2017

FOCUS DIGITAL TRANSFORMATION

Innovation Indicator

acatech
NATIONAL ACADEMY OF SCIENCE AND ENGINEERING

BDI
The Voice of German Industry

Fraunhofer ISI

ZEW
Zentrum für Europäische Wirtschaftsforschung GmbH
Centre for European Economic Research

On the German-language website of the Innovation Indicator you will find a detailed methodological report as well as further background material. You can also compare individual economies with "My indicator". The website can be used on all end devices from desktop PCs to smartphones.
www.innovationsindikator.de

Scan the QR code and go directly to the website.

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Preface

The Innovation Indicator 2017 shows: Germany's innovation system looks good at first glance. We cannot really stand out against the international competition, though. In a central future field of action, digital transformation, especially the United States and the United Kingdom seem to have a considerable advantage. The Digitalization Indicator specially developed for this report points to this.

The sustained good economic situation, the export power of industry and low unemployment in Germany should not give us a false sense of security. Faced with the speed and radical nature of technological change, past recipes for success could soon be a thing of the past. Most industries will experience a structural change in which "business as usual" is not a future viable option for companies. This concerns not only the use of new technologies. It is also a matter of company and work organization that promotes creativity, agility and networking in the innovation process.

The visions of Industrie 4.0, smart service world and learning systems provide guidance for the digital transformation. The consistent implementation is, however, not a sure-fire success. Small and medium-sized enterprises in particular have not yet jumped on the bandwagon. Education and training, IT security and new business models are key challenges. Likewise, so are international cooperation on standards and interoperability.

The Innovation Indicator can provide clues for the dialogue between science, industry, policy-makers and society on how we can jointly secure the future viability of Germany as a business location. Especially in the year of the *Bundestag* (German parliament) elections, it is a special concern for us to emphasize the central importance of innovations for prosperity and employment.

In this sense, we wish you an interesting read.

Henning Kagermann
President
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Dieter Kempf
President
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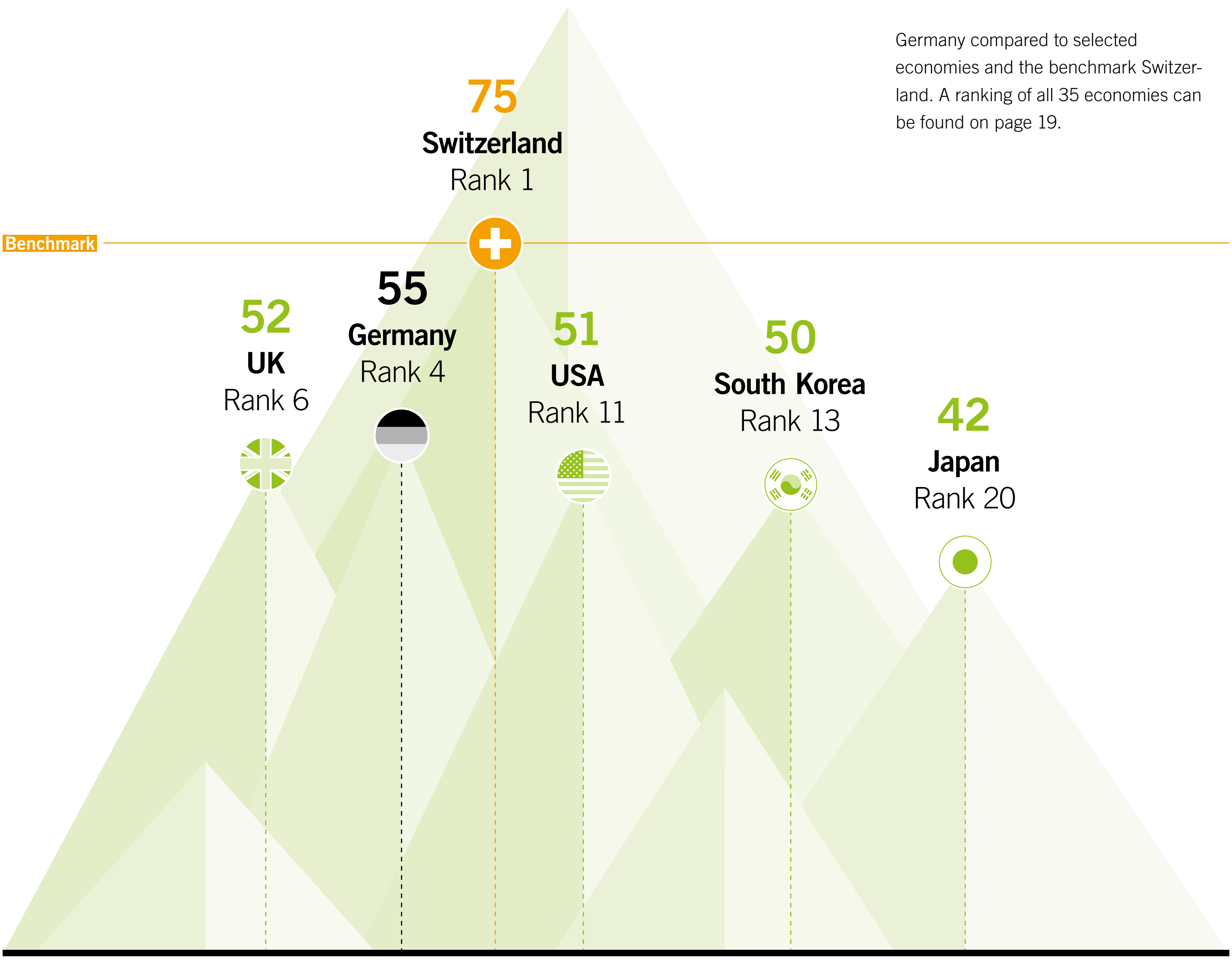
Key findings

Innovation Indicator

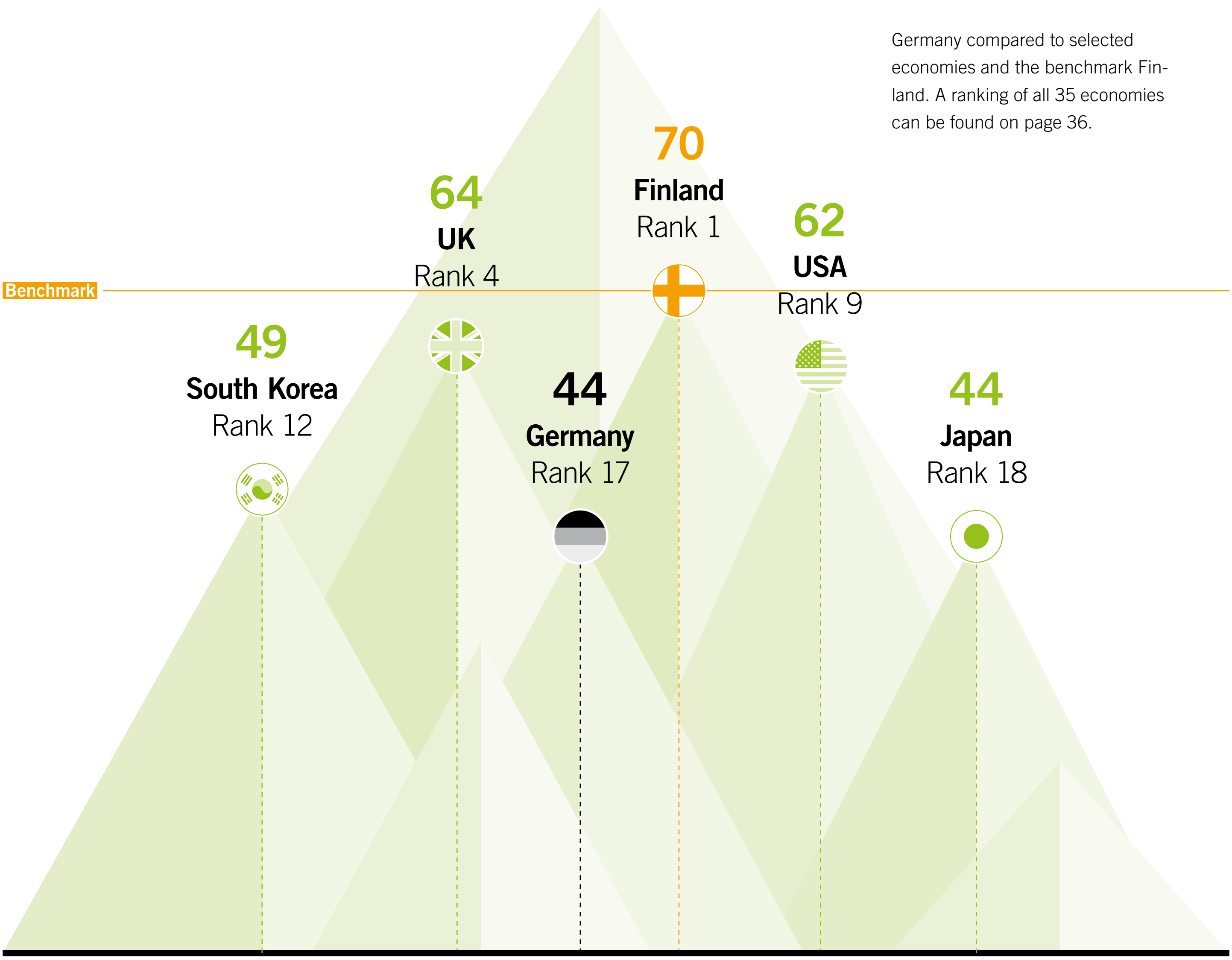
Germany is one of the most innovative countries in the world and, with an index value of 55, continues to rank fourth in the Innovation Indicator. However, the German innovation system does not reach a top spot in any of the five sub-areas examined: industry, science, education, state and society.



Germany compared to selected economies and the benchmark Switzerland. A ranking of all 35 economies can be found on page 19.

Digitalization Indicator

Measured by the Digitalization Indicator, which was prepared separately for this edition of the study, Germany is clearly behind other industries in position 17 with an index value of 44 points. The distance to the United Kingdom and the USA is particularly large. There is a need for action, in particular, in the areas of broadband network expansion, the digitalization of public administration, in parts of the areas of research and technology as well as in digital business models.



Germany compared to selected economies and the benchmark Finland. A ranking of all 35 economies can be found on page 36.

01 Summary

Germany is one of the most innovative countries in the world and occupies fourth place in the Innovation Indicator, the same as last time. However, the German innovation system does not achieve a top spot in any of the sub-areas industry, science, education, state and society.

- This year by far the highest values in the Innovation Indicator are again achieved by Switzerland and Singapore. **Switzerland** is the only country for which the Innovation Indicator shows very high values in all five areas of the innovation system.

- **Germany** is virtually neck and neck in the overall ranking of the Innovation Indicator with the other major industrial nations **USA, the United Kingdom, South Korea** and **France**. Within the five sub-areas of the innovation system, however, the countries show very different performances.

- The **strengths** of the German innovation system still lie in good vocational training and a high proportion of academics with top qualifications in the STEM subjects (PhD), a high contribution of high-tech industries to the value added, a relatively high level of state funding of the science system and a high number of patent applications per inhabitant. The rating of the education system has improved continuously over the past years after the PISA shock in 2000.

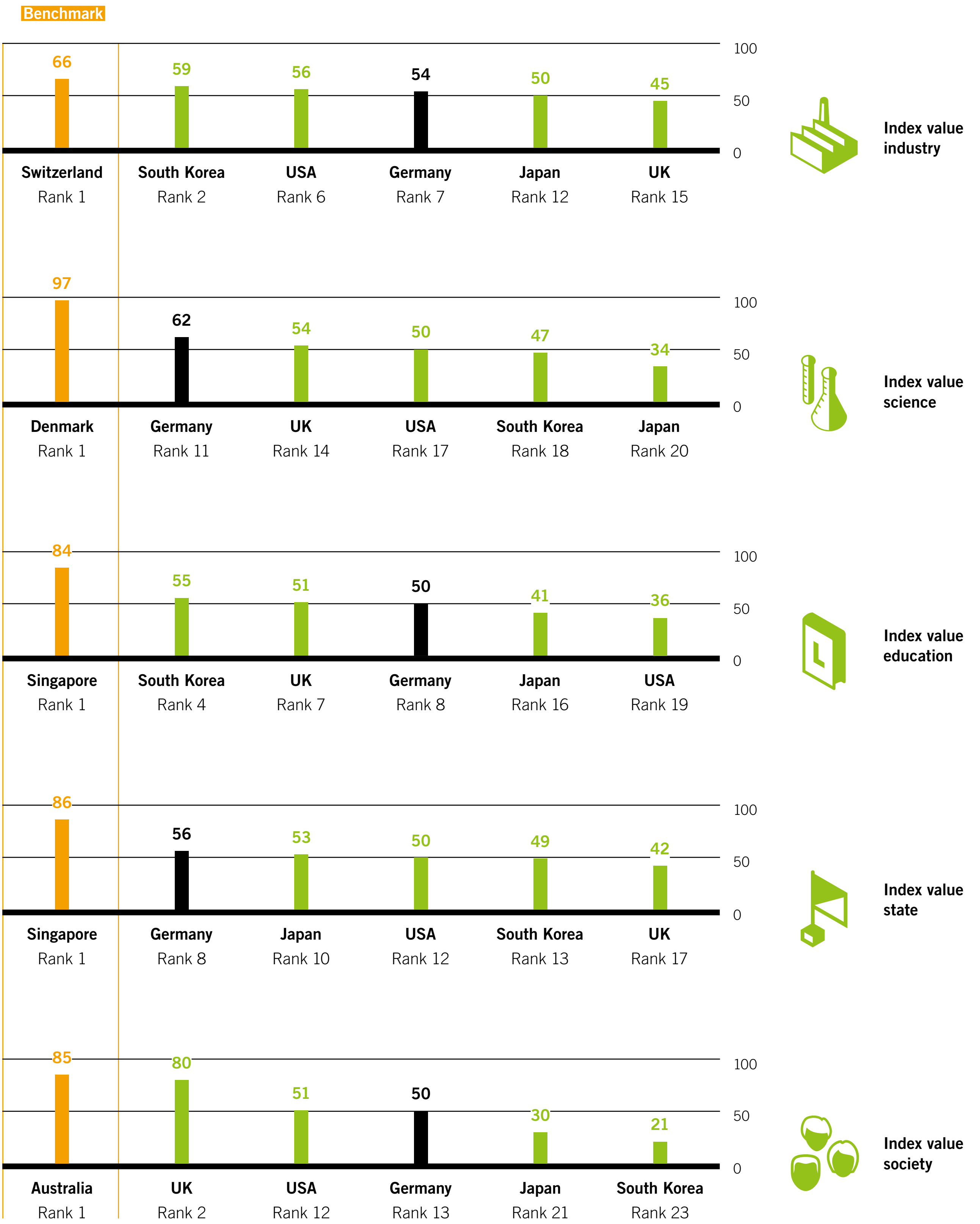
- There was, on the other hand, a **decline** in the German balance of trade in high-tech goods, the share of employment in knowledge-intensive services, and venture capital investments in relation to GDP. Unlike most other industrial nations, the state has so far refrained from tax incentives for research and development (R&D); the direct promotion of R&D in companies through grants or R&D contracts from the public sector is also comparatively low.

- The greatest strength of the **USA** lies in the innovative power of American companies, especially in the digital economy, which are among the most innovative and highly rated in the world. Further strengths of the economic system are the high intensity of domestic competition, high labor productivity, a high share of state-funded R&D and the highly developed venture capital market. The science system is weaker: the fact that some of the world's leading universities are located in the USA must not obscure the fact that the university system overall achieves an only average performance level. In comparison to many other countries, scientific institutions and companies are in their technology development activities also internationally networked to a much lesser extent.

- The innovation system in the **United Kingdom** has continuously improved its performance over the last five years. Particular strengths are the favorable social framework conditions for innovations and a good education system. The science system is characterized by high capability in basic research, although the

Sub-areas of the Innovation Indicator

Comparison of Germany and selected economies



research effort is often concentrated at a few elite universities. Deficits, on the other hand, exist in the low application orientation and in knowledge and technology transfer. The share of public research expenditure in relation to GDP is comparatively low.

- The innovative strength of the **South Korean** economy has significantly improved in recent years as measured by the assessment criteria of the Innovation Indicator. In the corresponding sub-area, South Korea is ranked second and therefore higher than the USA. The strengths of the innovation system are reflected in high R&D expenditure in relation to GDP (currently 3.36 percent), a high number of patent applications in the USA and a high contribution of the high-tech industries to the value added. Another strength is the performance capability of the education system. The values in the science sub-section are, on the other hand, lower in view of a relatively low output and a low tendency towards international cooperation within the science system.

- **China's** innovation system still has a much lower performance capability compared to other major industrial nations. In some industries, however, (Internet and telecommunications, for example), Chinese companies compete as equals on a global scale. Moreover, the quality of scientific research results is increasing. Chinese companies are also already involved in funding R&D at universities to a great extent.

Measured according to the Digitalization Indicator, which was particularly produced for this edition of the Innovation Indicator, Germany clearly lies behind other industrial nations (rank 17). This is especially true for research/technology (rank 16), education (rank 17) and infrastructure/state (rank 19).

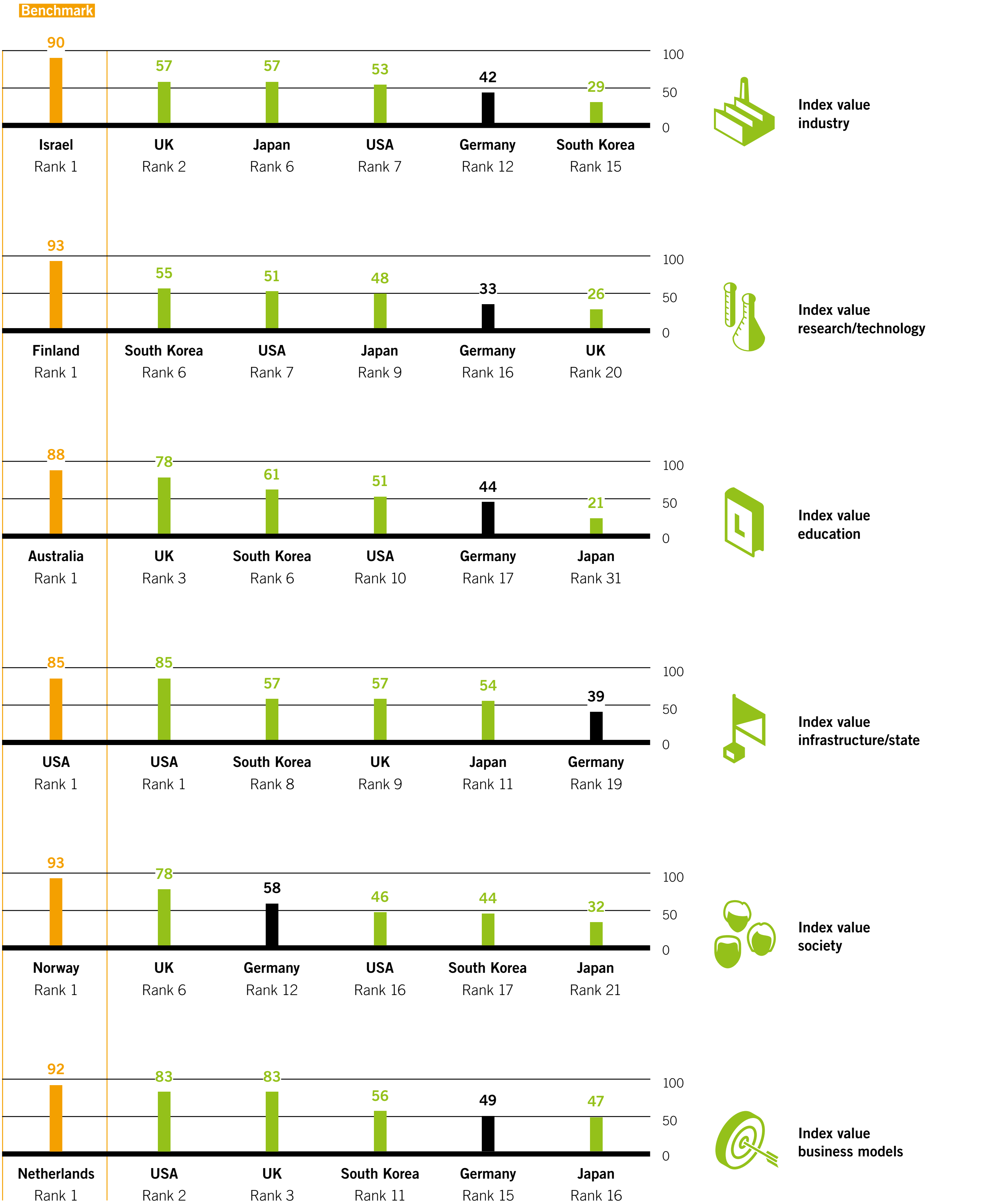
- The Digitalization Indicator shows a higher value for the **USA** than for Germany in all areas except the area of society. And, with the exception of research and technology, the values for the **UK** also clearly exceed the values for Germany.

- Germany's low rating in **infrastructure/state** is mainly attributable to inadequate broadband coverage and a lower level of digitalization of the public administration.

- In the area of **research/technology**, the Digitalization Indicator for Germany also has a significantly lower value than, for example, South Korea, the USA or Japan. With regard to the pervasion of digital technologies (for example, software solutions, cloud computing), German companies are only in the midfield. In small companies the diffusion is particularly low. The United Kingdom, Japan and the USA are significantly ahead of Germany in the **industry** sub-area of the Digitalization Indicator. In the area of digital **business models**, the gap to the USA and the UK is even greater. In the **education** sector, the UK and South Korea are clearly ahead of Germany.

- The Digitalization Indicator's highest value for Germany is in the area of **society**. A comparatively high degree of utilization of digital solutions/technologies in the population can be a measure of the social openness or acceptance of digitalization. Among the big industrial nations, only the UK scores higher values than Germany.

Sub-areas of the Digitalization Indicator
Comparison of Germany and selected economies



02

Approaches for innovation policy

In light of the results of the Innovation Indicator, the latest recommendations of the federal government's High-Tech Forum on the further development of the High-Tech Strategy (May 2017) and the Commission of Experts for Research and Innovation (Annual Report 2017) prove to be a rich source of good starting points for the future innovation policy. The editors of the Innovation Indicator would particularly like to emphasize the following three superordinate fields of action that are of central importance for the innovative capability of German industry and science in particular in the face of digital transformation.

1

Gear education, research and knowledge transfer to future challenges

- **Establish national competence monitoring** in order to be able to record key competences for future technologies in industry, science and society faster and compare and develop them more systematically internationally.

- Together with stakeholders from science, industry and civil society, formulate a cross-departmental **new national STEM strategy** that focuses not least on quality assurance, talent development and education in digital transformation.

- **To firmly anchor digital reference points** in all school subjects, in order to promote the competences of young people for the shaping of and participation in digital transformation. Basic knowledge in the field of information technology, as well as the knowledge of new working methods (for example, agile work, creativity techniques, evidence-based management) must be understood as new cultural techniques of equal value.

- Strengthen universities in the transfer of knowledge to industry and society (so-called **third mission**). On virtual and real-life transfer and experimentation, science and industry should be able to cooperate unbureaucratically in innovative ecosystems. Transfer centers and start-up centers should, with offers of suitable consulting and networking opportunities, enable companies to act increasingly on platform markets and in digital ecosystems in future.

- **Improve the basic funding of higher education institutions** and continue the federal and federal states (Länder) governments' program (**"Hochschulpakt"**) as well as the pact for innovation and research (**"Pakt für Forschung und Innovation für außeruniversitäre Forschungsorganisationen"**) for non-university research organizations beyond the year 2020.

- Also promote the **dual principle** at universities and develop a **common/comprehensive education concept** for the vocational and university education of tomorrow.

2

Strengthen competition as the priority principle of discovery for new ideas and innovations

- **Avoid the regulatory overload** of innovative business models, especially in the emerging data economy, and create a **level playing field** for established and new market players.

- Promote the development of a **new entrepreneurial culture**. Schools and universities should promote the corresponding values, role models and competences such as creativity, risk management, project management, corporate governance, basic entrepreneurial skills and learning from mistakes to a greater degree.

- Support close collaboration between science and industry in developing industry-specific **European/international norms and standards** for the Internet of things, data and digital services.

- To quickly realize the **European digital single market** in order to create uniform conditions of competition for the digital transformation in Europe and to enable companies to rapidly scale digital business models.

3

Improve the public framework conditions for innovation and drive structural changes

- Improve **funding possibilities** for innovations. Public project support and funding programs do not reach a part of the small and medium-sized companies conducting research. Most industrialized countries therefore also rely on indirect, tax-based R&D incentives. Germany so far lacks such an instrument. This international locational disadvantage should be remedied. In addition, Germany has to become more attractive as an investment location for private venture capital.

- **Introduce the innovation principle into the national regulatory impact analysis**. Innovation-inhibiting effects of new laws could thus be identified at an early stage in the legislative process.

- **Advance the expansion of high-capacity broadband connections** – especially in more rural areas to avoid a digital split of regions – and accelerate the digital transformation of public administration (e-government and open government data).

- **Create regulatory spaces for experiments**. Companies should be able to develop and test innovative technologies and new forms of work and organization in experimental rooms that are limited in time and space at first without any innovation-inhibiting regulations.

- Let companies have **legal leeway** to adapt their own structures quickly and flexibly to the new requirements of the digital working world. The company's management and staff can address the specific company's needs as well as the individual preferences of the employees regarding "good work" more precisely than across-the-board regulations.

Results

03

About the Innovation Indicator

New products, processes and services that prevail in markets, or also improving the quality of existing products and processes, in an economic regard are referred to as innovations. Innovation is the key to competitiveness and growth for most companies and entire industries. Germany is especially reliant on innovations in order to secure the growth of its economy and prosperity, as well as the public sector's capacity to act in the face of demographic change.

From an economic perspective, a variety of factors and influences promote private innovation actions or even render them possible in the first place. There are also numerous players – companies, research institutions, funding agencies, educational institutions, but also innovation financiers and buyers and users of innovations, who often improve and adapt services and products themselves – so-called user-led innovation. The interplay of these factors, influences and actors constitute the national innovation system.

A well-functioning innovation system allows companies to be innovative, and thus secures jobs and prosperity. However, the companies as providers of innovative goods and services face competition – and this is also true in a broader sense for innovation systems. It is important that companies and organizations as well as politics or public organizations can assess and pinpoint Germany's position in the global innovation competition. Only then can they take measures to secure or improve the situation. For this purpose, a differentiated analysis and international comparisons are indispensable.

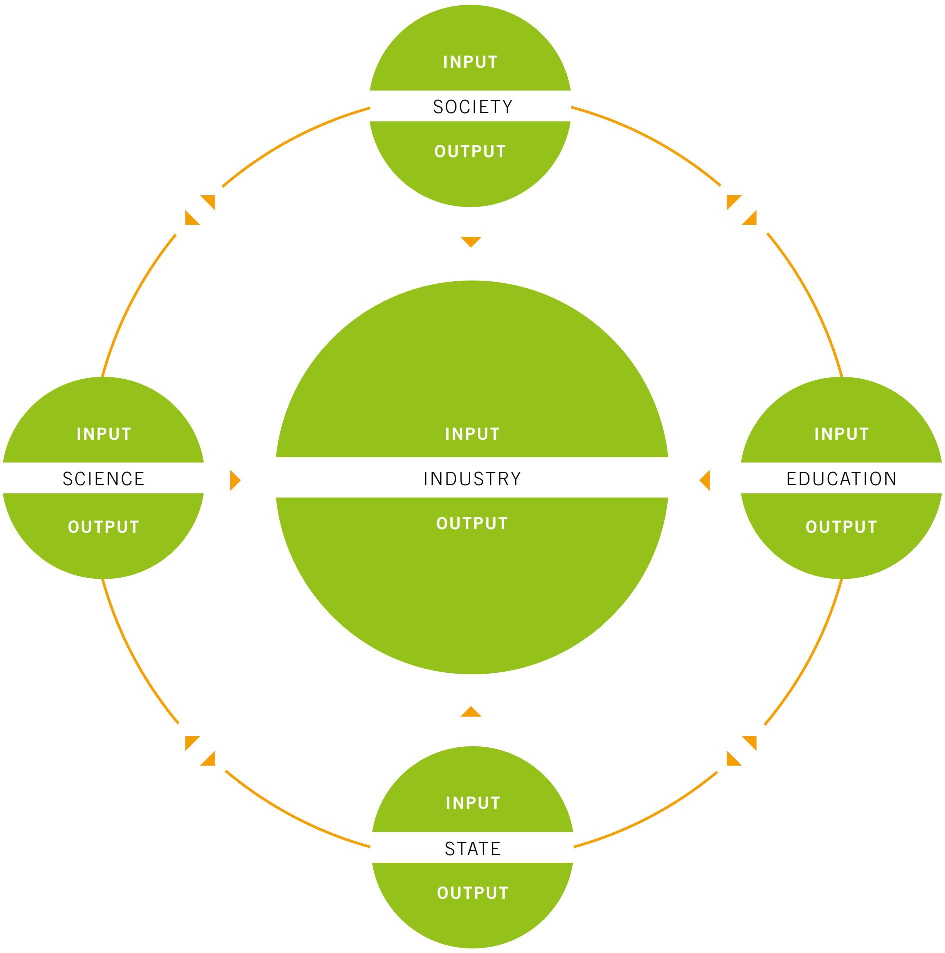
The Innovation Indicator has exactly this goal. On behalf of acatech – National Academy of Science and Engineering and the Federation of German Industries (BDI), 35 economies are examined to determine how innovation-oriented and -capable they are. The Innovation Indicator is created by the Fraunhofer Institute for Systems and Innovation Research (ISI) in Karlsruhe in cooperation with the Centre for European Economic Research (ZEW) in Mannheim. It compares the innovation performance of 35 countries based on 38 individual indicators.

Basic principles of the Innovation Indicator are:

1. Model-based approach to the selection of indicators: each of the 38 indicators was selected based on its statistically verified explanatory value for the national innovation performances. In this way, both clarity and the relevance of the results is ensured.
2. Sub-division of the indicators according to input/output and sub-systems (industry, education, science, state, society): this allows a detailed analysis of the strengths and weaknesses of individual countries and thus targeted recommendations for action.
3. Incorporating hard and soft indicators: innovation activities depend not only on directly measurable factors, such as the available financial and human resources, but also on rather soft, not directly measurable factors such as societal attitudes. The Innovation Indicator also collects relevant data of these soft factors to reflect innovation systems in their entirety. This sets it apart from many similar indicator systems.

Innovation is the key to competitiveness and growth. This study examines 35 economies and shows their innovative capabilities.

Main elements of the Innovation Indicator model



Quelle: authors' own illustration

4. Timeliness of the results by using forecasting and extrapolation methods (now-casting) for the individual indicators: all indicators relate to 2015.

Challenges in measurement

The Innovation Indicator is a so-called composite indicator, in which individual sub-indicators, relevant for the innovation system, are compacted by weighting to a summary measure. The Innovation Indicator uses an equal weighting in order to keep the calculation transparent and comprehensible.

However, other weighting methods would also be feasible and have been used in comparable analyses. To analyze the robustness of the results to different weights, the authors of the study use modern statistical simulation methods. Here, the results prove to be extremely robust and the classifications of the analysis therefore to be reliable.

Thus, although different weighting methods lead to slight differences in the actual performance of the countries, clearly recognizable assignments to certain groups of economies emerge, largely independent of the respective weighting. It can therefore be stated with great certainty whether a country, for example, is one of the pursuers or in the leading group. Accordingly, the interpretation of the ranking positions will focus mainly on this group membership and stable long-term development trends. Minor changes to the previous years, as well as shorter gaps between countries should not be over-interpreted.

Dynamic environment

Innovation systems are highly dynamic: they change constantly and often in ways difficult to predict. These changes can have a serious impact on the functioning of the innovation system. This in turn provides measurement models such as the Innovation Indicator with major challenges, because it captures the economy's innovative capabilities based on a previously defined set of indicators. Unexpected developments and structural changes, as, for example, can be expected in the wake of the digital transformation of the economy, on the one hand, require a constant critical examination of the appropriateness of the indicators used.

On the other hand, the approach of purely quantitative indicators must always be complemented by qualitative assessments that seek to anticipate developments that may be reflected in measurable figures only in years to come. For these reasons, the Innovation Indicator follows the approach of supplementing the quantitative results with qualitative assessments in a targeted manner, which explicitly seek to take into account both the current policy context as well as possible future developments.

Structure of the survey

The following chapter summarizes the results and points to future challenges for innovation policy and the innovation system.

The focus of the Innovation Indicator 2017 is the digital transformation of the German economy. The topic is examined from different perspectives, for example in an international comparison. Another focus is on the digital infrastructure in Germany. In addition, Germany's position regarding the future of production, in particular Industrie 4.0, is examined. A final chapter analyzes the transformation capability of Germany with regard to economy, society and politics.

Website with more information

The report includes the most important results of the analyses based on 2015 as reference year. Profiles for individual countries, the development of individual indicators as well as comparisons between different countries can be created on the website itself. There a detailed documentation in electronic form of the methods and indicators used is also available in the methodology report.

www.innovationsindikator.de

04

Germany fourth without any really top values

Switzerland has the strongest innovation system. France and the United Kingdom improve. The USA lies in the midfield. China displays strengths only in selected areas.

The Innovation Indicator measures the performance of 35 economies regarding their abilities to produce and use innovations. It takes into account both investments in the innovation system (input) and the results of innovation-oriented activities (output). Measured with the Innovation Indicator, Switzerland achieves the best marks. In all five sub-areas (industry, science, education, state and society) it is placed among the top four countries. Singapore and Belgium follow. Both countries also show a well-balanced innovation system with strengths in all five areas. Germany comes in fourth. It has good marks in all five sub-areas, but does not achieve top marks in any single one. Belgium and Germany head a larger group of countries with very similar innovation performances.

The USA are in the midfield of this country group, having significantly lost ground from their former top spot. In 2005 the USA still held third place. This is due mainly to an overall weaker performance in the science and education systems. Japan is the last in this group. The low degree of openness of the innovation and science systems, as can be seen in the low propensity towards cooperation both with international industry partners as well as between companies and science institutions in the country itself, have this negative effect. China still clearly lags behind the innovation-intensive countries. Although China managed to expand its innovation performance in the last few years, it still cannot keep up with the established innovation countries in any of the five sub-areas.

Switzerland at the top

Switzerland maintained its top position and has the most powerful innovation system in terms of the Innovation Indicator. It is the only country to achieve very high values in all five sub-areas of the Innovation Indicator. In industry, Switzerland takes first place in the ranking, in the field of education the country ranks second. In the fields of science and society, it is in the third place respectively. The innovation-oriented activities of the state also achieve very high marks in the international comparison. However, this is not due to the direct promotion of innovation in companies, as this is not implemented in Switzerland. Rather, it is the very well-equipped and predominantly state-funded education system and the state's high investment in scientific (basic) research, which let Switzerland achieve front rankings also in this part of the Innovation Indicator. In general, the science system, in which the universities play a central role, is one of Switzerland's outstanding strengths.

For most of the science indicators, Switzerland has the highest values among all the countries assessed. This is true both for the number of publications from public research in relation to population as well as for the quality of the research. Also, the intensity of international cooperation of Swiss science institutions is matched by few comparable institutions in other countries. Switzerland also has a well-developed system for the transfer of knowledge and technology: Well-working interfaces between science and industry support a transfer of research results into products and services. Apart from that Switzerland has an excellent infrastructure. Finally, start-ups profit from the large privately held wealth in Switzerland, which is also invested in innovative companies. Many competitive high-tech companies are located in Switzerland, which is reflected among other things with a trade surplus as far as high-tech goods are concerned.

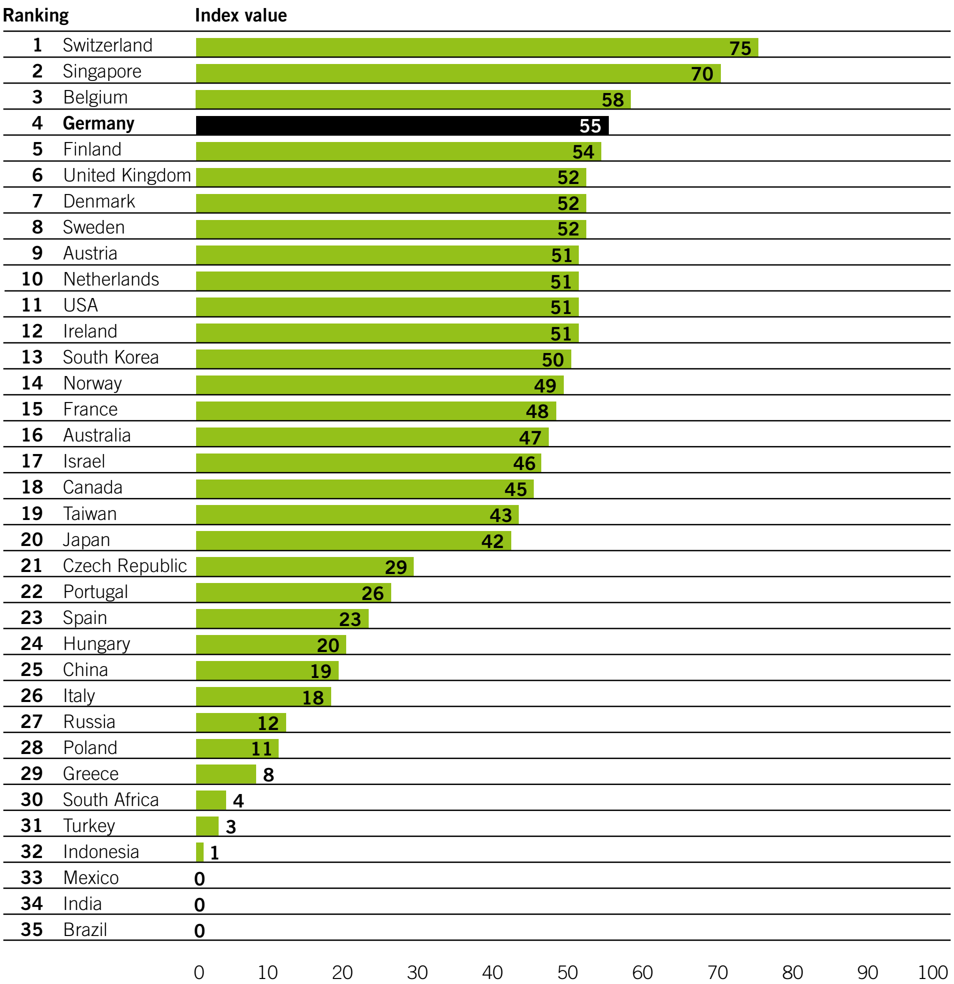
Singapore's high score, (second place in the Innovation Indicator 2017) is due mainly to the expansive state support activities. These include direct state support for research, support of research and development activities in companies via tax regulations, as well as a high public demand for new technologies, which create incentives for innovation. Regarding the number of employees with university degrees and also the indicators concerning the quality of the education system and the education results, Singapore achieved the highest values in the international comparison. The science system is evaluated as being the second best behind Switzerland. Especially the quality of the scientific output achieves high values. It is measured according to how often scientific publications of a country are cited on average. However, in addition to the high visibility of the scientific publications, companies also significantly contribute to Singapore's innovation system. The strength of Singapore's economy lies mostly in its international networking and is expressed in a trade surplus, as far as high-tech products are concerned.

Germany is fourth

Germany takes fourth place in the country comparison. The distance to the following countries, however, is small, therefore the actual position within this group has little meaning. However, in all sub-areas there are countries which are placed before Germany. The innovation performance of German industry, for example, is weaker than that of South Korea or the USA. Despite improvements in the last few years the education system still has some way to go to catch up with the best placed countries such as South Korea or Finland. The performance of the science system may be better than that of the other big industrialized countries, however it is still far from being as good as those of smaller ones. The strengths of Denmark, the Netherlands or Sweden are inter alia the high degree of international networking.

Germany's good results in the Innovation Indicator is mainly due to the fact that it does not do badly in any specific sub-area. This was not always the case. As recently as the mid-2000s Germany was ranked in the bottom half of the country ranking in the sub-areas education and state with a large gap to the respective leading groups. The efforts in education after the shock of the PISA report as well as the reorientation of research and innovation policy via the High-Tech

Overall result of the Innovation Indicator



Strategy have led to marked improvements. They contributed to Germany ranking no worse than place six since 2010.

Among the strengths of the German innovation system are, on the one hand, structural aspects such as the high percentage of contribution of the high-tech industry to the creation of added value, the high share of people with good vocational training as well as the intensive cooperation between industry and science. This can be seen among others in the high share of research and development (R&D) at universities and public research institutions, which is financed by companies. The increasing number of high-impact publications of German scientists and significant numbers of foreign students also have a positive effect. The high number of registered patents per inhabitant reflect the high degree of technological competence of companies and science and research institutions.

For a very long time the field of education was one of the biggest weaknesses in the German innovation system. Looking at the factors relevant for innovation, the German education system has improved in the past years. When looking in detail, the individual indicators show that Germany, as far as the evaluation of the education system as a whole is concerned, ranks quite well. For a long time, it managed to distinguish itself in the area of top-level qualifications, as measured by the number of doctors in the STEM subjects in relation to the population. In the recent past, Germany has achieved better values in the PISA international pupils' comparative test: in 2016, Germany again achieved results in mathematics, science and reading which are well above the OECD average. However, the results in the natural sciences in grammar schools have recently deteriorated. Furthermore, pupils' interest in natural sciences in all types of schools has been steadily declining since 2006. In addition, it can be inferred from the available data that the relative attractiveness of the German education system for foreign students has not yet reached the same level as in the 1990s, but recently increased slightly.

According to the indicators the societal openness towards innovation has increased. However, there are also indicators where the values for Germany have decreased. These include the trade surplus in high-tech goods, the share of employees in knowledge-intensive services and venture capital investments measured against the gross domestic product. Unlike most other industrialized nations, the state so far has not supported R&D via tax measures. The direct support of R&D in companies via subsidies or R&D commissions from public authorities is also comparatively low.

Total ranking of the countries 2000–2015

	2000	2005	2010	2014	2015
1	Switzerland	Switzerland	Switzerland	Switzerland	Switzerland
2	Sweden	Sweden	Singapore	Singapore	Singapore
3	USA	USA	Sweden	Finland	Belgium
4	Finland	Finland	**Germany**	Belgium	**Germany**
5	Belgium	Singapore	Finland	**Germany**	Finland
6	Singapore	Netherlands	Netherlands	Ireland	United Kingdom
7	Israel	Canada	Norway	Netherlands	Denmark
8	Canada	Denmark	Austria	USA	Sweden
9	France	Belgium	USA	Austria	Austria
10	**Germany**	**Germany**	Belgium	Sweden	Netherlands
11	Netherlands	Norway	Canada	Denmark	USA
12	Denmark	United Kingdom	Taiwan	United Kingdom	Ireland
13	United Kingdom	Austria	Denmark	South Korea	South Korea
14	Norway	Israel	France	Norway	Norway
15	Japan	France	United Kingdom	Australia	France
16	Australia	Australia	Australia	Israel	Australia
17	Austria	Ireland	Ireland	Canada	Israel
18	Ireland	Japan	South Korea	France	Canada
19	South Korea	South Korea	Israel	Taiwan	Taiwan
20	Taiwan	Taiwan	Japan	Japan	Japan
21	Czech Republic	Czech Republic	Czech Republic	Czech Republic	Czech Republic
22	Russia	Spain	Hungary	Portugal	Portugal
23	Hungary	Hungary	Spain	Spain	Spain
24	Spain	India	Portugal	Hungary	Hungary
25	India	Italy	China	Italy	China
26	Italy	China	Italy	China	Italy
27	Poland	Russia	India	Poland	Russia
28	Indonesia	Poland	Russia	Russia	Poland
29	China	Portugal	Poland	Greece	Greece
30	Greece	Greece	Greece	Turkey	South Africa
31	Portugal	South Africa	Indonesia	South Africa	Turkey
32	Brazil	Indonesia	South Africa	Indonesia	Indonesia
33	Mexico	Brazil	Brazil	Brazil	Brazil
34	Turkey	Mexico	Mexico	India	India
35	South Africa	Turkey	Turkey	Mexico	Mexico

United Kingdom and France in an upward trend

The innovation systems in the United Kingdom and France lately improved their performance according to the Innovation Indicator. The United Kingdom continued the upward trend that could be observed since 2010. Among the British strengths are advantageous societal framework conditions for innovations and a good education system. In the past few years, more British companies implemented innovations and the spending on research and development also increased. Since 2000 (for SMEs) and 2002 (for large companies) the government has supported research and development in companies with tax incentives among other things. This aims to increase the low expenditure of companies on research and development. This has only partially worked so far. At 1.1 percent the share of R&D expenditures of companies of the gross domestic product is still significantly lower than the level reached by the other big industrialized countries, such as the USA (2.0 percent), Japan (2.7 percent) or Germany (2.0 percent).

The science system of the United Kingdom lags behind in the international comparison. Although the United Kingdom has two elite universities in Oxford and Cambridge, which always achieve top places in global university rankings, the research performance of British universities as a whole however – apart from individual topic areas – is often only average. Due to the concentration of research funds on a few selected institutions, the research is very limited in scope in many universities, thus separating research and teaching. In addition to the high concentration of funds there is also the low overall expenditure measured as the share of public research expenditure in relation to the gross domestic product. At 0.58 percent, this share is only about half of that of Denmark or Sweden. Further problems are the low level of application orientation, deficits concerning the transfer of knowledge and technology and also the low number of patents stemming from public research.

Policy making is increasingly trying to alleviate these weaknesses. One of the measures implemented is the Catapult Programme. In eight technology fields (energy storage, materials, big data, satellites, robotics/autonomous systems, synthetic biology, regenerative medicine, agricultural technology) innovation centers were established, in which companies and scientists jointly work on new technological solutions. At the same time, the United Kingdom also sets great store on non-technological innovations, not primarily aimed at research and development, for example in the creative industry or the area of financial services (fintech). At present, it is impossible to predict how the British innovation system will develop in view of Brexit.

France was able to increase its index value in the Innovation Indicator. Responsible for this are the improved indicator values in the education area (number of people with doctorates, quality of school education), in the science system (share of the most frequently cited scientific papers, number of patent registrations by public research institutions) as well as in government support for research and innovation. The quality of the scientific (basic) research was improved. The ranking of France in the lower half of the innovation oriented industrialized countries in the Innovation Indicator is mostly due to the low contributions of the high-tech industry to added value, a bad position on international markets concerning high-tech products, low number of patent activities of the companies as well as a low propensity for cooperations between industry and science.

The state plays a more prominent role in the innovation system in France compared to that in other large economies. This is reflected in a high government financial contribution to the R&D expenditures of companies and a high public demand for new technologies. As far as e-government is concerned, however, measured according to the share of citizens/companies who contact public authorities via Internet, France lies in the midfield, at best.

Reforms to increase the performance capabilities of the players in the area of research and innovation were not implemented in a consistent manner in France. One example is the establishment of the Carnot Institutes. The research institutions were to institutionally copy the application-oriented Fraun-

Germany has a high contribution of high-tech industries to value added.

hofer Institutes in Germany. However, the project stalled halfway: Instead of creating new institutes, existing units were simply bestowed with the temporary title of “Carnot”. That seems more like a marketing measure rather than the systematic attempt to support application-oriented research. In 2005 the research funding was more strongly decentralized by creating the Agence Nationale de la Recherche (ANR), an organization similar to the German Research Foundation (DFG). Here for example decisions concerning funding are made on the basis of expert review processes and not through the government. The Pôles de Compétitivité, comparable to the German leading-edge clusters, were another attempt of the government to set a new course towards a performance-oriented allocation of funds.

USA in the midfield

The biggest strength of the USA is the innovative strength of their companies. The USA is home to some of the most innovative and at the same time most highly valued companies in the world, which determine what happens on many marketplaces – especially in the digital economy. As the individual indicators show, the American economy is distinguished by intensive domestic competition, a high demand of companies for technological products as well as high degrees of added value per hour worked. As far as input is concerned, the share of publicly financed R&D expenditures of companies must be mentioned: It is a lot higher than for example in Germany. The highly developed venture capital market in the USA offers extensive means of financing start-ups in the high-tech industries and young companies with good growth perspectives.

In the science system the USA, on the one hand, are home to many of the globally leading universities, but on the other hand, also a very large number of universities obtain significantly weaker results. Measured against country size, the US-American science system only achieves a middling value in the Innovation Indicator. The research institutions on average are no longer ranked at the top, for example in the – respectively standardized for country size – number of researchers, the number of scientific-technological journal articles, the number of citations of these articles and the number of patents stemming from public research. Additionally, the USA have a rather low level of international networking and are more oriented towards the domestic scene. Since however international openness and cooperation are among the essential success factors for innovation systems, this drags the index value for the USA down. With the new administration under Donald Trump, who supports isolation rather than stronger international openness, no improvements are to be expected in this area. In the sub-area education the USA still stand out with their high education expenditure per student and a high share of employees with a tertiary education. The other indicators – including for example the share of foreign students – have significantly lower values than most of the other countries surveyed. The USA, however, does take the top spot of the large economies in the area of digital transformation (see focus chapter).

South Korea’s economy strong

South Korea achieves a similar index value to the USA, however with a distinctly differently structured innovation system. The South Korean innovation system is strongly geared towards a few globally leading companies. Their innovative strength gains South Korea second place in the sub-area industry. The innovation ability of South Korean industry significantly improved in the past years according to the assessment criteria used here. The strengths of the South Korean system according to the individual indicators are among others a high R&D rate – the R&D expenditures in relation to gross domestic product was 3.36 percent in 2014 and are only surpassed by Israel – or the high number of patent registrations at the US Patent Office, as well as a clear trade balance surplus and high contributions of the high-tech industries to added value.

The second strength is the education system. South Korea is placed fourth in the international comparison in this area. Worth mentioning here is the share of the population who have at least finished secondary II level education and the

Apple was worth 568 billion euros at the stock exchange at the end of 2016. The technology corporation together with the Google Holding Alphabet and Microsoft is among the most valuable companies in the world.

number of university graduates in relation to the number of employees of fifty-five years of age or older. The results of the PISA surveys also speak for a well-performing education system. South Korea ranks well above the average of OECD countries with its results in natural sciences, reading ability and mathematics. In the sub-areas society, state and science South Korea however performs below average. The output of the science system is low, when measured against the population of the country. This also holds true for integration into international science cooperation projects. The society indicators also indicate weaknesses, especially where the share of working women or the reporting on progress in research and development are concerned.

Japan with its overall relatively low evaluation of the innovation performance in the indicator comes in at the bottom of the group of highly developed industrialized countries. After improving its index values in 2012 and 2013, Japan has returned lately to achieving lower values.

One weakness is the performance ability of the science system, where the number of publications per inhabitant lags significantly behind that of other large industrialized countries. Japan is also only loosely integrated into the international scientific community, which is reflected in the low number of joint publications with international partners.

The low values in the indicator area society show additional weaknesses in the Japanese innovation system. The share of working women in Japan lies markedly below that of most other countries surveyed and is only undercut by India, Turkey or

Indonesia. Although the lack of gender equality is not a general problem in Japan – in the Gender Inequality Index of the UN Development Programme Japan is in the upper midfield – the labor participation of women is especially relevant for innovations, since a low value indicates a low use of creative potentials. Apart from that, the awareness of research and development results in the media is low compared internationally.

As far as education is concerned, the Japanese innovation system achieves average results. The PISA results are good. However, in the long run there might be a lack of the highly qualified, since the number of university graduates in relation to the number of academics retiring due to old age is low in international comparison.

Japan's strength clearly lies in industry. Companies on average are highly technology-oriented. The high R&D share of companies and an above average number of patent registrations prove this. The high innovative capability of many large Japanese companies, that often are among the global technology leaders in their specific markets, is contrasted with medium-sized enterprises that are hardly innovative. The results of the current Japanese innovation survey show that in the period from 2012 to 2014 only 20 percent of the mid-sized enterprises introduced innovations.[1] In Ger-

Indicator values for the five sub-indicators

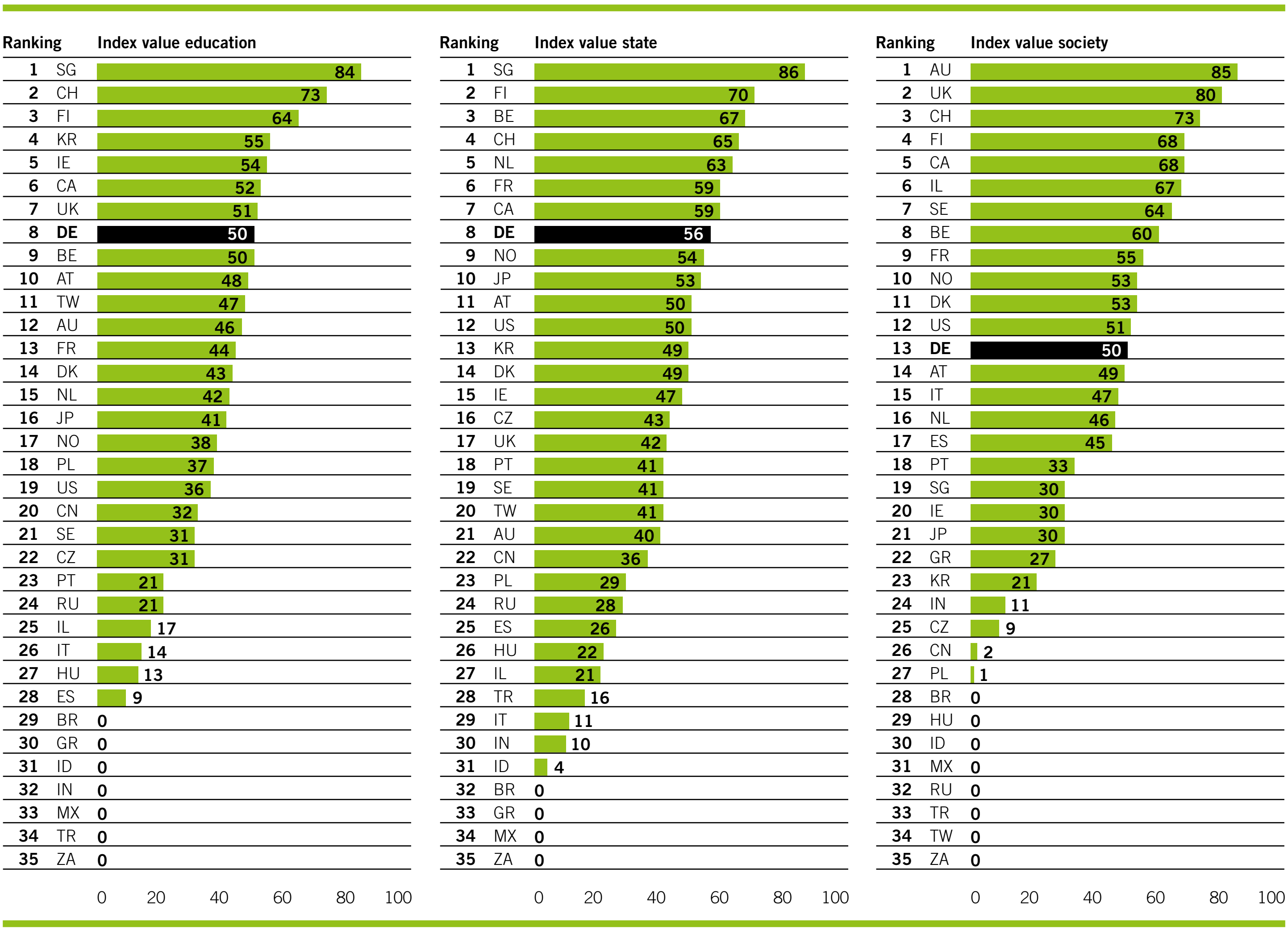
Ranking		Index value industry	Ranking		Index value science
1	CH	66	1	DK	97
2	KR	59	2	SG	96
3	BE	58	3	CH	93
4	SG	57	4	NL	74
5	TW	56	5	FI	74
6	US	56	6	SE	73
7	**DE**	**54**	7	BE	70
8	IE	54	8	NO	64
9	SE	53	9	AU	63
10	IL	53	10	AT	63
11	AT	51	**11**	**DE**	**62**
12	JP	50	12	FR	58
13	NO	48	13	IL	58
14	NL	47	14	UK	54
15	UK	45	15	CA	53
16	FR	43	16	IE	51
17	DK	42	17	US	50
18	FI	41	18	KR	47
19	AU	34	19	PT	39
20	CA	33	20	JP	34
21	CZ	32	21	CZ	34
22	HU	31	22	TW	29
23	ES	24	23	ES	23
24	CN	21	24	GR	22
25	PT	20	25	IT	20
26	RU	19	26	HU	17
27	TR	15	27	ID	9
28	IT	13	28	ZA	9
29	ZA	13	29	CN	1
30	ID	8	30	BR	0
31	MX	8	31	IN	0
32	GR	6	32	MX	0
33	BR	6	33	PL	0
34	PL	5	34	RU	0
35	IN	0	35	TR	0

AT (Austria), AU (Australia), BE (Belgium), BR (Brazil), CA (Canada), CH (Switzerland), CN (China), CZ (Czech Republic), DE (Germany), DK (Denmark), ES (Spain), FI (Finland), FR (France), UK (United Kingdom), GR (Greece), HU (Hungary), ID (Indonesia), IE (Ireland), IL (Israel), IN (India), IT (Italy), JP (Japan), KR (South Korea), MX (Mexico), NL (Netherlands), NO (Norway), PL (Poland), PT (Portugal), RU (Russia), SE (Sweden), SG (Singapore), TR (Turkey), TW (Taiwan), US (USA), ZA (South Africa) many this value is 43 percent, more than double. Additionally, the trade balance surplus concerning high-tech products has been declining in Japan since 2012, contributing to a sinking index value.

China only strong in selected areas

China still only achieves a low index value in the Innovation Indicator. This is because this indicator shows the innovative strength of the entire economy, including the entire education and science systems and not just the performance of individual internationally successful actors. Some Chinese companies such as Baidu in the field of digital platforms meanwhile are among the most successful suppliers and therefore play in the same league as the leading companies from the USA. There are also more than a few Chinese companies that have caught up as far as technology is concerned in their specific market places, so that they pose serious competition for European, East Asian and US-American market leaders.

If one were to look at the Internet and telecommunications industry separately for example, China would achieve a strong position even on the global stage. However, one has to consider that China strongly focusses on transactional platforms such as Baidu or Tencent, while innovative platform



China wants to get more start-ups off the ground via funding incentives.

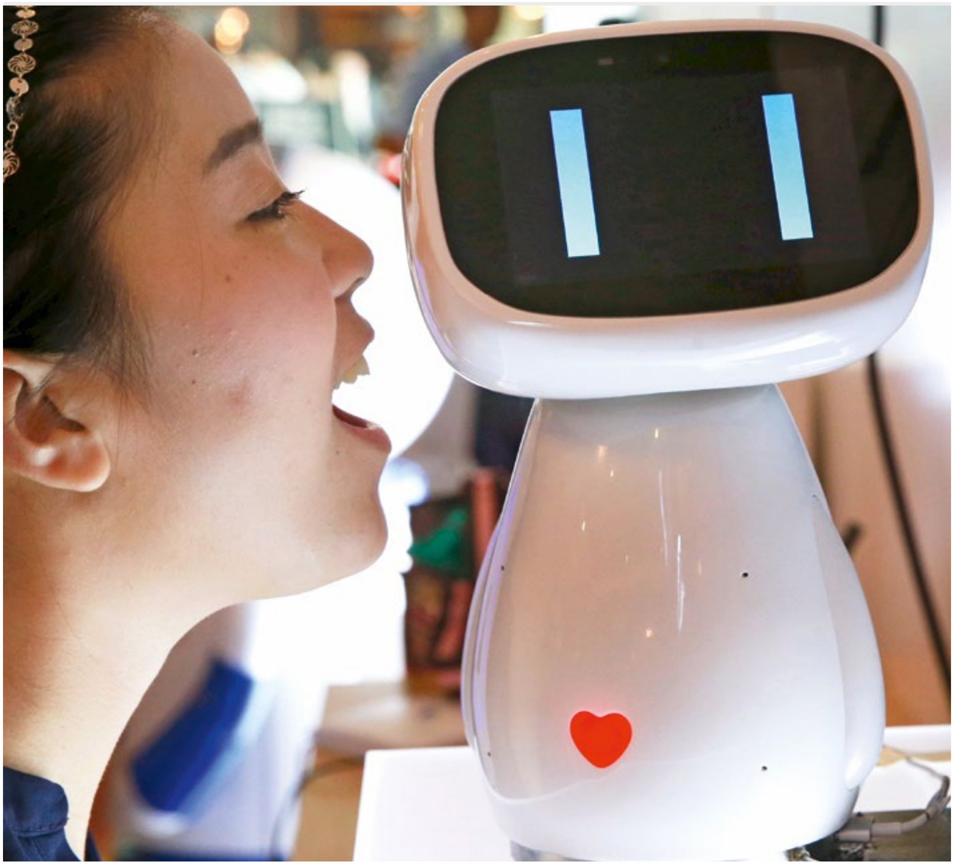
companies are mostly located in North America (for example Oracle or Microsoft).[2] Additionally, large segments of Chinese industry have low or practically no innovation activities.

Although the index value for China in the overall indicator has remained unchanged compared to the previous year, China shows marked improvements in individual output indicators, for example regarding the quality of the scientific research results. On the input side, however, many indicator values are stagnating. The investments in science and research, for example, have not increased recently in relation to the gross domestic product. Also, although China – like many other emerging countries – has innovative focus areas in individual industries and fields of technology, the innovation system is not well positioned across the board. Large parts of high-tech production consist of the assembly of finished products while the actual high-tech components are imported.

The determined target of the Chinese government is therefore to redirect the economy towards more innovations and high quality products with high shares of added value. The goals were set high in the 13th Five-Year Plan and especially with the innovation plan for the years from 2016 to 2020, which was adopted by the State Council in July 2016. Aims for example are a R&D rate of 2.5 percent of the gross domestic product and doubling of the number of patent registrations per inhabitant.[3] The accompanying strategy to "Internet plus" the digitalization strategy of China, includes among other things building up competences in the digitalization of the financial world, healthcare and passenger transportation, as well as measures in logistics, e-commerce, and e-government up to and including energy, ecology and agriculture.

Also, with its "Made in China 2025" China follows a very similar approach to Germany with its Industrie 4.0 strategy. The first demonstration centers

In the same league as the competition from the USA: China's IT giant Baidu has developed Xiaodu, a speech-controlled assistant who can keep up with Siri, Alexa and Co.



have been established and a large volume of public funding for public and private companies was made available – mostly for start-ups. The market is supposed to be able to act with more freedom and the shares of state-owned companies are supposed to be reduced. The Chinese economy is also supposed to be made more independent of international economic cycles and export markets. The government therefore aims to increase domestic consumption and strengthen the service industry.

In the Innovation Indicator China manages to clearly leave behind the other four BRICS countries. Among those, Russia ranks best, due to individual education indicators as well as a high government involvement in research funding. South Africa can also achieve high values in individual indicators, for example in the internationally open and strongly performing science system or a favorable expert assessment concerning the innovation ability of industry. India and Brazil are at the bottom of the list of 35 countries with zero points, since they do not manage to score higher in any of the indicators than the weakest country in the benchmark group. These two populous countries do have individual innovation focuses, such as software in the case of India and aviation in the case of Brazil. These however are too small to balance out the missing innovation prerequisites in most parts of industry and society.

1 K. Motohashi, T. Ichichi, K. Ikeuchi, Y. Ikeda, Y. Yonetani, H. Imai: Report on the Fourth Round of the Japanese National Innovation Survey (J-NIS 2015) (NISTEP Report No. 170), Tokio 2016.

2 P. Evans, A. Gawer: The Rise of the Platform Enterprise, www.thecge.net/wp-content/uploads/2016/01/ PDF-WEB-Platform-Survey_01_12.pdf

3 www.uscc.gov/sites/default/files/Research/The%2013th%20Five-Year%20Plan.pdf

Focus

05

The digital transformation

This year's Innovation Indicator focusses on digital transformation. It is driven by an ever increasing networking of people and objects via the Internet.

This focus has the aim to provide an overview of the current state of the transformation and to assess the players' ability to successfully utilize the potentials offered by transformation. To this end, existing qualitative analyses and studies are mainly used as a basis. At some points own empirical findings are introduced which, however, must remain cursory.

Forecasts difficult

Many developments are difficult to grasp with the indicators and methods available. This is due to the temporal perspective on the one hand, since many technological developments have only just begun. Therefore, there is no basis for robust trend analyses. In addition, disruptive changes are expected in the course of digitalization, especially for business models of companies and entire value-added structures. They cannot be reliably projected or mapped within existing indicator systems.

After a brief overview of the role of digitalization as a driver of transformation, four aspects of digitalization are examined in more detail: first, the extent to which companies, the state and citizens have taken up the current trends in digitalization, and how the digital transformation in Germany compares internationally are discussed. Afterwards, the central topic of infrastructure is briefly laid out. In view of the great importance that Industrie 4.0 has for digitalization in the German economy, a separate section is devoted to these challenges.

The chapter concludes with recommendations on how science, industry, politics and society can jointly shape the digital transformation.

Digitalization offers a wide range of opportunities for innovation. Science, industry, politics and society have to use them together.

06

New technologies make the world smarter

Digitalization changes the way innovations emerge. Companies have to rethink in order to not lose touch in Industrie 4.0 and the platform economy.

New digital technologies, a new dimension of information availability and new possibilities of networking in the Internet of data, services and things – all of these enable companies to react even more quickly and precisely to the needs of customers and to make their offers more distinguishable from those of their competitors. New data-driven business models help exploit new potentials for turnover. In part, they break up established value added structures within very short time periods.

Three big trends shape the current digital transformation:

- **New digital technologies** are able to capture, process, store, distribute, analyze and assess information in completely new ways. They can also link information with physical processes. Companies can avail themselves of in part radically new technologies, for example cloud computing, artificial intelligence, machine learning, analytical tools for big data, lightweight robots, cyber-physical and autonomous systems as well as flexible, decentralized and individualized manufacturing technologies. The new technologies affect nearly all fields of economic activity and encompass broad areas of the working world and our social environment.

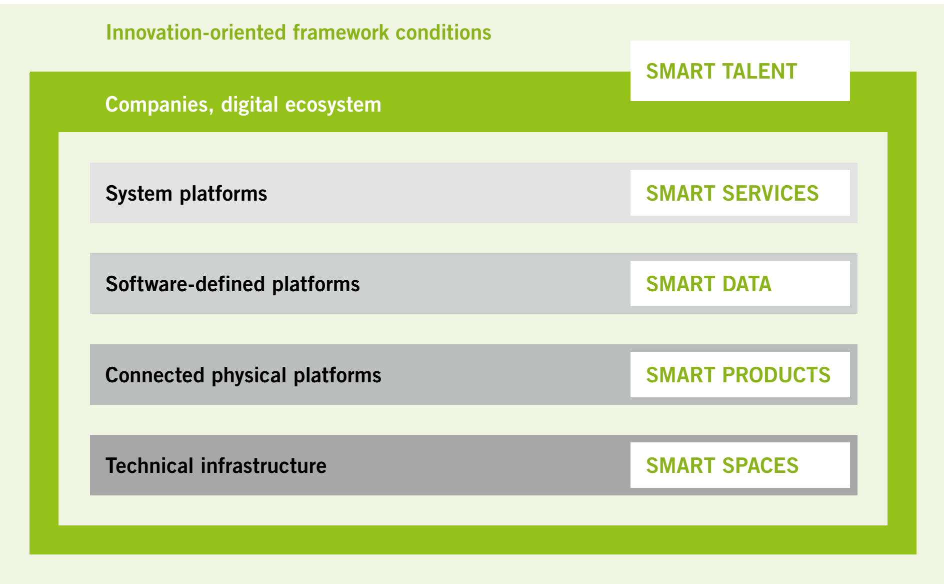
- **With the intelligent digital networking** of sub-systems, companies have many more possibilities to increase their productivity, improve the quality of products and services or develop new service offers. Digital networking encompasses processes, products and business models. The designation Industrie 4.0 sums up differing approaches to digital transformation in the production sector which lead to a flexible, self-directed and service-oriented production of personalized products. In this so-called "smart factory" all value-adding stages are digitally integrated over the life cycle of products and completely new forms of interaction between producers and users are enabled. Intelligent aggregation of large amounts of data (smart data) makes it possible to re-interpret information and leads to solutions with considerably higher utility. Networking in the fields of education, energy, health, transport and administration promises additional growth potentials and potential efficiency gains, for example through autonomous driving, e-health applications or networked devices for energy control.[4]

- **Digital platforms** are Internet-based forums for interaction and transaction. They use new digital technologies and digital networking to connect different user groups and service providers and offer services on the platform which give the users additional added value. This added value often stems from individualized, data-based offers. The digital platforms are increasingly turning into central locations for economic and social exchange. They enable new ways of connecting market players or of using goods efficiently – catchphrase the sharing economy. Apart from that, a new type of companies is created through the platforms: the platform entrepreneurs. Platforms are most often the basis for new business models. They bundle digital and digitally connected products in a data-centric manner with customer- and product-specific services to create innovative product-service-packages. These are differentiated and further developed with the help of user-specific apps. Following this, digital ecosystems develop surrounding one of these platforms, determining how platforms evolve further. A layer model in the following graph describes the connection of technical infrastructure, platforms and intelligent offers building on this, from smart spaces up to smart services.[5]

Emergence of a platform economy

Due to network effects most often only a few or even only one platform prevails for specific offers. For smaller companies, open access to platforms and the technologies they are based upon are central criteria to be able to participate in the chances offered by digitalization. Protecting content and the possibility to acquire innovation returns play a big part in this. If the innovative suppliers at the periphery of the platform gain no part of the value added of the platform functionality created by them, then the influx of new ideas and solutions can rapidly dry up. The ecosystem of the platform dries up. For companies, occupying platforms turns into a competitive factor, decisive for success. First and foremost, the providers of platforms which are surrounded by a large ecosystem have a good chance of becoming the leading supplier of digital business models and thus also to be successful in platform-relevant markets in the future. Otherwise intermediaries will take this position and occupy the customer and data interface with the intelligent connected services

Layer model of digital infrastructures



Source: DKFI/acatech/Accenture; authors' own illustration

Companies have to reposition themselves.

and products. If the platforms, which form the base of Industrie 4.0 are dominated by international platform companies from the IT industry, technologically and in organizational aspects, essential strengths of the existing German industrial innovation model could be lost. In the platform economy, platform operators from other industries can occupy the interface with the customers and demote established companies from the manufacturing sector to simple suppliers.

All in all, the platform economy requires rethinking in companies. Instead of optimizing centered on products, the innovation efforts and business models need to be oriented to the user and his needs. The companies are able to approach their customers with a data-based pinpointed approach and supply them with exactly tailored products and services and enable new user experiences. Individualized offers can be offered at the same price as mass produced goods. Many companies are still at the beginning of the digital transformation in this regard.[6]

The given strong customer orientation of many companies is a good prerequisite to position oneself well in the world of smart service. However, a change of strategy is necessary. It should entail moving away from the exclusively technical perfecting of individual components and products and towards a development of flexible product-service-packages, utilizing all possibilities of digitalization.[7]

The smart service world

In the platform economy, there is a shift in the shares of added value, which leads away from products to services as key competitive factors. In addition, a new decisive production factor emerges: data. The primary performance features of many traditional physical products that decided market success or failure are technical features, design, durability, ease of use, cost-effectiveness. In a platform economy, added value is created by connecting products, services and digital processes based on user-specific data.

The new smart service world is essentially based on the rapid and user-specific analysis of large amounts of data from which information relevant to competitiveness is generated. This way, big data turns into smart data. New service offers can be created from the combination of different data sources and the resulting information. Users can always expect a product-service-package tailored to their needs at any time and place.[8] For companies, this new world means that they have to reposition themselves in the market. New business models are needed that develop smart services on the basis of digital service platforms.[9] The smart service world not only transforms the services sector, but also many industrial applications as well as public administration. In that case it concerns the reorganization of the use of urban infrastructure on the basis of digital technologies, also called smart city.

Changed innovation processes

Digitalization also changes how innovations occur and how they are made accessible. The digital interaction between users and producers and the dissolution of the former separation between product and service in smart services is accompanied by new innovation processes:

- User-led, user-driven and user-integrated Innovations are new developments in which the users themselves significantly contribute to innovations, turning into co-producers or so-called prosumers.
- Innovation ecosystems develop around digital platforms. Platform providers use a pool of external innovation sources surrounding a platform, to continuously develop it further. At the same time, external innovators can dock onto these platforms with their own solutions, contributing to a constant change and expansion of its functionality and possible uses. The ecosystem of a platform is essential in deciding the attractiveness of the platform's offer and often is the actual provider of utility for the end customer.

Lots of technology and infrastructure forming a uniform and integrated whole: Songdo, a district in the South Korean city of Incheon which has more than a million inhabitants, is a global showcase of a smart city.

- Cooperations for the development and implementation of new offers are steadily becoming more important and more complex. The classical innovation cooperation along the technological development phases is superseded by the joint development of solutions for the customer within an innovative ecosystem. Instead of structured innovation projects with pre-defined steps, there are open processes in which the participants share their knowledge and ideas and benefit from each other. This development also influences the distribution of work between science and industry in the innovation system. It requires science to open up to the topic of digitalization in all its facets and to process it from different disciplinary angles.

Digitalization in education and society

Digitalization necessitates and supports agile work methods and demand-based learning. It also enables new, more flexible ways of working – from teleworking to autonomous working.[10] Through digitalization responsibility is decentralized and a higher degree of independence is required from employees, for example, concerning the interaction with customers within the framework of smart services. The increased flexibility of work requires a high degree of autonomy and the ability to organize oneself. It requires new forms of organizations in companies. At the same time, the digitalization leads to a change in the world of manufacturing within the framework of Industrie 4.0 concepts.

This also necessitates adjustments in the education system. Academic qualifications will become increasingly more important. Vocational training has to be more open towards new key competences such as organization and communication skills as well as the ability to judge in complex situations. At the same time, new assistance systems and other kinds of human-machine-interactions can also support employees with low levels of qualification in performing complex tasks and open up new job possibilities for members of this group.[11]

With digitalization new digital living environments arise. Digital communication platforms, social media, rearrange the relationships between people and change communication, information procurement and social interactions. Patterns of consumption change fundamentally through the use of online platforms and new shopping experiences are created. Digitalization enables new kinds of family life and leisure activities, more needs-based, individualized and transparent consumption options, better healthcare provision and new possibilities of learning in all life stages.

4 BMWi (Ed.): Strategie Intelligente Vernetzung, Berlin 2016.

5 acatach (Ed.): Smart Service Welt. Digitale Serviceplattformen – Praxiserfahrungen aus der Industrie. Best Practices, Munich 2016.

6 The majority of managers did not yet know the expression platform economy, see www.bitkom.org/Presse/Presseinformation/Digitale-Plattformen-sind-vielen-Top-Managern-kein-Begriff.html.

7 Commission of Experts for Research and Innovation (Expertenkommission Forschung und Innovation – EFI) (Ed.): Gutachten 2016, Berlin 2016.

8 Arbeitskreis Smart Service Welt/acatech (Ed.): Smart Service Welt – Umsetzungsempfehlungen für das Zukunftsprojekt Internetbasierte Dienste für die Wirtschaft. Abschlussbericht, Berlin 2015.

9 acatech (Ed.): Smart Service Welt: Digitale Serviceplattformen – Praxiserfahrungen aus der Industrie. Best Practices, Munich 2016.

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07

Germany far from the top group

Where traditional markets are transformed into platform markets, digitalization often leads to the disruption of established value added structures and can cannibalize hitherto successful business models. Old structures dissolve, and new ones emerge, often through new competitors, such as start-ups or companies from abroad which are swifter in seizing digitalization opportunities. In some industries, which might change less radically, processes, products and services are gradually expanded by digital applications and transformed into digital offers bit by bit.

In any case, companies, employees, citizens and the state are called upon to face new developments and to take advantage of the opportunities offered by digitalization. This chapter examines how well prepared they are. First, indicators for the spread of digitalization in an international comparison are presented. Such indicators, however, can provide only the first rough indications, since although the key figures between countries can be compared, they do not adequately reflect important trends in digitalization.

Digitalization Indicator

In order to obtain a first impression of the spread of digitalization in Germany in an international comparison, six sub-indicators are considered and combined to form a total indicator value, analogously to the Innovation Indicator. The sub-indicators are research and technology, industry, society, state and infrastructure, education as well as business models. A total of 66 individual indicators are used.[12] They are based on indicator lists used by other studies with similar objectives.[13] The same 35 countries as in the Innovation Indicator are examined.

Unlike in the Innovation Indicator, for the Digitalization Indicator, Germany is in the midfield (17th place). In particular, there is a considerable gap between, Germany and a group of eleven countries, which show a significantly higher valuation for this indicator. This group includes the four Scandinavian countries, the USA, the UK and Australia, the Netherlands, Switzerland, Israel and Singapore. But South Korea is also several points ahead of Germany. Germany, France and Japan are neck to neck.

A review of the results of the Digitalization Indicator by the six sub-areas shows that Germany has significantly lower values than the USA in nearly all of them. The distance in the infrastructure/state category is particularly large. Here Germany achieves only 39 points, against 85 for the USA. Japan is also well ahead of Germany with 54 points. An important reason for Germany's midfield position is the low level of broadband coverage. Also the digitalization of public administration has not yet been implemented as strongly as in many other countries, by far.[14] For instance, Germany is only 19th in the EU concerning the dissemination of e-government.[15]

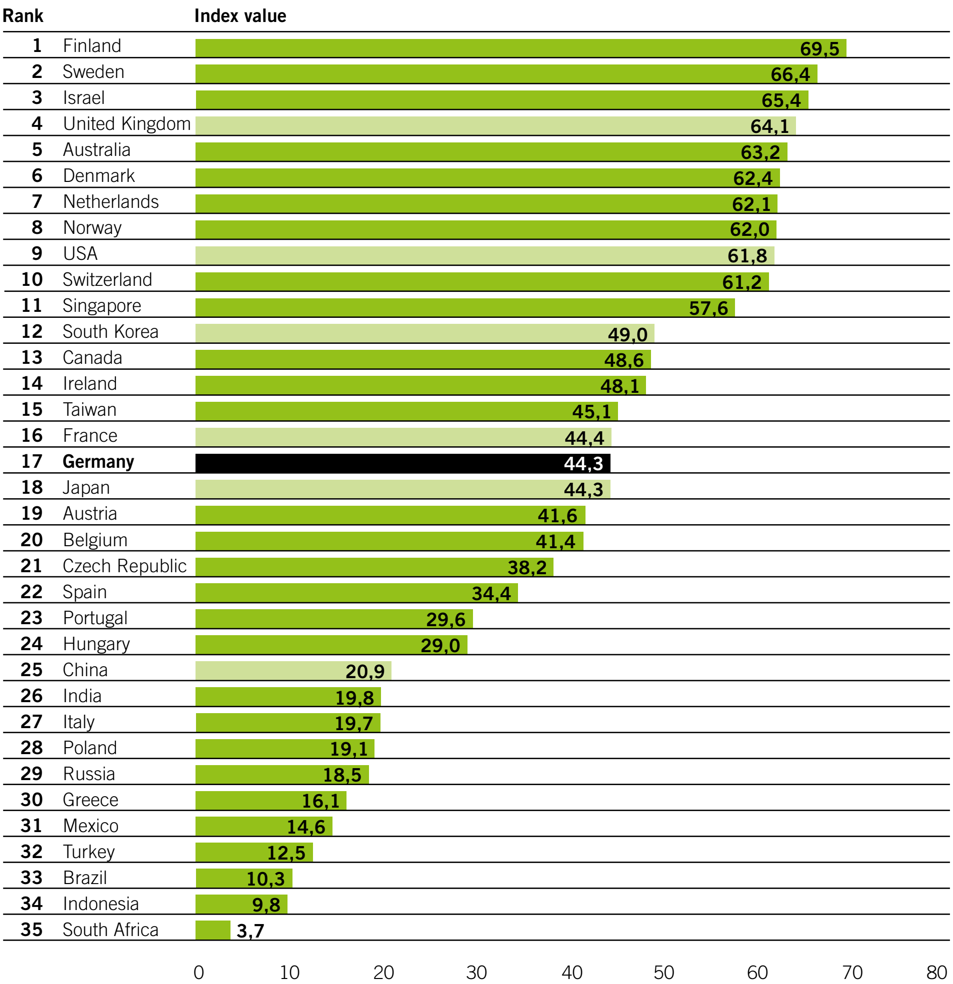
The gap is also significant in the field of research and technology, which covers research and development (R&D) expenditure, patent applications and scientific publications in the area of digital

Digitalization offers great opportunities. However, Germany has not yet positioned itself sufficiently well in many areas.

technologies. In this sub-system, however, the USA and Japan do not perform well either. This is mainly due to the strong specialization of some smaller countries in software and technology development for digital applications (Finland, Israel, Taiwan, Singapore).[16]

The German innovation system with its companies, universities and research facilities is highly productive in the development of new hardware for digitalization such as communication technology, computer technology and microelectronics, but this area is relatively small as measured by value added. In the area of software and computer sciences, the position of the German innovation system is better, with regard to the level of R & D expenditures, and the distance to leading countries such as the USA or Israel, but also Finland, Singapore or Switzerland is considerable. However, it should be stressed that the German innovation system has a good competitive position, especially in embedded software, i.e. hardware-embedded software controls.[17] By contrast, German companies have weaknesses regarding operating systems, digital business models and Internet applications.

Digitalization Indicator



Source: ISI and ZEW calculations; an overview of the individual indicators can be found at www.innovationsindikator.de

A positive aspect in Germany is the high degree of utilization of digital solutions and technologies in society. With 58 points this is the sub-indicator with the highest value compared to the other sections. The main reason for this is the high percentage of the population who shop online – with 80 percent Germany claims the third highest value – and the high number of households connected to the Internet. Here, compared to the Scandinavian countries with 80 to 90 points, the gap to the top is also considerable.

For the sub-indicator industry, the use of various digitalization applications by companies in Germany – from the use of software to the employment of IT specialists and online solutions to cloud computing – is only average with 42 points. Particularly in the case of small companies and in the less technology-intensive sectors, the pervasion of digital applications is low. And the informationalization of production processes is by no means as intense as the intensity of the public discussion about Industrie 4.0 would suggest.

In the case of the indicators for digital business models, the value for Germany is 49 points, in the middle of the field. The Netherlands with 92 points as well as the USA and the UK with 83 points respectively can boast the highest scores. South Korea lies ahead of Germany.

In the sub-area of education Germany's score of 44 points is lower than that of most of the comparison countries. The high proportion of graduates in the subjects of mathematics and computer science, the high percentage of teachers participating in further training courses on IT-subjects and the software equipment of schools are positive factors. However, there are major deficits in the use of online continuing education in the general population, the use of the Internet in school teaching and computer hardware in schools.

In the following, the results of the Digitalization Indicator are supplemented with results from current studies on the central topics of digitalization. These include, for example, platforms, the smart service world and digitalization in society. As a result, the position of Germany in these trends is to be considered more from a qualitative point of view.

Digital platforms still rarely the basis of new business models

Many studies on the position of Germany in the platform economy confirm that the German economy is not one of the leading countries in using new business opportunities offered by digital platforms. Although platforms have also repeatedly been successfully established in Germany and a large number of start-ups are concerned with platform solutions[18], however, the big players worldwide are from the USA and China.

There are good conditions for Germany taking a strong position in the platform economy in the core industrial sectors of automotive and mechanical engineering as well as in logistics. Here many companies have integrated value chains that can form the basis for digital ecosystems in which German companies as platform operators can fundamentally shape the future development. However, speed is of the essence as there is a risk that competitors from other sectors might be able to establish digital platforms more quickly in the market. With the emergence of a platform economy in these sectors, core competences in mechanical engineering, for example, can become obsolete or companies can be pushed into a subcontracting position with a declining share of value added.[19] The main challenges are seen in the following three areas:

- In general, stronger thinking in terms of business models is necessary. According to expert estimations, German companies are here clearly lagging behind the USA, but also East Asian countries. Instead of starting from the product and its technical characteristics, business models need to take the customer requirements as the starting point of their development. Thereby the possibilities of smart services must be taken into account at all points in order to strengthen customer loyalty, drive product differentiation, but also to realize efficiency gains and access to new markets.

- On the technological side, the integration of digital technologies such as artificial intelligence, big data and smart data, machine learning, autonomous systems and IT security is to be advanced. For this purpose, there has to be investment especially in the appropriate digital skills of employees. At the same time, however, a purely technology-centric way of thinking must be avoided. The focus here too has to lie on customer service and the realization of smart services.

- Strategic and organizational skills required to take advantage of the opportunities offered by a platform economy are, on the other hand, already well-established in the automotive and mechanical engineering sector according to expert opinions. They should be able to cope with the challenges of the platform economy. The biggest chances for German companies are seen in the B2B area. However, deficits are seen in the logistics sector.

Among the obstacles on the way to a platform economy in Germany are, inter alia, the lack of top IT specialists and experts with hybrid competences such as engineers with software/data competences and business management knowledge. Other obstacles include IT security and legal regulations as well as the question of how to deal with the necessary openness of interfaces.[20]

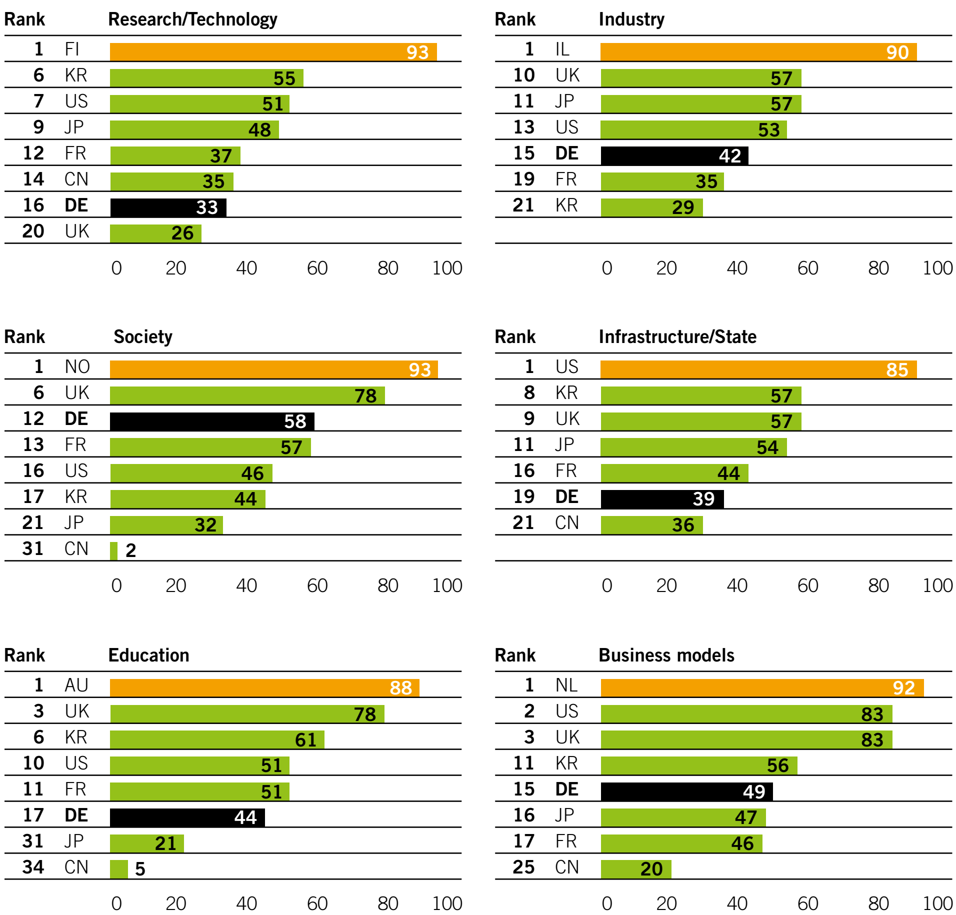
In its report in 2016, the Commission of Experts for Research and Innovation (Expertenkommission Forschung und Innovation – EFI) concludes that German companies lag behind their competitors in other countries in the application of cloud computing and big data approaches. Software, digital technologies and new business models are too often seen as cost drivers and too rarely as opportunities to position oneself in a promising competitive position.[21] There are still large deficits, particularly in small and medium-sized enterprises (SMEs), as they still underestimate the significance of the changes wrought by digitalization.

Transformation in classical industries

Large companies are already involved in the development of smart products, service platforms and the digital transformation of business models.[22] The automotive industry and the mobility sector are so far the most advanced in Germany. In production and automation technology, it is mainly large companies such as Siemens, Bosch, ThyssenKrupp or Trumpf, which offer platforms and data-centric services over the Internet. A major challenge is the scalability of the offerings: "Only when disruptive smart service business models grow at high speeds can they penetrate established value-added chains and create innovative value-added networks."[23]

Digitalization Indicator by sub-areas – comparison of large countries

Benchmark



AU (Australia)
CN (China)
DE (Germany)
FI (Finland)
FR (France)
UK (United Kingdom)
IL (Israel)
JP (Japan)
KR (South Korea)
NL (Netherlands)
NO (Norway)
US (USA)

The prerequisites in Germany for a successful move to the smart service world are good. Being world market leaders in the field of mechanical engineering, engineering and production technology, as well as in the production of intelligent, complex products gives companies a favorable starting position. They can introduce production-related smart services with a global application perspective, quickly achieve scalability and assume an actively shaping role in the emerging platform ecosystems. The existing system knowledge concerning value-added networks makes it easier to build combined smart services. Germany's strengths in networked physical systems can be used to further develop them into digital service platforms using software-defined technologies.[24]

In the international comparison, Germany is well positioned in the areas of sensor networks and cyber-physical systems, big data and semantic technologies. Cloud computing is dominated by the USA, and China and Singapore are key players. The dominance of the USA in cloud solutions is often viewed critically against the background of the topics of legal frameworks, data protection and data security. The development of own cloud solutions is of particular importance for the creation of software-defined products. These again are of critical importance for smart services.

However, interest on the part of SMEs is currently growing only slowly. Many companies are still unaware of the strategic importance of the current change for their own businesses or lack the organizational, financial and human resources to meet the challenges of a comprehensive digitalization.[25] SMEs often lack role models, which demonstrate how they can enter the smart service world, which competences they need to build internally and what external support they need. The BMWi (German Ministry for Economic Affairs and Energy) has therefore launched a "Smart Services World" support program, which supports SMEs in the development and use of smart services.

The main obstacles cited by medium-sized companies concerning digitalization are IT security issues, lack of own expertise, the issues regarding interfaces and standards, as well as technical infrastructure such as broadband coverage.[26] Financing is not considered a crucial impediment by companies.[27] This might be due to the fact that many, especially smaller companies, estimate the investment need for digitalization projects as low.[28] The reason for this can in turn be that many companies judge the cost-benefit ratio of digitalization projects as being unfavorable.[29] Therefore they primarily pursue small projects and only rarely a fundamental digital transformation of their business activity.

Medium-sized businesses are approaching the topic of digitalization half-heartedly.

12 A table of the 66 indicators as well as the results for all six indicator sections can be found at www.innovationsindikator.de.

13 World Economic Forum: Global Information Technology Report 2016, Geneva 2016. ITU: Measuring the Information Society, Geneva 2015. OECD: Digital Economy Outlook 2015, Paris 2016. European Commission: Digital Economy and Society Index (DESI), Brussels 2016. S. C. Müller, M. Böhm, M. Schröer, A. Bakhirev, B.-C. Baiasu, H. Krcmar, I. M. Welpe: Geschäftsmodelle in der digitalen Wirtschaft (Studien zum deutschen Innovationssystem 13-2016), Commission of Experts for Research and Innovation (Expertenkommission Forschung und Innovation – EFI) (Eds.), Berlin 2016.

14 Cf. Commission of Experts for Research and Innovation (Expertenkommission Forschung und Innovation – EFI) (Ed.): Report 2016, Berlin 2016.

15 Cf. J. Fromm, C. Welzel, L. Nentwig, M. Weber: E-Government in Deutschland: Vom Abstieg zum Aufstieg. Kompetenzzentrum Öffentliche IT (Eds.), Berlin 2015.

16 The technological focusses of the countries differ: In Finland network technology is prevalent, in Israel it is software technology, in Taiwan it is microelectronics and in South Korea it is communications technology.

17 R. Frietsch, P. Neuhäusler, K.-J. Melullis, O. Rothengatter, S. Conchi: The economic impacts of computer-implemented inventions at the European Patent Office, 4iP Council (Eds.), Munich 2015. R. Frietsch, K. Lichtblau, B. Beckert et al.: Elektroindustrie als Leitbranche der Digitalisierung – Innovationschancen und Innovationshemmnisse für die Elektroindustrie, Frankfurt 2016.

18 S. C. Müller, M. Böhm, M. Schröer, A. Bakhirev, B.-C. Baiasu, H. Krcmar, I. M. Welpe: Geschäftsmodelle in der digitalen Wirtschaft (Studien zum deutschen Innovationssystem 13-2016), Commission of Experts for Research and Innovation (Expertenkommission Forschung und Innovation – EFI) (Eds.), Berlin 2016.

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20 BMWi (Eds.): IT-Sicherheit für die Industrie 4.0. Produktion, Produkte, Dienste von morgen im Zeichen globalisierter Wertschöpfungsketten. Berlin 2016. BMWi (Eds.): Plattform Industrie 4.0. Technischer Überblick: Sichere Identitäten. Ergebnispapier, Berlin 2016. BMWi (Eds.): Plattform Industrie 4.0. Technischer Überblick: Sichere unternehmensübergreifende Kommunikation. Ergebnispapier, Berlin 2016.

BMWi (Eds.): Plattform Industrie 4.0. Digitalisierte Industrie – Analoges Recht? Ein Überblick der Handlungsfelder. Ergebnispapier, Berlin 2016.

21 Commission of Experts for Research and Innovation (Expertenkommission Forschung und Innovation – EFI) (Ed.): Report 2016, Berlin 2016.

22 Accenture: Digitalisierung entzaubern. Wie die deutschen Top500 digitale Blockaden lösen, 2016.

23 acatech (Ed.): Smart Service Welt: Digitale Serviceplattformen – Praxiserfahrungen aus der Industrie. Best Practices, Munich 2016, p. 9.

24 acatech (Ed.): Smart Service Welt: Umsetzungsempfehlungen für das Zukunftsprojekt Internetbasierte Dienste für die Wirtschaft, Berlin 2014.

25 M. Astor, C. Rammer, C. Klaus, G. Klose: Innovativer Mittelstand 2025 – Herausforderungen, Trends und Handlungsempfehlungen für Wirtschaft und Politik. Studie im Auftrag des Bundesministeriums für Wirtschaft und Energie, Berlin and Mannheim 2016.

26 V. Demary, B. Engels, K.-H. Röhl, C. Rusche: Digitalisierung und Mittelstand. Eine Metastudie, IW-Analysen, Nr. 109, 2016.

27 C. Rammer, M. Berger, T. Doherr, M. Hud, P. Hünermund, Y. Iferd, B. Peters, T. Schubert: Innovationsverhalten der deutschen Wirtschaft. Indikatorenbericht zur Innovationserhebung 2016, Mannheim 2017.

28 M. Saam, S. Viete, S. Schiel: Digitalisierung im Mittelstand: Status Quo, aktuelle Entwicklungen und Herausforderungen, Mannheim 2016.

29 S. Wischmann, L. Wangler, A. Botthof: Industrie 4.0. Volks- und betriebswirtschaftliche Faktoren für den Standort Deutschland. Eine Studie im Rahmen der Begleitforschung zum Technologieprogramm AUTONOMIK für Industrie 4.0, Berlin 2015.

08

Digital infrastructure with weaknesses

High-capacity data networks are indispensable in order to exploit the opportunities and innovative possibilities of digitalization. Accordingly, all actors involved in the "Digital Agenda" emphasize the importance of network expansion and the renewal of network infrastructures. Broadband expansion was at the top of the agenda, both at the National IT Summit 2015 in Berlin and 2016 in Saarbrücken. All actors in politics, business and science have a sensitivity regarding the importance of the IT infrastructure.

According to estimates by the TÜV Rheinland, the nationwide expansion of fiber-optic connections in Germany would require investment of around 100 billion euros all in all.[30] The implementation of these investments promises an additional value added of 60 to 120 billion euros per year.[31]

An expert commission of the German Federal Ministry for Economic Affairs and Energy on strengthening investment in Germany concludes that broadband expansion has not yet advanced far enough and is not progressing fast enough.[32] In international comparison, Germany is significantly behind, especially in the expansion of future-proof fiber-optic infrastructure.[33] This results in competitive disadvantages for the German economy. The reason given for the hitherto slow investment in high-speed networks is, above all, a lack of investment protection.

Fast and reliable connectivity to the Internet, whether cable-bound (DSL, cable modem, fiber-optic), portable (WLAN) or mobile (4G, LTE, 5G), is essential for digital applications and new digital business models. This applies to the business as well as the end customer segment. A good Internet connection also allows companies in rural areas to use digital processes for the provision of services.

A study[34] for the Office of Technology Assessment at the German Bundestag in 2014 concludes that the further dissemination of cloud services depends on a better broadband provision. Cloud services are seen as pacesetters for more digitalization in almost every industry. A high-capacity broadband infrastructure is also a prerequisite for technological innovations. And it serves the goal of the federal government's Digital Agenda, namely to make Germany a technology leader in digitalization and a trailblazer in digital markets.

In fact, high-performance networks are the indispensable foundation for digital business models and smart services.[35] It is exactly the intelligent networking in applications with a large number of users – from energy and mobility to health, education and government services – which requires reliable and rapid data communication. The next stage of energy saving and optimization relies on smart devices and intelligent energy control systems. The opportunities presented by the integrated use of information in the field of health – the key word: electronic patient records – also appear to be enormous.

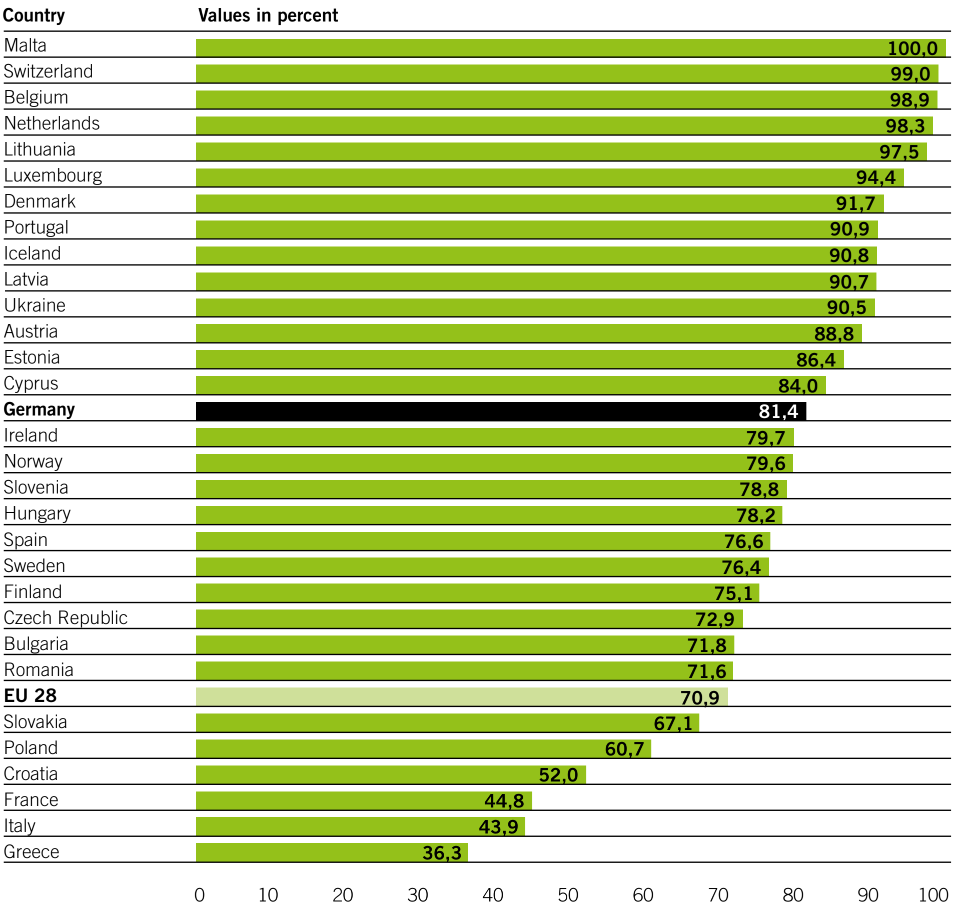
In the area of mobility, Internet connections will also be of crucial importance in the future. Although today's driver assistance systems do not

A digital future is not conceivable without powerful data networks. Germany still has some catching up to do in this area.

require an Internet connection, future car-to-car systems are not conceivable without fast and reliable mobile Internet communication. Autonomous driving also requires fast Internet connections, since high-precision maps must be constantly updated and the contact with other vehicles must be maintained. With a future comprehensive use of car-to-car systems and autonomous driving, an information infrastructure that goes far beyond what is currently available is a prerequisite.

The network infrastructure must also be improved in other areas, such as e-learning or private consumption, in order to be able to implement new applications.

Overview average broadband coverage by country



Source: Broadband Coverage in Europe 2015, p. 27.

Complement broadband expansion by fiber-optic network

In Germany, to a large extent, there is coverage with Internet connections in the middle range, i.e. about 30 megabits per second (Mbit/s). However, some rural areas are still not adequately supplied in this regard. The current figures of the European Commission show a coverage rate of 81.4 percent for broadband technologies across the whole of Germany. This middle Mbit/s range is called the NGA Coverage (NGA = Next Generation Access Networks). In its Digital Agenda, the Commission has formulated the goal of enabling all European households to access Internet connections at a speed of at least 30 Mbit/s by 2020.

Looking at the rural areas, an availability of 30 Mbit/s is only found in 36.4 percent of households in Germany. An even more critical picture is obtained by looking at the high-bit-rate, fiber-optic connections Fiber to the Home (FTTH) and Fiber to the Property (FTTP). Fiber-optic connections enable speeds of 100 Mbit/s to up the Gigabit/s range, while meeting very high quality requirements such as up-download symmetry, real-time capability and stability. For many future Internet applications in the private and business environment, these properties are becoming increasingly more important. This is why the supply of fiber-optic connections is an indicator of the future viability of the Internet infrastructure in a country. In the case of fiber-optic connections, however, Germany in all statistics is found in the group of the worst-performing countries in Europe. In the above-mentioned study by the European Commission, for example, Germany takes rank 28 out of 32.

Currently, the federal government aims at making broadband connections with a transmission speed of 50 Mbit/s available throughout Germany by 2018. However, many companies already want higher bandwidths right now to implement new business models. Various studies, such as the study by the Vodafone Institute[36] for Society and Communications, therefore see the current goal of the federal government merely as an interim target. In order to be sustainable in the longer term, they recommend more ambitious goals based on the highest demands, rather than on a broad average. A study commissioned by the German Electrical and Electronic Manufacturers' Association (ZVEI)[37] concludes that an Internet access fit for industry – i.e. symmetrical, stable and with low latency – is an essential prerequisite for the diffusion of digitalization in Germany.

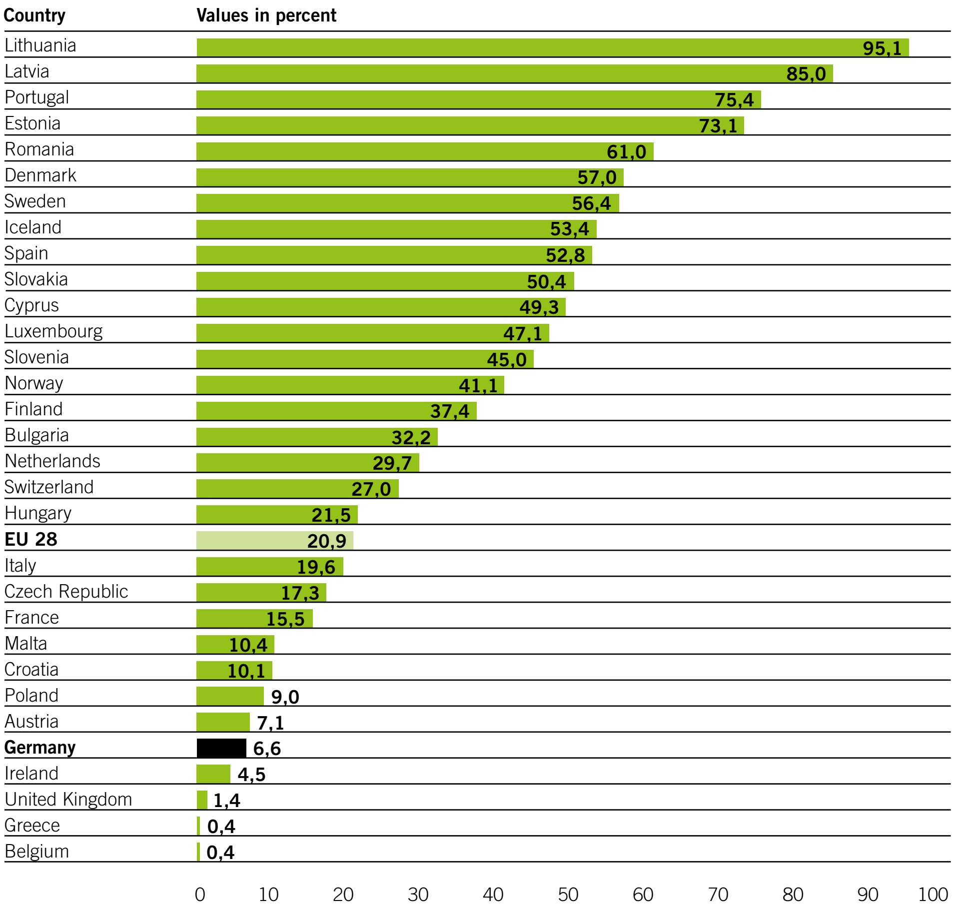
The necessity to support the construction of fiber-optic networks in Germany is now seen by many. For example, the German Federal Ministry of Economic Affairs and Energy (BMWi), in its Digital Strategy 2025, calls for the existing German broadband strategy, which is mainly aimed at providing asymmetrical connections, to be supplemented by a fiber-optic approach beyond 2018.

Federal funding is concentrated on technology mix

The federal government's current funding measures, however, are still based on achievable transmission speeds, currently at least 50 Mbit/s download. An infrastructure goal that is specifically aimed at fiber-optic cables, as is currently being attempted, for example, in Schleswig-Holstein and other federal states, is currently not being discussed at the federal level.

Rather, the indicative funding is intended for expansion projects, which pursue a mix of technologies and optimization methods, such as vectoring. At the federal level, around 1.3 billion euros are currently available from the license auctions and another 1.4 billion euros budget funds.[38] Lastly, the Federal Ministry of Transport and Digital Infrastructure (BMVI)[39] had envisaged an investment volume of 4 billion euros for broadband expansion and provided the federal funding program for the nationwide NGA expansion. In its program for digitalization, the BMVI even calls for 10 billion euros to equip a future investment fund for expansion in rural regions and peripheral regions.[40] The concrete implementation steps for grid expansion have recently been published by Netzallianz, a group of telecommunications and network companies willing to invest and innovate under the direction of the BMVI and with the participation of the Bundesnetzagentur (Federal Networks Agency), various associations and science.[41] Hence, the goal of connecting all households to at least 50 Mbit/s until the end of 2018 is achievable. However, the need is also seen to lay new fiber-optic cables in previously undersupplied industrial parks. The expansion is to be further advanced until 2025 and, in particular, the next mobile communication generation is to be included. Then the complete coverage with 5G ought to have been obtained and a comprehensive "gigabit-capable convergent infrastructure" ought to be available.

Overview of fiber-optic connections by country



Source: Broadband Coverage in Europe 2015, p. 29.

Data traffic is expected to also grow enormously in rural areas.

Funding for the profitability gap and for network expansion

According to Netzallianz, the BMVI is striving to provide 10 percent of the federal net investment for digital infrastructure, which would mean annual funding of around 3 billion euros. The federal government provides funds for the expansion of the grid, which can be spent by local authorities according to a given procedure.[42] A distinction must be made between funds that close the profitability gap of private companies and funds for the expansion under municipal direction. The lack of profitability arises because telecommunications companies cannot refinance the expansion in rural areas to the same extent as is the case in metropolitan areas. However, in order to encourage companies to expand coverage, the state assumes the difference compared to expansion in densely populated areas.

The other model is the so-called "build–operate–transfer model": Here, the municipality itself commissions the expansion of the technical infrastructure, mostly optic-fiber networks, and finances this by means of public funding. Subsequently, it leases the network to commercial providers of services such as Internet, telephone, television. In principle in a municipal fiber-optic network, different service providers can come into play at the same time-. For example, users can choose between two Internet service providers, since the local authorities are bound to the open access network model mentioned.

Both models are currently being used in Germany to improve supply, whether in rural areas or where there are no or limited private-sector expansion activities. Enormous growth in data traffic is also expected in rural areas as is the creation of capacity reserves with large-scale coverage.

Network expansion in rural areas expedient

The federal government assumes that the network capacities are achieved by market forces alone. Fiber-to-home and, in particular, the connection to companies is therefore likely to be implemented in the agglomeration areas before it is available extensively in rural areas. It speaks for efforts to bring the fast networks into the countryside that many innovative companies are not based in large cities.

At the same time, investment in agglomeration areas must actually be triggered, as here the greatest coverage is achieved at relatively low costs. In addition, major effects such as increased technology demand, new business models or economies of scale will be possible in a shorter timeframe. This requires investment security, for example in the case of vectoring versus optic fiber, and good framework conditions, such as regarding the regulation of construction measures. The BMWi's digital strategy also provides for this: "In order to accelerate the expansion of the gigabit network, it must be possible to simplify procedures, accelerate protracted planning and reduce construction costs."[43] Now the project must be realized. The BITKOM study also emphasizes the importance of coordinating the actors and above all the legal and regulatory framework conditions for the investments.

The supply with fiber-optic connections cannot proceed quickly enough. Cable network operator Unitymedia has set up so-called micro-trenching for the first time in a pilot project in Lauchringen, in which the company lays empty tubes faster and without elaborate civil engineering work.

30 TÜV Rheinland quoted according to BMWi: Digitale Strategie 2025, Berlin 2016, p. 14.

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32 Expertenkommission im Auftrag des BMWi: Stärkung von Investitionen in Deutschland, Berlin 2016.

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34 T. Leimbach, D. Bachlechner: Big Data in der Cloud, TAB-Hintergrundpapier Nr. 19, Büro für Technikfolgen-Abschätzung beim Deutschen Bundestag (Eds.), Berlin 2016.

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39 http://www.bmvi.de/SharedDocs/DE/Artikel/DG/dobrindt-investitionen-breitbandausbau.html.

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41 Netzallianz: Zukunftsoffensive Gigabit-Deutschland, BMVI (Eds.), Berlin 2017; http://www.bmvi.de/SharedDocs/DE/Anlage/Presse/029-dobrindt-netzallianz-zukunftsoffensive.pdf?__blob=publicationFile

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43 BMWi: Digitale Strategie 2025, Berlin 2016, p. 15 and 30.

09

Into the future with Industrie 4.0

In Germany there are advantageous starting conditions for Industrie 4.0. But the change needs better framework conditions, especially for SMEs.

The digital networking and the wireless communication of machines and devices will be one of the big challenges for industrial production in the next few years. So-called Industrie 4.0 encompasses large innovation and competition potentials for industrial manufacturers. Especially in Germany as a traditional manufacturing location this leads to wide-reaching chances. Among other points the location benefits from a strong technological basis in industrial production, a high share of industry, a production optimized towards high process efficiency, a high societal standing of manufacturing activities, a good level of training through the German vocational education and training system, known as the dual training scheme, a strong orientation of industry towards sustainability as well as a high degree of international orientation and networking.[44]

Most of all the well-established added value networks in Germany and the strong customer orientation of companies specialized in industrial process technologies, form advantageous conditions for a quick implementation of Industrie 4.0 concepts. One point also indicating that an "Industrie 4.0 made in Germany" could be globally implemented is that Germany managed to establish the expression internationally: it is seen as the decisive pilot respectively lead market in many countries.[45] This simplifies the establishment of international Industrie 4.0 standards.

Apart from the changes to production procedures and the increased automation, potentials mostly arise through additional data and its analysis in real time. Through the connection of humans, objects and systems, dynamic, real time-optimized and self-organizing cross-company added value networks are created, which can be optimized according to a variety of criteria. Parts of the vision of Industrie 4.0 have already been realized today. The complete implementation however will still pose significant challenges for companies in the years to come.

Germany as lead market and lead supplier

The aim of the evolution in the manufacturing industry towards Industrie 4.0 in Germany is, on the one hand, to establish a lead market, i.e. to achieve an intensive use and implementation of the technologies and processes. This results in the opportunity to become the leading provider of hardware components for Industrie 4.0 as well as, on the other hand, the opportunity for new business models and services related to future production technologies. Software and platform solutions will therefore in future also be offered from Germany for the world market. The strong market position[46] in mechanical engineering, production technologies, logistics and embedded systems[47] provides a good starting point for the development towards a leading provider.

The technical core and essential innovation drivers of the Industrie 4.0 vision of the future are software- and data-intensive, embedded, mechatronic manufacturing systems based on modern information and communication technology. These systems are referred to as cyber-physical systems (CPS).[48] Utilizing digital networks, machines and facilities are supposed to communicate in real time. The technical solutions of a digital factory currently under development are intended to help plan, design and control manufacturing systems and complete value-added networks through intelligent horizontal and vertical digital networking in value-added processes. Through networking, fundamental progress is expected in productivity and flexibility, which ought to lead to rapid improvements in production.

The high pressure to change in the leading industries of the German economy such as mechanical and automotive engineering and the growing trend towards individualization of products are important drivers of Industrie 4.0 in Germany. In addition, manufacturing companies must continually increase their efficiency, in order to maintain their international competitiveness. This is an important impetus to deal systematically with the subject, especially for SMEs.

Requirements in international comparison

While the position of the Germany economy is good in a few central technologies, similar technological focus points can also be found in other countries. Therefore, for example a foresight study of acatech[49] on the international comparison also sees clear chances for South Korea and Japan to also turn into or stay important players in the equipment industries. With regard to key technologies, a ZVEI study[50] shows a special need for action on the part of the funding authorities and also industry to become increasingly involved in network communication and data analysis, in particular big data analytics and semantic procedures. Above all, education and training efforts are necessary in this area. Research and knowledge transfer should be strengthened in the fields of microelectronics, sensor technology, actuator technology and embedded software.[51] The Commission of Experts for Research and Innovation appeals to the industry to reduce its gap to the leading international countries, especially in the areas of cloud computing and big data approaches.[52]

It is Industrie 4.0 after all which enables the emergence of entirely new and partly disruptive business models, based on the use of data and on platform technologies, thanks to horizontal networking and the creation of value-added networks. Services linked to manufacturing and products will become significantly more important. This would apply to the provision of production capacities respectively production as a service to a higher degree than before. In future, mechanical engineering companies will no longer sell machines, but the utilization times of the machines with all the aspects related to this. These include predictive maintenance, software-based retrofitting and thus short set-up times while maintaining high flexibility, up to autonomous or semi-autonomous production procedures, which are made possible by the horizontal integration of suppliers and customers with the manufacturing company.

Analyses on the basis of a broad survey among manufacturing companies prove: although IT-related or IT-supported processes arrived in industrial reality years or sometimes even decades ago the large majority of the companies, however, cannot be said to have a networked production in the sense of the vision of Industrie 4.0 yet. The dissemination of Industrie 4.0-related technologies varies a lot, depending on the technology and the type of company. While software systems are very widely used for production planning and control, product lifecycle management systems for example are comparatively rarely used.[53]

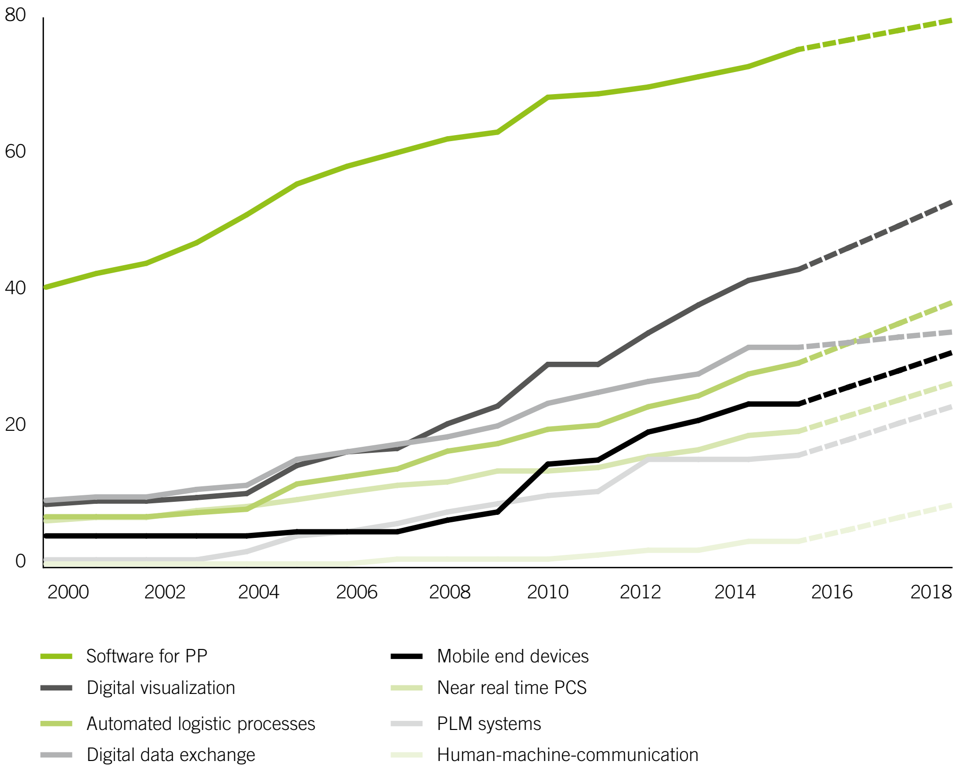
Wireless human-machine communication is already a reality in the form of visualization in numerous manufacturing operations, while programming and operating devices still are disseminated to a significantly lower degree. While wireless human-machine communication is already used by a relevant proportion of companies, there is a high unused user potential here too.[54]

Cyber-physical systems such as near-real time production control systems, the automation of internal logistics, or the digital data exchange with customers and suppliers are comparatively widespread. Safe human-machine cooperation is used less frequently.

Since 2005 there has been a steady dissemination of all technologies. Only a few companies now function without digital production planning and control. The user rate of most of the digitalization technologies looked at has multiplied during this time. The diffusion of safe human-machine cooperation only began in 2010. With 3 percent, the technology's industrial application is still in its infancy.

Dynamic when distributing the technologies of the digital factory

Share of firms which use preparatory Industrie 4.0 technology, description in percent



Source: Erhebung Modernisierung der Produktion 2015, Fraunhofer ISI.

Continuous diffusion of technologies for Industrie 4.0

The graph to the left also shows a prospective development via the dashed line. It refers to the companies which are planning to use the respective technologies by 2018. This shows that all in all further development is still to be expected. However, it is also clear that no sudden increase in the user quotas is to be expected, so the change to Industrie 4.0 will not take place in the short term. The I4.0 Readiness Index[55] of IW Consult shows that only half of the industrial companies are concerned with the subject matter and only very few have had substantiated experiences with the implementation of technologies similar to Industrie 4.0.

In a survey conducted by the Centre for European Economic Research (ZEW) in 2015, only 18 percent of companies knew the term Industrie 4.0 and only 4 percent mentioned ongoing or planned projects in this context. These were, in particular, large companies and individual companies from the IT and telecommunications, electrical and mechanical engineering sectors. In the other sectors, prevalence was much lower.

All in all, it can be inferred from the current results that the majority of the technologies examined are spreading in the manufacturing sector and have already unfolded a certain dynamic in recent years. Large parts of these companies therefore already use isolated technologies for the digitalization of their production processes and are thus on the way to Industrie 4.0. However, in the coming years, only moderate growth is to be expected.

With regard to the implementation and the realization of digital and fully horizontal integrated production, there is still great potential in many parts of the manufacturing sector. The reduction of Industrie 4.0 to aspects of efficiency gains in many companies is at the same time also a danger.[56] Industrie 4.0 it is not primarily the reorganization of production processes, but the use of networked, intelligent systems for a repositioning of the company in the market. Development opportunities for Germany are still clearly seen particularly in the case of service-based business models in manufacturing.[57]

Low-threshold solutions are needed especially for small and medium-sized companies in order to enable them to overcome obstacles and to develop and implement suitable Industrie 4.0 technologies. SME-specific funding programs, as well as networking and cooperation promotion with science and large companies, can contribute to this. Large companies, on the other hand, can benefit from technological pilot solutions.[58]

Good starting position, but also big challenges

In a perspective study[59], Germany is credited with good starting opportunities, which are based primarily on existing strengths in mechanical engineering and production technologies. Other analyses also come to this conclusion. Obvious big challenges exist particularly in international comparison, when there is the possibility of persisting with current approaches and procedures, while the opportunities for new business models are not sufficiently seen and addressed. In addition, the future study also cites a risk of over-engineering, that is, a too differentiated and too problem-oriented rather than solution-oriented perspective. Thirdly, data protection and data security play an important part. Accordingly, a study commissioned by the ZVEI[60], emphasizes that anticipatory and comprehensive legal regulation, on the use of machine-generated data, for example, may at this time have an inhibiting instead of supporting effect on innovation. Competition could be distorted to the detriment of German players.

Regulatory framework conditions and challenges

Another challenge is to ensure information protection for digital data and content. Small and medium-sized companies in particular are afraid of an outflow of know-how. Surveys show that solutions for IT security are seen as critical to the success of Industrie 4.0.[61] This is important in that the manufacturing industry in Germany has a high proportion of SMEs, which are often overwhelmed by trying to directly develop and implement a comprehensive IT security concept.[62]

The new risks and challenges include, in particular the following aspects:[63]

- In the future, the networking of industrial facilities will not only be across organizations and countries, but above all also more dynamic than before. In order to ensure IT security, trust and reliability must be established between all players in the value-added network.
- The amount of data exchanged between players for functional reasons increases significantly. This also includes data that is not only viewed as business secrets from the point of view of an individual company, but are also subject to stringent legal requirements regarding confidentiality.
- Decisions are increasingly taken autonomously by the technical systems themselves in Industrie 4.0. These decisions and the resulting changes to processes and participant configurations can result from events from different domains and partner systems as well as from the analysis of data from different sources. Decisive for the success in this aspect of Industrie 4.0 is the integrity as well as the authenticity of the data and data sources used.

Regulation: technical perspective

Existing technical IT security measures can in principle provide a good basic protection in the context of Industrie 4.0. However, this basic protection must always be viewed and implemented subject to the respective safety architecture after appropriate risk analysis. However, for some of these measures, there are often currently neither corresponding products on the market nor all-encompassing concepts, but rather only individually created special solutions.

Regarding the requirements for the protection of data, necessary basic technologies are available. However, it is for example still unclear how availability requirements of manufacturing can be linked with existing IT security concepts. In addition, concepts and solutions must be developed based on how the structure and operation of basic technologies and methods in production environments can be represented. There is a sim-

Only few firms still function without digital production planning nowadays.

ilar issue with the hardware-based trust anchors for production systems. Furthermore, approaches to continuous IT security monitoring of production systems are still rather in the early stages.

Regulation: organizational perspective

Many of the organizational IT security measures which nowadays are recommended for the industrial environment and have already been implemented there, are also suitable for Industrie 4.0. By overcoming company boundaries, however, numerous new interfaces emerge and new processes are needed. Organizational measures are needed, which are most likely to be captured in total if the upcoming change is viewed as a key innovation issue within the company and is addressed on an equal footing from all perspectives.

Regulation: Legal perspective

Issues that are currently viewed more intensively from a legal point of view, especially data protection, concern the actual problems with the implementation of Industrie 4.0 only in parts. Priority should be given to measures that eliminate uncertainties about concrete requirements, create effective implementation mechanisms, lead to uniform contractual practice, establish standards and certifications on the basis of which companies can offer and further develop their services.

The German IT Security Act (IT-Sicherheitsgesetz) provides impetus for the development of IT security regulation. However, not least because of its incompleteness and ambiguity, it clearly shows the need for further development of the legal framework. An example would be the targeted protection of information, including an unambiguous clarification of the rights to data. The certification of IT security based on legal regulations and, in particular, the development of transparent, public standards would make it possible to achieve an improvement in IT security across the board. However, there is currently a lack of certification as well as of a uniform international legal framework concerning the allocation of data to a legal entity or a beneficiary.

Regulation: standardization as a solution approach

As far as standardization is concerned, the topic of IT security should be structured as part of the work on an Industrie 4.0 reference model, and with it the necessary standardization work should be classified. Numerous standards are also applicable to industrial manufacturing. However, they need to focus on the interplay of IT security requirements and protection objectives with other non-functional requirements such as safeguarding against failure, real time and availability. A robust assessment of the relevance of existing technical IT security standards for Industrie 4.0 is only possible on the basis of the structure and the selected technologies of Industrie 4.0 reference architectures. Regulatory and standardization work have to take into account the global market situation of Industrie 4.0 and can therefore from the onset be dealt with only in a cooperative, internationally oriented network of industry, research institutions, associations and political institutions.

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10

Shaping digital change together

There are no standard solutions for digital transformations. Willingness to experiment, to learn and innovation-friendly framework conditions are needed.

Digitalization offers many innovation possibilities: from smart products and smart services to new business models and digitally interconnected value added chains up to more efficient resource allocation via digital applications in the mobility, energy or construction areas. In order to use these possibilities and master these challenges, which in part lead to disruptive changes, transformation capability is needed – on the side of companies, citizens and the state. This section summarizes the results of current studies that looked at how the transformation capability in Germany can be increased.

Willingness to experiment

Possibly the most important prerequisite for transformation capability is an openness for new things together with creativity, flexibility and readiness to experiment, as well as the opening of companies towards external partners. These abilities, which are central for innovation in general, gain special importance in the age of digitalization. The innovation cycles are especially short for digital products and applications and leaps in technology are especially common. In parts completely new framework conditions arise for the markets with the platform technology and the smart service world, thereby rendering established routines and innovation approaches obsolete.

To cope with such disruptive events and actively shape them, agility, willingness to change and a culture of risk-taking play an important part. New beginnings have to be encouraged and failing of innovation processes must not be stigmatized. Since there is no standard solution for a digital transformation, experiments are necessary. For this appropriate freedoms and a willingness to change are needed. As part of the digital transformation companies have to most of all change their organization inwards. New approaches of company and work organization as well as leadership must be oriented more strongly towards promoting creativity and flexibility. The prerequisite for this is ambidexterity – the ability of an organization to work in parallel in both the old and the new, in this case the digital world.

A second central element of the transformation capability is the willingness to learn and develop one's own competences further. This applies to individuals and organizations, be they in industry and science, in the education system or in politics and administration alike. New digital technologies are not only the occasion for qualification measures, but can also be tools for expanding competences. Digital, networked education offers offer new possibilities of individualized and interlinked learning.

Apart from that, assistance systems for example can ease and support the development of competences of people when dealing with new digital technologies. Examples for individual competences which will be essential in future are process know-how, hybrid competences, data appraisal and analysis, STEM knowledge, self-management, learning how to learn, interdisciplinary thinking and acting, as well as leadership competence.[64]

The transformation capability of industry will also depend on a lively start-up scene and its integration into innovative digital ecosystems. Start-ups entering established markets with new business models and attacking the incumbents can be drivers for disruptive innovations.[65] Uber and Airbnb are examples for a series of, especially US-American, start-ups which turned into dominant players in the digital economy in a short period of time. In Germany there is no lack of start-ups with good digital business ideas. Rather, only very few manage to establish and scale their business models in a short time in a way which turns them into larger companies with a dominant position in their respective ecosystems. One reason: young innovative companies in Germany often still lack the financial means for a period of growth. The Expert Commission on Research and Innovation in this context called for the introduction of a separate stock exchange segment for young companies with digital business models.[66] Since March 2017 Deutsche Börse offers a segment for young growth companies and small and medium-sized companies.

Contributions of politics

Politics can contribute to increasing the transformation capability and to better utilize the chances offered by digitalization. It should

- make future-proof digital infrastructure available which supports innovation.
- adjust the education and further training system to the requirements of the digital world.[67]
- via labor laws enable new forms of work and working time organization, which among others consider the development towards individualization, mobile work, digital work and freelance work adequately.[68]
- encourage and enable universities to fulfill their "third mission", commitment towards society, stronger than before. This way new knowledge and new insights stemming from research can quickly be further developed towards commercial use. Spin-offs from within universities and a stronger commitment to further training can contribute to this.[69]
- create a regulatory framework for data protection and data security, which both strengthens trust as well as leaving enough freedom for innovations. To this end, the European Data Protection Board should carry out a weighing of interests and impact assessments based on the intensity of the intervention, which will both safeguard the rights of those concerned and enables new Industrie 4.0 scenarios. The technical possibilities of anonymization and pseudonymization should be used to protect personal data while enabling the provision of big data analytics services. In addition, uniform legal requirements for IT security and verifiable standards should be established.[70]
- promote digital technologies and their use by supporting research cooperation and securing the preconditions for entrepreneurial innovation such as funding and skilled workers. To this end, a future-oriented research agenda on digitalization is an essential building block.[71]
- offer high-quality e-government to demonstrate the benefits of digitalization to citizens and stimulate demand.[72] The municipalities play a key role here, as they are the ones with which citizens are primarily in contact. The federal government and the Länder should support the local authorities with components for e-government both professionally and financially.[73]

The probably most critical point of Germany's digital transformation capability is the reorientation of today's economic structures towards platform economy and smart services. Here, a fundamental rethinking is required, particularly in the leading German industries. For a long time, the strong position of German companies in the world market was based on high technological competence and leads in innovation as well as an orientation towards market segments with exacting quality requirements with highly efficient production. It is now necessary to revamp the business models towards the customer and to pursue customized product-service-packages and open platform approaches. In addition, innovation processes need to be relaunched, much more openly and collaboratively than in the old economy, and above all at a much higher speed.

The transformation can only work if digital competences are widespread.

The transformation that companies now have to carry out as quickly as possible, especially internally, is a fundamental challenge for many companies in classical industries as well as for the service sector. This is especially true for finance and insurance, commerce, media, communications and transport.

In order to pave the way to this new world, especially also for SMEs, various measures are necessary:[74]

- Promoting non-discriminatory access to platforms and fair conditions of competition on platforms within the framework of competition law. The federal government and the European Commission are called upon here.

- Fast access for small and medium-sized enterprises by providing expertise in the development of digital service platforms from the conception and development of data-driven business models, positioning in sector-specific ecosystems and the development of digital roadmaps up to the scaling of smart services. One instrument could be a so-called onboarding factory for SMEs, which offers support when entering the platform economy. Such activities could be supported by trade/industry associations or initiatives of the federal government.

- Establishment of competence centers for smart service platforms and expert forums for the leading industries of mobility, production technology, logistics, health and energy. Both the federal government and the Länder are called upon here.

- Establishment of knowledge platforms for cross-company product and service development through associations or sector-specific initiatives.

- Establishment of industry-convergent, national competence centers for smart service platforms, e.g. within the framework of the BMWi's digitalization initiatives.

- Development of an integrated research agenda for software-defined platforms by the BMBF.

- Rapid advancement of a digital single market Europe by the European Commission.

Industrie 4.0 offers chances

A promising approach to show the possibilities and opportunities of digitalization to the majority of small and medium-sized businesses is Industrie 4.0. It can combine traditional strengths of industrial SMEs in Germany, such as integrating different technologies into complex systems and aligning production processes with specific customer requirements, with digital business models most easily.

In order to further advance the Industrie 4.0 in SMEs, current studies propose various measures:[75]

- Promote acceptance through a common understanding of Industrie 4.0's goals and opportunities.

- Advance a holistic industrial 4.0 concept and at the same time develop pragmatic solutions with a high external effect.

- Expand competences through the establishment of a qualification "industrial security" and the development of big-data knowledge.

- Promote the exchange between start-ups as well as the openness of platforms and interfaces and adapt the intellectual property rights for digital products and services.

- Establish solutions and standards in the area of IT security, in order to reduce uncertainties on the part of SMEs.

- Inform SMEs about the importance of collaborative business activities, e.g. through advisory programs and awareness measures.

- Establish platforms for industrial content and thus advance the development of new business models.

- Actively use the strong brand Industrie 4.0 and use of international standardization as a catalyst for cooperation.

- Strive for an active steering role in leading international standardization bodies.

- Promote the commercialization of Industrie 4.0 solutions by creating reference factories, lighthouse projects, testbeds, and industry-specific integration platforms.

- Pave the way for SMEs to international markets, for example via piggyback strategies with large corporations.

Digital competences of essential importance

In the long term, the transformation towards the digital economy can only be achieved if the necessary digital competences are widely available. This is why educational policy, in-company continuing education and training and in-company competence building are of central importance:[76]

- Schools do not need digitalization as a separate subject, but have to provide good information technology basics in particular in the STEM subjects with corresponding application references. Furthermore, processing of knowledge and not so much the accumulation of knowledge should be the focus and the digital touch brought into all subjects. This also includes integrating self-evident forms of use of digital technologies into teaching. However, the most important leverage for digital transformation in education is willingness to change, agility and creativity.

- The German vocational education and training system, known as the dual training scheme, has to be strengthened through adjustments to the contents of the vocational courses, equipping the training locations with up-to-date technology as well as education and further training of the teachers. Traditional kinds of education and further training must be complemented by digital methods of competence development with a high need for qualification in the areas of data analysis, process management and customer relationship management.[77]

- Academic education must be adapted to the needs of digital transformation. The focus is on data analysis, interacting with digital networks, development of innovative business models and systems engineering. Attempts to develop full-time Industrie 4.0 workers or digital engineers in the education system seem unlikely to achieve anything. Specializing in too narrow a field goes against the requirements of the new working world in which interdisciplinarity, connected thinking and working, customer experience and business model innovations are decisive.

- Lifelong learning must be adapted to demand and supported according to individual requirements.

- Counseling offers, conveying strategies for the implementation of digital business models have to be created.

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Federation of German Industries

The BDI is the umbrella organization in the field of industrial enterprises and industry-related service providers. As representative of the interests of industry, the BDI contributes to the opinion-forming and decision-making of its members. It provides information on all areas of economic policy. The BDI thus supports enterprises in the fierce competition that comes with globalization.
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The Fraunhofer Institute for Systems and Innovation Research analyzes the origin and impact of innovations. It explores the short- and long-term developments of innovation processes and the societal impacts of new technologies and services. On this basis, the institute provides its clients from industry, politics and science with policy recommendations and perspectives for key decisions.
www.isi.fraunhofer.de

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