therefore precisely identify their role in the future business model and be constantly alert to anything that might pose a long-term threat to their own business model. Consequently, they should ensure that any Industrie 4.0 cooperation initiatives form an integral part of their long-term corporate strategy.

- **Focus on Industrie 4.0 platforms**

Many large US companies are working on the development of software platforms for Industrie 4.0 or the Industrial Internet of Things. Established platforms are often controlled by a single company. Over the longer term, this means that German SMEs are in danger of being left out of the loop, supplying data but without receiving their share of the resulting profits. In view of the important role played by SMEs in German business, industry-specific platforms should be developed that create a level playing field for them vis-à-vis the large Internet companies and guarantee their sovereignty over their own data.

- **Actively manage ideas and talent**

In America's pragmatic, implementation-focused approach to Industrie 4.0, ideas and talent are often regarded as more important to success than technology. As a result, start-ups enjoy extensive access to venture capital. The fact that several start-ups are often working on the solution to a particular problem at the same time accelerates the pace of implementation. Successful commercial solutions subsequently become established as de facto standards on the US market. International start-ups' ability to revolutionise traditional business models should not be underestimated.

At the same time, Germany's university research landscape has huge potential to develop innovative Industrie 4.0 solutions. German businesses should engage in active ideas and talent management and enhance their own innovation culture through cooperation with selected partners in order to create a dynamic environment along the lines of America's start-up culture.

In Germany, incubators with links to universities are particularly well placed to develop practical, marketable Industrie 4.0 solutions. More should be done to strengthen the infrastructure and opportunities for cooperation between the research community, established companies and start-ups – businesses should seek to engage in strategic, long-term partnerships with applied research institutions. To this end, active approaches should be made to the United States with a view to combining German technology with American start-up culture.

3.4.6 United Kingdom

Industry's share of GDP fell by more than twenty percent in the UK between 2001 and 2012.[60] At the same time, the importance of the service sector has grown to such an extent that it now accounts for 79 percent of GDP,[61] with the financial services industry playing a particularly significant role. The UK's commitment to developing Industrie 4.0 is motivated by a desire to restore the role of manufacturing industry in the British economy in order to provide it with a solid foundation that is less dependent on unpredictable financial markets. It is hoped that a more balanced economy, both sectorally and regionally, will help to mitigate the potential impacts of an economic downturn in the event of another financial crisis. Consequently, the government is pursuing an active industrial, research and export policy, with particular emphasis on creating a Northern Powerhouse by locating industries and opening research centres in the north of England.

Manufacturing industry currently accounts for 14 percent of GDP.[62] As part of the current reindustrialisation drive, the deployment of Industrie 4.0 solutions is seen as one means of promoting the reshoring of manufacturing. The digitalisation of manufacturing and the resulting productivity gains are key to the competitiveness of British industry. As a result, a national funding programme has been launched with the aim of making the UK the best place in the world for science and business.[63] To this end, the government plans to invest six billion pounds in science by 2021. Together with the research and business communities, the government has identified eight "great technologies" that are particularly promising for the UK. These technologies are being promoted through the development of a network of elite technology and innovation centres known as "Catapults". A key part in this programme is played by the innovation agency Innovate UK which reports to and is funded by the Department for Business Innovation & Skills. Innovate UK funds, supports and connects innovative British firms through a range of programmes.

On the whole, the UK regards Germany as a pioneer and role model in the field of Industrie 4.0. Unlike in Germany, however, the primary focus of UK businesses is on combining information about customer requirements, the operational status of manufacturing facilities and supplier networks so that they can respond more flexibly and adaptably.

The Catapults are a key component of the strategy for promoting Industrie 4.0 in the UK (see Table 6). These research centres allow businesses and researchers to work together in order to transform critical technologies – the basic principles of which have already been observed in universities – into tested systems that are proven to work in the relevant area of application and may in some cases even be successfully deployed in an operational environment. Figure 24 shows where the Catapults fit in on the Technology Readiness Level (TRL) scale. They bridge the gap between universities and industry, ensuring that high-potential technologies do not fall by the wayside before they can be brought to market. The Catapults' other goals include reducing the risk of innovation, accelerating the pace of business development and creating sustainable jobs and growth. Particularly as far as Industrie 4.0 is concerned, they play an important and valuable role in enabling innovative solutions to be tested and visibly demonstrated in a dedicated environment. The innovation centres' work has a strongly industry-driven focus. Moreover, the involvement of several leading UK universities provides policymakers with the confidence that the government funds invested in the Catapults will be used for the future public good.

Initiative	Field/Goal	Promoted by
Catapult centres	Driving innovation; Industrie 4.0 is one of the sub-themes	Government
High Value Manufacturing	Catapult centre for digitalisation of manufacturing, focus on physical aspects	Government
Satellite Applications	Catapult centre for digitalisation of manufacturing, focus on ICT	Government
Manufacturing Technology Centre (MTC)	Part of the High Value Manufacturing Catapult	Government
Advanced Manufacturing Research Centre (AMRC)	Part of the High Value Manufacturing Catapult	Government

Table 6: Key Industrie 4.0 initiatives in the UK

There are currently ten Catapults in areas with high global market potential that are particularly promising for the UK economy.

60 | See Spath et al. 2013.
61 | See Auswärtiges Amt - Großbritannien – Wirtschaft 2016.
62 | See Hauser 2014.
63 | See HM Treasury 2014.

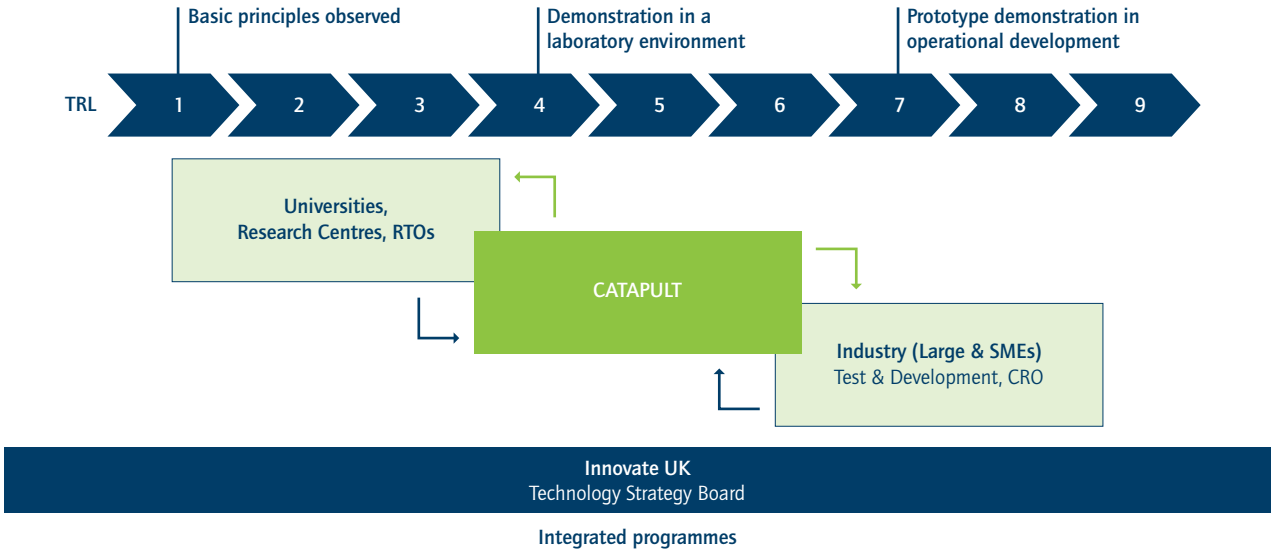

Figure 24: Position of the Catapults on the Technology Readiness Level scale (source: Hauser 2014)

The Catapults with the greatest focus on the digitalisation of UK manufacturing are the High Value Manufacturing Catapult (comprising seven physical centres), the Digital Catapult and the Satellite Applications Catapult. The Catapults also offer German businesses the opportunity to work with researchers in order to transform new ideas into commercial concepts. Companies such as Siemens, DMG Mori, Kuka and Bosch Rexroth are already members of the Manufacturing Technology Centre (MTC), one of the High Value Manufacturing Catapult's innovation centres.

The Advanced Manufacturing Research Centre (AMRC) and the Manufacturing Technology Centre were visited during the course of this study. Both also have training centres on their campuses. These training centres offer graduate and apprenticeship programmes geared towards tackling the shortage of skilled labour in manufacturing industry and establishing a direct link between the development of advanced technologies and the training of the people who design, implement and use them. The training centres are also involved in defining new occupational profiles and upskilling skilled workers. This is an important area for cooperation, since it will be necessary to ensure that new occupational profiles are internationally compatible in order to facilitate future global collaboration.

The Catapult programme represents an important move by the British government to promote the fourth industrial revolution. The next stage is to ensure that the relevant ideas and measures are implemented in industry. However, only limited progress has so far been made in this regard. Suppliers in particular have yet to fully appreciate the benefits of Industrie 4.0 – they tend not to have very forward-looking attitudes and are generally reluctant to retool. Meanwhile, although OEMs do understand the need for Industrie 4.0, they feel that implementing it is too difficult. UK companies are generally risk-averse and many still use very old machinery. Furthermore, they are a long way behind countries like Germany in terms of automation, meaning that they lack one of the key requirements for the introduction of Industrie 4.0. There is also no consistent vision or policy roadmap. The Department of Business Innovation & Skills is currently working on an innovation plan that will provide a national framework for the UK.

As far as standardisation is concerned, the British Standards Institution (BSI) is working with the German Institute for Standardization (DIN) and a number of joint workshops have been held. There is every chance that any standards agreed on as a result of this cooperation will be adopted throughout Europe. However, the two sides have yet to reach agreement on the extent to which the British government should be involved in the standardisation process.

The UK's strengths lie in research and education and in particular the combination of the country's world-famous universities with applied research and development centres such as the Catapults. In the past, however, the cooperation and commercialisation

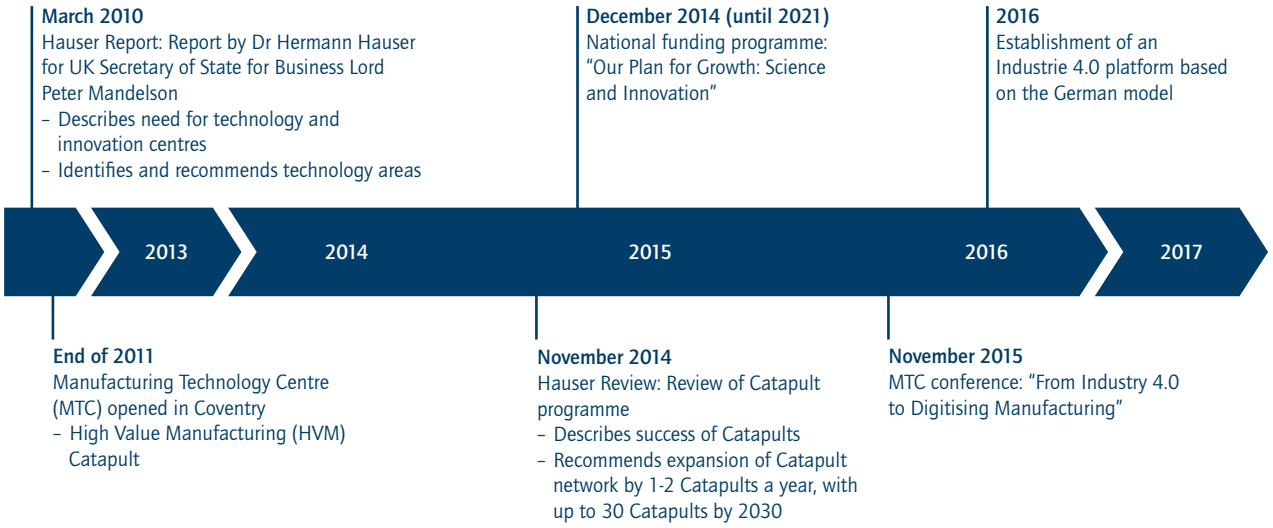

Figure 25: Milestones in the development of Industrie 4.0 in the UK (source: compiled by authors)

capabilities needed to successfully transform this expertise into commercial products have been lacking. However, the UK does already have a well-established position in the software market.

Current challenges involve translating research into technologies and getting industry to invest. Many businesses fail to recognise the benefits of upgrading to Industrie 4.0. This is compounded by a very strong national focus. There is a far greater emphasis on short-term investment returns than on helping to shape the future of Industrie 4.0 at a global level.

Although Germany and the UK are still at very different stages in the development of Industrie 4.0, there are still plenty of good reasons for Europe's two largest economies to cooperate with each other. The creation of joint standards is a particularly promising area, since it would afford both countries considerable influence over the rest of the European market. It is important that both businesses and research institutions should cooperate in this field – collaboration with the Catapult centres would be especially valuable. Moreover, the UK's strengths in smart services and e-commerce solutions can help to give Industrie 4.0 a stronger commercial focus by encouraging the establishment of connected ecosystems built around software platforms and the associated data-driven business models. The extensive collaboration that already exists between Germany and the UK, the current innovation landscape and the high priority placed by the British government on the digitalisation of manufacturing all mean that there are numerous opportunities for cooperation.

Conclusions for the United Kingdom

- **Get involved with innovation centres (Catapults)**

The network of elite technology and innovation centres known as "Catapults" forms a key component of the UK's innovation strategy. These highly successful centres allow researchers and industry to work together under one roof. Individual companies can also come together there for short periods to work on projects in a neutral environment. Some German businesses have already joined Catapults and are cooperating with researchers in order to transform ideas into commercial concepts. More German companies should follow in their footsteps and use the Catapults as testbeds for innovative Industrie 4.0 solutions and for cooperating with other businesses and research institutions.

- **Observe non-manufacturing sectors with a view to know-how transfer**

Germany is more advanced than the UK in production automation and Industrie 4.0. However, networking, digitalisation and

the requisite basic technologies are also being developed in other sectors outside of manufacturing industry. It is therefore important to observe industries that use Industrie 4.0 methods outwith the manufacturing environment and ensure that the relevant know-how is transferred to German industry. The relevant sectors should be identified, for instance smart building and smart infrastructure but also automation in everyday life situations. The goal should be to identify and adapt technologies, techniques and business models so that they can be applied in the manufacturing environment.

- **Use British services expertise to develop smart services**

Although German industry is good at using modern technology, it is not always so good at selling it. One of the possible reasons could be the business models that are currently prevalent in Germany. The service sector accounts for almost eighty percent of Britain's GDP and the UK is also home to some of Europe's leading business schools. Cooperation with the UK therefore provides the opportunity to generate valuable synergies. German businesses and researchers should collaborate with leading British economists in order to drive the development of new business models and smart services and improve the marketing of innovative Industrie 4.0 solutions.

4 Conclusion

The concept of Industrie 4.0 has had a dynamic impact on innovation policy both in Germany and in other countries around the world and has helped to promote the realisation that the digitalisation of industry is a key innovation for our future. Close cooperation between businesses, the trade unions, the relevant associations, academia and government has increasingly allowed the vision to be conceptualised, refined and implemented. The Plattform Industrie 4.0 has played an important role in institutionalising the implementation of the strategic initiative Industrie 4.0 and consolidating its status as a leading industrial policy issue for all of Germany's political parties and government departments.

In Germany, the implementation of Industrie 4.0 is now being energetically pursued by both business and society as a whole. Numerous companies and their employees have already started tackling the challenges of digitalisation. At an academic level, meanwhile, the strategic initiatives *Industrie 4.0* and *Smart Service Welt* have resulted in the establishment of research programmes by the relevant ministries. Furthermore, the early involvement of the trade unions and social partners in the Industrie 4.0 project has helped to further strengthen relations between management and employee representatives.

In the past few years, several companies in Germany have established new factories and a competence centre network modelled on Industrie 4.0 projects such as the smart factory and the learning factory. As a result, Germany is currently around two to three years ahead of other industrialised nations in the field of Industrie 4.0.

The *INBENZHAP* project sets out detailed targets for Industrie 4.0 that should be achieved in Germany by 2030. Assuming that the relevant actors make full use of their influence and work together, it should be possible to realise this vision of a healthy balance between people and technology, effective government engagement and Germany as a leading global player. However, as outlined in this report, the race is on among the industrialised nations for global leadership with regard to Industrie 4.0 norms, standards and business models. Consequently, specific measures are required to ensure the long-term success of Industrie 4.0 in Germany.

Recommended actions for businesses

German machinery and plant engineering, business IT and high-tech firms have an excellent reputation all over the world. In order to secure this strong position over the longer term and take advantage of the business opportunities provided by digitalisation, they must play an active role in shaping the future of Industrie 4.0 at an international level.

As far as products are concerned, there will be a requirement for innovative technological solutions to enable the establishment of highly flexible value networks. At the same time, German businesses – especially SMEs – should contribute their expertise to the intensive global efforts that are currently underway to develop norms and standards for Industrie 4.0 applications. This will require new forms of cooperation, aided and supported by both government and the relevant associations and organisations.

Large, predominantly multinational corporations should avoid developing silo solutions for Industrie 4.0. It is not true to say that universal products (e.g. analytics tools for the large volumes of data generated by Industrie 3.0 processes) have no commercial value. On the contrary, the value of such products can in fact be increased if they possess open interfaces that allow them to be integrated with the solutions of several different suppliers.

Products that conform to standards can also make it easier for SMEs to enter the market. Universal modular products with open interfaces allow them to integrate their own solutions without falling prey to buyer lock-in. This benefits both SMEs by allowing them to market specialised modules in specific areas and the large corporations by providing them with a wide user base.

Participation in the relevant international standardisation bodies provides large German corporations and SMEs with an insight into current Industrie 4.0 developments in other countries, enabling them to target these markets with appropriate technological solutions. German businesses can also acquire valuable know-how through joint projects with international partners – e.g. testbeds – that allow them to benefit directly from knowledge transfer.

To ensure that German machinery and plant manufacturers do not lose their traditional strengths, small and medium-sized enterprises should accelerate the development of industry-specific software platforms for Industrie 4.0. This will enable greater use of network effects in order to create a level playing field vis-à-vis the global Internet companies.

SMEs are responsible for many key Industrie 4.0 innovations even today. In order to position themselves globally as high-tech partners, they need to establish a presence in the key industrialised nations. Cooperating with large German corporations allows them to reduce the risks and gain access to established networks. In order to access global markets, SMEs should adopt a "piggyback strategy" in conjunction with large corporations. They can either use customers with a global presence to enter the market directly or use these customers' partner company networks to enter it indirectly. This approach allows SMEs to make use of established local networks, obtain informal information about the market and pursue a global expansion strategy without needing to invest large amounts of resources.

One important goal is to further strengthen the innovativeness of German businesses, especially SMEs. The culture of innovation within a company provides the foundation for its long-term success as a business. It can be strengthened through active in-house ideas and talent management and strategic partnerships with start-ups and applied research institutions. Strategic networks of partners containing a high number of actors with shared business interests can provide SMEs with rapid access to material resources, information and skilled personnel.

Companies that are active in platform-based Industrie 4.0 ecosystems should also contemplate rapid global expansion, quickly identifying sustainable, data-driven business models and the necessary financing options. Businesses should develop new business models in tandem with new technologies right from the outset – especially since these can act as drivers of standardisation. The establishment of their own platform solutions and the targeted development of established platforms are both currently valid strategies for scaling up data-driven Industrie 4.0 business models.

Active involvement in international innovation networks and centres can boost SMEs' innovativeness by providing them with better access to resources such as cooperation partners, personnel, capital and networks. In order to make the most of the innovation centres' potential, their infrastructure should be used to build and expand targeted business networks in the relevant countries.

Recommended actions in brief: Businesses

- Engage actively in international standardisation activities
- Focus on interoperability, modular products and open interfaces
- Participate in testbeds and industry-specific integration platforms
- SMEs to employ a piggyback strategy so that they can share the resources of large corporations
- Develop new business models in tandem with Industrie 4.0 technologies
- Make full use of the potential of innovation centres

Recommended actions for researchers, associations and initiatives

Associations play an important role in technology development. Both large corporations and SMEs should be more active on Industrie 4.0 issues within their respective associations. It is important to clearly define which technology areas should be standardised and which are explicitly regarded as proprietary intellectual property by the companies involved.

Associations must also cooperate with each other, both nationally and globally. This cooperation must be long-term and agile in order to keep up with the rapid pace of developments in the field of Industrie 4.0. German Industrie 4.0 consortia should therefore adopt a more open attitude towards international partners and their perspectives, whilst at the same time promoting their own understanding of Industrie 4.0 with its focus on the ad-hoc networking of smart machines, products and systems. Flexible cooperation arrangements with national and international Industrie 4.0 initiatives can vary in scope from regular exchanges of information to the joint development of testbeds to demonstrate the global impact of the fourth industrial revolution.

It is important to adopt a highly pragmatic approach. To avoid falling behind in the global race to establish widely accepted Industrie 4.0 standards, German Industrie 4.0 consortia should rapidly agree on beta standards for the pragmatic implementation of cross-company solutions. These will provide greater security to companies wishing to invest and will thus foster further innovation. Overall, a dual strategy is recommended. Germany should continue to push ahead with the formulation of an integrated Industrie 4.0 strategy including the development of reference architectures, norms and standards. At the same time, however, it should also develop pragmatic, high-profile solutions that provide concrete benefits to businesses. Particular emphasis should be placed on standard data formats and interoperability. High-quality norms and standards can be developed through open, consensus-based processes involving a wide range of actors.

This would be helped by the establishment of industry-specific working groups focused on the development of marketable demonstrator solutions. Current initiatives and research projects should also place greater emphasis on showing how Industrie 4.0 can benefit businesses.

In order to help SMEs in particular, the development of industry-specific Industrie 4.0 software platforms should be supported by the relevant organisations and associations. The focus should be on open platform solutions and enabling interoperability. Associations can make a valuable contribution by employing use cases and showrooms to provide employees and decision-makers with targeted information about the technological innovations and benefits of Industrie 4.0. These visual illustrations and tangible physical examples of the technological, organisational and commercial opportunities of Industrie 4.0 can provide SMEs and start-ups with targeted support for complex investment decisions.

The digitalisation of the economy is leading to the emergence of new actors. Associations should therefore establish more cross-industry dialogue formats for innovative start-ups and established SMEs in order to promote closer networking between different sectors. A broad mix of new actors and more established small and large companies is necessary to meet Industrie 4.0's requirement for cooperation across all the different value-added processes. Networking events and access to informal contacts can help businesses to recruit skilled personnel, learn about global markets, gain access to customers and cooperation partners and become more closely involved in digital ecosystems.

Incubators can be a valuable means of bringing SMEs, large corporations and start-ups together. The expansion and development of existing incubators at home and abroad will help German businesses to make initial contacts when searching for cooperation partners and achieve targeted growth of their networks in the relevant countries. SMEs in particular should take advantage of the innovation that can be accessed through these networks.

Associations and organisations should also play a major role in raising awareness among SMEs about the transformations required for Industrie 4.0 in their particular industry. The aim should be to prepare businesses for the coming changes to products, business models and processes and to jointly develop industry-specific adaptation strategies with the companies in question. Consultancy services, digital check-ups and reference installations can provide firms with valuable guidance in the complex field of Industrie 4.0.

Recommended actions in brief: Researchers, associations and initiatives

- Clearly define which technology areas should be standardised
- Develop pragmatic solutions with concrete benefits for businesses
- Ensure open, consensus-based processes involving a wide range of actors
- Support the development of industry-specific Industrie 4.0 software platforms
- Use showrooms and use cases to demonstrate the benefits of Industrie 4.0
- Coordinate consultancy services, digital check-ups and reference installations
- Carry out industry-specific awareness-raising among SMEs regarding the transformations required for Industrie 4.0

Recommended actions for government

Government has a vital role in implementing the recommendations described above. It should use structures like the Plattform Industrie 4.0 to try and prevent buyer lock-in and encourage large corporations to participate in national and international standardisation activities. It should also provide assistance to SMEs, which are unable to influence standards without the relevant support and thus run the risk of becoming dependent on larger companies. The role of government also includes bringing the various associations together and promoting the necessary cooperation with regard to standardisation. This entails the targeted promotion of activities involving multiple associations and actively supporting standardisation organisations.

German companies rate the threat to their data security as the chief risk of Industrie 4.0. In order to ensure that cooperation with global partners is both attractive and commercially successful for German businesses, Germany's economic policymakers must work with partner country governments to create a binding legal framework geared towards protecting intellectual property and data security.

The legal framework should be developed in a targeted manner in order to meet the new requirements of connected industry. Key aspects of data processing and data protection law should be reviewed and adapted to reflect the needs of a digitally connected economy. The establishment of legal certainty for Industrie 4.0 solution suppliers, users and cooperation partners should be a matter of priority. The legal framework should take account of the right to information and data sovereignty whilst at the same time providing the necessary freedom for the commercial implementation of data-driven business models. This will require a regulatory dialogue in which Industrie 4.0 specialists and legal experts work together to develop a future-ready legal framework.

An integrated approach should also be taken to the cross-cutting theme of IT security and the necessary expertise should continue to be developed in this field. In addition, application-oriented test and analysis laboratories can facilitate access to security solution testing environments, especially for SMEs.

In order to accelerate its digital transformation, Germany needs a future-ready technology infrastructure capable of handling rising volumes of data and increased connectivity. This will require the expansion of high-performance, high-speed networks and smart networks and the digitalisation of analogue infrastructure. These policy measures will be absolutely key to ensuring the long-term success of Industrie 4.0 for the German economy.

Government can play an important role in fostering data-driven business models by allowing businesses to use government data to develop innovative business models. This can benefit both established companies and start-ups and will serve to strengthen the Industrie 4.0 start-up scene.

Further efforts will also be required to develop digital training in schools, vocational colleges, companies, universities and continuing education institutions. Regional, national and EU-level competence initiatives should be promoted and pooled in order to allow the necessary digital skills to be rapidly identified and brought together in an Industrie 4.0 continuing professional development roadmap.

German companies are globally regarded as the partners of choice in the field of Industrie 4.0. In order to make the most of the potential markets, economic ties should be strengthened with major industrialised nations such as the US, China, Japan, South Korea and the UK. The establishment and consolidation of government-coordinated business networks will help SMEs in particular to export their Industrie 4.0 technologies. It will be necessary to pool the resources of industry, the relevant associations, the regions and the EU in order to accelerate the much-needed development of global Industrie 4.0 standards.

Flagship projects can also make a valuable contribution to bringing together key Industrie 4.0 actors within the regions, pooling expertise and strengthening Germany's visibility as a supplier of Industrie 4.0 solutions. The conditions for the emergence of digital ecosystems and innovative Industrie 4.0 environments can be enhanced by forging closer links between researchers, SMEs and large corporations within incubators and strengthening networks within existing industry agglomerations.

Recommended actions in brief: Government

- Use flagship projects to strengthen the visibility of Germany as a supplier of Industrie 4.0 solutions
- Help SMEs in particular to access the platform economy and create digital ecosystems
- Initiate a regulatory dialogue in order to create a binding legal framework for Industrie 4.0. This should take account of the right to information and data sovereignty whilst at the same time providing the necessary freedom for the commercial implementation of data-driven business models
- Continually monitor the standardisation organisations relevant to individual Industrie 4.0 areas
- Upgrade to a future-ready IT infrastructure
- Continue to develop the necessary expertise in the cross-cutting theme of IT security
- Make the most of the role that government can play in fostering data-driven business models
- Identify the digital skills that will be needed in the future and continue to develop the relevant training provision

If Germany manages to actively address these challenges, it will be able to extend its current lead over other nations and make Industrie 4.0 a success for the whole of German society. If business, academia, government, the relevant associations and the trade unions all remain true to the vision of Industrie 4.0 and systematically implement its strategy, Germany will be able to strengthen its position as a leading manufacturing nation and industrial equipment supplier. This will make it possible to turn the vision of networked manufacturing and production-related services into a global reality.

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Authors/Editors:
Prof. Dr. Dr.-Ing. E. h. Henning Kagermann
acatech – National Academy of Science and Engineering
Pariser Platz 4a
10117 Berlin

Prof. Dr.-Ing. Reiner Anderl
Department of Computer Integrated Design
Technische Universität Darmstadt
Otto-Berndt-Straße 2
64287 Darmstadt

Prof. Dr.-Ing. Jürgen Gausemeier
Heinz Nixdorf Institute
University of Paderborn
Fürstenallee 11
33102 Paderborn

Prof. Dr.-Ing. Günther Schuh
RWTH Aachen University
Steinbachstraße 19
52074 Aachen

Prof. Dr. Dr. h.c. mult. Wolfgang Wahlster
German Research Center for Artificial Intelligence GmbH
Stuhlsatzenhausweg 3
66123 Saarbrücken

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acatech Office
Karolinenplatz 4
80333 München
T +49 (0)89/52 03 09-0
F +49 (0)89/52 03 09-900

Berlin Office
Pariser Platz 4a
10117 Berlin
T +49 (0)30/2 06 30 96-0
F +49 (0)30/2 06 30 96-11

Brussels Office
Rue d'Egmont/Egmontstraat 13
1000 Brüssel (Belgien)
T +32 (0)2/2 13 81-80
F +32 (0)2/2 13 81-89

info@acatech.de
www.acatech.de

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The transformation of the economy being brought about by Industrie 4.0 is leading to the emergence of highly flexible value networks. Businesses now need to network their production activities both in-house and with the systems of external partners. This in turn requires new forms of cooperation, both nationally and globally. Common norms and standards enabling interoperability between different systems are equally essential.

This acatech STUDY analyses the opportunities and challenges for businesses of international cooperation and the current competition to establish norms and standards. It is based on interviews and discussions with more than 150 experts from Germany, China, Japan, South Korea, the US and the UK. Detailed country profiles describe the background situation and Industrie 4.0 status quo in the focus countries. Finally, the study makes a number of recommendations for German actors regarding cooperation with international partners.