HEINZ NIXDORF INSTITUT
UNIVERSITÄT PADERBORN

WZL

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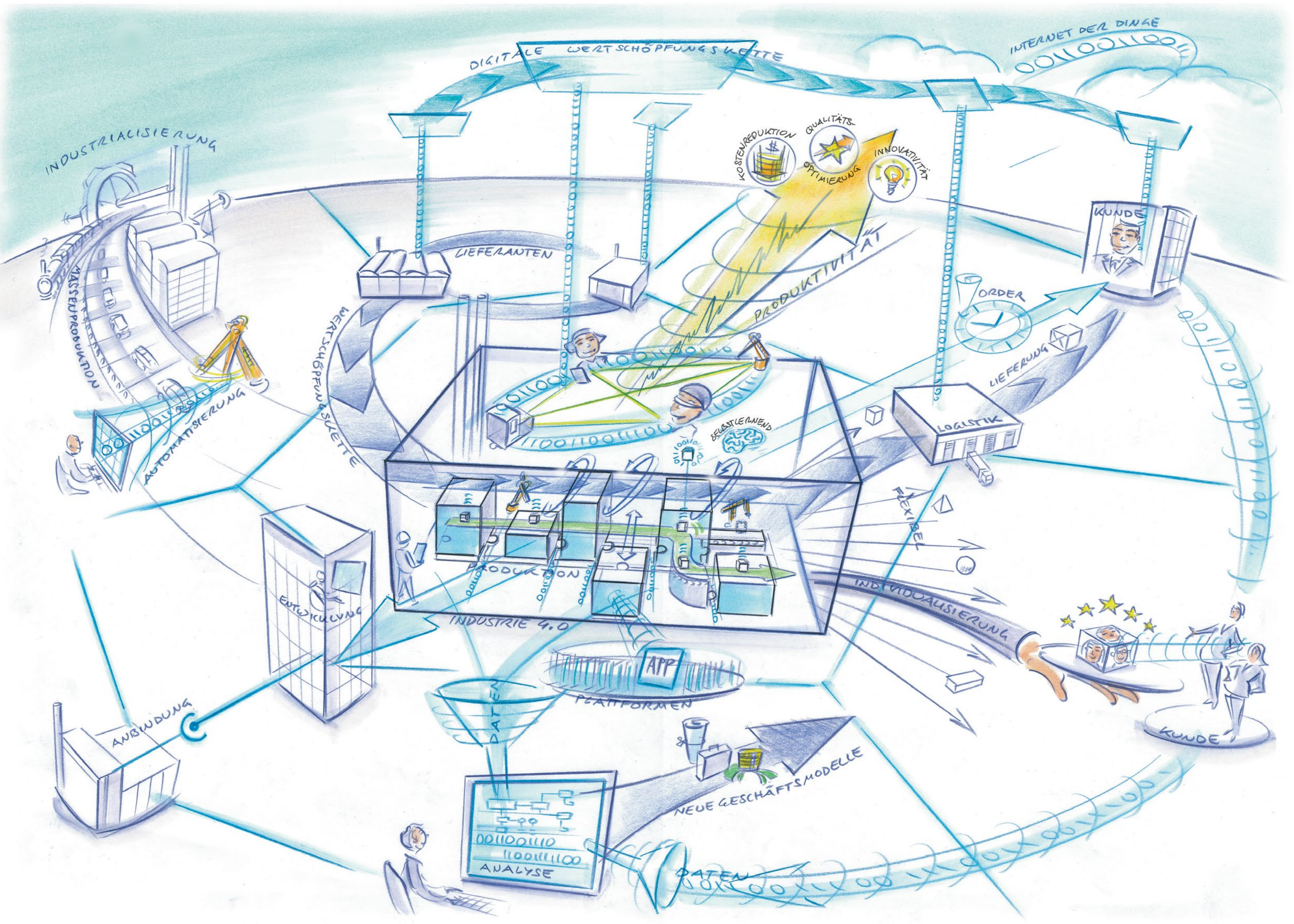
NATIONAL ACADEMY OF
SCIENCE AND ENGINEERING

Industrie 4.0

International Benchmark, Options for the Future and Recommendations for Manufacturing Research



For additional documents please refer to www.inbenzhap.de

Foreword

Industrie 4.0 is on successful course towards becoming keyword of the decade. The hype affects the majority of social aspects and dominates the CIM euphoria that emerged a quarter of a century ago. Many have already prematurely subscribed to calling traditional industrial production and established structures of value creation dead and buried, without a comprehensive and thoughtout understanding of current developments. The question of how one can make money with Industrie 4.0 is rarely considered. If one thing is clear, however, it is that digitalization, the Internet of Things and other novel approaches in the field of innovation and communication techniques offer fascinating opportunities for business success and job creation. Industrie 4.0 holds potential for disruptive innovation.

These developments call for a realistic conception of the current performance of Industrie 4.0 in comparison with other industrial nations as well as anticipating its future developments in the global competitive arena. In this regard, a central question arises: Does Germany have the potential to become the leading market as well as leading supplier? This question marks the starting point for the study. In order to give a well-informed answer to this question, we start with a comprehensive benchmark, led by the Laboratory of Machine Tools and Production Engineering WZL of RWTH Aachen University. Overcoming diagnosed weaknesses and capi-talizing on present strengths will not be enough to successfully deal with future challenges. We have therefore predicted the future of Industrie 4.0 with the help of scenario planning and developed future scenarios of manufacturing up to 2030. The Heinz Nixdorf Institute at Pa-derborn University led and oversaw this step. Based on these steps (benchmark and scenarios of future manufacturing), we formulated some key recommendations set within a wider field of production research.

Over the course of this study, we have conducted countless interviews with experts in Germany as well as abroad. The intermediate results were discussed and evaluated by experts in the fields of academia, research and industry, as well as representatives of other social groups in four WorldCafe workshops, each with 50 participants. The active participation of these groups of people in all four workshops, despite busy personal schedules, is an outstanding achievement. It seems to indicate that the prospect of interesting work was an attractive one. We hereby wish to thank our workshop participants as well as the many interview partners in Germany and abroad. They have contributed crucially to this project. Furthermore, we would like to thank BMBF and the supervisors of Karlsruhe as project administrators for their professional support of our work.

Confronted by 600 pages of project documentation, we pondered how to make our knowledge available in a compact, yet – if desired – detailed form. This remains the task of our project partner acatech – National Academy of Science and Engineering – and the present brochure marks a first step in this direction.

What would we professors be without our assistants and research consultants? They do the majority of the work and deserve a special mention alongside a heartfelt thank you: Dr. Martina Kohlhuber, Christian Dülme, Daniel Eckelt, Patrick Kabasci, Nico Schön and Stephan Schröder. We now wish our readers a pleasant and informative read.

Jürgen Gausemeier
Fritz Klocke May 2016

Foreword by the funding body

Germany's economic power – especially in comparison to the other European countries – is remarkable: Over the past 25 years, this country has been worldwide export champion on numerous occasions. Nowhere else there are more companies in a leading role within the world market. Whilst experts speculated on the concrete secrets behind this success, no one will doubt the direct correlation between it and the strength of manufacturing in Germany. Not only is our country a leading centre of production but also the world's industry supplier. The German government's high-tech strategy aims at strengthening and developing this position.

In 2011, the future-oriented project Industrie 4.0, which emerged from this high-tech strategy, instigated a lively discussion about the future of manufacturing. The term 'Industrie 4.0' was intended not only to be a concrete vision, but also the shared focus for future-oriented investments in the manufacturing sector. Governmental research and innovation policies in this sector were subsequently shaped in accordance with the future-building project Industrie 4.0. By means of a shared platform, industrial consortia emerged and industrial associations joined forces.

In the context of a final report given by the Industrie 4.0 work group, first recommendations for implementation were presented to the Federal Government in April 2012. Besides Germany, countries like the US and China have been channelling their funding activities as a reaction to changing technical conditions in production caused by increasing digitalisation. At this point in time, the status quo of Industrie 4.0 was largely unknown to many countries. Furthermore, not only consistent visions for the future in order to ensure the well-targeted development and promotion of basic and applied technologies relevant for Industrie 4.0 were missing. Also the specification and definition of potential development paths, as sketched out in the final report, was lacking. Therefore, strategic recommended guidelines in politics, industry, research and organisations for protecting a centre of production in the face of international competition could not yet be formulated sufficiently.

In order to close this gap, the project *Industrie 4.0 – International benchmark, options for the future and recommendations for manufacturing research* (INBENZHAP) was initiated in 2013. Besides the core team consisting of the Heinz Nixdorf Institute, the Laboratory for Machine Tool and Production Engineering at RWTH Aachen University and acatech, around 80 specialists with backgrounds in economics and research and members of various social groups were involved. The shared goal was to develop a national strategy for Industrie 4.0. Over 200 experts from different countries were included in the process. As a result of the international benchmark and forecast, 44 recommendations were formulated that should serve the advancement of Germany as a manufacturing centre and thus ensure the further prosperity of the country.

The future-oriented project Industrie 4.0 placed Germany at a favourable starting position. Investments in Germany as a manufacturing centre are profitable. Companies and their employees are taking on the challenges of digitalisation. We are experiencing a time of unique opportunities:

our idea of networked manufacturing and services tightly linked to production can become the global standard.
In order to achieve this, we all have to subscribe to the Industrie 4.0 vision and implement the strategy step by step. Germany's leading role as a worldwide centre of manufacturing and industry supplier will continue to gain strength as a result. I want to thank all the contributors to this project and wish the partners continued success.

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Content

Introduction

Information and communication technologies have been a driving force behind technological developments in mechanical engineering and related sectors such as the automotive industry. Current changes are taking place in the form of a development away from classic mechanic-oriented systems towards mechatronic systems. These systems are based on the close linkage of mechanics, electronics and software. So-called 'intelligent systems' have emerged in the recent past, including cyber-physical systems. Cyber-physical systems denote real systems, for example a production machine, an industrial robot or vehicle, which display inherent intelligence and communicate or cooperate over the Internet. The term 'Internet of Things' should be understood within this context. Intelligence is the decisive factor for constructive communication between linked systems. So-called 'active systems' mark the starting point: sensors capture the state of a mechanical basic system. Based on these results, information processing – in most cases this is the controller – produces control signals for the actuators which then feed information back to the basic system. We may speak of a type of intelligence when the governing information processing is replaced by a 3-level model concept of intelligence developed by cognitive science. According to this model, the lowest level is responsible for control, as just explained. The middle level – the associative regulation – comprises certain functions allocated for conditioning. The highest level contains functions that may be categorised as cognition. This includes planning, the modification of goals and learning. The ability of a technical system to self-optimise can be attributed to this level.

The concept of cyber-physical systems is the basic principle behind multiple so-called 'smart' applications. When linked in a production process, they create the smart factory. Applications used in the health sector become 'Smart Health' and applications in the mobility sector become 'Smart Mobility'. Cyber-physical systems can of course also communicate and co-operate beyond the limits of these applications. Intelligent components select the next appropriate machine or factory. Given the fact that billions of objects, systems and other devices are connected to the Internet today, the potential for further development is limited only by our imagination.

This is especially true for the design of manufacturing, encapsulated as such in the term Industrie 4.0. We define Industrie 4.0 as the ability of ad hoc networking between intelligent machines, production facilities, components as well as storage and transportation systems via the Internet to form powerful value networks. Proponents of Industrie 4.0 anticipate manifold advantages, an example being the production of a custom made product of high quantity with the minimal use of time and resources. The concepts of cyber-physical systems and Industrie 4.0 open up new perspectives for Germany as a centre of production, a market leader as well as leading supplier.

Several questions become relevant in this context:

- What conditions have to be fulfilled to make Germany a leading market?
- Where are the markets for leading supplier industry located and what do they demand?
- What competitors will the German leading supplier industry be facing?

- How could the leading supplier industry develop in order to be successful in a future market?

To read answers to the preceding questions please read the following paragraphs

What conditions have to be fulfilled to make Germany a leading market?
Paragraph 3.2

Where are markets for leading supplier industry situated and what do they demand?
Paragraph 2.2, 2.3 and 2.4

What competitors will the German leading supplier industry be facing?
Paragraph 2.2, 2.3 and 2.4

How could the leading supplier industry develop in order to be successful in a future market?
Paragraph 3.3

The project **aims** at formulating partial answers to such questions. A special focus is placed on the formulation of options for shaping the future of manufacturing and the strategic action of the leading supplier industry. The report is structured into four chapters. **Chapter One**, 'Methodology', describes our work processes and how we formulated our recommendations. This includes definitions of the analysed fields – topics and countries in question – the methodology behind the international benchmark as well as the methodology behind the 2030 forecast. The following chapters present the results of the study.

Chapter 2 'Status and Perspectives of Worldwide Developments', describes the results of the benchmark. These lead to current key conditions for realising the Industrie 4.0 vision. Fur-thermore, the relevant countries' proficiency levels are analysed in relation to Industrie 4.0. This results in drivers of this development as well as challenges yet to be overcome. Our perspective focuses on expected developments in the global competitive arena up to the year 2030. This includes market and context scenarios in six relevant countries. Furthermore, we attempt to predict whether or not Industrie 4.0 structures are likely to develop in these countries, which would then increase competitiveness among global actors for the supply of Industrie 4.0.

Chapter 3 'Industrie 4.0 in Germany' builds on the current position as defined through the benchmark and possible developments in Germany. This leads to the presentation of a manufacturing vision for 2030, representing a desirable but also possible future. Furthermore, we identify chances and risks as well as strategic paths for future developments of Germany as an Industrie 4.0 hub.

Chapter 4 'Recommendations' proposes 44 recommendations that can shape the future development of Industrie 4.0 in Germany in accordance with the formerly identified strategic paths for a successful accomplishment of the 2030 vision.

Project leadership: The project leadership was headed by Prof. Jürgen Gausemeier (Heinz Nixdorf Insitut, Paderborn University) and Prof. Fritz Klocke (Laboratory for Machine Tool and Production Engineering WZL, RWTH Aachen University). Both institutes in addition with acatech – German Academy of Science and Engineering form the core team, consisting of Christian Dülme, Daniel Eckelt, Patrick Kabasci, Dr. Martina Kohlhuber, Nico Schön und Stephan Schröder. Another core team met for regular workshops. It was divided into a research group, an industry group and social groups. Among other participants, university departments from the fields of production, informatics and sociology were involved in the research group. Social groups included, for example, representatives of unions and associations. A total of 86 experts were part of the core teams. For the benchmark research and forecast, we travelled to six countries and while experts from additional countries were asked to contribute. We conducted a total of 150 expert interviews with over 200 people.

Reading advice: Accompanying the study you will find summaries of chapters that provide a first overview for readers. You will also find QR codes in the document that link you to additional documents, which provide a complete and clear image of the comprehensive study. To access these documents, scan the QR codes with your mobile device. You will be led to a document in PDF format. Hereby, we are hoping to pay justice to our readers' different backgrounds and interests. We wish you an informative read.

Summary

Industrie 4.0 opens up new perspectives for Germany as an economic centre. But international competition is growing. Where does Germany stand? And how should it evolve as an industrial centre? One can formulate a vision for Germany's digitally networked future based on a profile of Germany in international comparison, as well as an analysis of currently notable and expected developments of markets and business environments. Germany is in the best possible position to eventually claim the role of leading market and leading supplier. Manufacturing is a priority whilst training for engineers and skilled workers is of the highest international standard. Germany lacks, however, a widespread competence in Internet technologies amenable to innovative business models. In this context, the study makes recommendations for relevant actors in politics, business and social sectors. Pursuant to this, over 150 interviews were conducted with important figures from business, research and politics as well as stakeholders, mainly in Germany, but also in the US, Brazil, China (including Taiwan), Japan, Singapore and South Korea.

Status of worldwide development

Industrie 4.0 is developing into a global brand. Worldwide, a large number of relevant concepts and activities can be identified which are tailored towards the specific views and emphases of the respective countries or areas.

Europe: Local initiatives emphasise the sub-goal of harmonising the digitalisation of industrial value creation with the demands of a human-centred working environment. Industrie 4.0 is regarded as a socio-technological challenge. A further aim remains the increase of productivity and sustainability. Excellent infrastructure, cultural affinity, well-developed competences in industrial IT and manufacturing place companies in a favourable position within the global competitive arena. Especially in Germany, technology leadership in manufacturing is supposed to foster supply leadership of intelligent production systems.

USA: The US focus on the aim of providing additional customer value, for example by means of innovative services. Ideas like the Internet of Things or business models with a direct impact on stimulating tomorrow's business success are prioritised. There is some evidence suggesting that disruptive developments up to a fundamental paradigm change in manufacturing are more likely to emerge as results of a data-driven service approach.

Japan and South Korea: The further strengthening of powerful mechanical engineering and electronics companies' productivity through networked, intelligent production systems is a priority. This is also intended to counteract the swift and substantial consequences of demographic change. Furthermore, one can expect a substantial supportive push for small and medium sized companies through the persistent and widespread introduction of networked, intelligent production systems.

Japan already makes widespread use of intelligent technologies such as digital Kanban systems. It also stands out with its use of smart devices within intralogistics as well as a high degree of automation. South Korea is characterised by focused interventions from politics and industry that are aimed at strengthening the international competitiveness of small and me-dium-sized businesses. The strong semiconductors and display industries possess a rich knowledge base in collecting and analysing field data.

China: The digitalisation of society is an important field of action within the state-administered strategy for the country's advancement. It is pursued with exceptional vigour. An important subgoal is closing the gap with world leaders of advanced manufacturing. There are numerous efforts to improve the level of automation – particularly in small and medium-sized businesses. A unique supply network and competence cluster has already enabled China to build supply chains for new products within a relatively short time frame.

Further country-specific highlights: Flexible organisational structures, a progressive work culture and high affinity with and acceptance of technology enable the use of intelligent production systems in **Sweden**. **Finnish** society is very accepting of innovation. Core competencies are the collection and analysis of field data as well as sensor technologies. **Spain** aims for intense participation in European initiatives and programmes. The Basque country stands out in particular. **France** is focusing on reindustrialisation and also aims at significant influence within the consumer-oriented Internet of Things. **Italy** is characterised by an industrial structure with potential for high performance; small and medium size businesses are, in particular, highly specialised and internationally competitive. At the moment, however, no comprehensive strategy for Industrie 4.0 can be identified. After years of prioritising the financial sector, **Great Britain** is now advancing its efforts at reindustrialisation. Sensor and data analysis systems as well as efficient logics and value chains are among the country's core strengths. **Taiwan** is particularly quick at introducing products and manufacturing ramp-ups. It also displays excellent competency with the information and telecommunication technologies and the semiconductor industry. In the race towards the future, Singapore wins points for its well-developed start-up ecosystem in the field of data-driven technologies, local headquarters of companies leveraging high volumes of data and the successful attraction of international talent.

Drivers and challenges: The three main global drivers for Industrie 4.0 are 1) sustainability 2) user-orientation and 3) collaboration. The four global challenges are 1) security, 2) standards, migration and interoperability, 3) business models as well as 4) the fulfilment of expectations tied to the brand Industrie 4.0.

Perspectives for worldwide development – the global competitive arena in 2030

The 26 countries of primary interest were looked at through cluster analysis, resulting in 6 clusters represented by the country of reference. The most plausible situation in 2030 as seen from today's perspective was developed according to the reference country.

Brazil: Change within a prosperity-enhancing value system is restricted to the thriving metropolitan areas. Foreign investors reinvest a substantial part of their profits into education and R&D. The country is an attractive market for Industrie 4.0 outfitters, but does not play a significant role as a provider.

China: The party's autocratic and strategic lead includes its role in directing economic change. In worldwide comparison, China has the highest R&D costs and is often successful in orchestrating the extraordinarily high R&D capacities towards the realisation of strategic goals. For years, China ranks amongst the top ten most innovative nations. Together with the US, they are the largest leading market and leading supplier.

Saudi Arabia: Saudi Arabia sees itself as an exemplary state of Islamic governance. The unspoken deal struck is: allegiance in exchange for money. Research is not regarded as a basis for affluence, and thus, no research-focused reasoning emerges as such. In the global competitive arena of Industrie 4.0, the country only plays a market role, if any role at all.

Spain: The Spanish economy has recovered; the young generation, in particular, has an optimistic perspective towards the future. European integration is very advanced and the majority of the population regards this as a blessing. European innovation programmes such as the Knowledge and Innovation Communities (KICs) have fuelled growing momentum in the Europe-wide innovation business. Spain profits from this. The country is an attractive Industrie 4.0 market and is increasingly becoming a serious Industrie 4.0 outfitter within the international market.

South Korea: The country's elites are successfully orchestrating the nation's development. Manufacturing is a building block for such success. Employees have a huge share in the country's economic success. South Korea is a highly developed, leading market for Industrie 4.0 and one of the world's leading outfitters for smart factories.

USA: A very pronounced free-market economy prevails. The economy is superior in the areas of Internet and big data based business models. In relation to other innovative fields such as biotechnology and defence, manufacturing research plays a secondary role. Reindustrialisation is progressing slowly. Besides China, the US is the biggest leading market and dominant leading services supplier.

Current German position in international comparison

Germany is making an effort to transfer its engineering expertise to the digital world and act as leading market and leading supplier for the worldwide Industrie 4.0 economy. Germany can rely on several strengths: outstanding competencies already exist in the field of mechanical engineering (and their related sectors) and manufacturing. The basic level of technology to be used in data analysis and networking is high, even though little has been applied so far. The standing of engineers both in a company and society is high, and employment in the industrial sector is therefore comparatively attractive. The dual education system has significant advantages in international comparison due to a strong focus on applied practice. There is also a broad base of theoretically – as well as practically – qualified experts.

Current weaknesses of Germany are mainly due to a lack of ICT infrastructure and a compe-tent base for internet technologies. Competence is also missing among providers of B2C products within the IT sector and use of web-based technologies in the design of intelligent products, manufacturing systems and B2B services.

Drivers for development in the Industrie 4.0 sector are changes in established businesses such as the emergence of new players in the competitive arena and a change from hardware to software in the product portfolio. These factors lead to increasing individualisation and a continuous push for international competitiveness in the cost-sensitive production sector. German companies are worried that disruptive changes in the context of Industrie 4.0 may be a threat to the core competences and market position of machine and plant engineering and the closely linked manufacturing industry.

There are several challenges: overcoming the insistence on existing business models, overcoming concerns about data protection and data security as well as avoiding overengineering. The latter prevents the development of future-oriented solutions that meet the demands of tomorrow's potential mass markets.

Vision for the Industrie 4.0 economy in 2030

The forecast is intended to inform about Germany's most favourable position in the context of Industrie 4.0. The corresponding vision results from the prediction of a German environment in 2030 which essentially describes the determining factors for Industrie 4.0. The vision results equally from the choice of design option for Industrie 4.0 that most satisfies the needs of this environment. By means of the scenario technique, four self-sufficient environment situations for 2030 were developed: 1) Balance of humans, technology and the state as a basis for success, 2) Consequent digitalisation, technology-centred work environments, 3) Impediments to digitalisation due to many obstacles 4) Global and heterogeneous digitalisation. These situations were then evaluated by experts with respect to their probability and effects on Industrie 4.0. According to this, scenario one is favoured over the others, which we will briefly characterise.

Environment 2030 – "balance of humans, technology and the state as a basis for success":
The world is highly digitally interconnected. Information and communication technologies (ICT) both facilitate life and support people. New possibilities of ICT are implemented in the fields of teaching and learning, such as the 'Teaching and Learning Factory'. IT security is guaranteed. The state provides good conditions. Innovation is dynamic: Open Source is widespread, open standards prevail and agile alliances shape the value networks.

This is a very advantageous environmental scenario and also realisable if relevant stakeholders use their influence and insist upon relevant interventions. For a definition of the vision, this environmental scenario is accompanied by the design option that fits best as described below.

Design option "Sovereign global player":
Germany is on its way to develop a nationwide information and communication infrastructure. The emphasis on so-called 'soft factors' which support the compatibility of family, free time and professional life, makes Germany an attractive destination for living and working. Germany ranks amongst the world's highest in regards to its capabilities in central technology fields, services and platforms. Economy and civil society have choices of different supply alternatives.

Based on their ability to cleverly integrate services and in-kind transfers, to create relevant business models and to consequently implement them into global value networks, German businesses primarily pursue integrated value networks.

From this vision follows the desirable and also achievable position for Germany: it holds chances but also bares risks. Among those chances are high job satisfaction and motivation. It remains also possible to establish digital sovereignty and, consequently, high IT security. Risks arise from high-maintenance technologies and other cost-intensive capacities of production engineering which are not met with readiness to pay in the global market. Such chances and risks result in five prospective strategic paths. These strategic paths represent the implications of designing Germany as an Industrie 4.0 centre and giving impulse to developing visions for future-oriented concepts.

Recommendations for manufacturing research

The genesis of 44 recommendations is based on the results of the benchmark and the forecast. The structure of the recommendations is informed by the strategic paths which are briefly characterised in the following paragraph. Each strategic path is linked to several recommendations. These are described in detail in further online documentation.

1) **Fostering acceptance (A):** Industrie 4.0 causes substantial change to the working environment. To shape it in the best interests of all parties involved, a common understanding of the aims and possibilities of Industrie 4.0 and the best path towards to achieving it must be shared.

   A2: Initiate rational debates regarding security

   A4: Create the function of a data custodian

   A5: Keep digital best agers active longer in work life

2) **Grow competencies (K):** Industrie 4.0 is based on the evolution of the organisation of technology and work with regards to a general overhaul of industrial value creation. For this purpose, existing competencies need to be enlarged and new competencies need to be introduced at the right moment.

   K2: Establish an 'industrial security' qualification

   K5: Promote usability-by-design

   K10: Build competencies in industry intelligence (Big Data)

3) **Improve the innovation system (I):** The innovation system comprises all actors, organisations and technologies that contribute to innovation. Industrie 4.0 makes diverse and high demands on the innovation system.

   I1: Reform intellectual property protection

   I2: Promote the disclosure of interfaces

   I4: Expand possibilities for exchange among start-ups

4) **Facilitate collaboration, shape business models (G):** Industrie 4.0 and the consequential dynamic development of the global competitive arena require new forms of collaboration, value creation and value appropriation.

G1: Define guiding principles for collaborative business activities

G3: Know, protect and use immaterial assets

G8: Build 'Industrial Content' platform

5) **Market competences, cultivate brand (M):** With Industrie 4.0, Germany has successfully established a brand associated with high levels of competence, particularly in the Asian market. This advantageous position, especially for outfitters, has to be expanded.

M5: Establish exemplary greenfield and brownfield factories

M6: Market ecological footprint as a label

M9: Spread ontologies for manufacturing

It is to be expected that Industrie 4.0 will have considerable impact on our lives and work, on technologies and business models, as did industrialisation, mass production and automation. Despite all the optimism, one should not disregard the fact that the cumulative introduction and usage of ICT systems forms the end of a thought-through trade chain, not the beginning; the cart should not be put before the horse. This means in effect: effective ICT systems require well-structured business processes. Business strategy and business success should aim at exhausting all potential successes in the future. If we want to spare Industrie 4.0 the same development as Computer Integrated Manufacturing (CIM), it requires business-savvy and future-oriented action.

1 Methodology

This chapter addresses those amongst our readers who wish to know more details about how we approached the research, which methods were used and how the recommendations were finally produced. Those readers who are mainly interested in the results and findings are advised to skip this chapter.

1.1 Scope

In order to achieve an overview of existing theories and concepts related to Industrie 4.0, we analyse approaches from within Industrie 4.0 as well as related topics such as the Industrial Internet, Smart Manufacturing and the Internet of Things. Their main drivers, challenges and stakeholders are identified. The aim is to give an overview of the prominent paradigms and views that stand behind approaches regarding the future of the industrial system.

Core enabler fields
A benchmark for the application of Industrie 4.0 in the rigorous sense of the word is not yet possible since Industrie 4.0 has not been implemented thoroughly. Instead, we delineate 15 core enabler fields within the broader clusters technology, people, organization and the political and business environment. These include business models, security and user-friendliness, among others (Image 1-1, Chart 1-1). In the view of experts, these categories represent probative factors of distinction when considering competition for market and supply leadership.

Basis
Results that cannot be allocated to a core enabler fields are aggregated within the basis of the relevant dimension (Image 1-1). Those results are not presented as separate fields in the country profiles.

Market observation clusters
Special questions that serve the purpose of market observation in Industrie 4.0 comprise four categories (Image 1-1, Table 1-2). These categories do not inform a country-specific analysis but are rather analysed and discussed from a global perspective. The category 'Brand Industrie 4.0' takes on a special role. Only during the research for the project has this category shown to be of heightened relevance. We are therefore adding it for a better presentation of the outcomes.

Countries in question
Countries were picked following four macroeconomic indicators: 1) worldwide mechanical engineering turnover (VDMA) 2) engineering product exports (VDMA) 3) natural resources (World Bank) and 4) global competitive markers (WEF). By applying these markers, 26 countries could be identified. These are analysed on the basis of relevant studies such as the Global Competitiveness Report (WEF), the Global Innovation Index (INSEAD and WIPO) and the Measuring the Information Society Report (ITU) regarding similar conditions for Industrie 4.0.

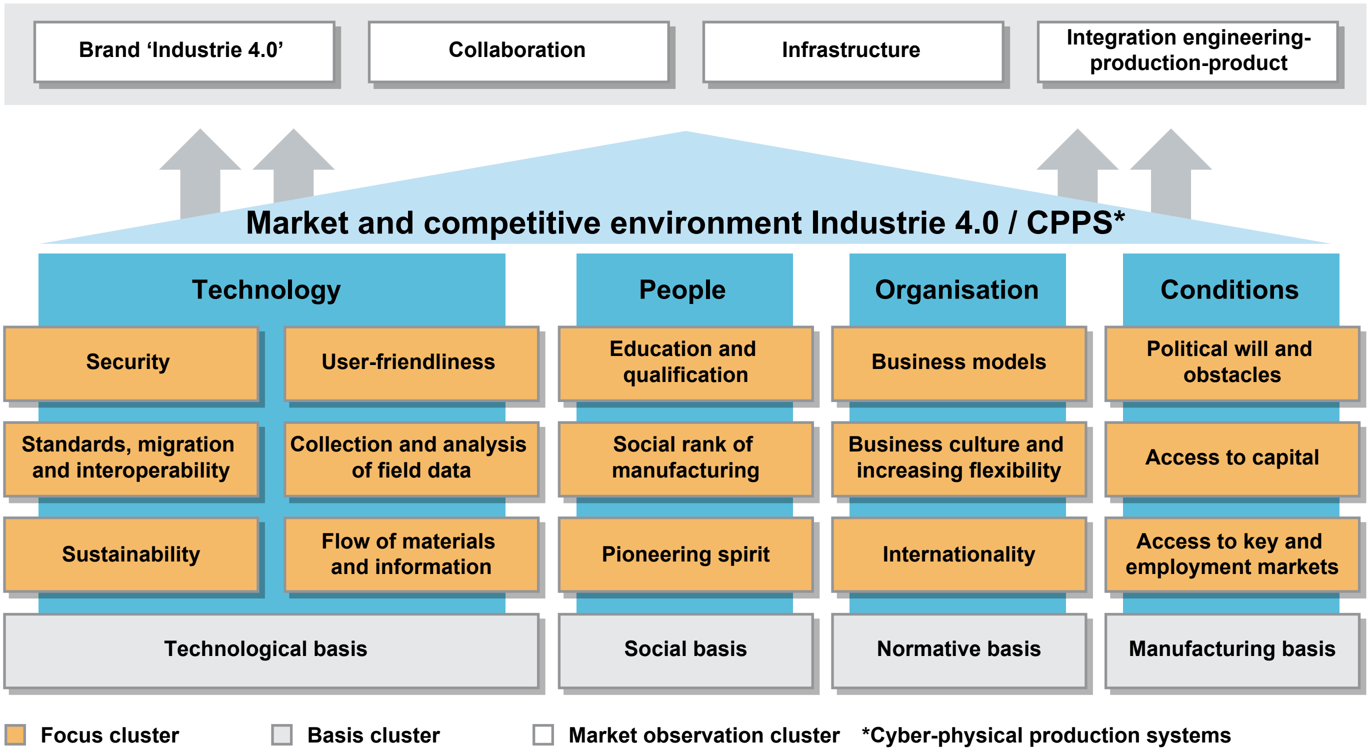


Image 1-1: Overview of clusters

Table 1-1: Details for the relevant focus clusters (Part 1 of 2)

Focus cluster	Aspects in question (abstract)
Dimension Technology	
Security	• Industrial security concepts • Attitude towards industrial security and cyber security • Security concepts for cyber-physical systems
Standards, migration and interoperability	• Drivers, restraints and industrial approaches to standardisation • Participation in international standardisation processes • Standardisation paradigms, perception of open standards
Sustainability	• Valuation of sustainably-produced goods • Drivers for sustainability concepts
User-friendliness	• User interface concepts and paradigms for IT user interfaces • Human engineering, work safety, user-friendliness paradigms and drivers for new concepts
Collection and analysis of field data	• Maturity of technology, competences and application of up-to-date data analysis • Use of data collection and analysis in an industrial environment

Table 1-1: Details for relevant focus clusters (Part 2 of 2)

Material and information flow	• Intralogistical competencies and technologies • Competencies in industrial software • Ability of different branches to attribute information to physical objects
Dimension People	
Education and qualification	• Quality of engineering training at academic and vocational level • Life-long learning and intergenerational exchange of knowledge • Interdisciplinary training
Social importance of production	• Respect for work in the manufacturing sector and importance of the manufacturing industry for the economy • Perception of manufacturing as technology or crafts oriented • Perspective on manufacturing as driver for cost or value
Pioneering spirit	• Aversion to risk • Culture of Entrepreneurship • Innovation through employees
Dimension 'Organisation'	
Business models	• Environment for start-ups • Business model innovation in the manufacturing sector • Competence in services innovation, examples of local market disruptors
Corporate culture and flexibilization	• Interdisciplinary approach and dynamic organisational forms • Paradigms for business growth • Work flexibility in engineering and manufacturing industry
Internationality	• Attracting talents • Market knowledge • International collaboration
Dimension 'Business environment'	
Political will and restrictions	• Programs similar to Industrie 4.0 • Reindustrialisation and industry growth strategies • Regulatory level for piloting new technologies
Access to capital	• Risk capital • Research funding • Motivations for technology transfer
Access to supply and demand markets	• Regional clusters • Access to testing markets • Access to suppliers of components and technologies • Market reach and understanding of clients

Table 1-2: Details for relevant market observation clusters

Market observation cluster	Aspects in question (abstract)
Collaboration	• Areas that invite collaboration • Increase of productivity through increase of collaboration productivity • Market circumstances for the increase of collaboration productivity in manufacturing
Infrastructure	• Quality of infrastructure • Transaction costs and waiting time • Weaknesses of infrastructure as obstacle for introducing innovative production systems
Integration engineering-production-product	• Interface handling • Focus of R&D activities • Engineering business models

Based on the results, country clusters are identified and countries for analysis agreed upon. The benchmark analyses 13 countries and the European Union while the forecast analyses seven countries (Image 1-2).

Nr.	Country	Cluster	Benchmark	Forecast
1	Germany	Germany	On-site study	Future scenarios
2	Finland	European-Industrial	Telephone interviews	
3	France		Telephone interviews	
4	Italy		Telephone interviews	
5	Sweden		Telephone interviews	
6	Spain		Telephone interviews	Future scenarios
7	Great Britain	Anglo-Saxon	Telephone interviews	
8	USA		On-site study	Future scenarios
9	Japan	Asian-Democratic	On-site study	Future scenarios
10	Singapore		On-site study	
11	South Korea		On-site study	
12	China	Asian emerging countries	On-site study	Future scenarios
13	Brazil	East. Europ./emerging countr. of the Americas		Future scenarios
14	Saudi Arabia	Raw material suppliers		Future scenarios
15	Taiwan, China	*Not clustered*	On-site study	
16	European Union	*Not clustered*	Telephone interviews	

Image 1-2: Overview of relevant countries

The international benchmark focuses on the identification of drivers and challenges of leading supplier status for CPPS as well as on approaches, best practices and key stakeholders in the field of Industrie 4.0. Primary raw material suppliers as well as Eastern European and emerg-ing countries of the Americas are therefore not considered in the benchmark. Countries are analysed in two detailed steps: Research on-site and interviews via telephone. On-site studies were conducted in Germany, the U.S., Japan, Singapore, South Korea, and China including Taiwan. Germany is the starting point of the study. In North America, the U.S. represents the world's biggest economy within the benchmark. China and Taiwan are studied because of their global relevance as manufacturing centres. Japan and South Korea are considered powerful export nations and are thus analysed through on-site research. Singapore represents a regional centre for the emerging manufacturing region of South East Asia. In addition, telephone interviews were conducted for the studies of Finland, France, Italy, Sweden, Spain, Great Britain and the European Union.

Beyond the leading supplier position, the forecast also addresses the leading market for Industrie 4.0 solutions in which all country clusters are considered. Similar conditions for Industrie 4.0 within a country cluster imply the choice of one country of reference per cluster (Image 1-2). The choice of reference countries was made based on an indicator ranking as well as conversations with experts. Reference countries are: Germany, Spain, USA, South Korea, China, Brazil and Saudi Arabia. Scenarios for the future up to 2030 are produced for each of these countries.

15 core enabler fields were identified for the dimensions of technology, people, organisation and business environment. These focus clusters represent distinctive factors in response to competition to achieve market supply leadership on the way towards Industrie 4.0. This benchmark analyses 13 countries and the European Union, while the forecast looks at seven countries.

1.2 Benchmark

The benchmark aims to identify drivers and challenges for the development, implementation and application of Industrie 4.0 solutions in different relevant markets. Towards this end, we analysed which markets have a demand for Industrie 4.0 solutions, as well as which markets offer potential and competence to offer these solutions themselves. The method underlying the international benchmark is divided into four phases (Image 1-3).

In the course of a **basic analysis** (Phase 1), country-specific studies are analysed. The focus clusters provide the starting point for the search. The analysis serves to identify relevant approaches and stakeholders and based on the results hypotheses for drivers and challenges can be made. In order to test the hypotheses, we formulate criteria for each focus cluster, based on the previous findings.

A **detailed analysis** (Step 2) is conducted for countries, which have shown up promising approaches in the course of the general analysis. Country-specific studies are analysed in a step analogous to Phase 1. Here, the criteria per focus cluster provide a starting point. The analysis aims to found a solid information basis and questions for personal interviews were formulated on such a basis.

In a next step, **personal interviews** with chosen experts for relevant countries were conducted (Phase 3). Experts come from the fields of industry, research, society and politics. Semi-structured interviews on chosen focus clusters are designed in direct relation to the relevant expertise. The aim is to **validate hypotheses** (Phase 1) and to extend the set of criteria by qualitative aspects.

In the **synthesis of results** (Phase 4), insights from the analyses and interviews are aggregated per country, resulting in country profiles. In the course of a synthesis, relative highlights as well as drivers and challenges in different countries can be identified.

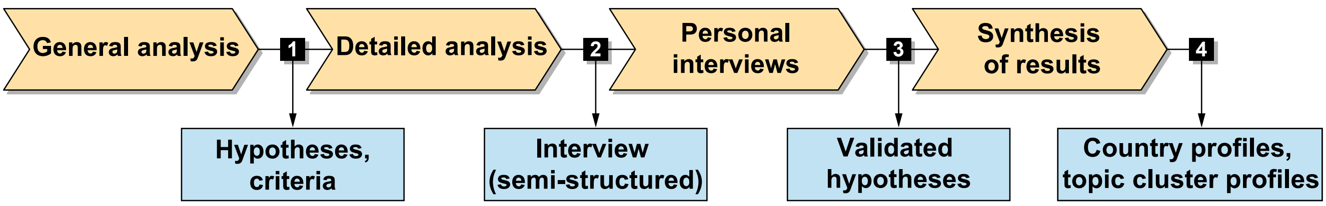


Image 1-3: Overviews of hypothesis-informed proceedings of the benchmark

1 Highlights should not be understood as critical factors for Industrie 4.0 success per se. The developing Industrie 4.0 environment is still at an early stage and is globally too heterogeneous to study its impacts systematically and to define best practices. Based on the observation of matured but related concepts one can nevertheless assume that a strong positioning of the identified features will play a key role for the success of Industrie 4.0 in the relevant countries.

In a further step, a country-wide aggregation of results associated to focus clusters takes place resulting in cluster profiles. These profiles put a special emphasis on differences and commonalities of drivers and challenges within these clusters. Country and topic cluster profiles mark the core areas of the benchmark and will be summed up in a detailed benchmark report (Paragraph 2.3).

The benchmark is conducted in four steps: A general analysis provides first hypotheses on drivers and challenges for each country, which are in turn made concrete through a detailed analysis of certain criteria. The results are validated through personal expert interviews (semi-structured). The results for all countries and all focus clusters are hence looked at in an aggregated form in order to identify relative important features as well as drivers and challenges.

1.3 Forecast

The forecast aims to determine a target position for Germany in the Industrie 4.0 sector. The target position details how to shape a favourable position for Germany in the case of supply leadership. In order to understand the multiple chances for Germany to establish itself as an industrial centre within Industrie 4.0, limits of conventional thinking have to be done away with. On the search for products, services and business models for tomorrow, the scenario technique proves an appropriate tool for identifying future potentials for success [aka12]. With KURT SONTHEIMER, the scenario technique is less about prediction and more about thinking ahead into the future [Son70]. A scenario is a comprehensible description of a possi-ble future situation based on a complex network of specifications (projections) of influences. The perspective focused on the future leads to several scenarios, factoring in several possible developments according to influence into calculation. Development and analysis of the scenarios is undertaken in five phases within the frame of scenario management. Phases two to four of the scenario generation are depicted in image 1-4 [GP14, p. 49 ff].

The **scenario preparation** (Phase 1) comprises fixing the project aim and project organisation as well as definition and analysis of the potentials for intervention. The forecast distinguishes between the environment and the potential for intervention. The environment describes fu-ture conditions for the Industrie 4.0 economy; direct options for shaping it derive from the configuration options. Identification of the environment scenarios as well as the configuration options occur based on the scenario technique.

The **scenario field analysis** (Phase 2) describes the scenario field by means of influencing factors. We analyse the systemic behaviour of influencing factors and their relevance with regard to their effect on configuration options.

The **project development phase** (Phase 3) lays out alternative possible developments (projections) of the previously determined key factors following the

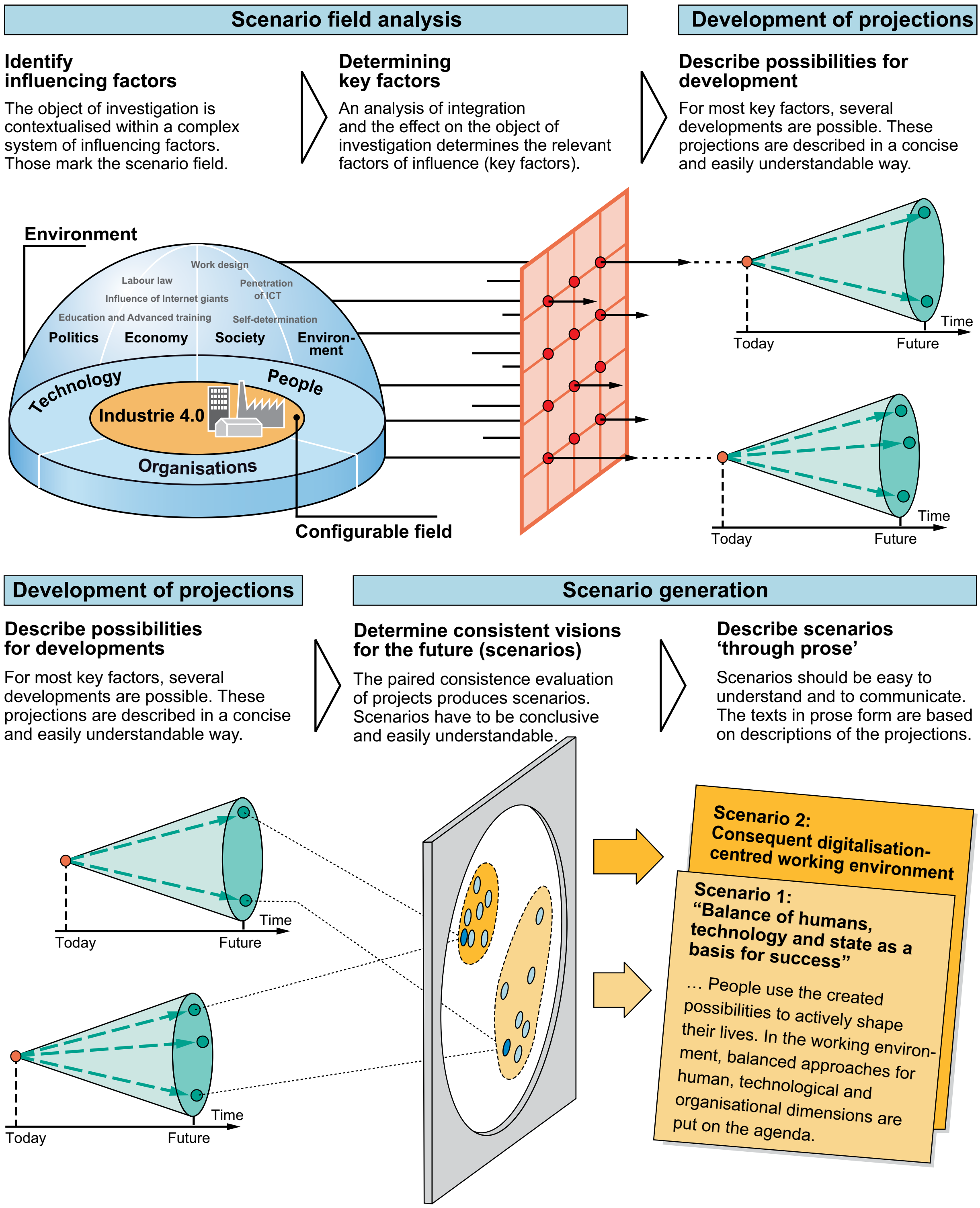


Image 1-4: Scenario creation – from influencing factors to future projection to the scenarios [GP 14, p. 49]

multiple futures principle. This should also consider the 'unthinkable'. Experience shows that it is often not the seemingly probable but rather the 'unthinkable' that manifests as reality later on. Examples include the success story of the personal computer and the collapse of the Eastern Block.

In the course of the **scenario formation** (Phase 4), scenarios are generated from the key factor-informed projections. These are based on the paired evaluation of projections in a consistency matrix and on subsequent consistency analysis. It produces consistent projection bundles; these are combinations of projections, one per key factor. Because many of these bundles are similar, they are summed up by means of the cluster analysis. In the end, the cluster analysis produces three to five clusters of similar projection bundles. Because the cluster elucidates which projections it includes and the projections have also been described in the previous phase, the text for each scenario can be produced on this basis.

In the context of environment scenarios and configuration options, the **scenario transfer** (Phase 5) raises the question for Germany's most advantageous position in the Industrie 4.0 context. The relevant vision is determined through a matrix. Attempts to answer which configuration options best fit the most probable environment scenario leads to the vision. This implies the desirable position for Germany, which offers possibilities but also contains risks. Furthermore, we can deduce strategic paths for developing Germany as a manufacturing centre as well as for realising supply leadership. The strategic paths also form part of the basis for formulating recommendations.

Besides Germany, future scenarios are developed for Brazil, China, Saudi Arabia, Spain, South Korea and the USA, which serve as reference countries. These describe possible situations of local business environments in 2030. This in turn indicates whether the country in questions is attractive for German suppliers of Industrie 4.0 solutions, or rather, whether a local supply industry is growing which will also participate in the global competitive arena.

With the help of the scenario technique future developments will be anticipated systematically within the scope of the forecast. A scenario is based on the consistent combination of the influencing factors' (so called projections) conceivable development. Based of the fact, that per influencing factor several projections have to be considered, various scenarios arise. From the analysis of these scenarios result chances and risks for the observation; their study leads to strategic paths concerning the development of the manufacturing location Germany and the realisation of the leading providership.

1.4 Genesis of recommendations

As indicated in Image 1-5, the so-called critical enabler fields and strategic paths from the vision 2030 – as well as categories of added value and needs – form the basis for a series of recommendations for manufacturing research in a comprehensive sense. Below, we provide examples of how such recommendations can be generated for each of the four areas.

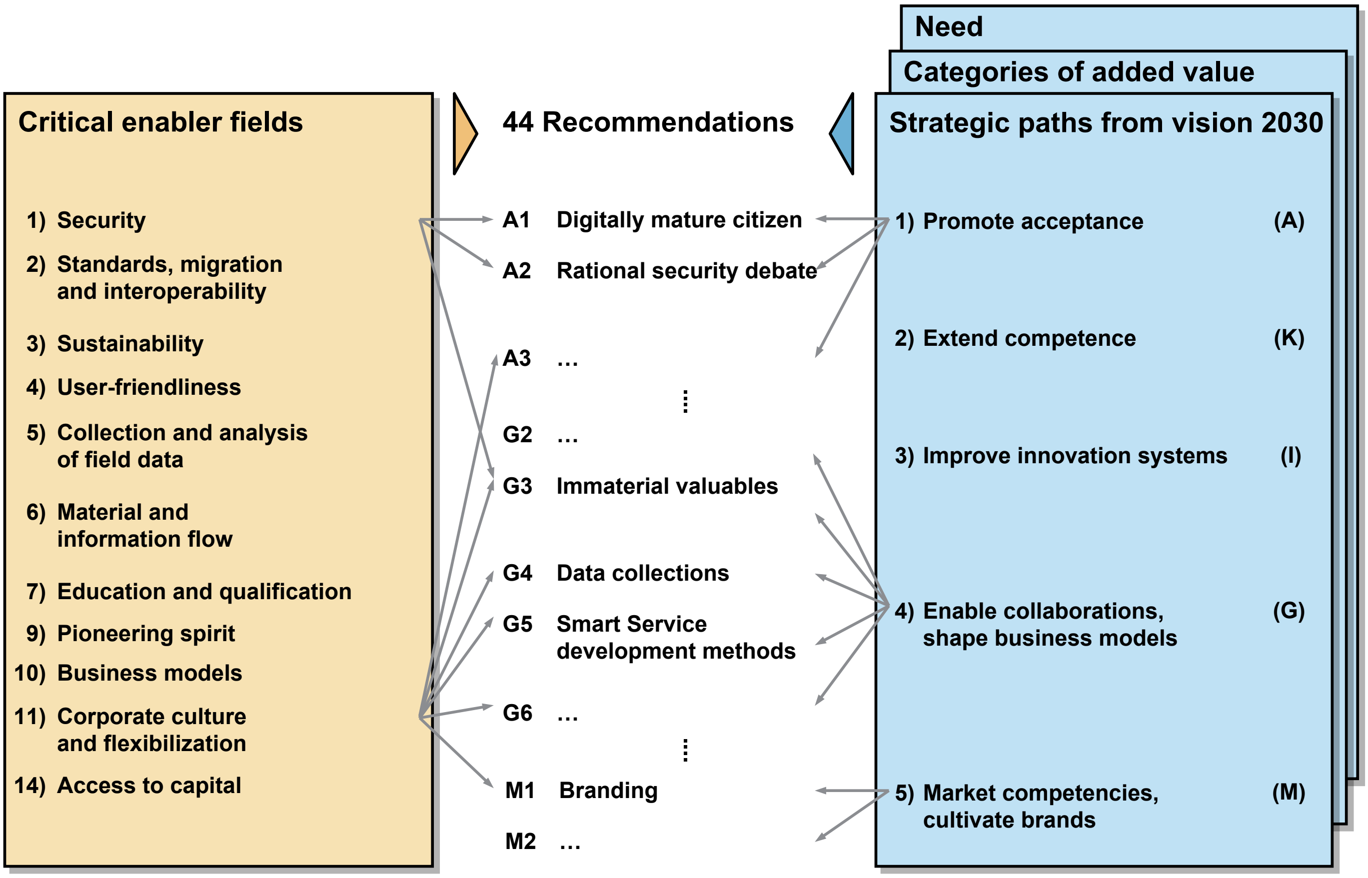


Image 1-5: Genesis of recommendations

Critical focus enabler fields: The evaluation of focus enabler fields regarding Germany's internationally leading position in comparison (benchmark) as well as future significance (forecast) results in the portfolio displayed in Images 1-6. The red area marks fields of high relevance in which Germany does not perform well enough. This indicates need for action. The green, balanced areas show a balance in Germany's position in relation to the focus enabler fields' salience and its strengths

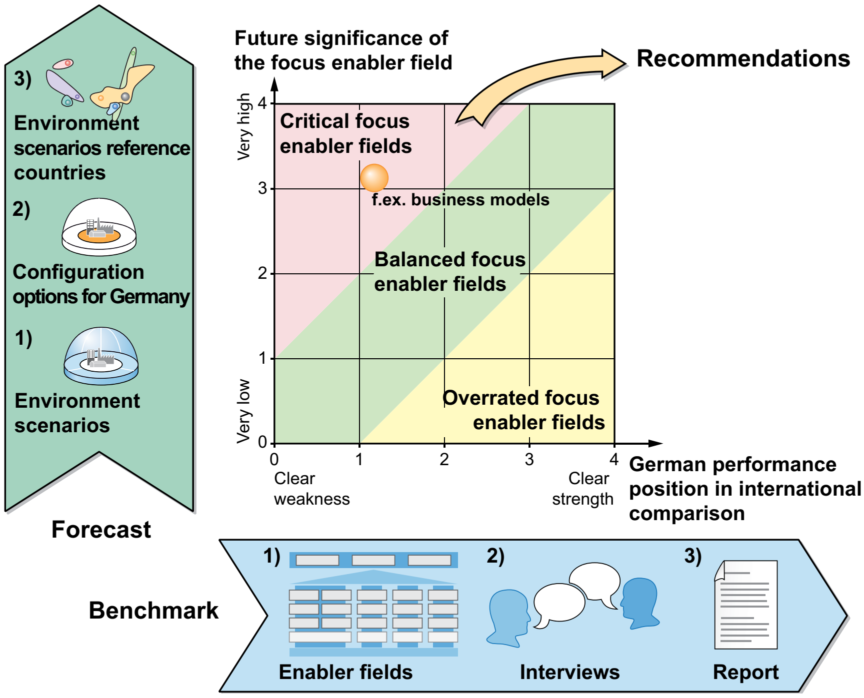


Image 1-6: Determination of critical enabler fields as basis for generating recommendations

and weaknesses. If focus enabler fields are situated in the yellow, 'overrated' area, this means that Germany holds a strong position here but the significance of the focus enabler fields in relation to competition is relatively low.

Image 1-6 shows that the enabler field 'Business models' is a current German weakness and at the same time will be of high significance in the future. Germany lacks a persistent and ongoing orientation towards uses and services. The US remains superior in the field of data-driven business models. This is where the recommendation for **data collections** starts:

Industrial value networks and the applications of industrial products produce big and diverse data collections, which often open up perspectives of profitable market services. In this context, the aim is to develop methods for the analysis of this potential and for the use of the data collections, as well as to edit relevant case studies.

Strategic paths: The vision 2030 implies, for example, the strategic path 'Enable collaborations, shape business models' (Paragraph 3.4). It relates to the context that any development accompanying Industrie 4.0 allows for new forms of collaboration, value creation and value appropriation. Projections like *Networked World* (key factor: penetration of ICT) and *Agile Alliances* (key factor: cooperation in value networks) hint to this. Internet platforms have significant leverage with regards to shaping new business models. The recommendation **Platform Industrial Content** refers to this in detail:

Germany holds exceptional expertise and resources within the manufacturing sector. Looking forward, this will also include product and manufacturing data, also known as industrial content. In the course of digitalisation, data has become a profitable commodity able to generate information and hence a profitable business. A large part of this business with industrial content is facilitated through Internet platforms, which can serve as a junction for data transfer as well as a market place for supply and demand. The aim is to position German companies as organisers of such platforms. This opens up very promising potentials for new businesses but equally for businesses in traditional branches like mechanical engineering. Furthermore, leading competitive positions of German manufacturing businesses can be stabilised and extended.

Categories of added value: In order to shape manufacturing in Germany, paragraph 3.3 develops configuration options. The option 'Sovereign Global Player' describes a consistent and favourable image of the future manufacturing landscape. The configuration option addresses six categories of added value: 1) Conditions for digital sovereignty 2) Increasing flexibility of manufacturing 3) Business models and value networks 4) Use of clouds and service platforms 5) Pragmatic evaluation of technology risks and 6) Transparency and big data in manufacturing and management. Category 1 expresses that any effort towards digital sovereignty demands customised conditions. For example, pursued forms of collaboration demand new approaches which protect results of shared value creation to the outside and distribute them fairly towards the inside. The recommendation **'Protection of intellectual property'** addresses this point::

The protection of intellectual property is guaranteed by means of patents, brands or design patents. These protections do not meet requirements of new forms of collaboration aimed at generating innovation. For example, patents lose their importance through open source. Furthermore, globalisation has made it next to impossible to deal adequately with the registration of patents. Institutions for the protection of intellectual property (patents, brands, etc.) need to be reshaped to fit the conditions of digitalisation and globalisation. Besides the existing patent office structures, new tools for protecting intellectual property need to be established. Among oth-er steps, clear rules need to be developed which distribute shares of an invention in crowdsourcing networks as well as that of copyright laws for automatically generated data.

Needs: Results from the international benchmark and the forecast indicate four general findings from which one can determine distinct needs for the aspired distribution of Industrie 4.0. A basic need, for example, is the reduction of current barriers. The enabler field 'Security' demands an overcoming of cultural barriers and the creation of particular legal conditions. This aspect leads to the recommendation, **'Rational Security Debate'**:

The superior aim is overcoming the so-called 'privacy paradox' whereby a discrepancy exists between the theoretical valuation of protecting private data and the lived lack of caution with which people treat their privacy. This requires a realistic and rational debate about security within society that also fosters emotional acceptance. Similar to foreign policy security, there needs to be a debate within the media about industrial and IT security, dealing with realistic protective measures on all levels (technological, social, normative) as well as making risks more concrete. Currently, unrealistic expectations towards the possible impacts of security technology prevail.

The often observed feeling of powerlessness leads to avoiding uncritical activities based upon diffuse fears, yet critical action is suppressed based on the idea that 'nothing can be done anyway' without the proper security measures.

There are m:n relations between the four fields (critical enabler fields, strategic path, categories of added value and needs) and their concluding recommendations. This means that several strategic paths are derived from one enabler field, but similarly, several enabler fields may inform one recommendation. The latter is true of the recommendation 'Platform Industrial Content': it stems from the 'Enable collaborations, shape business models', the enabler field 'Business models', as well as from the category of added value, 'Cloud use and service platforms' and the need 'Develop solutions'.

2 Current state and perspectives of global development

There is a global trend towards the holistic integration of digitalisation, networking and new forms of collaboration with both everyday life and production. The development of strategies to establish Germany as leading market and leading supplier requires keeping the current and future global competitive situation in mind. For this purpose current regional hotspots in the context of Industrie 4.0 are presented (Section 2.1). For all countries considered by the project, selected highlights (Section 2.2), as well as drivers for and challenges to the development of Industrie 4.0 (Section 2.3) are then identified from the current perspective. In conclusion, the global competitive arena in 2030 for representative countries of comparison is previewed (Section 2.4), taking the status quo as a basis for the inquiry.

2.1 Current focuses

Industrie 4.0 is becoming a global brand. All over the world, a number of pertinent concepts and activities can be identified, each tailored to specific perspectives and the focuses of particular countries. At the moment, in accordance with Image 2-1, four focuses can be identified within the global field of action, which are briefly discussed below.

Europe

Based on a strong technological position for Industrie 4.0, the focus of European initiatives is on the implementation of strategic concepts, balancing the opportunities of digitalisation in industrial value creation with the needs of a human-centric world of employment. Industrie 4.0 is seen as a socio-technological challenge. In many fields the overarching goal is reclaiming industrial competitiveness – especially as a manufacturing location – as well as the creation (or preservation) of sustainable jobs to counteract the effects of the financial and economic crisis. The German High-Tech-Strategy or the French *La Nouvelle France Industrielle* are examples for corresponding European initiatives.

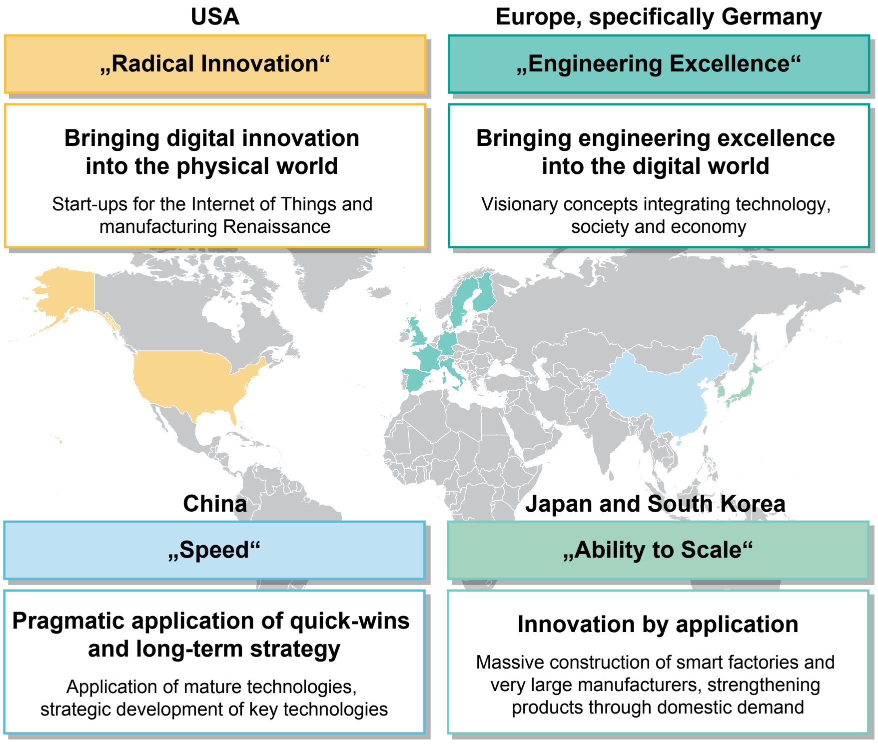


Image 2-1: Current focuses of selected countries and regions in the context of Industrie 4.0

Especially in Germany, technological leadership in manufacturing has enabled the country to become a leading provider in the field of intelligent manufacturing systems. On the one hand, manufacturing technology will remain a differentiating characteristic over the course of the digital transformation. On the other hand, Germany aspires to become a competitive provider of new business models in the manufacturing industry.

United States

With respect to Industrie 4.0, American activities are characterised by two fundamental directions of strategic action: On the business side, implementation of intelligent technologies is driven by pragmatic advantages and value for the customer. In particular, Silicon Valley has great potential for radical innovation due to existing competences and the available innovation system in the field of data-driven services. In contrast to Germany, the focus is mainly on the realisation of new products and services, innovative business models and promises of benefits for the customer. Already existing technologies are only selectively used in production – for example, improving quality control. Following the economic crisis, reindustrialisation of the country and job creation have been prioritised. In order to achieve this goal, the United States needs to rebuild its attractiveness as a manufacturing location and reestablish the competitiveness of local manufacturing in global competition.

Japan and South Korea

The focus of Japan and South Korea is on establishing strong local corporations in mechanical engineering and electronics in the new business segment of "networked manufacturing systems". A primary goal is averting looming productivity losses caused by rapid and pronounced demographic changes. Initially, the OEM conglomerates characterising and dominat-ing the economy of both countries develop smart manufacturing solutions for internal use. Once their solutions achieve market readiness commercialisation is pursued to take advantage of economies of scale. Corresponding public support programmes – such as the one to construct at least 10000 smart factories in South Korea – allow conglomerates to achieve their planned economies of scale through comprehensive implementation of their technologies.

China

In China, speed is crucial. Technologies available to the market are pragmatically implement-ed where they provide obvious benefits ("Smart Factory 1.0"), however, the country's low average automation level prevents large-scale comprehensive implementation. Catching up to global competitors in key technologies of advanced manufacturing is part of a national strategy.

The overarching goal of all Chinese activities is maintaining the global leadership role in manufacturing and associated jobs, whilst at the same time, raising the standard of living to the level of other industrialised countries.

2.2 Country-specific highlights

In this project, parameters relevant to the realisation of Industrie 4.0 and their current implementation level were considered on the basis of defined enabler fields. The following chapter briefly summarises relevant insights of detailed reviews for the assessed countries and regions. Salient properties, parameters or approaches are further emphasised as country-specific highlights. Detailed information on each country can be found in the benchmark reports.

Highlights European Union[2]
The integration of competencies is seen as a key factor within the European Union. Even though necessary technological competence is already present, it is not yet sufficiently integrated. In general, three trends become visible: 1) Reindustrialisation (e.g. France, Great Britain), 2) Advancement of new technologies and development of existing fields of technological strength (e.g. Germany, Italy) and 3) Promotion of innovations in the fields of digital interconnectivity and data-driven business models (e.g. Sweden, Finland).

The European states' overarching strategy is the holistic integration of production and society. The main goal of EU support programmes is to increase productivity and sustainability. Strict European regulations drive strong market demand for sustainable products and process technologies. Adoption of such high regulatory standards by countries outside of the EU is becoming apparent. Regional and Europe-wide clusters, strongly supported by EU funding, are closely collaborating. Excellent infrastructure, cultural proximity, and different competencies in industrial IT and manufacturing result in a strong businesses position within the global market. The realisation of cost-effective individualisation and personalisation processes in manufacturing are important goals.

Sustainability
Social awareness for sustainable products is driving the implementation of Industrie 4.0. High demand for sustainable products and a Europe-wide homogenisation of high standards create a research focus on sustainable production processes.

Internationality
Cultural proximity and complementary competence in industrial IT and production lead to the close cooperation and collaboration of industry, research, and politics all over Europe.

Access to supply and demand markets
Existing regional, national and European clusters are actively supported. Strong European countries are leading providers and leading markets for highly developed production techwnologies; due to excellent infrastructure, supply chains within Europe are short.

Highlights Sweden
Sweden is a nation of pioneers, and the near-ideal test market for Industrie 4.0 technologies and concepts. Flexible organisational structures, an open culture of work and the high acceptance of and affinity for technology allow for the use of intelligent manufacturing systems. Compared to other European countries, fears regarding data security or "transparent employees" are less pronounced. The Swedish economy is one of the world's most digitally connected. The same is true of the competence level and for the diffusion of automation technology. Sweden possesses core competence in the field of ICT, and its traditionally strong orientation toward

Benchmark report

Profile European Union

Country profile Sweden

2 The European Union is considered despite that it is not a single sovereign state. Nevertheless, as a union of states and the world's largest single market with its own parliament, executive branch and EU-level coordination of research and innovation in the field of manufacturing, the European Union is highly relevant.

Country profile Finland

Country profile Spain

exports enables adaption to global market demands. In contrast to software and component providers, Sweden is lacking large system integrators.

Corporate culture and flexibilization
Flexibility is crucial. Flat hierarchies and flexible working time models are common and allow for creativity and innovation; solution-oriented approaches prevail over process-oriented approaches.
Pioneer spirit
Sweden is the European test market for innovation. This test market is characterised by a high acceptance of and affinity for technology, and an open culture towards working and information.
Internationality
Sweden is traditionally export-oriented, with an intuition for global markets. An open society and a high standard of living make Sweden highly attractive to international employees. At the same time, Swedes treat employment abroad as a means to acquire a sense for foreign markets.

Highlights Finland

Finnish society is highly accepting of innovation. Industrial enterprises are very engaged in testing pilot applications. The conditions for the development of global innovations on a local production level are very favourable. Core competence exists mainly in the sectors of field data collection and analysis and sensor technologies. Data security is not seen as an obstacle, and does not impede the implementation of new technologies for data evaluation and analy-sis. Finland is eager to hold and advance its position in the field of Industrie 4.0. International collaborations are actively sought in order to develop complementary competence. Industrial and support projects are focused on the targeted data utilisation of networked (field-) devices in industrial applications and the development of corresponding data-driven business models. Businesses and research facilities cooperate closely to transform innovation potentials into actual products. Due to its international leadership role in education and the increasing popularity of STEM subjects, Finland‘s society is a great basis for the sustainable development of technological competence.

Collection and analysis of field data
Finland is a pioneer in sensor technologies and has developed competence in field data collection and analysis. Open standards and the selective opening of interfaces e.g. for start-ups lead to “bottom up” innovation.
Social importance of production
ICT and data analysis for manufacturing are among the most developed technological fields and are systematically expanded. Industry, especially in the fields of mechanical and plant engineering, is export-oriented. Pilot applications in local production are a preferred solution, as the potential utility of innovation is generally seen as outweighing the expected technical risk.
Social basis
In comparison to other industrialised countries, the culture of innovation is remarkable. Finland has one of the world‘s best educational systems, with a special status accorded to STEM subjects.

Highlights Spain

Industrie 4.0 in Spain is mainly driven by the active participation in European initiatives and programmes. The autonomous regions feature different strategies and programmes, however comprehensive coordination on a national level is still lacking. The recently launched initiative, Industria Conectada 4.0, is meant to close this gap. Due to lingering effects of the financial crisis, the strategy is focused on strengthening the Spanish manufacturing industry and the development of local technological competence in this field. The Spanish economy is characterised by small businesses and a lack of larger corporations. Private investments in R&D are accordingly small. Economically strong regions like the Basque country feature a solid technological basis, a high level of innovation and actively support digitalisation. Despite this, the majority of CPPS components are imported. Local providers focus mainly on specialised solutions for niche markets. Research institutes with essential competence in relevant areas of research exist but technology transfer to industry is often lacking. This complicates early access to innovative technologies, especially for SMEs.

Highlighted region: Basque country
The Basque country is an industrial and academic hotspot for Industrie 4.0 activities within Spain. A high level of technological competence and rapid adoption of new technologies enable industry to keep pace with international technological development. The Basque approach to intelligent production is highly technology-centric. The goal is generating competitive advantage through application of high technology. Technology is understood broadly, and is not simply concentrated in digitalisation and cyber-physical products. A weakness is limited competence in the field of business model and service innovation. The education level is very high, with a flexible education system. First-class private universities allow for quick and flexible adoption of Industrie 4.0 training programmes and its developing demands for qualification.

Highlights France

France focuses on reindustrialisation with a comprehensible, future-oriented strategy. The reason is a contraction of the manufacturing industry, despite good parameters like competitive research, large and economically important companies and a stable economy. Govern-ment tries to counteract the decline of the manufacturing industry with its high-tech oriented strategy *La Nouvelle France Industrielle.* Companies are supported in their application of new manufacturing paradigms, for example cloud computing. Important actors in industrial software such as Dessault Systèmes, aim at a leadership position in the systems market for Indus-trie 4.0. France also aspires to significant influence in the consumer-oriented Internet of Things. Industrie 4.0 is understood as an approach requiring European cooperation; especially collaboration with Germany is explicitly demanded.

Country profile France

Highlights Italy

Small and mid-sized enterprises in the north of Italy are the economy‘s backbone. Industrie 4.0 is mainly promoted by industry associations. Germany is seen as a benchmark and trendsetter for Industrie 4.0. However, many Italian SMEs lack a concrete understanding of the German intention behind the concept of Industrie 4.0. Thus, many SMEs expect competitive disadvantages. But competence for Industrie 4.0 already exists driven by continual improve-ments in automation technology. In particular, digitalisation and machine networking open up previously untapped potential in the areas of work organisation and human-machine-interfaces. SMEs in particular invested only hesitantly or even not at all, which constricts the space for the development of basic technology. Additionally, the collaboration between industry and universities is only moderately pronounced.

This currently inhibits the promotion of innovation in the manufacturing sector. To counter this, regional collaborations and applied research activities are supported by government and managed by industrial associations.

Country profile Italy

Country profile Great Britain

Country profile United States

Country profile China

Technological basis
Small and mid-sized enterprises possess high degrees of technical specialisation and global competitive strength. Modern production technologies are primarily used in mechanical engineering and textiles but lack a defined high-level strategy for Industrie 4.0.

Highlights Great Britain

Great Britain is promoting the process of reindustrialisation after years of prioritising the financial sector. The start-up scene increasingly features young entrepreneurs oriented towards technology and manufacturing. Research clusters like the Catapult Centres were founded with the goal of furthering manufacturing sector innovation. The country's strengths lie in sensor and data analysis systems, efficient logistics and value creation chains. Widespread skills for integrating singular fields of competence into holistic Industrie 4.0 solutions are, however, currently lacking. Flexible and sustainable production is seen as a major driver for Industrie 4.0 applications. Broad European cooperation in standardisation is seen as an "enabler" of Industrie 4.0. However, the political situation may endanger or slow down these processes.

Collection and analysis of field data
A remarkable start-up scene in London, a strong sensor industry and companies providing intelligent products and solutions for production assisted by real-time data form an excellent environment for developing Industrie 4.0 solutions.

Highlights United States

The United States are focused on customer value. Adding value for the customer through indi-viduality, service or quality is understood as the primary function of Industrie 4.0 applica-tions. The reduction of manufacturing costs is seen as secondary. Industrie 4.0 solutions are primarily implemented in specific-use cases, less to realise consistent production concepts. American providers will mainly offer Industrie 4.0 solutions where potential exists for fun-damental paradigm shifts in production, such as business model innovations. The American market offers sales potential for foreign providers especially in cases where Industrie 4.0 solutions – requiring comprehensive domain knowledge in the field of production – allow for specific performance increases. However, this sales potential is contingent on whether fundamental business model changes for these Industrie 4.0 solutions fail to materialise.

Business models
Customer-oriented business innovations dominate purely technical innovations. Start-ups rapidly introduce new technologies, business models and products to the market.

Standards, migration and interoperability
A pragmatic approach to norms and standards ("Done is better than perfect") allows for more rapid collaboration between interdisciplinary actors. Competing standards are accepted. Activity is focused on the compatibility between standards.

User-friendliness
Simplicity and intuitiveness are decisive for the development of human-machine interfaces: The focus is on simple, value-adding, single-purpose applications achieving optimal user and usability experience.

Highlights China

In China, speed is crucial. Rapid wage increases reduce the competitiveness of very labour-intensive manufacturing. Thus, the focus of government and industry is increasingly on automation technology. The critical factor for migration is less capital than time: Rising costs significantly endanger the competitiveness of Chinese companies. China wants to avoid falling behind in automation technology and manage the leap from its current low automation level to implementation of the most modern technology available. However, Industrie 4.0 is still in its early stages and an understanding of the concept in industry is still developing. The local automation industry is not yet mature enough to satisfy local demand and high quality standards. In the mid-term, the Chinese market for automation technology and Industrie 4.0 technologies will lead to strong (global) growth.

Access to supply and demand markets
An unparalleled network of suppliers and competence clusters for selected technologies allow for the rapid development of supply chains for new production.

Business models
The strength of Chinese companies is innovation tailored to the specific demands and financial possibilities of customers. Companies successfully apply the "fast follower" strategy. Business-oriented innovations by companies are complemented by state-driven technological innovations in selected strategic fields.

Production basis
A high demand for productivity increases the amount of available capital, and small irreversible costs of existing production lines justify expectations of large increases in demand for automation technologies.

Highlights Taiwan

Taiwan distinguishes itself by rapid introduction of products as well as start off production. Highly flexible supply chains and high vertical integration allow for production start-up for new products, especially in consumer electronics (e.g. smartphones), within a single week. Taiwan possesses pronounced competence in the ICT and semiconductors industries. Industrie 4.0 concepts are mainly seen as an opportunity to shift the local product portfolio from cheaper products to those of higher quality and higher value. Focused increases in productivity enable Taiwan to regain manufacturing output lost to the mainland. Local providers of Industrie 4.0 applications are focused on developing solutions for both the horizontal and vertical integration of production data.

Highlights Singapore

Singapore is a hotspot of regional headquarters. Smart technology and CPS approaches in Singapore are mainly focused on technologies for realising smart grid and smart city concepts. Still, local production on a world-class level is a focal point of politics, which supports research of advanced technologies accordingly. Core industries like semiconductors and logistics promote the industrial application of technologies for data analysis. The start-up scene is robustly positioned in developing data-driven services. Initiatives

Collection and analysis of field data
A developed start-up ecosystem in the field of data-driven technology, regional headquarters of data-intensive companies and the vision of a smart, data-driven nation characterise the current environment of Industrie 4.0 in Singapore. Strong industries like the semiconductor industry are driving the analysis and use of data in production..

Internationality
Singapore, with its high standard of living, its status as a focal point for economic and indus-trial activity in East Asia and its high concentration of regional company headquarters is a magnet for international talent.

Access to capital
Singapore is an influential regional banking location with good access to venture capital. Strong government incentives for supporting world-class production and industrial R&D are available on short notice.

Country profile Taiwan

Country profile Singapore

Country profile Japan

Country profile South Korea

and programmes specifically focused on exporting intelligent production solutions could not be identified. Good infrastructure, the rule of law, political stability and a number of free trade agreements has made Singapore the centre for the regional headquarters of multinational corporations and investors on the Asian market. The manufacturing industry is focused on the development of world-class products in the fields of electronics, chemicals and medicine. Accordingly, there is high demand for state-of-the-art technologies.

Highlights Japan

Japan is focused on productivity increases and ergonomics. The paradigm underlying Industrie 4.0 is seen as a chance to further increase competitiveness with China and South Korea, and counteract the effects of demographic change through automation technology. Solutions like digitalised (RFID-based) Kanban systems or intuitively operable tablets and handhelds to support assembly and intralogistics processes are already implemented in highly automated factories of major corporations. The aspiration is vertical integration of the whole value creation process through implementation of ICT. Distribution of solutions developed for internal use to external customers is considered, but existing solutions for the Japanese market are not yet mature enough to meet global requirements. High level competence in automation technology, in combination with the proximity to growing markets like China, is a great chance for the Japanese automation and ICT industries. In comparison with Japan's strengths in the field of hardware, competence in the field of software is fairly low, not reaching global standards.

Materials and information flow
The strong vertical integration of companies, supported by the application of intelligent technologies like digital Kanban systems, use of smart devices in intralogistics and a high degree of automation characterise the competence of Japan in the field of material and information flow.

Normative basis
Japan is a leader in the development and strict implementation of bold concepts and processes in production. A process-oriented approach to thinking and working is deeply ingrained in society.

Social importance of production
Japan is proud of its manufacturing and wishes to maintain it even in the face of demographic change and increasing competition from other Asian countries.

Highlights South Korea

South Korea already implements Industrie 4.0 solutions in industry, driven mainly by the activities of large Korean corporations ("Chaebols"). Government supports application-oriented measures using the slogan "Manufacturing Industry Innovation". Focus is on the straightforward implementation of Industrie 4.0 solutions in SMEs and the gradual development of up to 10000 smart factories with varyingly defined degrees of technological maturity. South Korea aspires to more efficient and secure production. The large Korean corporations in the semi-conductors and display industries are already highly automated. These corporations pilot new solutions in manufacturing technology in internal production prior to being offered to global markets. Focus of developments is vertical integration of IT.

SMEs in South Korea are tightly integrated into the value creation chain of corporations and very dependent on them. Government support motivates large corporations to share their knowledge with SMEs. Because they are positioned comparatively poorly and heterogeneously with regards to technology, however, simple adaptations of automation solutions are encouraged.

Political will and restrictions
All relevant government ministries support application-oriented measures meant to transform SMEs into "smart factories" in two implementation steps until 2020.

Collection and analysis of field data
The strong semiconductor and display industries possess broad knowledge bases in field data collection and analysis for process controlling. Available know-how for predictive maintenance is surpassing the demands of the German concept of Industrie 4.0.

Technological basis
Korean corporations possess developed core competencies in systems integration, automation and integration of different IT solutions in production. Additionally, these corporations are very quick and flexible in adapting globally developed high-tech basis technology.

2.3 Drivers and challenges

In collecting current country-specific parameters, specific drivers and challenges in the context of Industrie 4.0 were identified across markets. Following the aggregation of these drivers and challenges into thematic areas, some areas in turn emerged as global drivers and global challenges to the implementation of Industrie 4.0. The three most significant global drivers and four most significant global challenges are described below.

Drivers

Sustainability: Sustainability in the sense of greater energy and resource efficiency was identified as a global driver for the application of Industrie 4.0 solutions. However, motivations for more sustainable production vary widely internationally:
While the implementation of sustainable technologies in Germany is currently driven primarily by ideological aspects, the global focus is primarily on cost savings and the avoidance of resource bottlenecks. Especially for countries already featuring high levels of energy and resource efficiency, sustainability is a selling point for Industrie 4.0 solutions.

User-friendliness: Demographic change is a challenge facing industrialised countries all over the globe. Aspects of Industrie 4.0 are seen as opportunities to improve usability and ergonomics of industrial jobs significantly, thus guaranteeing effective and efficient manufacturing despite demographic changes. On the other hand, digital support enables lowering demands as to the qualification of employees and allows for on-the-job training for low or unskilled employees. Some Asian countries understand this as a driver for Industrie 4.0 implementation in particular. In Germany, however, higher usability is seen as an opportunity to improve transparency and decision-making abilities of workers.
Collaboration: Technological advances in networked, virtual cooperation in combination with innovative human-machine interfaces, allow for radically new forms of collaboration – both within and across companies. Resulting innovations are seen as drivers of Industrie 4.0. New forms of cooperation primarily contribute to increasing efficiency of overheads and thus lead to a better utilisation of existing potential.

Challenges

Security: Industrial security is an obstacle for interlinking devices and machines and their integration in external networks globally. Even though it has been identified as a challenge, no comprehensive global security solutions have been found. As a consequence, two-layered networking strategies develop, envisaging, first, data exchange within a closed network with-out Internet access (e.g. within a factory), which is then, secondly, connected with external partners. In order to evaluate these risks there is a great demand for structured risk assessment.

Standards, migration and interoperability: Following the motto "better done than perfect", speed trumps perfection in standardisation. Only globally established standards allow for a successful implementation of the different technological aspects of Industrie 4.0. Additionally, standards guaranteeing upgradability of components and software are needed to make investments in corresponding solutions future-proof. Start-ups and SMEs may promote the implementation of Industrie 4.0 and contribute to diverse solutions, but only open, interoperable standards will open up the market for them.

Business models: Industrie 4.0 will enable new – sometimes radically new – business models in the manufacturing industry. Corresponding best practice examples are still rare, however. Crucial impulses for new business models are to be expected from start-ups. However, a vital start-up ecosystem featuring pertinent enablers is still lacking; especially platforms and platform strategies in production as can be found in the field of B2C.

Industrie 4.0 brand: The German concept Industrie 4.0 has become a global brand due to its high political pertinence, intensive marketing efforts and the global leadership of Germany in manufacturing technology. Especially Asian countries vigorously pursue the German initiative and its progress. In order to benefit from the brand, it is now important to "suit the action to the word". Initial technological solutions have to be developed quickly, demonstrators need to be built and appropriate products brought to market. In doing so, the central question will be: "Is Germany able to leverage the Internet?" Foreign countries need to be persuaded by Germany's ability to continue establishing Industrie 4.0 as a brand.

2.4 The global competitive arena 2030

Future scenarios, describing conceivable settings of local business environments in the year 2030, were developed for the reference countries of Brazil, China, Saudi Arabia, Spain, South Korea and the United States. From this, conclusions can be drawn as to whether the respective country is attractive for German providers of Industrie 4.0 services and whether local industry of providers will also enter the global competitive arena. These country-specific scenarios are based on eight key components:

- Self-determination
- Working conditions
- Training and further education
- Government involvement
- Research policy
- Labour law
- Innovative capacity and
- IT security

With respect to each key component, three conceivable settings (projections) for the year 2030 were identified for each country and then combined into a number of internally consistent scenarios. The developed future scenarios were evaluated as to their probability of occurrence and the strength of their impact on manufacturing research in Germany. On the basis of this evaluation, one reference scenario was selected for each reference country. In the following, the currently most probable reference scenario for each country is described. Links to further materials can be found in the marginalia.

Brazil 2030 – "Cautious growth due to external impulses"

Self-determination and working conditions: The transformation of the value system towards lower power distances and more pronounced individualism is restricted to the pulsing metropolises. Omnipresent availability of information due to the Internet and a strong presence of Western companies are important drivers of this transformation. With respect to working conditions in economic sectors, Brazil has mostly surpassed the level of an emerging economy. However, inefficiency and corruption still inhibit comprehensive improvement of working conditions; government programmes such as those to combat informal employment, for example, have not yet had their full effect.

Training and further education: Foreign investors setting up enterprises in Brazil are dependent on well-trained employees and since their interest in the South American market is high, they are already investing in formal education programmes. These initiatives create more high-quality positions in schools and universities, but due to government reluctance, a productive and just educational system is still a long way off.

Government involvement, research policies and labour laws: Government is effectively involved, but currently cutting back such involvement. Through targeted support and assistance of foreign investors, the Brazilian economy continues to gather momentum. Both the private share of R&D expenditures and total R&D expenditures have increased. Both universities and companies recognise the added value of collaborating in innovative projects and significantly intensified their cooperation with foreign companies especially involved. Additionally, the Brazilian government massively invested in the expansion of public "model universities" in the metropolises. Brazil scores first successes in selected technological sectors of Industrie 4.0. Labour laws have been fundamentally reformed. Government restricts itself to setting the framework for transparent, individual coordination of employers and employees. The influence of trade unions is declining.

Innovative strength and computer security: Politics has been promoting foreign investment and settlement for years. This has also led to significant investments by Brazilian companies which have increased the innovative strength of the country. Brazil shows an upward trend on the Global

For Brazil, three scenarios are given:

Scenario 1:
"Corruption, lack of transparency and inefficiency prevent further development of the country"
Scenario 2:
"On the path to an industrialised nation"
Scenario 3:
"Cautious growth due to external impulses"

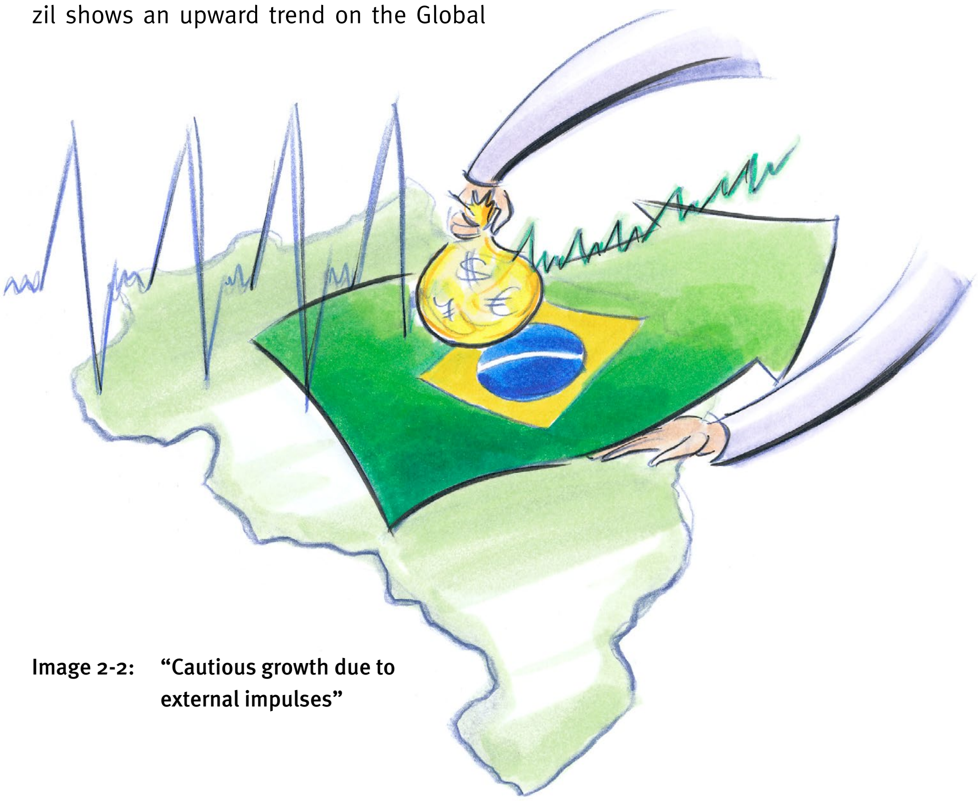


Image 2-2: **"Cautious growth due to external impulses"**

Innovation Index. The country is primarily a leading market for Industrie 4.0 services but it cannot yet compete with leading providers. The Brazilian government attaches major importance to the challenge of IT security. But Brazil has neither proven R&D strengths in this area nor enough expertise in local companies. Thus, the government invests in foreign solutions to guarantee the IT security of society and economy. The development of local expertise succeeds only timidly.

> The transformation of a prosperity-supporting value system is restricted to the pulsating metropolises. Foreign investors reinvest a considerable amount of profits in education and R&D. Brazil is mainly a leading market for Industrie 4.0 services. The country can not yet compete with leading providers.

China 2030 – "Determined authoritarian state"

Self-determination and working conditions: The Communist Party is leading this country of a billion people in an autocratic fashion. Company structures show a similar picture; the authority of supervisors is not questioned. The power disparity is high. Ideas of individualisation are underdeveloped. Increasing prosperity and education levels and the availability of information from the Internet have led the middle class to more actively demand civil rights and participation. There are two classes of companies: large model companies on the one hand, and small and very small companies on the other. While working conditions at large technology leaders approach Western standards, the situation in other companies is still antiquated.

Training and further education: There have been minor increases to educational expenditure. Available funds are specifically targeted to expand elite schools and universities. The education gap between rural and urban communities has further increased. Access to elite and foreign educational institutions is available only to selected, well connected persons. "Normal" schools and universities follow the motto "quantity over quality". Development of vocational training following the German model has been abandoned. Educational content has been revised as part of a "return to ideology", while Western ideas, if not conforming to promoted values, have been eliminated.

Government involvement, research policies and labour laws: The Communist Party is leading the country powerfully and strategically. Politics and business are tightly interlocked. A great number of companies are state-owned enterprises, whose strategies are co-authored by local government. In part, markets were liberalised as part of economic agreements between the West and China. The country is the global leader in research and development spending. Research is centrally organised and research projects are strictly managed. This is especially true of focal topics like automation and digitalisation, which are funded by programmes worth billions. Universities are global leaders in these fields. China takes its own path in respect to individual labour rights. Ambitious economic goals are paramount. Organisations and individuals campaigning for greater rights for employees are pressured by government. The ACFTU is only timidly transforming into a trade union with bargaining power.

Innovative strength and computer security: China's companies and research institutions have developed to be the most innovative worldwide. Again and again, government and large companies manage to orchestrate large numbers of researchers and developers, and focus all possible forces on achieving strategic goals. The successful economic implementation of innovation is reflected in the financial strength of the country and its companies. China belongs to the Top 10 most innovative countries, and is – besides the United States – both the leading market and leading provider. The government is expanding IT security with all its strength. Due to strong international pressure, it has weakened its demand for information control. Government institutions and enterprises utilise the large number of available IT experts and develop innovative IT security solutions; sales both within and outside the Chinese market are good.

The party's autocratic and strategic leadership reaches deep into the economy. In global comparison, China has the highest investments in R&D; the exceptionally high capacities for R&D are repeatedly orchestrated towards achieving strategic goals. For years now, China has belonged to the Top 10 most innovative nations. The country is, besides the United States, the largest leading market and at the same time largest leading provider.

For China, three scenarios are given:

Scenario 1:
"Modern industrialised nation through comprehensive reform of the system"
Scenario 2:
"Entrenched structures prevent breakthrough"
Scenario 3:
"Determined authoritarian state"

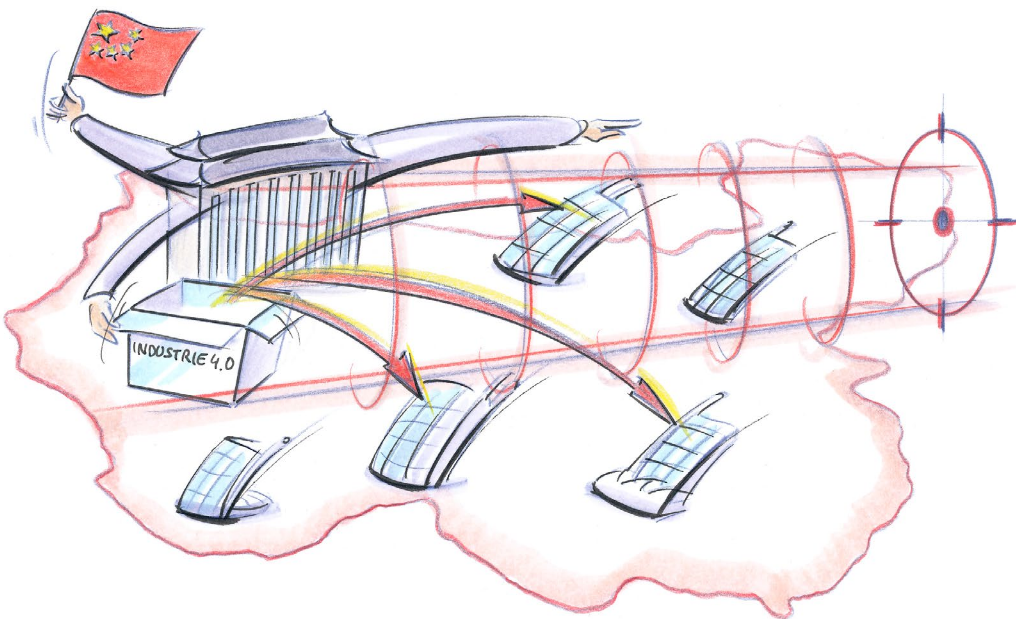


Image 2-3: "Determined authoritarian state"

For Saudi Arabia, three scenarios are given:

Scenario 1:
"High innovative strength"
Scenario 2:
"Stagnation"
Scenario 3:
"Cautious growth"

Saudi Arabia 2030 – "Stagnation"

Self-determination and working conditions: A strict interpretation of Sharia law shapes society. Saudi Arabia sees itself as an Islamic model state. Women continue to have no rights of self-determination. Public life is characterised by social boundaries. Nascent protest movements are stifled from their very beginnings. The social deal is: Loyalty for money. Unemployment benefits, for example, are constantly being raised. The public sector is still bloated and dominated by Saudi locals. They enjoy the luxury of excellent working conditions (high salaries coupled with short working hours) based on oil revenues. The private sector primarily employs foreigners with locals making up less than 20 percent of the workforce. The working conditions for foreigners in the private sector are poor.

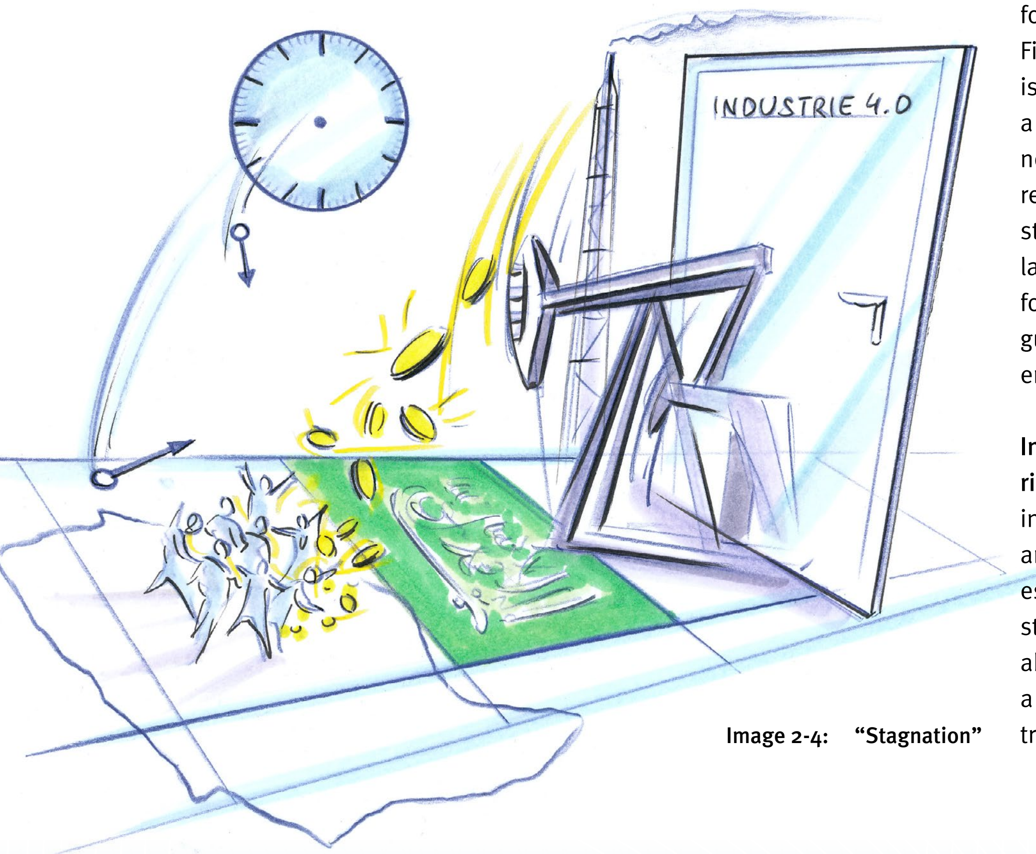


Image 2-4: "Stagnation"

Training and further education: Educational expenditures have only increased marginally over the previous decade. The educational system is shaped by Islam and in many respects does not conform to modern educational and sociopolitical standards. Direct instruction and rote learning dominate to the detriment of creativity and social skills. Islamic subjects dominate the curriculum. Know-how is imported nonetheless by sending young Saudis to top international universities at government expense.

Government involvement, research policies and labour laws: State liberalisation efforts were too half-hearted; autocratic state intervention is very common. Foreign investors groan under the weight of regulations and shun the country. Saudi Arabia is not a research location. The expenditures for R&D have risen only insubstantially. Finding foreign partners to catalyse efforts is difficult due to cultural parameters and a lack of financial incentives. Science is not considered essential to prosperity; a research mentality is lacking. Sharia is still the basis for the design of labour laws. There is no equal opportunity for foreign employers, as labour laws distinguish between Muslim and non-Muslim employees.

Innovative strength and computer security: Saudi Arabia is lacking creative and innovative forces for development. Basic and applied research are not interlocked, especially not in companies. There are still deficits in knowledge diffusion and absorption. The country is far from being a leading provider of equipment for Industrie 4.0; investment in modern production facilities is minor. There is little awareness for security needs – the exceptions rely on foreign solutions. The country missed the opportunity to follow up on oil by taking a global leadership role in computer security.

Saudi Arabia understands itself as an Islamic model state. The hidden deal is: State loyalty for money. Research is not seen as essential to prosperity, and a research mentality is lacking. In the global competitive arena of Industrie 4.0, the country plays a relevant role only as a market.

Spain 2030 – "Success through European integration"

Self-determination and working conditions: Spain's economy has recovered. Especially young people are to the future with optimism. They are striving for responsibility and success in their jobs. Besides large companies, innovative small and midsize enterprises are increasingly investing in research and development. This led to the creation of a number of attractive jobs. Government supports job creation in manufacturing and related areas. Training of specialists in focal areas and the creation of "technological hotspots" arouse the interest of foreign companies. Shifting manufacturing locations to Spain is a success; subsequently foreign companies established local R&D departments.

For Spain, three scenarios are given:

Scenario 1:
"Awakening on its own strength"
Scenario 2:
"Success through European integration"
Scenario 3:
"Unwillingness to change leads to continuous crisis"

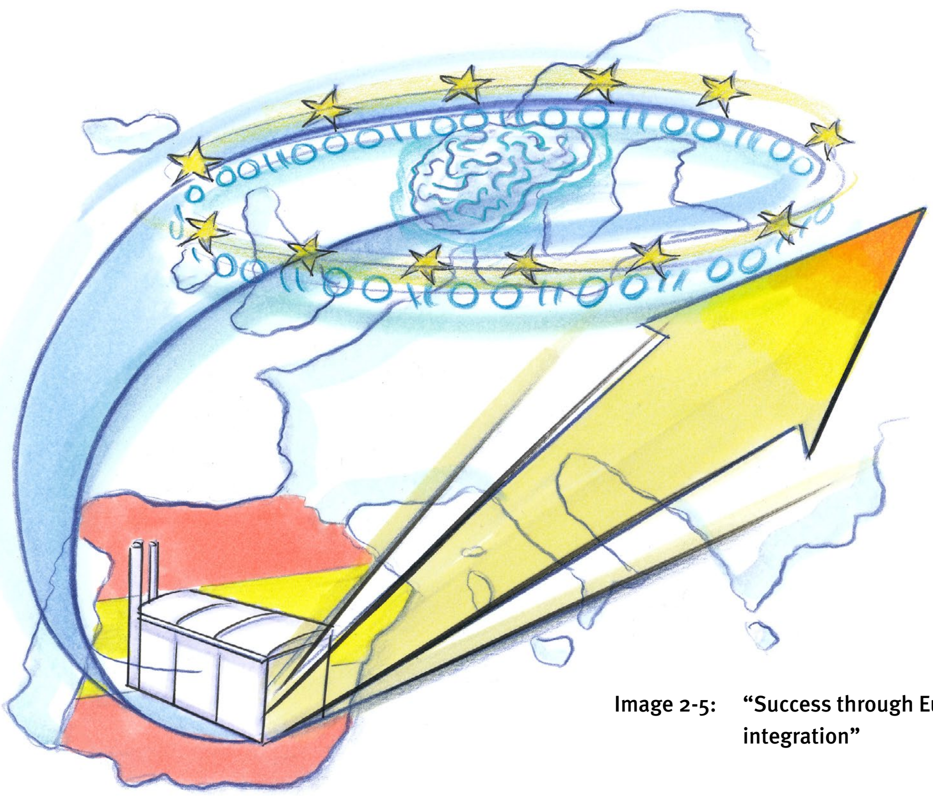


Image 2-5: "Success through European integration"

Training and further education: The Government is increasingly investing in improving tertiary education; tuition fees have been lowered. The share of students in the population is high. STEM subjects enjoy high status. Vocational training is only slowly developing; in some areas the dual system of vocational training and academic education has been successfully adapted. Spanish skilled labour is seen as highly qualified. Competence corresponds to employer demands.

Government involvement, research policies, and labour laws: European integration is extremely advanced and seen as overwhelmingly positive by the vast majority of the population. The European Union exerts a considerable amount of influence over the economy and public life. Targeted support of innovations and correcting market failures brought new momentum to the country's economy. Cutting-edge research takes place on a European level. Institutions like the European Institute of Innovation and Technology (EIT) and its research facilities supported by the European Parliament are well represented in Spain. The country takes part in European cutting-edge research and creates innovative start-ups. Within the EU, national borders play only a minor role with respect to the job market, which is regulated on a European level. The free movement of workers within the EU is realised.

Innovative strength and computer security: Within extremely advanced European integration, the EU gives decisive impulses for increasing innovative strength. Programmes supporting innovation such as Knowledge and Innovation Communities (KICs) lend a highly dynamic character to innovative activity all over Europe. Spanish innovation performance has greatly benefited from European activities: Spain has risen in the Global Innovation Index. Venture capital is available. The country is a leading market in the area of Industrie 4.0 and increasingly appears as a capable provider of Industrie 4.0 equipment within global markets. The national government recognises that bundling resources is necessary for the success of IT security. Here as well, the focus is on Europe. European IT security is a brand all over the world, which benefits Spain's economy.

> Spain's economy has recovered. Young people in particular look to the future with optimism. European integration is highly developed and is seen by the majority of people as overwhelm-ingly positive. EU innovation programmes like Knowledge and Innovation Communities (KICs) lend a highly dynamic character to innovative activity all over Europe, which greatly benefits Spain. The country is a leading market for Industrie 4.0 and increasingly appears as a capable provider of Industrie 4.0 equipment on global markets.

South Korea 2030 – "Preserving the good and daring the new"

Self-determination and working conditions: South Korea has largely adapted to the West. Employees are calling for participation and self-determination. Young South Koreans demand changes and often change employers. Individual desires are becoming increasingly important. Industrial production is the basis for the country's success; job creation in manufacturing and related areas is subsidised. While working conditions in the conglomerates reach that of Western standards, in other companies a lot still needs to be done.

Training and further education: A majority of the population are students or graduates. At the same time vocational training becomes more important, as there is high demand for highly qualified professionals. Spending for vocational training is increased accordingly.

Government involvement, research policies, and labour laws: The South Korean government exerts much influence on the economy, as well as on public and private life. Targeted support and assistance of foreign investors further propel the country's economy. The historically-based technological orientation of South Koreans in research and development pays its dividends in Industrie 4.0: in this area research attains sophisticated levels. The government uses its authority and regulates labour law, although liberalisation efforts are underway. Importance and influence of trade unions is increasing.

Innovative strength and computer security: Concerted political and business activity strengthens the innovative capacity of the country. South Korea is among the five most innovative countries worldwide. South Korean companies are among the most successful global providers of Industrie 4.0 equipment, based on a highly-developing – and prospering – leading market. In the field of IT security, South Korea is one of the pioneers internationally and a successful provider of corresponding solutions.

> The country's elites successfully orchestrate South Korea's development. Industrial produc-tion is a basis for the country's success: it is a highly developed leading market for Industrie 4.0 and one of the leading global suppliers for smart factories. Employees participate in the country's economic success.

For South Korea, four scenarios are given:

Scenario 1:
"Unwillingness to change, dominating conglomerates"
Scenario 2:
"Preserving the good and daring the new"
Scenario 3:
"Government retreat, decreasing dynamism"
Scenario 4:
"Social market economy"

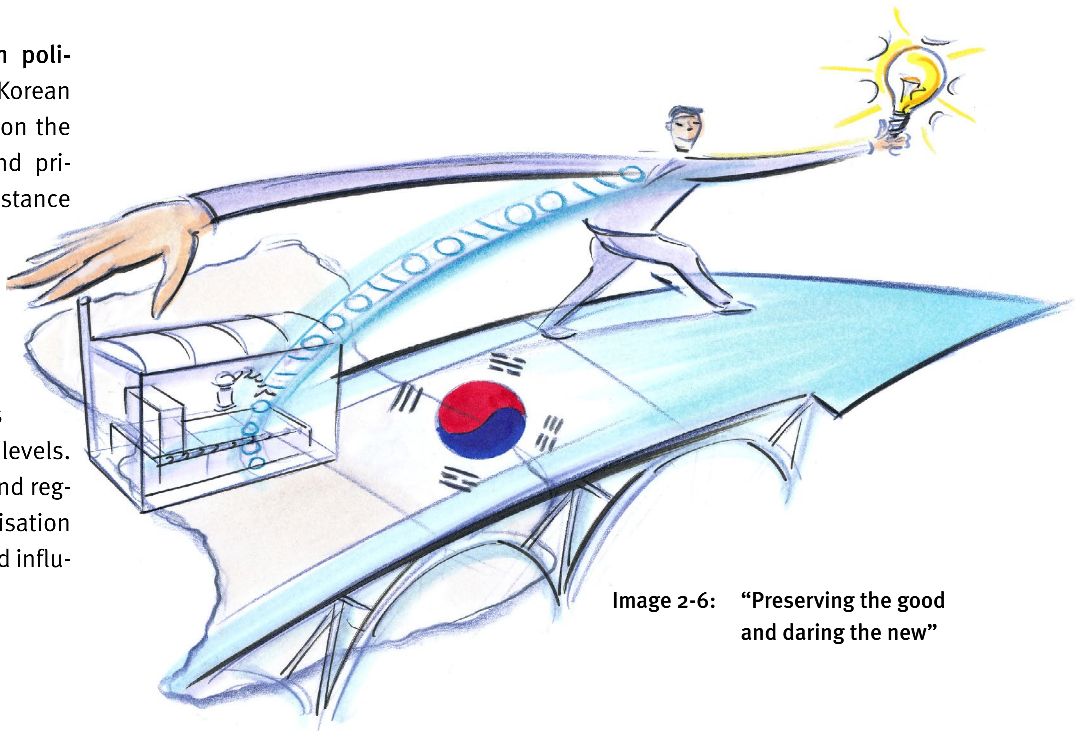


Image 2-6: "Preserving the good and daring the new"

For the United States, three scenarios are given:

Scenario 1:
"Government-led reindustrialisation causes sustainable success"
Scenario 2:
"Deepening service orientation on the basis of current successes"
Scenario 3:
"Polarisation of society and universities paralyses the economy"

United States 2030 – "Deepening service orientation on the basis of current successes"

Self-determination and working conditions: The maxims of American society are freedom and happiness. The "American Way of Life" is still characterised by self-determination and individualism. Initiative and creativity are supported. The social status of manufacturing jobs is increasing. Services are drivers of growth. In this area, human-oriented working models and full employment are widespread. Average real wages and job quality are higher than in manufacturing, although the working conditions in manufacturing have improved.

Image 2-7: "Deepening service orientation on the basis of current successes"

Training and further education: Expenditure for public education has risen significantly. As part of a large-scale reform of higher education, tuition fees for public universities have been lowered dramatically. The massive utilisation of online courses (MOOCs) allows everyone access to the best lectures. Regional differences in the educational level have been adjusted. The training of skilled labour has also improved. The dual system of vocational training and academic education has been partially adapted as an increasing number of businesses recognise its value.

Government involvement, research policies and labour laws: Government influence on the economy is weak; a free market economy prevails. The United States are focused on key areas like biotechnology and defense, where significant expenditure is used to further expand their leading position. Reindustrialisation and the connected strengthening of manufacturing research are only slowly progressing. Politics perceives large potential for success in key areas like biotechnology and the service sector. Besides China, the USA is the largest market for Industrie 4.0, yet relatively few companies enter global markets as dominating providers of Industrie 4.0 equipment. Labour laws are liberal. Government restricts itself to setting the framework for transparent coordination between employers and employees. A flexible job market is another factor for the success of the American economic engine.

Innovative strength and computer security: American companies and universities globally dominate business model innovations especially in the fields of Internet services and multimedia. Innovations in manufacturing play a subordinate role. The United States are falling behind the leading providers for Industrie 4.0, but still make it among the Top 7 in innovation rankings. The breakthrough in IT security did not succeed across the board. The established Internet giants influenced and partially undermined political programmes in their interests: Emerging discussions on security were stifled, unsecured systems declared secure and security vulnerabilities were patched up only tentatively. An increasing number of companies discover IT security as an underrated economic sector. New players enter the market for IT security; first successes are evident. In the area of IT security, the country is mostly a latecomer.

The country is characterised by a free market economy. Business dominates the field of the Internet and big data-based business models. Manufacturing research plays a smaller role compared to other fields of innovation like biotechnology and defense; reindustrialisation progresses only slowly. The US is, besides China, the largest leading market and a dominating leading provider of services.

3 Industrie 4.0 in Germany

Following a dual “Dual Strategy”, Germany aims to position itself as a leading market and leading provider. A corresponding strategy points towards achieving this vision. In this chapter, we describe the current position of Germany in international comparison (Section 3.1) and the vision in the form of an objective. Parameters (Section 3.2) and configuration options (Section 3.3) for Industrie 4.0 economy are developed with 2030 as a temporal horizon. Following this, Section 3.4 will illustrate chances and challenges resulting from the objective, as well as strategic paths to achieve it.

3.1 Current position of Germany in international comparison

Germany aspires to transfer its engineering expertise into the digital world. Industrie 4.0 as a holistic concept for the future implies an integration of technology, society and industry. The goal of intelligent solutions in manufacturing is to increase productivity in collaboration and to reduce costs for product development and production. Some companies have realised pilot applications in operating business to research this type of utility. There is significant uncertainty as to how Industrie 4.0 can produce profits and what corresponding business models would look like. Nevertheless, large companies and a few SMEs are already investing in order to provide high-end solutions for Industrie 4.0 on the global market. The focus is mainly on solutions on the level of the shop floor.

Strengths

Technological basis: Companies develop, manufacture and assemble the core functionalities of their products primarily in Germany. Differentiation is created through focusing on product individualisation and quality. Both in terms of research and industry, Germany possesses very high domain knowledge in the area of manufacturing technology with a focus on hardware. Examples are sensors and intralogistics. There is a high level of basic technologies in the areas of data analysis and networking, although few are integrated into applications.

Social importance of production: Production is seen as a high-technology field and is successfully maintained within the country. “Made in Germany” is a mark of quality and a selling point, also on the domestic market. Engineers enjoy a very high status within companies and society as a whole, and industry is perceived as attractive employment accordingly. The wage level is high and the working conditions in manufacturing are attractive and progressive. The power relations between industry, politics and trade unions are balanced.

Training and qualification: Due to it being strongly application-oriented, the dual system of vocational training and academic education holds great advantage in international comparison and creates a broad base of theoretically and practically qualified skilled labourers and engineers. Experts in the areas of mechanical engineering, manufacturing and management are held in high esteem.

Weaknesses

Infrastructure: The current state of digital infrastructure in Germany is insufficient for meeting the self-determined conditions necessary to realise the vision of Industrie 4.0. Moreover, Germany lacks competence in providing B2C products in the field of IT, which could be transferred to corresponding manufacturing technologies, products and services in B2B currently developing.

Internet technologies: Germany has competence gaps in the area of internet and networking technologies. “Is Germany able to leverage the Internet?”: that is the question. There are doubts internationally whether Germany will be able to broaden its existing core competence in manufacturing technology with complementary digital competence.

Drivers

Changes in established business: Fear of disruptive changes in the context of Industrie 4.0 endangering the core competencies and market leadership in manufacturing technology - or in mechanical and plant engineering, respectively - create an enormous sense of urgency in politics, relevant university research and industry.

Individualisation: Increasing demand for personalised or individualised products drives the development of manufacturing technologies which enable batch size 1 production for the cost of mass production.

Competitiveness: Germany as a high wage country is especially exposed to the increasing global pressure on costs. This situation is coupled with sustained efforts to maintain and reinforce the attractiveness and competitiveness of Germany as a manufacturing location.

Challenges

Insistence on established business models: German companies are strongly focused on security and continuity of business models. This approach needs to be overcome, as it is opposed to rapid adaptation of business operations and business models requisite for the new demands of digitalisation.

Concerns regarding data protection and data security: These complicate the collection, provision and analysis of data in the field of manufacturing and upstream and downstream processes. Besides a very emotionally charged debate about data protection, resulting in a few practical consequences (“paradox of privacy”), a view of data security which fails to consider cost-benefit analyses, is a significant problem. This results in the challenge of both rapidly realising pragmatic and sustainable solutions for guaranteeing data protection and data security and, at the same time, gaining the acceptance of stakeholders.

Overengineering: Highly complex solutions for products and production systems and aspirations to develop technologies and products on the highest level prevent the entering of larger markets which, on the contrary, expect pragmatic solutions for considerably lower prices.

Country profile Germany

Image 3-1 displays the consolidated result of expert assessments at the workshop in summary, relevant to the position of Germany in respective core enabler fields (the basic topics are not shown) and a comparative overview of highlights (Section 2.2) in the countries explored in the benchmark.

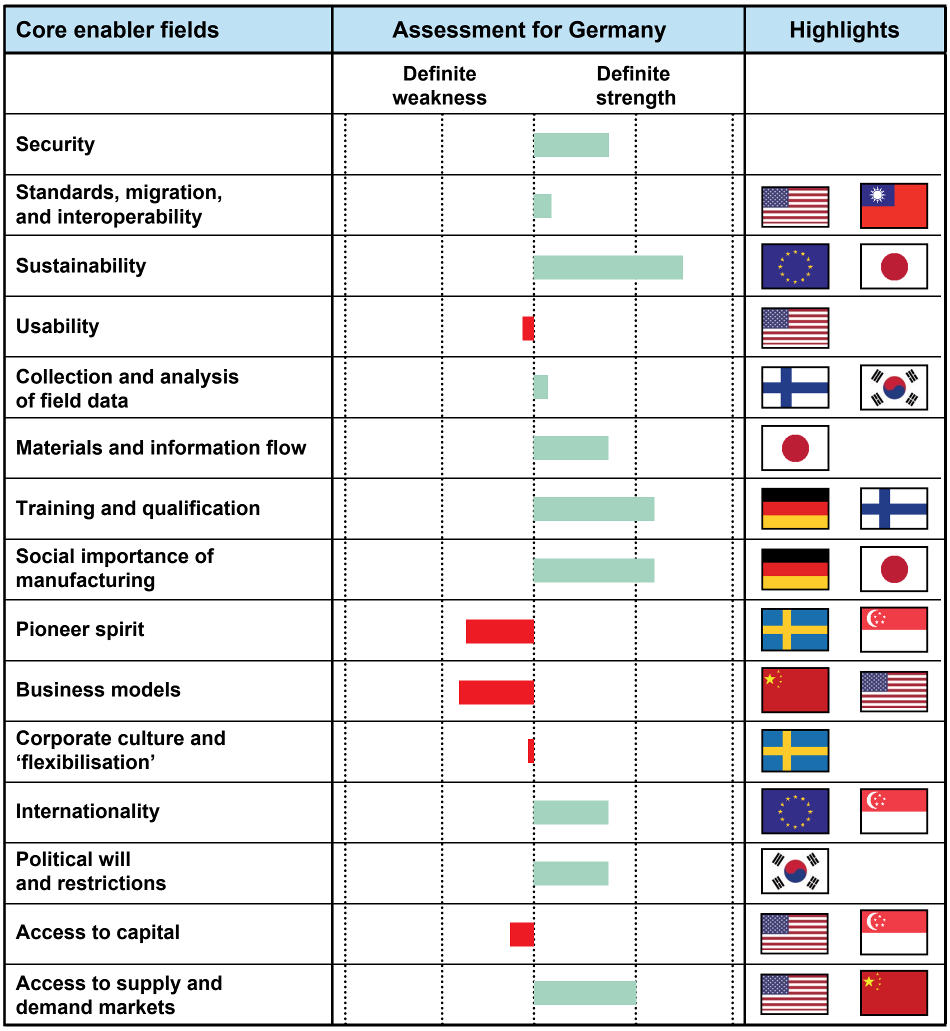


Image 3-1: Strengths and weaknesses of Germany with respect to the core enabler fields

3.2 Parameters for the Industrie 4.0 economy 2030

The forecast distinguishes between environment and configuration field. Environment describes future parameters of the Industrie 4.0 economy in Germany. 20 key components determine the future environment (Image 3-2). These components can only be indirectly influenced by the Industrie 4.0 economy. Direct configuration opportunities arise in the so-called 'configuration field'. The corresponding options are based on 13 configuration components (Section 3.3, Image 3-5). Both the establishment of environment scenarios and of configuration options are based on the scenario-technique. In the following, we will briefly illustrate how the environment scenarios were developed and present them.

As part of a workshop with the extended core team, alternative development possibilities were developed for each of the 20 key components, the so-called projections. Each projection was described in detail. For example, given the key component, "ICT saturation" (Image 3-3), a further increase of the rapid saturation of the worlds of work and recreation with information and communication technology is conceivable. The new possibilities of intuitively operable systems dazzle people; security risks are repressed. The maximally networked world moves ahead (Projection A). On the other hand, it is also conceivable that only few are able to utilise the technological possibilities and generate information from

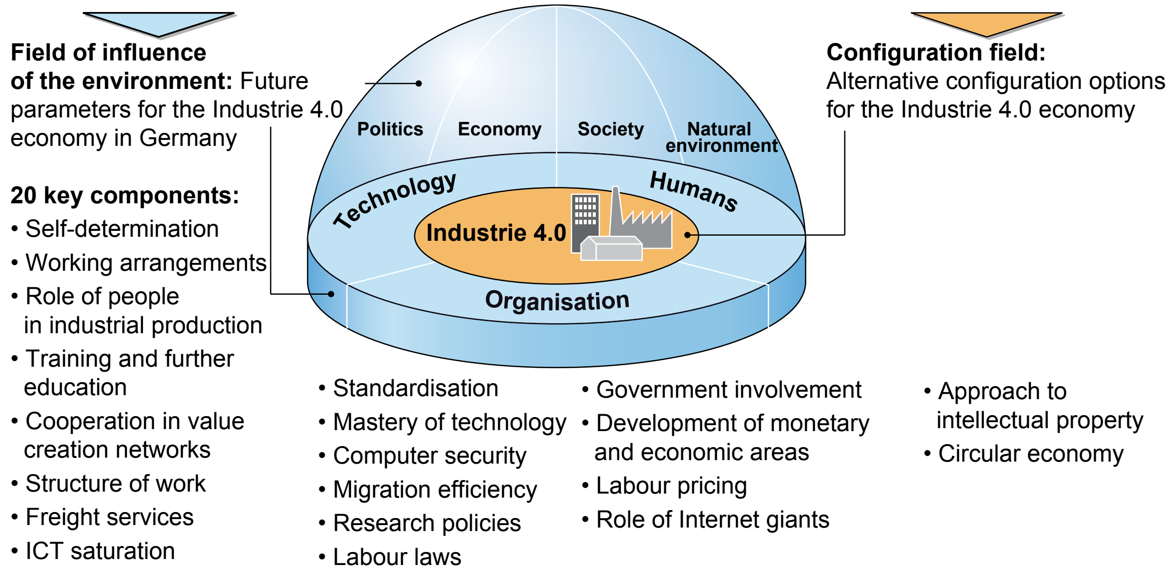


Image 3-2: Environment Germany and configuration field Industrie 4.0, List of 20 key components

data. Information elites form (Projection B). A third possible projection is skepticism about ICT further increasing as the effects of a "lax" approach become slowly visible (Projection C).

In a further step, the developed projections are combined into consistent pictures of the future. This is based on a pair-wise consistency evaluation and a resulting consistency analysis. The results are four environment scenarios: Scenario 1) "Balance of humans, technology, and government as the basis for success", Scenario 2) "Rigorous digitalisation, technology-centric world of work", Scenario 3) "Digitalisation gets struck by many obstacles", and Scenario 4) "Digitalisation – global and other-directed". In the following, we will characterise the environment scenarios 1 and 4 with some brief sentences; these were evaluated as especially probable by experts.

8A Maximally networked world

The rapid saturation of the worlds of work and recreation with information and communication technology has further increased in recent years. Everyone has access to information and services - everywhere, and at all times. The deployment of semantic technologies allows for efficient mastery of the abundance of available information. Intuitively operable systems have especially prevailed. The fascination of new possibilities dazzles people: Security risks such as the transmission of sensitive data are repressed. There is a conflict between the theoretical value and the lived carelessness in dealing with one's privacy.

8B Information elites

The amount of data produced daily reaches an ever-bigger scale. Many perceive new opportunities barely dreamed of. As has been widely predicted, the immense abundance of data turns out to be the equivalent of gold for the 21st century. But the free availability of data is deceptive. Only a few manage to utilise the latent technological possibilities and generate information from data: Information elites form who then master the algorithms and rigorously utilise data. There is obviously no scarcity of information; but people do not feel informed.

8C IT-Frustration

The ICT hype in the world of recreation has not entered the field of production. The necessarily high demands on the reliability of IT systems are not realised. The expected increases in efficiency have failed to materialise. In private as well, dealing with ICT changes. Skepticism regarding ICT strongly increases as results of a "lax" approach slowly become visible. People are confronted with total transparency and strive in turn for privacy. Privacy means the ability to self-define and self-regulate one's visibility on the net.

Image 3-3: Projections for the key component "ICT saturation". For image sources see the image credits (Imprint)

Scenario 1: "Balance of humans, technology, and government as the basis for success"

Self-determination, working arrangements, training and further education: People are using the resulting diverse opportunities to shape their lives. In their professional lives they are demanding balanced solutions in the dimensions "Humans", "Technology" and "Organisation"; technology should serve people. Digitalisation has greatly changed education and training; teaching and learning are done primarily independent of time and location; Massive Open Online Courses are increasingly catching on. The number of teachers has significantly decreased.

Role of people in industrial production, structure of work and the pricing of labour: In spite of high systems intelligence and automation, people are in demand as decision-makers; a symbiosis of man and machine prevails based on performant human-machine interactions. Innovative assistance systems and collaborative robots support the worker at the teaching & learning factory. Generally speaking, wages are aligning globally. Social inequality has decreased.

Government involvement, research policies and labour laws: Government is effectively involved, even though there are tendencies to lessen government involvement. Research funding shows great success. The social partnership, successful for years, is under pressure; liberalisation of labour laws is progressing.

For Germany, four scenarios are given:

Scenario 1:
"Balance of humans, technology, and government as the basis for success"
Scenario 2:
"Rigorous digitalisation, technology-centric world of work"
Scenario 3:
"Digitalisation gets struck by many obstacles"
Scenario 4:
"Digitalisation – global and other-directed"

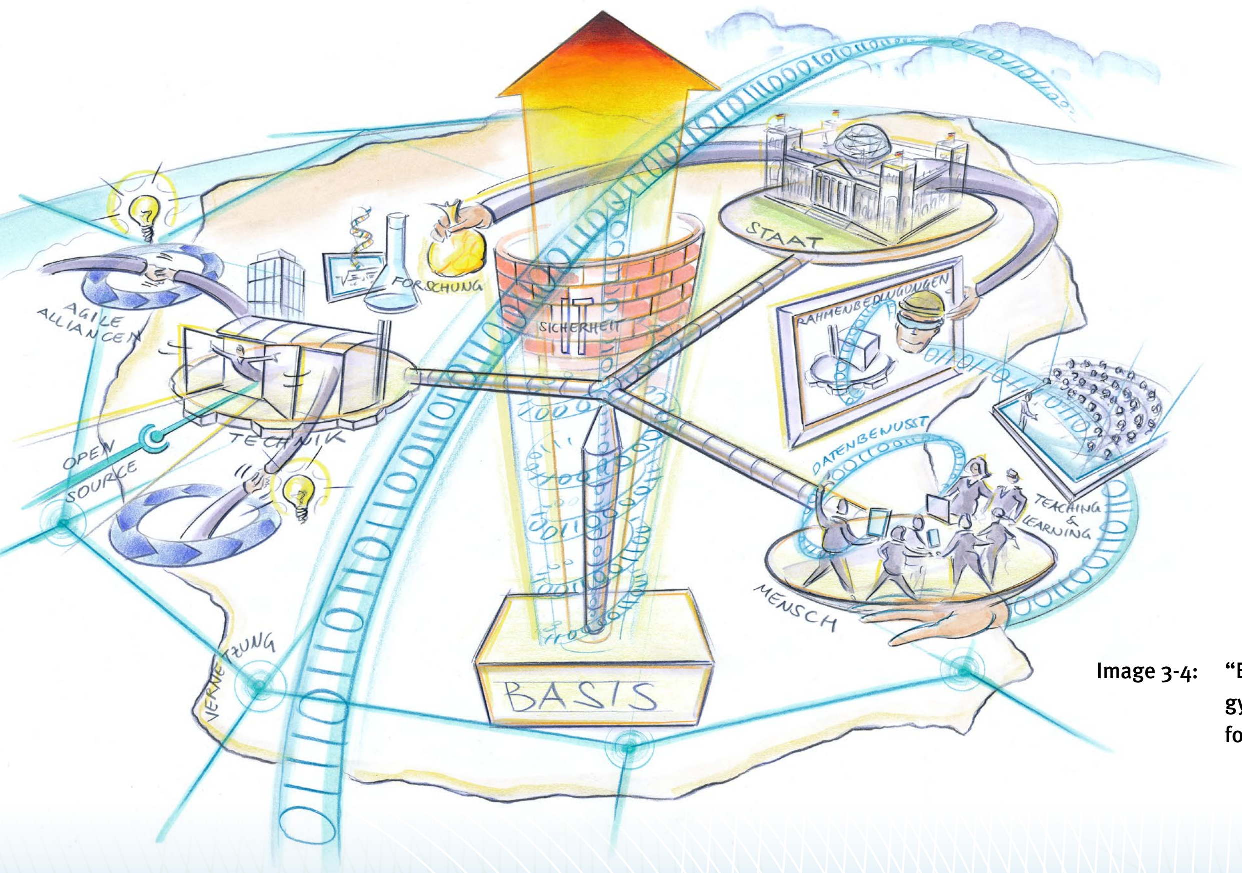


Image 3-4: "Balance of humans, technology, and government as the basis for success"

Development of monetary and economic areas, influence of Internet giants: nation-independent economic areas are established. The influence of Internet giants on the economy and society is far below current circumstances. Citizens value highly the ability to control their own data. Diversity has prevailed.

Saturation of ICT and cooperation in value creation networks: Global digital interconnectedness is high. Agile alliances characterise value creation networks.

Approach to intellectual property and standardisation: Innovative dynamics are high: Open Source is very common; Patents lose their importance. Open standards prevail.

Migration efficiency, technological mastery, and IT security: The migration efficiency is high: With the help of innovative upgrade technologies, legacy machines and facilities can be transferred to the age of digitalisation with little effort. Usability is high and IT security is guaranteed.

Circular economy and freight services: Environmental awareness is strongly pronounced; environmental protection is very important. Circular economy has prevailed; in all reasonable circumstances commodities are produced locally.

Global digital interconnectedness is high. Information and communication technologies un-burden and support people. New opportunities of ICT for learning and training are utilised, for example the "teaching & learning factory". IT security is guaranteed. Government creates good general conditions. Innovative dynamics are high: Open Source is very common; open standards prevail; agile alliances characterise value creation networks.

Scenario 4: "Digitalisation – global and other-directed"

Self-determination, working arrangements, training and further education: A focus on technology characterises the world of work; machines set the pace; people are, in part, puppets of the algorithms. Digitalisation has changed education and training; learning and teaching are increasingly independent of time and location. In many areas people are still resorting to tried and tested concepts; human contact and mentoring are still valued.

Role of people in industrial production, structure of work and pricing of labour: Highly flexible automation is common. Only a relatively small number of tasks are more sophisticated, handlers have become deciders. Simple tasks in manufacturing have been partly eliminated. Generally speaking, wages are aligning globally.

Government involvement, research policies and labour laws: Government has retreated from many areas. Research funding has also decreased, leading to a second-rate research environment; cutting-edge researchers have left for the world of business or other countries. The liberalisation of labour laws is progressing.

Development of monetary and economic areas, influence of Internet giants: The economic crises of the past have tested existing monetary and economic areas. This led to a convergence of their respective countries. Driven by progressing digitalisation and the spread of virtual currencies (Bitcoin), economic areas are also developing independent of national boundaries. The influence of Internet giants has risen by unforeseen proportions.

Saturation of ICT and cooperation in value creation networks: Two classes of cooperation partners have taken shape: creative framers and replaceable executors. This development is furthered by the rise of information elites. They are able to utilise the technological possibilities to create information and knowledge from data.

Approach to intellectual property and standardisation: Standardisation is not progressing, as the leading industrialised nations are primarily driven by their own national interests. Standards only seldom prevail. In the face of occasional uncontrolled developments and overt engineering efforts in automation, a proportion of users prefer products from dominant providers even when they are less innovative and more expensive: You know what you get. Based on this background, efforts are made to rationalise and globally organise patent law.

Migration efficiency, technological mastery and IT security: In selected areas, the dynamic development of information and communication technology makes technological systems with inherent partial intelligence possible. Often mastery of the complexity of technology is lacking. Digitalisation and automation are connected with great effort. Both the population and businesses lack awareness of issues of security, the Privacy Paradox is pervasive, meaning a contradiction between the theoretical value and the lived carelessness in dealing with data.

Circular economy and freight services: Environmental awareness is low; circular economy is still a minor issue. Freight transport leads to continuous traffic jams; investments in developing intelligent freight services are timid.

A focus on technology characterises the world of work; machines set the pace. Highly flexible automation is common. Two classes of cooperation partners have taken shape: few creative framers and a great number of replaceable executors. This development is furthered by the rise of information elites. Government has retreated from many areas. The Internet giants dominate many fields of the economy.

3.3 Configuration options for the Industrie 4.0 economy 2030

For Germany, four options are given:

Option 1:
“Smart Economy”
Option 2:
“Cautious digitalisation”
Option 3:
„Global Sourcing“
Option 4:
“Confident Global Player”

The 13 configuration components listed in Image 3-5 were the point of departure for determining the configuration options. As part of a workshop with the extended core team, alternative expressions were developed for each configuration component (analogous to the envi-ronment projections) and then described in detail. For example, with regard to the configura-tion component, “Digital sovereignty”, it is conceivable that Germany will possess no competence in central key technologies by 2030. Others decide our actions (Expression A: Other-directedness). On the other hand, it is also conceivable for Germany to possess local capabilities at a world-class level in central fields of technology, services and platforms and autono-mously choose from alternative capable partners, thus ensuring both provider and user sovereignty (Expression B: Sovereignty). A third possible expression is Germany developing technologies independently and always giving preference to them even in instances where they are less productive (Expression C: Autarky).
Following this, the developed expressions are combined into consistent configuration options, once again based on pair-wise consistency evaluation and analysis. The results are four configuration options: Option 1) “Smart Economy”, Option 2) “Restrained digitalisation”, Option 3) “Global Sourcing”, and Option 4) “Sovereign Global Player”. Below, options 3 and 4 are characterised with a few brief sentences each, as they are more or less favourable from a German perspective.

Option 3: „Global Sourcing“
Digital infrastructure, appeal of manufacturing location and digital sovereignty: Germany possesses comprehensive information and communication infrastructure and favourable conditions for thorough digitalisation. With respect to the attractiveness of the manufacturing location, government is focused on hard factors like taxes, subsidies and legislation, and additionally advancing infrastructure projects. The necessary key technologies are sourced from abroad and then adapted.

Types of employment: Standard employment contracts are still very common, while new possibilities like individual availability calendars are improving the compatibility of family and work, and the balance of work and recreation. Increasingly new forms of employment can be found which primarily meet the high demands for flexibility in industrial production.

Concepts of value creation, production strategy, dynamic of collaboration and horizontal integration: The companies leading value creation cooperations are building up system heads. Other very productive companies position themselves as intelligent production service providers, economically manufacturing in high-wage Germany. Companies mainly follow the production strategy “Local for Global”; they decide on locations possessing the best parameters for their respective products in order to introduce them to the global market. Companies prefer long-term value creation partnerships in order to benefit both operationally and strategically from one another. Increasingly ad hoc alliances on the basis of service platforms arise, together with the development of an increasing number of manufacturing companies becoming replaceable executors. Horizontal integration of partners is decided upon pragmatically on a case-by-case basis.

Usage of cloud service models and application of cloud types: Cloud service models are used in their full breadth. With respect to cloud types, companies rely on a combination of private and public clouds.

Vertical integration and equipping employees with assistance systems: Vertical integration within companies also takes place pragmatically: Networking across hierarchy levels of operational information processing is realised if it rapidly results in significant benefits. Ubiquitous Computing (context-sensitive and pervasive information processing) enables the broad realisation of the Augmented Operator concept. Training and further education of employees in how to use such assistance systems is highly valued by companies.

Management Information Systems (MIS): Automated Management Information Systems (Business Intelligence) are customary. They merge diverse data and process them with respect to the demands of the company. Many companies understand the potential benefit of Big Data and are integrating Big Data analysis into their management processes.

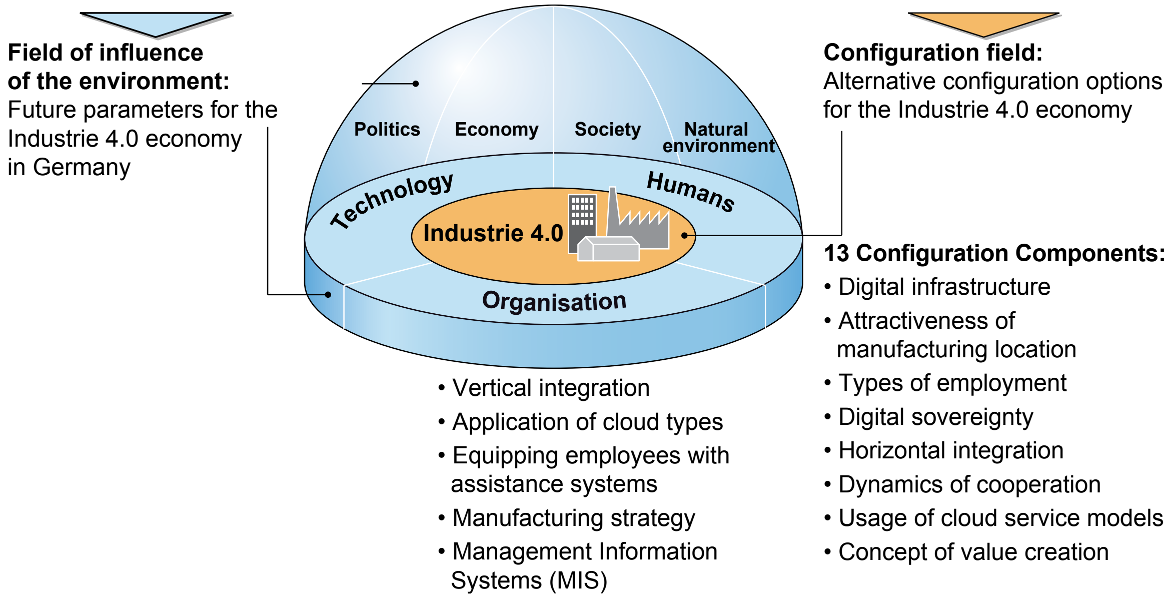


Image 3-5: Environment Germany and configuration field Industrie 4.0, List of 13 configuration components

Germany possesses comprehensive information and communication infrastructure and favourable conditions for thorough digitalisation. Government is focused on hard factors like taxes, legislation and infrastructure projects. The necessary key technologies are sourced from abroad and are then adapted. The companies leading value creation cooperations are building up system heads. Other, very productive companies position themselves as intelli-gent production service providers. Increasingly ad hoc alliances on the basis of service platforms arise, together with the development of an increasing number of manufacturing companies becoming replaceable executors.

Option 4: "Confident Global Player"

Digital infrastructure, attractiveness of manufacturing location and digital sovereignty: Germany is moving towards a comprehensive information and communication infrastructure. Only a few rural regions are still lagging behind. Further parameters for digitalisation are good. In particular, the improvement of so-called 'soft factors', resulting in a good work-life balance makes Germany an attractive location for living and working. Digital sovereignty is high: Germany possesses local capabilities in central fields of technology, services and platforms at a world-class level (provider sovereignty). Businesses and civil society are able to choose from alternative options (user sovereignty).

Types of employment: Standard employment contracts are normal. Increasingly, new forms of employment can be found, primarily to meet the high demands for flexibility in industrial production.

Concepts of value creation, production strategy, dynamic of collaboration and horizontal integration: Based on the ability to skillwfully connect products and services, creating respective business models and rigorously realising them in global value creation networks, German companies follow a holistic conception of value creation. The frequently chosen production strategy is "Local for Local": companies locate their international manufacturing facilities close to their customers, to adequately serve local markets and be able to react rapidly to changing constellations of competition and new customer demands. Partners prefer long-term value creation collaborations in order to benefit both operationally and strategically from one another. Increasingly ad hoc alliances on the basis of service platforms arise, together with the development of an increasing number of manufacturing companies becoming replaceable executors. Horizontal integration develops into a key competency vital for the competitive success of German companies. This way they are able to create and maintain ad hoc value creation networks effectively and efficiently.

Usage of Cloud Service models and application of cloud types: "Platform-as-a-service" is preferably used among cloud service models. Other models can also be found. With regard to cloud types, companies count on public clouds and also partly on hybrid clouds.

Vertical integration and equipping employees with assistance systems: Vertical integration exists continuously on all levels of the operational information processing

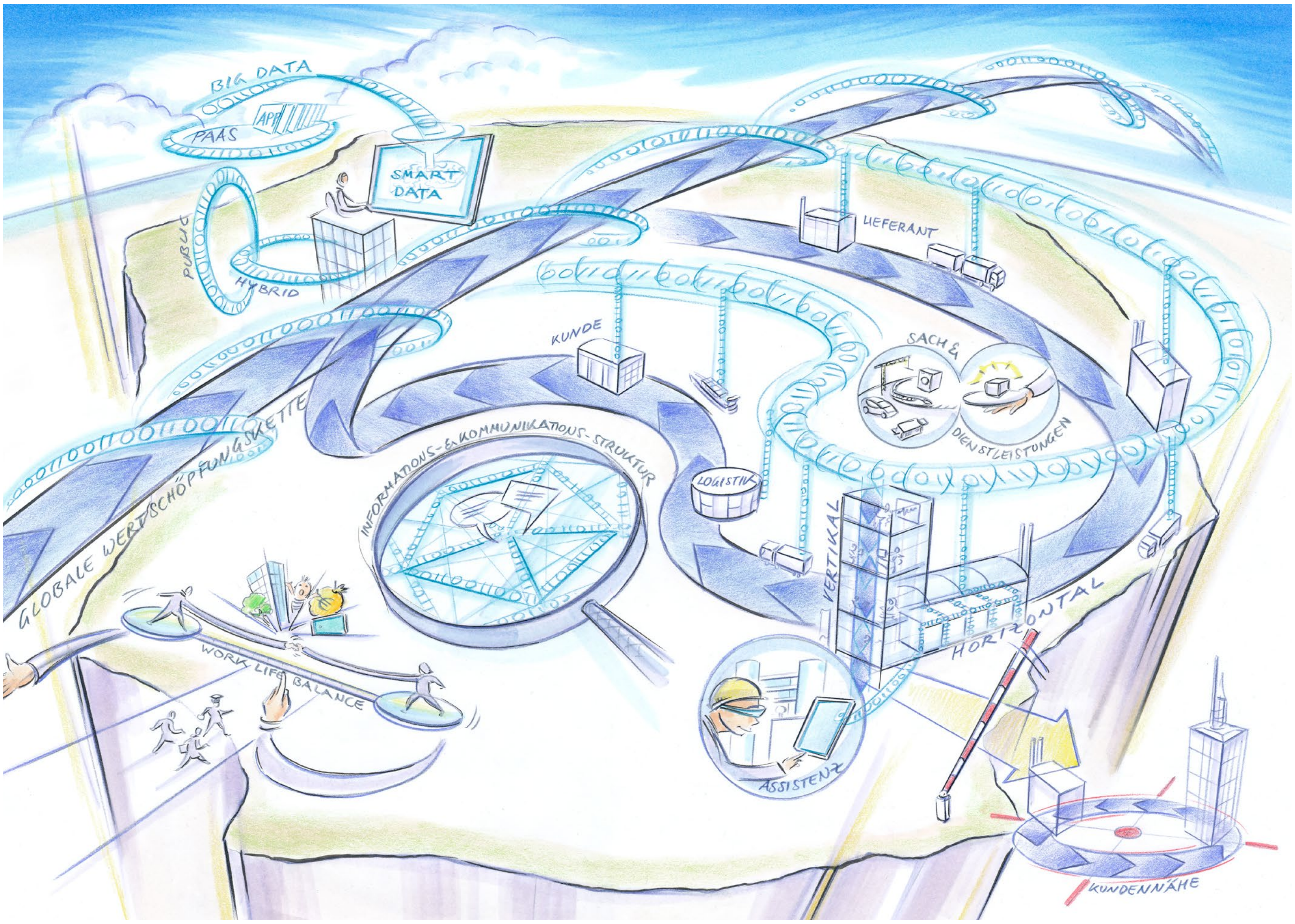


Image 3-6: "Confident Global Player"

hierarchy. Ubiquitous Computing (context-sensitive and pervasive information processing) is used pragmatically. New technologies are utilised only where their use is obvious and possible data protection and security risks are tolerable. Risk impacts and efforts for risk prevention are taken into account.

Management Information Systems (MIS): Management Information Systems show a very high performance level. Most companies understand the potential benefits of Big Data and are integrating Big Data analysis into management processes.

Germany is moving towards a comprehensive information and communication infrastructure. The emphasis on so-called 'soft factors', resulting in a good work-life balance, makes Germany an attractive location for living and working. Germany possesses local capabilities in central fields of technology, services and platforms on a world-class level. Businesses and civil society are able to choose from alternative options. Based on the ability to skilfully connect products and services, creating respective business models and then rigorously realising them in global value creation networks, German companies mainly follow a holistic conception of value creation.

3.4 Opportunities and threats, strategic paths

The environment scenarios and configuration options were developed form a solid basis to identify future opportunities for success, but also possible threats to current business. It also helps form a basis to deduce strategic paths for shaping Industrie 4.0 in Germany. Generally speaking, focusing on the most likely scenario is advisable. Whilst trying to prepare for all eventualities would be a future-robust approach it would also waste resources given that only one of the four futures will occur. Yearly evaluation as to whether the chosen environment scenario is actually occurring is the task of premise-controlling. The environment scenarios were evaluated as part of a workshop with the expanded core team and representatives of the scientific advisory board of the Platform Industrie 4.0 and the acatech thematic network "Product development and manufacturing". The result is shown in Image 3-7.

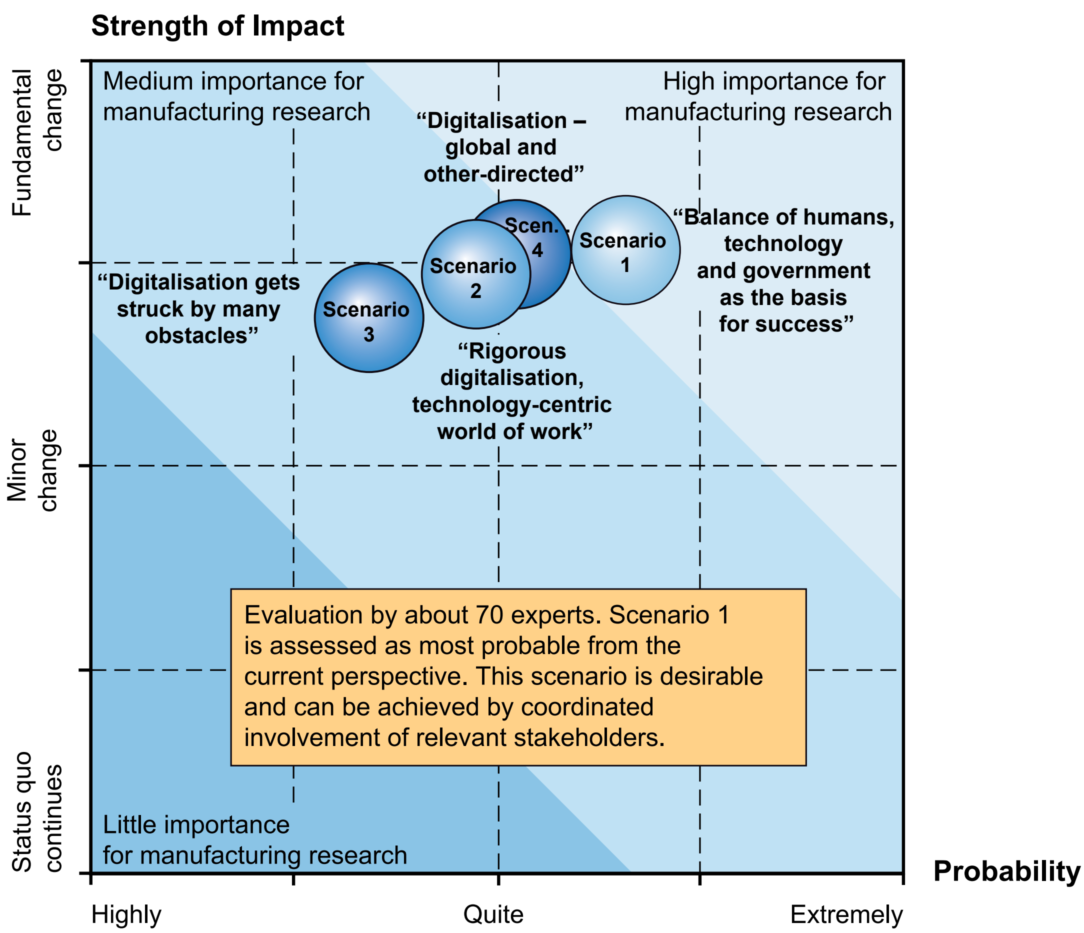


Image 3-7: **Choice of reference scenario**

Scenario 1: “Balance of humans, technology and government as the basis for success” appears as the highest probability of occurring and having a high impact, and is thus chosen as the reference scenario. This environment scenario is highly favourable and also achievable if the relevant stakeholders use their influence and coordinate their respective actions. The three other environment scenarios are also internally consistent, but as they are detrimental to Germany as a location for Industrie 4.0, they are not desirable.

With this background, the question arises to the beneficial positioning of Germany in the context of Industrie 4.0. The corresponding objective is identified using the matrix shown in Image 3-8. Answering the question as to which configuration option is particularly fitting to the most probable environment scenario leads to the concrete objective. This results in the position to be aimed at for Germany; it contains chances, but also dangers, briefly summarised in Image 3-9.

From a present day perspective probable environment scenarios.

Combination of a probable environment scenario and a well-fitting option to design Industrie 4.0 in Germany.

Environment scenarios	Configuration options: Option 1: “Smart Economy”	Option 2: “Cautious Digitalisation”	Option 3: “Global Sourcing”	Option 4: “Confident Global Player”
Scenario 1: “Balance of humans, technology and government as the basis for success”	+	− −	+	+ + Target image
Scenario 2: “Rigorous digitalisation, technology-centric world of work”	+ +	− −	+	+
Scenario 3: “Digitalisation gets stuck in many obstacles”	− −	+ +	−	− −
Scenario 4: “Digitalisation – global and other-directed”	+	−	+ +	− −

+ + Very high consistency − − Total inconsistency

Image 3-8: Objective Industrie 4.0 in 2030. For image sources see the image credits (Imprint)

World of work	▪ Equality of chances, high investment in training and further education, compatibility of work and family and work-life balance lead to high **satisfaction with the work** and high **motivation**.	▪ **Willingness to pay** for products and services "Made in Germany" does not justify the relatively high labour costs.
Technological position and ICT-Infrastructure	▪ Excellent research system, effective government involvement and the pronounced interaction of business and research community lead to **digital sovereignty**. ▪ Very good ICT infrastructure, high diversity of Internet service providers and high security standards are a catalyst.	▪ Digital sovereignty can result in **lagging behind the dynamic global development**. ▪ Security and data protection risks resulting from lived carelessness in dealing with sensitive data.
Dual Strategy	▪ Germany is a **highly developed leading market**, lending domestic suppliers operating on global markets a very **high reputation** and propelling them into pole positions.	▪ Solutions tried and tested in Germany are **overengineered**; domestic measures introduced into the world of work do not correspond to the **priorities of potential customers** on global markets.

Image 3-9: Opportunities and threats for Germany from the objective (Excerpt)

With respect to the **world of work**, compatibility between work and family and a pronounced work-life balance leads to a high satisfaction with work and accordingly high motivation. However, it should be noted, the willingness to pay for products and services "Made in Germany" may not justify the comparatively high cost of labour. **Technological position and ICT-Infrastructure:** Digital sovereignty from the technological position can be achieved by an excellent research system, effective governmental involvement and pronounced interaction of the business and research communities. However, this could also lead to Germany lagging behind dynamic global development. The very capable ICT infrastructure is another advantage. However, the lived carelessness in dealing with sensitive data could lead to risks. With regards to realising the so-called **'Dual Strategy'**, German providers of Industrie 4.0 equipment benefit decisively from the highly developed domestic market. Dangers result from the development of intricate technologies and other high-cost concepts for production organisation, resulting in a global market unwilling to pay what was hoped. Based on these opportunities and threats, **strategic paths** towards the development of a comprehensive strategy have been derived. For the Industrie 4.0 economy in Germany these are:

1) **Furthering acceptance:** Industrie 4.0 will lead to profound changes in the world of work. In order to shape them for the benefit of all participants, a shared understanding of the goals and opportunities of Industrie 4.0 and the road to Industrie 4.0 is needed.
2) **Expanding competence:** Industrie 4.0 is based on the evolutionary development of technology, organisation and

work, with a view towards a fundamentally new organisation of industrial value creation. For this, existing competence needs to be expanded and new competencies created in a timely manner.

3) **Improving the innovation system:** The innovation system consists of all actors, organisations and technologies involved in the creation of innovation. Industrie 4.0 has diverse and stringent requirements for the innovation system.
4) **Enabling collaboration, designing business models:** Industrie 4.0 and the corresponding dynamic development of the global competitive arena demand new forms of cooperation, of value creation and value acquisition.
5) **Marketing competence, managing the brand:** With Industrie 4.0 Germany succeeded – especially on the Asian market – in establishing a brand connected to high expectations of competence. This favourable position, especially for the supplier industries, has to be expanded.

These strategic paths highlight the consequences for shaping Germany as a location for Industrie 4.0 and generate stimuli for developing visions in terms of future concepts. These strategic paths further represent fields of research for recommendations for action.

With regards to the parameters for the Industrie 4.0 economy in Germany in the year 2030, scenario 1 “Balance of humans, technology, and government as basis for success” is the most probable and desirable. Should this situation occur, configuration option 4 “Sovereign Global Player” will lead to an especially favourable position of Germany in the global competition for Industrie 4.0. In order to capitalise on the resulting opportunities and avoid its threats, the following strategic paths should be pursued: 1) Furthering acceptance, 2) Expanding compe-tences, 3) Improving the innovation system, 4) Enabling collaboration, designing business models and 5) Marketing competence, managing the brand.

4 Recommendations for action

The recommendations for action are based on surveying four areas, as shown both in princi-ple and with examples in section 1.4: 1) Critical enabler fields, 2) Strategic paths based on the objective 2030, 3) Categories of added value, and 4) Needs.

The **critical enabler fields** result from the portfolio as displayed in Image 4-1; these are core enabler fields that will be of very high importance in the future, but in which Germany is currently not strong enough in comparison to international competitors – of the 15 core enabler fields discussed this is true of 11. The core enabler fields were determined and evaluated as part of a workshop with the extended core team.

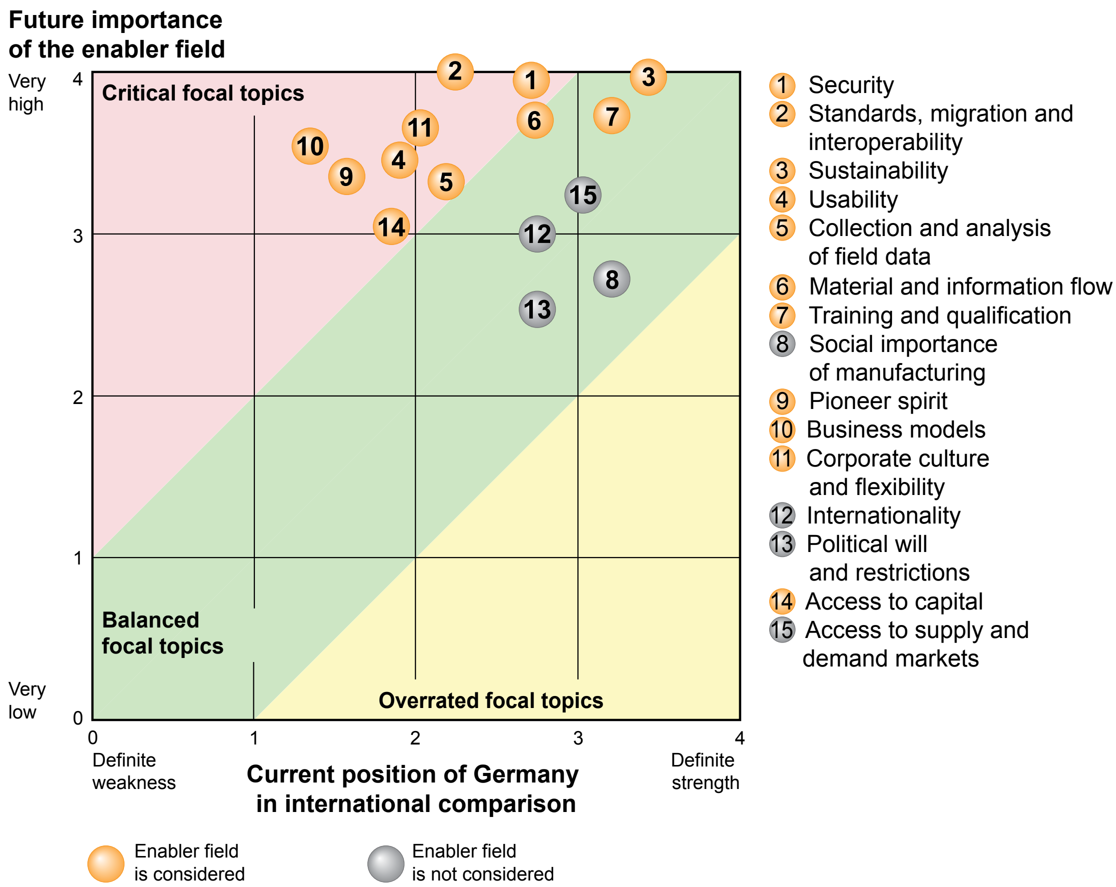


Image 4-1: Critical enabler fields point to need for action

The previously mentioned five strategic paths result from the opportunities and threats of the 2030 objective. The strategic paths are guiding principles for the development of Germany both as a manufacturing location and for realising its position of leading supplier.
Section 3.3 developed configuration options for manufacturing in Germany. The selected con-figuration option, “Confident global player” depicts the desired future of the manufacturing landscape. Six categories of added value are addressed: 1) Parameters of digital sovereignty, 2) Flexibilisation of industrial production, 3) Business models and value creation networks, 4) Use of clouds and service-platforms, 5) Pragmatic evaluation of technological risks, and 6) Transparency and Big Data in manufacturing and management.

The results from the international benchmark and the scenario analysis warrant the conclusion that there are four generic needs – as displayed in Image 4-2 – which have to be satisfied on the path to the desired vision of Industrie 4.0: 1) The prerequisites for the dismantling of barriers for Industrie 4.0 are often still lacking today, 2) Start of application: broad application is often lagging behind already-existing solutions, 3) Development of solutions, as already-existing solutions often do not exhaust technological possibilities, 4) Vision-driven development of basic technologies, as technological development points to new use potentials.

There are m:n relations between the four areas (Critical enabler fields, strategic paths, categories of added value and

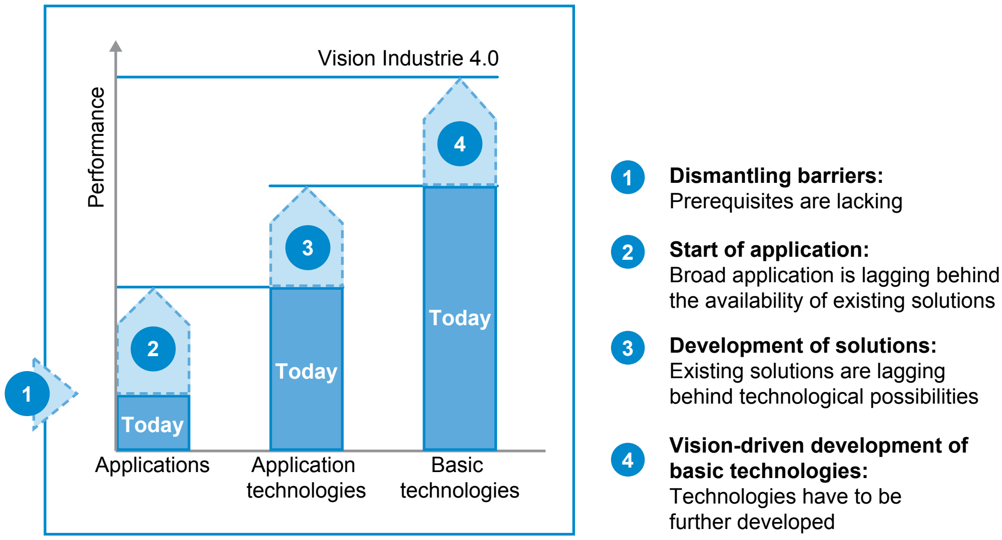


Image 4-2: Needs on the path to the vision Industrie 4.0

needs) and the derived recommendations for action. That is, several recommendations for action originate from one area, and similarly, one recommendation for action may result from several areas. A total of 44 recommendations for action were developed this way, ten of these are described below. The structure of these recommendations for action follows the five strategic paths with the following abbreviations:

- Furthering acceptance **A**
- Expanding competence **K**
- Improving the innovation system **I**
- Enabling collaboration; designing business models **G**
- Marketing competence; managing the brand **M**

The recommendations for actions relate to manufacturing research and how it is embedded within the innovation system in Germany. The link to the full catalogue of recommendations for action can be found in the marginalia. As an example, ten recommendations for actions are further discussed below (Table 4-1).

Table 4-1: Excerpt from the catalogue of recommendations for action (Part 1 of 3)

Furthering acceptance	
	**A1 – Digitally responsible citizen** The goal is the digitally responsible citizen – realising and evaluating the advantages and risks of digitalisation and thus deciding which opportunities and services he uses. It is recommended to establish the foundations of a "Citizenship Education", where young children are sensitised to both the chances and dangers of digital systems in a comprehensible and persuasive fashion by means of application scenarios. A useful addition would be public information campaigns, especially for "Digital Immigrants".
	**A4 – Data custodian** In order to collect, store and share sensitive business data such as data relating to ergonomics or labour protection, the establishment of the position of 'Data custodian' is recommended. This data is used for optimising operational procedures and harmonising the world of work with supervision by social partners.
Expanding competence	
	**K1 – Digital sovereignty** In central fields of technology, services and platforms, local capabilities are needed at the highest level (Provider sovereignty). At the same time, business and civil society must be able to autonomously choose from alternative partners (User sovereignty). For this, the creation of a demand profile of competence (software and hardware technologies, conceptual research) and a provider profile is recommended. Dependence on external technologies (like, for example, open source encryption versus "Black Box" chips) has to be identified. Self-developed security solutions are not necessarily more secure as other available solutions; a lack competence might lead to security gaps. Open-source security solutions, which have to face the watchful eye of the professional public, have a better reputation in professional circles

Table 4-1: Excerpt from the catalogue of recommendations for action (Part 2 of 3)

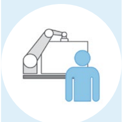
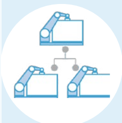
	**K2 – Qualification Industrial Security** Industrial security is a world-wide factor of differentiation in Industrie 4.0 solutions. At the moment there is a lack of appropriately trained experts. It is thus recommended to promote competence centres for industrial security, which, besides research, unite the qualification and further education in the areas of plant security (for example, preventing physical access to critical plant components), network security (for example, controlled interfaces between office and plant networks) and system integrity (for example, access protection mechanisms integrated into automation components). The ability to create threat analyses and develop adequate security conceptions should be further supported. A basis for such models could be maturity levels and processes of risk management, which should be oriented towards aspects of industrial security.
Improving the innovation system	
	**I1 – Securing intellectual property** Patents, brands and design patents allow for the security of intellectual property. These forms of protection do not do justice to the new forms of collaboration that generate innovation. For example, open source reduces the importance of patents. Additionally, due to globalisation the registration of patents has taken on dimensions that are hardly controllable. Arrangements for protecting intellectual property (patents, brands, etc.) have to be adapted to the parameters of digitalisation and globalisation. Besides the existing structures resident in patent offices, the establishment of new forms of securing intellectual property is recommended including strict guidelines for how to distribute shares in inventions within crowdsourcing networks, while copyrights for automatically generated data have to be developed.
	**I3 – Access to infrastructure** The entrance barriers of start-ups in cost-intensive areas like manufacturing are significantly higher than in areas like e-Commerce, where infrastructure is cheaper and can often be rented. An Industrie 4.0 start-up ecosystem does not just include office buildings with access to servers and the Internet, but also manufacturing environments, where, for example, innovative techniques for data analyses can be piloted. It is recommended to provide start-ups with according facilities at low cost.
Enabling collaboration, designing business models	
	**G1 – Guidelines for collaborative business activities** In the course of digitalisation, new forms of collaborative-competitive cooperation ("Coopetition") develop. Activities spanning multiple companies, like the relocation of manufacturing resources and the distribution of development tasks will increasingly take place ad hoc and without long-winding contract negotiations. Drafting guidelines for organising such value-creation systems is an important goal. This should be supplemented by a methodology for developing business models, case studies (best practices) and internationally-accepted model contracts.

Table 4-1: Excerpt from the catalogue of recommendations for action (Part 3 of 3)

	**G8 – Platforms Industrial Content** Germany possesses extraordinary expertise and resources in the manufacturing sector. In the future this will also include product data and production data, known as ‘Industrial Content’. In the course of digitalisation, data becomes a profitable commodity and the information generation from data becomes a profitable business. The majority of business with industrial content operate via Internet platforms which can serve as a node for data transfer and as a mar-ketplace for supply and demand. The goal is to position German companies as providers of these platforms. This opens up very promising business potentials for new companies, but also for companies in established areas like mechanical engineering. Additionally, the leading competitive position of German manufacturing companies can be strengthened and expanded.
Marketing competence; managing the brand	
	**M5 – Green- and Brownfield reference factories** Potential users of Industrie 4.0 with well-organised, efficient manufacturing systems, have a hard time identifying points of contact for digital transformation. To overcome this deficit, establishing reference factories is recommended. Two approaches present themselves: 1) So-called ‘greenfield’ reference factories show how to develop manufacturing systems based on Industrie 4.0 and how they can be integrated into new value-creation networks. 2) So-called ‘brownfield’ reference factories address the challenge of companies gradually introducing Industrie 4.0 in their currently successful production systems in the sense of evolutionary development. These reference factories showcase the approaches, the solutions and the methodology leading to these solutions for how to organise the desired evolutionary devel-opment.
	**M9 – Ontologies for manufacturing** German competence in manufacturing is recognised all over the world. Industrie 4.0 has the potential to establish German standards internationally, as occurred with ERP systems in relation to aspects of management theory. The development and application of ontologies were central to this. There are no generally available ontologies for manufacturing at the moment. It is recommended to develop appropriate ontologies and apply them to semantic analyses for optimising manufacturing systems. The international application of such ontologies would be tantamount to a *de facto* standard.

Abbreviation Index

Abbreviation	Full meaning
ACFTU	All-China Federation of Trade Unions
CPPS	Cyber-physical Production Systems
EIT	European Institut of Innovation and Technology
ICT	Information and Communication Technology
INSEAD	European Institute of Business Administration
ITU	International Telecommunication Union
KIC	Knowledge and Innovation Community
MIS	Management Information Systems
MOOC	Massive Open Online Course
OEM	Original Equipment Manufacturer
R & D	Research and Development
SMB	Small and medium-sized businesses
VDMA	Verband Deutscher Maschinen- und Anlagenbau e. V. (Mechanical Engineering Industry Association)
WEF	World Economic Forum
WIPO	World Intellectual Property Organization

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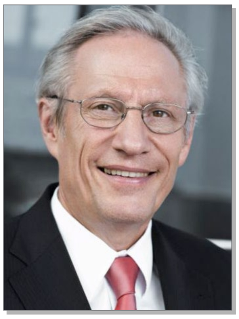

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