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Information technologies are not one of Germany's strengths but of vital importance as technologies of the future

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Author: Dr Volker Zimmermann, phone +49 69 7431-3725, volker.zimmermann@kfw.de

Which emerging technologies will be relevant in Germany in the coming decade? Where can (sustainable) growth come from? In which new technologies is Germany well-placed and where does a new course have to be set today? KfW Research has commissioned a study to identify technologies of the future from a German perspective. Its focus was on technologies that may already achieve high market relevance in the medium term. Particular emphasis was placed on information technologies that form the basis for digitalisation.

The study found that Germany has a differentiated technological profile with many starting points for future value creation. Examples include the automotive industry and production technology, as well as climate and environmental technologies.

Information technologies, however, are not among these strengths. Based on patents or scientific publications, Germany's competencies in these technologies are merely below average. Information technologies thus present a challenge for Germany. After all, they are gaining increasing importance as 'general-purpose technologies' in many other technological fields and economic sectors. What is also of importance in this regard is that the various information technologies are often closely interrelated. A niche strategy – focusing on selected individual technologies – is not promising.

Under these conditions it appears hardly realistic to assume that Germany could catch up with other countries in developing such technologies within a few years simply by conducting more research and development. Particular emphasis should therefore be placed on making Germany internationally competitive in the application of these technologies.

A wide range of approaches can make this possible. Building the necessary competencies within enterprises would be important, for example in production technology companies. The further integration of information technologies requires software development and implementation companies that can develop corresponding solutions and provide consulting services. Promoting relevant start-ups can provide important impetus in this direction.

A key element in strengthening information technologies is to expand corresponding training. Skills shortages and lack of expertise are major barriers for enterprises. More efforts therefore need to be undertaken in basic and advanced training.

Using information technologies in day-to-day operations can contribute to building expertise within enterprises through 'learning by doing and using'. The diffusion of information technology applications is thus helpful in preparing companies for more complex applications. This will contribute to speeding up the expansion of digital technologies.

How is Germany positioned with respect to new, emerging technologies? Do Germany's strengths include technologies that are relevant to digitalisation? For a highly developed country poor in natural resources like Germany it is vital to be highly competitive by innovating and making progress in key technological areas and to generate growth in this way. That is the only way it can create future-proof jobs and safeguard and, in the best of cases, increase prosperity.

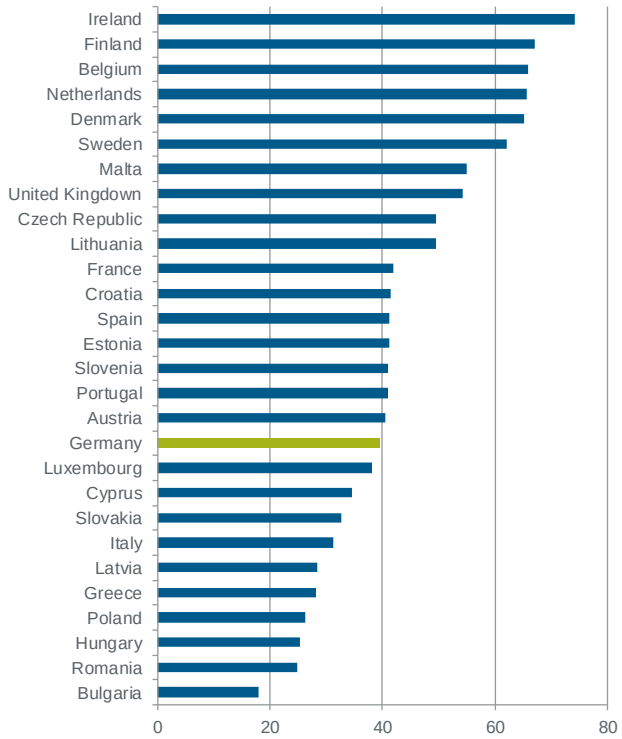
KfW Research therefore commissioned a study with the Fraunhofer Institute for System and Innovation Research (ISI), Karlsruhe to identify technologies of the future from a German perspective.[1] The main criterion for their selection was that they should gain high market relevance in the medium term, in other words, in a period of around five to ten years. This means technologies that are commercially usable within a foreseeable period and have significant economic potential. Information technologies that form the basis for the digitalisation of the economy and society played a particular role in the study.[2] Given the great importance of these technologies, the key findings of this study in relation to information technologies are shown below. The overall findings were already summarised in the Focus on Economics No. 321 entitled 'Technologies of the future for Germany'.[3]

Deficits in the application of information technologies in Germany

Although the penetration of information technologies into the economy and society is not a new trend,[4] Germany ranks mid-range at best in the application of digital technologies in a EU comparison. It ranks 12th within the EU 28 on the Digital Economy and Society Index of the European Union (DESI).[5] The country also merely ranks 18th in integrating digital technologies into business processes (Figure 1). Other studies confirmed this finding: According to the *Wirtschaft DIGITAL* economic monitoring report, Germany does not possess any pronounced digitalisation-specific strengths. The report identified a distinct export weakness in information technologies as a symptomatic consequence.[6] The study of the Fraunhofer Institute compared this analysis from the aspect of application with the development aspect of new technologies.

Figure 1: Application of digital technology in business

In index points

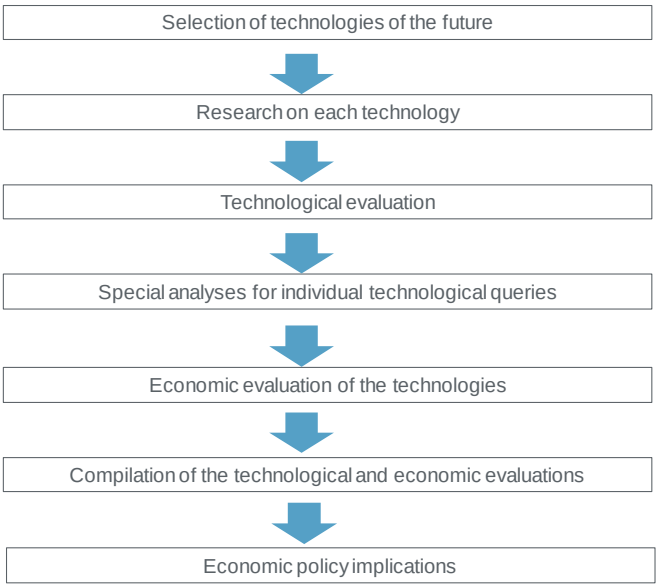


Source: DESI (2020)

Identifying technologies of the future based on Germany's technological position

The study examined in detail how well Germany is positioned in the development of new technologies currently regarded as 'technologies of the future'. The preselection of potential technologies of the future from a German perspective was based on a range of German and international studies on technologies of the future and societal challenges. External experts and experts of the Fraunhofer Institute for System and Innovation Research were also interviewed. On that basis, a list of a good 30 technologies was compiled for further analysis. These technologies cover a broad spectrum and, in particular, include a wide range of information technologies.[7]

Figure 2: How the study was carried out



Source: Schmoch et al. (2021)

For each of these technologies, the study determined a set of indicators relating to patents, scientific publications and brand applications that illustrate the dynamics of the development of these technologies and Germany's technological position. These indicators were combined into a composite indicator so as to enable the technologies to be ranked (see box on methodology at the end). The study also conducted in-depth analyses on individual technologies and determined their economic relevance on the basis of their current market value from a German perspective. On that basis, the examined technologies were evaluated and conclusions drawn for economic policy (Figure 2).

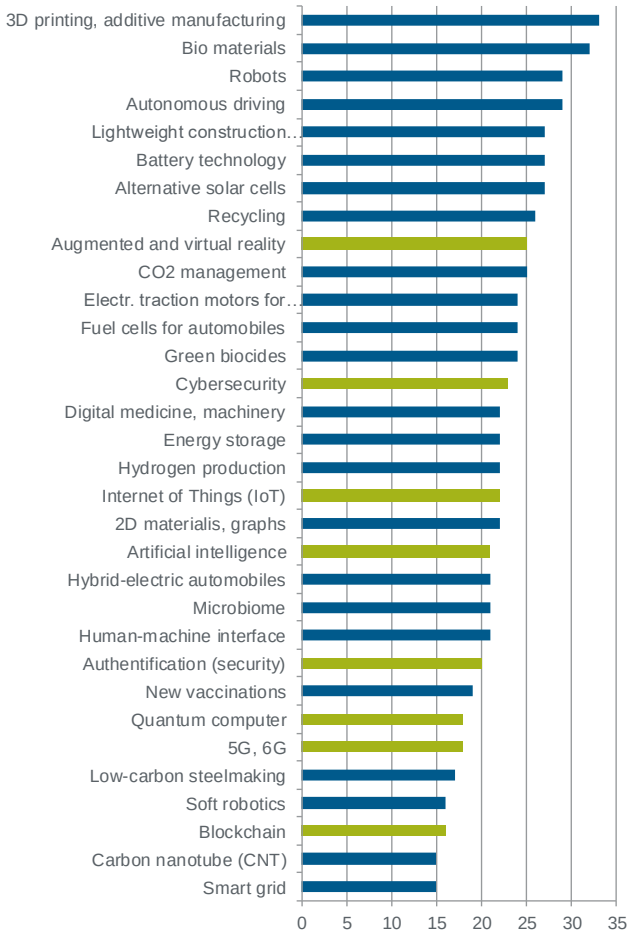
Information technologies predominantly rank at the bottom of the list of Germany's strengths ...

The ranking of each technology reflects how promising a technology is from a German perspective based on the dynamics of its development worldwide and Germany's participation in it.

In this assessment of the position of a technology from a medium-term perspective, additive manufacturing, biomaterials and robotics occupy the top ranks (Figure 3). Additive manufacturing or 3-D printing is the generic term for all manufacturing processes in which materials are deposited layer upon layer to create three-dimensional objects. Biomaterials are important because they can mitigate the problem of dwindling conventional raw materials as they are derived from renewable resources. Robots, on the other hand – especially industrial robots – have long been one of Germany's strengths. Given the rapid developments taking place in this field (e.g. service robots), robotics should also be seen as a technology of the future.[8]

Figure 3: Ranking of technologies of the future by technological indicators from a German perspective

In index points



Source: Schmoch et al. (2021)

Information technologies that are fundamental to digitalisation have risen to 14th rank with cybersecurity for the first time. This refers to technology aimed at safeguarding internet security. Most of the information technologies examined, on the other hand, occupy positions from 18th rank. The Internet of Things, for example, which is important for Industry 4.0 applications from a German perspective, occupies this position. It involves linking physical and virtual objects. Blockchain technology, the subject of intense public debate (which involves coupling information in secure chains, for example to document transactions in a decentralised administration), even ranks only 30th. Between them, artificial intelligence[9], which has also come under intense public scrutiny (involving advanced self-learning computer systems that solve problems such as classifications, statistical forecasts, clustering, detection of anomalies or rankings), ranks 20th. The development of the future mobile telecommunication standards 5G and 6G occupies rank 27.

Overall, information technologies are not among Germany's strengths in technological development. Thus, Germany does not occupy a very prominent position in technologies that are fundamental to digitalisation.

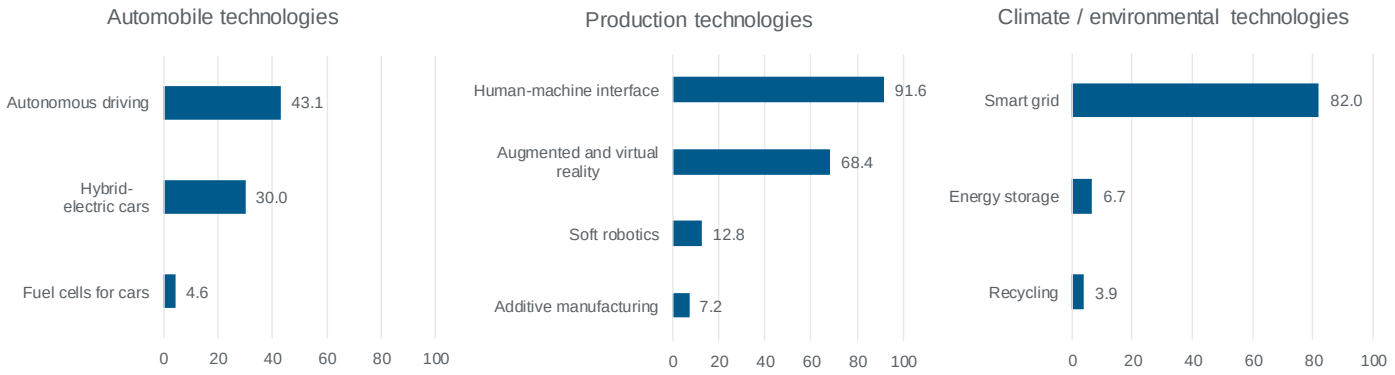
... but they are of great importance as general-purpose technologies

Information technologies therefore pose a challenge for Germany. As general-purpose technologies, information technologies are of increasing importance for other economic sectors and technological fields as well, such as motor vehicles, production technologies and climate and environmental technologies (Figure 4). Any dependence on foreign producers in this area is regarded as particularly problematic.

Already, high shares of German patents in these fields relate to applications of information technologies. In technologies that are relevant to the automotive industry, for example, this applies to autonomous driving and hybrid electric vehicles, where 43 and 30% of patents refer to information technologies. In production technologies, information technologies at the human-machine interface even account for nearly 92%, and still a good 68% among patents relating to augmented and virtual reality. In climate and environmental technologies, smart grid technologies involve a very high share of information technologies – 82%.

Figure 4: Share of patents with information technology in other technological fields

In per cent



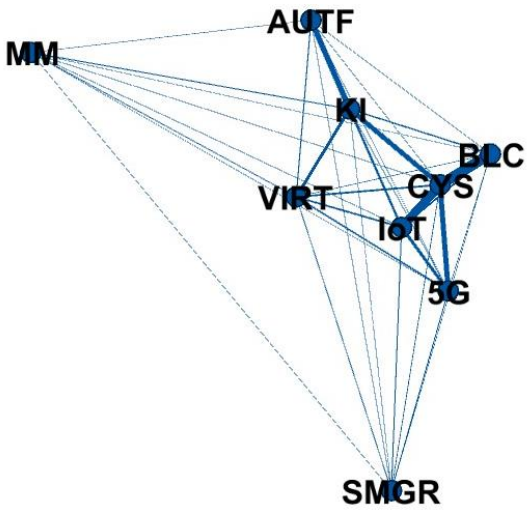
Source: Schmoch et al. (2021)

Convergence phenomenon makes niche strategies in information technologies less than promising

A further characteristic of information technologies is the phenomenon known as 'convergence of information technologies'. This refers to the coming together of multiple technologies across industries. Developments in one technology stimulate and accelerate further development stages in other digital technologies. Progress in computing power and data availability, for example, facilitate the further development of artificial intelligence.[10]

Figure 5 illustrates these correlations on the basis of patent applications. It visualises the overlaps of patent applications across multiple technological fields. The connecting lines in the network diagram show what different technologies are addressed in a patent. Technologies with many parallel references to other technologies are shown at the centre of the network.

Figure 5: Network of information technologies



Note: KI=artificial intelligence, BLC=blockchain, CYS=cybersecurity, IoT=Internet of Things, 5G=5G, MM=human-machine interface, VIRT=augmented and virtual reality, AUTF=autonomous driving, SMGR=smart grid

Source: Schmoch et al. (2021)

Artificial intelligence, cybersecurity, blockchain, the Internet of Things and 5G occupy a key position among information technologies. They are very often interconnected as well as connected to other information technologies. By contrast, the smart grid or the human-machine interface – which can also be regarded as applications of information technologies – tend to be on the fringes of the network but they still have a wide range of links to the other information technologies.

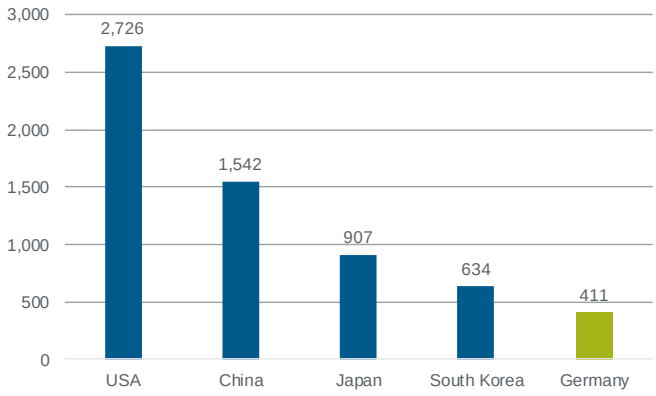
Thus, there are close links between information technologies, and they have intensified in recent years. These links are expected to continue to grow stronger in the future. It therefore does not appear reasonable to focus on specific information technologies alone. After all, having strengths in a specific information technology alone is not very helpful as they have to be supplemented by competencies in other information technologies. Particularly in information technologies, a niche strategy is therefore less than promising.

In the medium term, Germany will hardly be able to catch up in information technology development ...

It must be emphasised that Germany's specialisation in all areas of information technology (IT) is well below average in patents and publications. It appears hardly realistic to attempt to catch up here with other countries in just a few years by investing more in research and development. In order to illustrate this by way of example, Figure 6 compares the patent applications of important IT locations for artificial intelligence with those from Germany. Germany clearly lags behind countries such as the US, China, Japan and South Korea. In 2018 US patent applications in the field of artificial intelligence exceeded those of Germany nearly sevenfold. China, too, submits nearly four times as many patent applications as Germany.

Figure 6: Patent applications in the technological field of artificial intelligence in 2018

In index points



Source: Schmoch et al. (2021)

... so it needs to become competitive, particularly in the application of information technologies

To be sure, the development of information technologies should be supported. The first critical step, however, is to improve competencies in the application of information technologies in manufacturing in order to become internationally competitive in the application of these technologies. A fast follower strategy has already proven successful for Germany in individual technological areas in the past.[11]

This can involve developing relevant expertise in manufacturing technology companies, for example. Businesses that specialise in software development and implementation and possess manufacturing technology skills, for example, are important to achieve this, as they can advise companies on the introduction of digital technologies such as Industry 4.0, for example. Promoting start-ups can provide important impetus in this direction.

Not least, expanding relevant education in mainstream and vocational schools, colleges and universities is a key element for strengthening information technologies. Continuing education and training measures should also be taken into consideration. This would allow the skills shortage already existing in this area to be addressed in the medium term. The

need for further training in digital skills in particular has grown strongly of late. Just under half of SMEs (46%) had a medium or high need for training in this field at the beginning of the year 2021 – more than for core occupational skills (44%) or any other topic.[12]

Using information technologies can also contribute to building expertise within enterprises through 'learning by doing and using'. The diffusion of basic information technology applications can help to prepare businesses for the use of more complex digital applications.[13] Broader diffusion of information technologies can thus accelerate the growth momentum of digital technologies itself.

Conclusion

Germany has a differentiated technological profile with many starting points for future value creation. These strengths should not be frivolously jeopardised but continuously developed further. Examples include the automotive industry and production technology, as well as climate and environmental technologies. Building on national strengths in technological competitiveness and keeping the acquired profile strong in the long term has generally proven to be a successful strategy.

With respect to information technologies, however, it is imperative to expand the range of competences in this direction. Otherwise Germany will not succeed in developing important value creation potential for the country. Moreover, it also appears to be appropriate to develop own information technology competencies and achieve sufficient relevant autonomy in the context of the debate on technological sovereignty.

But it appears hardly realistic to assume that Germany could catch up with other countries in just a few years merely by stepping up research and development efforts. Particular emphasis should therefore be placed on building competencies in the application of these technologies and becoming internationally competitive in their application.

Considerable efforts will be necessary to achieve this in the future as well. After all, neither the development nor the application of information technologies is currently one of Germany's strengths. The digital transformation is facing multiple barriers. Another recent challenge is that the coronavirus crisis has made it even more difficult for enterprises to decide between strengthening their crisis resilience and investing in their future.

Methodology

Calculating the overall indicator for assessing a technology

In order to assess the technologies, we examined the technological development and Germany's contribution. We availed ourselves of patents, research publications and trademark registrations. Patents reflect the short to medium-term development of a technology, while research publications tend to show the more long-term development. Trademark registrations are an indication of how easily a technology is already available in the market.

With regard to patents, we used transnational patent applications.[14] They provide the advantage that their multinational character gives them high value. They also make international comparisons easy as there are no 'home advantages' as there would be in the assessment of patent applications with national patent offices. To obtain specific indicators of application activity, for each technology we identified the global trend in the development of patent applications, Germany's specialisation in the relevant technology, the absolute number of German patents and the size of the patent families (e.g. the number of countries in which a patent is applied for). In an alternative calculation we also took into account the share of SMEs in patents.

With a view to research publications, parameters that can be taken into account are the development of the global trend over time, the specialisation of German publications in the relevant technology, the absolute frequency of German publications and their rate of citations.[15] With respect to trademark registrations, we also took into account the global trend, Germany's specialisation and the number of German trademark registrations.[16]

The relevant global trend stands for the development trend of a technology overall. For patent applications this value is based on the 2010–2017 period, for publications 2010–2019 and for trademarks 2010–2018. Germany's specialisation was measured on the basis of relative specialisation in a technology.[17] The degree of specialisation and the number of German patents, publications and trademarks represent Germany's position in a technology. The data on specialisation and the absolute number in Germany refer to the 2015–2017 period for patents, 2017–2019 for publications and 2016–2018 for trademarks. The size of the patent family and the rate of citations in publications are measures of the quality of a patent or publication. They refer to the 2014–2016 period and the year 2017. The underlying time periods are based on data availability and the requirements of the calculation.

The values of all individual indicators were stratified into a five-point scale. Sub-indicators were then calculated for patents, publications and trademarks by adding the values for the individual key figures. For the patent figures the number of German patents and the size of the patent family were multiplied by the factor 1.5. The three sub-indicators thus obtained were then aggregated into a total index. The sub-indicator for patents was weighted 1.0, publications 0.5 and trademarks 0.3.

[1] Cf. Schmoch, U. et. al (2021): Identifizierung und Bewertung von Zukunftstechnologien für Deutschland (*Identifying and assessing future technologies for Germany* – our title translation, in German only). Final report to KfW.

[2] The study also took into account Germany's existing technological profile, societal challenges such as climate change, the situation of small and medium-sized enterprises (SMEs) with regard to these technologies and the current debate on technological sovereignty.

[3] Cf. Zimmermann, V. (2021): Technologies of the future for Germany: The country is well placed in many areas, but some need readjustment, Focus on Economics No. 321, KfW Research.

[4] Examples of earlier digitalisation waves were the New Economy Boom of the second half of the 1990s, the rise of the PC since the 1980s, and industrial robots since the 1970s.

[5] Cf. DESI (2020); https://ec.europa.eu/digital-single-market/en/desi; last retrieved on 6 April 2021. The United Kingdom is still included in the indicator.

[6] Cf. latest version: Federal Ministry of Economics and Technology (2018): Monitoring-Report Wirtschaft DIGITAL 2018 (in German). Der IKT-Standort Deutschland und seine Position im internationalen Vergleich (*Germany as an ICT location and its position in international comparison* – our title translation, in German only).

[7] Although robotics is comprehensively defined as one technology, the study additionally examined the new sub-segment of soft robotics, which enables increased flexibility and adaptation to tasks, as a separate technology.

[8] Thus, the Commission of Experts for Research and Innovation, for example, also regards robotics as a technology of the future. Cf. Commission of Experts for Research and Innovation (2016): Report on Research, Innovation and Technological Performance in Germany. 2016 Report.

[9] Cf. Zimmermann, V. (2021): Artificial intelligence: high growth potential but low penetration in SMEs, Focus on Economics No. 318, KfW Research.

[10] Cf. Zimmermann, V. (2021): Artificial intelligence: high growth potential but low penetration in SMEs, Focus on Economics No. 318, KfW Research.

[11] Cf. Legler, H. et al (2000): Germany's Technological Performance: A Study on Behalf of the German Federal Ministry of Education and Research, ZEW Economic Studies 8.

[12] Cf. Leifels, A. (2021): Weiterbildung bricht in der Krise ein – Bedarf an Digitalkompetenzen wächst (*Continuing education drops during the crisis – digital skills needs are growing* – in German only), Focus on Economics, No. 329, KfW Research.

[13] Cf. Saam et al. (2016): Digitalisierung im Mittelstand: Status Quo, aktuelle Entwicklungen und Herausforderungen (*Digitalisation in SMEs: status quo, current trends and challenges* – our title translation, in German only), research project commissioned by KfW Group.

[14] Transnational patent applications are applications in patent families, with at least one application filed with the World Intellectual Property Organization (WIPO) via the PCT process or an application with the European Patent Office. Cf. Neuhäusler, P. and Rothengatter, O. (2020): Patent Applications – Structures, Trends and Recent Developments 2019, Studien zum deutschen Innovationssystem 4-2020.

[15] The research on publications was conducted in the multidisciplinary Web of Science (WoS) database in the Scisearch version of the provider STN.

[16] The research was based on European trademarks with the European Union Intellectual Property Office (EUIPO, Alicante).

[17] This is the RPA value that is customary in patent analyses. Cf. Soete, L. and Wyatt, S. (1983): The use of foreign patenting as an internationally comparable science and technology indicator. In: Scientometrics 5(1), p. 31–54.