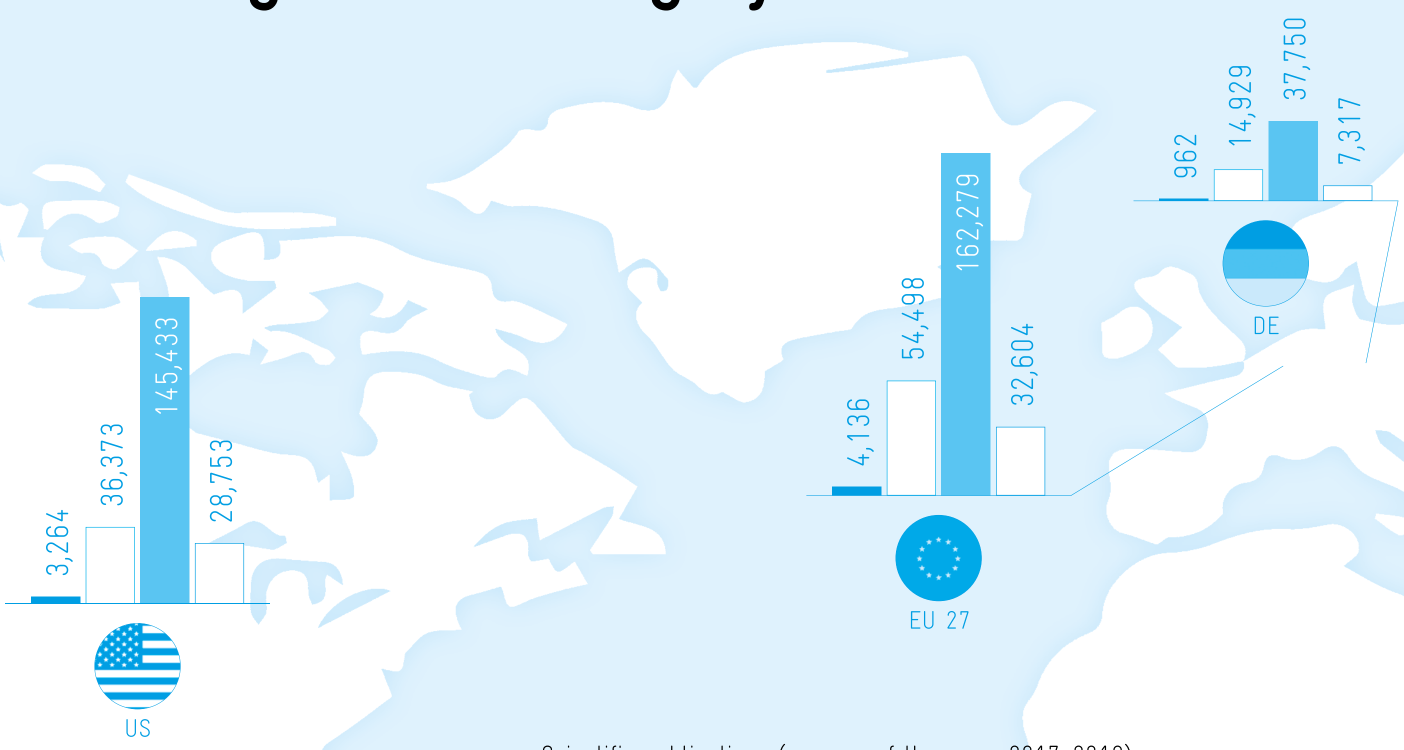
B 1 Key Enabling Technologies and Technological Sovereignty

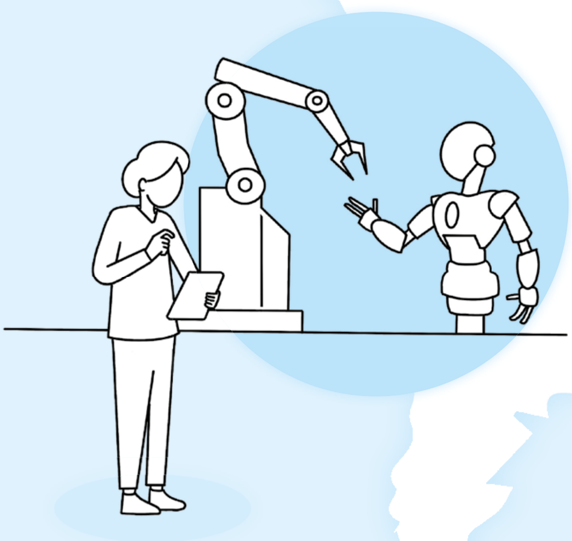


Scientific publications (average of the years 2017-2019)

- Production Technologies
- Materials Technologies
- Bio- and Life Sciences
- Digital Technologies

Production Technologies

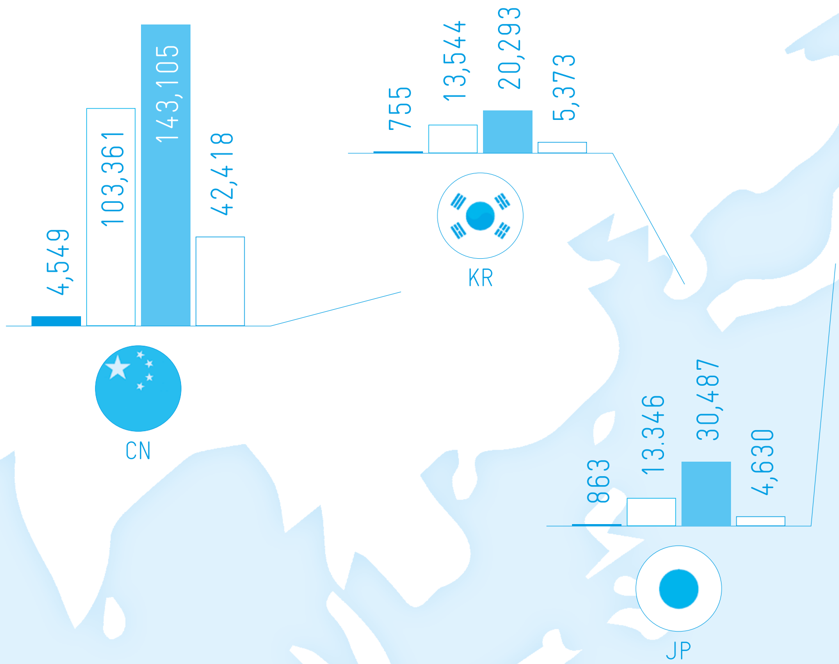
Advanced Manufacturing, Robotics, Photonics



Materials Technologies

New Materials, Nanotechnologies

Key enabling technologies open up high potentials for a prosperous technological and economic development of a national economy and thus for prosperity. They are of central importance for current and future value creation activities. Unique selling propositions and innovations in key enabling technologies contribute to the competitiveness of an economy's companies in these technologies. For this reason, key enabling technologies have increasingly moved into the focus of politics. In order for a national economy to be able to act with technological sovereignty in established as well as future key enabling technologies and not fall into welfare-reducing dependencies, political decision-makers see themselves compelled to develop suitable strategic concepts.

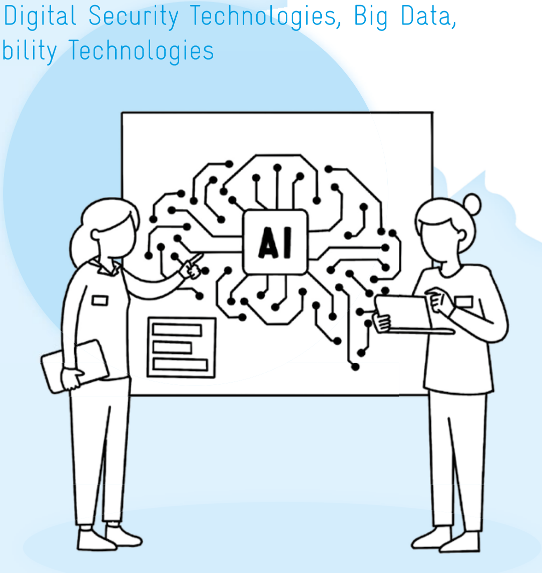


Bio- and Life Sciences

Bioeconomy, Life Sciences

Digital Technologies

Microelectronics, Artificial Intelligence, Internet of Things, Digital Security Technologies, Big Data, Digital Mobility Technologies



B 1 Key Enabling Technologies and Technological Sovereignty

Key enabling technologies are technologies that play key roles in technological and economic developments. One of these roles results from the importance of a key enabling technology for the innovative further development and application of other technologies (enabler function). For example, powerful control chips play a particularly important, often irreplaceable role in many areas of modern production (Industry 4.0), in the provision and further development of new energy and mobility concepts, and increasingly in domestic consumption (smart home). These technologies also play a key role through their central contribution to the emergence and development of large and dynamic global markets. By 2024, for example, global sales of the artificial intelligence (AI) market are expected to exceed the US$500 billion mark, with a five-year compound annual growth rate of 17.5 percent and total sales of US$554.3 billion.[128] In addition, key enabling technologies are seen as playing a key role in important transformation processes in the economy and society. For example, sustainability-relevant technologies in the fields of bioeconomy or high-quality healthcare can come into play in addressing the grand societal challenges and pursuing the Sustainable Development Goals.[129]

Key enabling technologies open up high potentials for a prosperous technological and economic development of a national economy and thus for prosperity. They are of crucial importance for current and future value creation activities. Unique selling propositions and innovations in key enabling technologies contribute to the competitiveness of companies and other stakeholders in the R&I system of an economy. Finally, they open up the possibility for an economy to actively shape global economic and social transformation processes and to contribute to the solution of the grand societal challenges.

To be able to pursue these goals in a self-determined manner and to use the associated potential, an economy must have a high degree of technological sovereignty in dealing with key enabling technologies. If an economy loses its international connection and thus its sovereignty, dependencies can arise that reduce welfare and are difficult to eliminate in the short or medium term.

For this reason, key enabling technologies have increasingly become the focus of political decision-makers, who must develop suitable strategic concepts so that an economy can act with technological sovereignty in established as well as future key enabling technologies and does not fall into welfare-reducing dependencies.

B 1-1 Key Enabling Technologies and Their Relevance for Technological Sovereignty

Key Enabling Technologies Defined by Three Criteria

The definition of the concept of key enabling technologies lacks consistency and precision both in scientific literature and in political discussion.[130] The following three criteria[131] are proposed in the existing literature[132] for the identification of key enabling technologies:

1) Broad applicability in a variety of technology areas or economic sectors

2) Strong, non-substitutable complementarity to a variety of other technologies

3) High potential for performance enhancement in a key enabling technology itself and in its application areas

Criteria one and two relate directly to the application side of key enabling technologies, that is, a broad application in other technologies, and very often without technological alternatives. Criterion three focuses on the innovation potential of a key enabling technology and its application technologies.

In R&I policy and economic policy practice, the classification of a technology as a key enabling technology is not systematic and definition-driven but results discursively from the political processes. An instrumentalization of the concept of key enabling technologies for the enforcement of particular interests cannot be ruled out with such an approach. To avoid this, clear criteria, corresponding to the three mentioned above, must be used in the political process to classify a technology as a key enabling technology.

Portfolio Analysis of Key Enabling Technologies Important

A portfolio analysis is important for determining the international position of an economy in the development and use of established and future key enabling technologies. The established key enabling technologies to be considered can be identified based on the criteria mentioned above. In the case of future key enabling technologies, the extent to which a technology can be expected to fulfil these criteria in the future must be examined. The identification of a future key enabling technology in the early phase of its development is empirically difficult and associated with a high degree of uncertainty. One possible approach is a dialogue-based strategic foresight process[133] that involves experts from science, politics and business and is led by a strategic advisory body.[134]

This strategic advisory body can also be given the task of building and developing a portfolio of established and future key enabling technologies. This task would include regularly reviewing the classification of a technology as a key enabling technology within the portfolio.

The systematic development of a portfolio can help to identify key enabling technologies at an early stage by means of a long-term perspective and to support their development with suitable measures if necessary. In the case of established key enabling technologies, weaknesses and resulting dependencies can be identified in an international comparison.

Mastery and Availability Essential for Technological Sovereignty

The term technological sovereignty has been used in German politics since around the beginning of the 2010s and initially focused on digital technologies and digital security. Over time, the term was expanded to include all areas of technology. Digital technologies and security aspects are now discussed under the term digital sovereignty, which is considered an essential component of a country's technological sovereignty.[135]

In the literature, the concept of technological sovereignty is described and defined quite differently.[136] A suitable definition starts at the level of a national economy and refers to a single technology. The definition of the Commission of Experts builds on the Fraunhofer ISI's definition[137] and adapts it accordingly:[138]

> A national economy has technological sovereignty if it can itself provide and further develop a technology it deems critical for its welfare, competitiveness and ability to act, and if it can participate in its standardization and is able to apply and to source this technology from other economic areas without one-sided structural dependency.

Key enabling technologies, which by definition contribute significantly to welfare and competitiveness in a national economy and occupy central, system-relevant positions, are undoubtedly among the technologies for which the question of the technological sovereignty is of particular relevance. If the technology is not sufficiently available, welfare-reducing bottlenecks can occur – especially in crisis situations.

Technological sovereignty results, on the one hand, from the degree to which a national economy masters the application and use of a certain technology and, on the other hand, from the degree to which this technology is available to a national economy for further use. The dimension of mastery measures the knowledge and skills that exist within a national economy with respect to a particular technology. The dimension of availability measures the extent to which a national economy has a particular technology at its disposal for further use, whether through its own production or through full or partial procurement from outside via international trade.

Technological Sovereignty Threatened by Gaps in Key Enabling Technologies

How the mastery of a key enabling technology can become a critical factor can be explained with a model of technological knowledge building.[139, 140] According to this model, the process of building knowledge in a particular technological field takes place in a cumulative, self-reinforcing way. This means that further knowledge growth in a technology area depends on the level achieved so far in that area. In relation to a key enabling technology and the innovation competition between countries, this mechanism implies that initially existing differences in technological knowledge increase. As a result, a growing technological gap[141] builds up between countries.

How this development affects the two dimensions of technological sovereignty of an economy is illustrated by the example of a single key enabling technology as follows: regarding the dimension of mastery of a technology, the leading economy in a key enabling technology always has a high or complete technological sovereignty. As the technological gap increases, however, the degree of mastery of this key enabling technology decreases step by step for the technologically following economy, and its technological sovereignty declines.

However, this decline in sovereignty can be compensated for by the following economy taking advantage of the international division of labour and importing the latest version of this key enabling technology and the associated application expertise from the technologically leading economy. Technological sovereignty would thus be secured for this economy in terms of the dimensions of availability and mastery of the technology. Yet this approach implies that the comparative disadvantages for the following economy increase as the technological gap grows and its terms of trade deteriorate.[142] Accordingly, the import of the key enabling technologies, including application expertise, becomes increasingly expensive, with the consequence that both the degree of availability and the degree of mastery decrease. In this way, the technological sovereignty of the following country is continuously reduced and its dependence on foreign countries increases.

If the examination is extended to several or very broadly positioned key enabling technologies, then it is conceivable that economies specialize in certain key enabling technologies and build up comparative advantages in them over other economies. In this context of a portfolio of key enabling technologies, the question of technological sovereignty in a particular key enabling technology plays a lesser role. Accordingly, economies can each specialize in key enabling technologies and are then mutually dependent on each other for key enabling technologies, making unilateral dependencies less likely.

An economy's involvement in foreign trade is determined by its comparative advantages and disadvantages in relation to other countries. The concept of comparative advantage can be divided into two types: static and dynamic comparative advantage. Static comparative advantages are due to contextual factors, such as natural conditions; they cannot be influenced or can hardly be influenced. Dynamic comparative advantages, on the other hand, are due to changeable factors. These include technologies that can be improved and developed through technological change and innovation.

An economy that specializes in areas with existing static comparative advantages in such a way that key enabling technologies must be imported from abroad runs the risk of losing technological sovereignty in one or more key enabling technologies due to increasing technological gaps and thus becoming dependent.

One way out of this situation is to stop specializing in areas with existing static comparative advantages. Rather, it makes sense to pursue the development of one's own comparative advantages in key enabling technologies with appropriate funding measures. This 'wrong' specialization from a static point of view is initially associated with welfare-reducing effects.[143] In a dynamic and long-term perspective, however, these can be overcompensated by welfare gains resulting from comparative advantages in key enabling technologies that have been built up in the meantime.[144] South Korea in the 1980s is a good example of this.[145] Its very successful industrialization and its way into the group of technologically leading economies are based precisely on the fact that it did not rely on existing static comparative advantages in rice cultivation and other technologically less demanding areas. The development towards technology- and knowledge-intensive sectors and industries, pushed by the state and supported by intensive promotional measures, has enabled the country to establish comparative advantages in these demanding technology areas after a certain period of time.

B 1-2 Germany's Positioning in Current Key Enabling Technologies

Current Key Enabling Technologies Very Heterogeneous

The Commission of Experts points out that identifying key enabling technologies is a complex and controversial undertaking. For this reason, the Commission of Experts uses for this chapter a study[146] commissioned by it, which employs a selection of key enabling technologies for its analyses that has already been prepared for monitoring and strategy papers at the European and German levels.[147] In this study, 13 individual technologies (see figure B 1-1) were identified that can be assigned to four thematically overarching key enabling technology areas: production technologies, materials technologies, bio- and life sciences, digital technologies.

Since the sectors and products in which a key enabling technology is used play only a minor role in the classification of a technology as a key enabling technology and in the technological sovereignty of a country, the selected key enabling technologies are not considered from an application standpoint in the following. Accordingly, the technologies are analyzed below in terms of how intensively they are being researched and developed and how international trade in them is taking shape. This empirical study is thus based on a supplier-side characterization of key enabling technologies.

First, it is shown whether the worldwide inventions assigned to a key enabling technology, measured in terms of patent applications, originate predominantly from a few or from many different sectors; it is thus a question of the breadth of the development activities associated with it.[148] In addition, it is shown to what extent the worldwide patent applications that can be assigned to a key enabling technology are limited to a clearly defined field of technology or are broadly distributed across different fields of technology.[149]

In figure B 1-1, the key enabling technologies are arranged according to these two dimensions and compared with each other.[150] A heterogeneous structure emerges. For example, while big data technology is being further developed by companies in many sectors, its technological basis is comparatively specific. Microelectronics, on the other hand, is developed by companies from only a few sectors, with a technological base of medium breadth. Advanced manufacturing and new materials technologies are characterized by both a comparatively broad technological base and development activities in comparatively many sectors.[151]

Indicators for International Comparison

Indicators from the areas of research (scientific publications) and development (transnational patent applications), trade (trade balances and specializations) and standard setting (participation in standardization bodies) can represent Germany's position in an international comparison.[152] The degree of mastery of a key enabling technology can be estimated based on publications and patent applications. Trade balances provide information on their availability. Standard-setting activities allow conclusions to be drawn about both the mastery and availability of key enabling technologies.

Scientific Publications: China Particularly Dynamic

To determine Germany's position in an international comparison of research on key enabling technologies, scientific publications worldwide published from 2000 to 2019 are considered.[153] Since changes over time and thus changes in position are of interest, the mean values of the first three years of the period under consideration (2000-2002) and those of the last three years (2017-2019) were calculated and compared. The change factor indicates how the publication figures of the last three years relate to the publication figures of the first three years.

The difference in the change factors between two countries can be used to assess how the gap, in this case the scientific gap, between two countries has developed. For example, if one country lagged

Fig. B 1-1 Development activities and technological basis

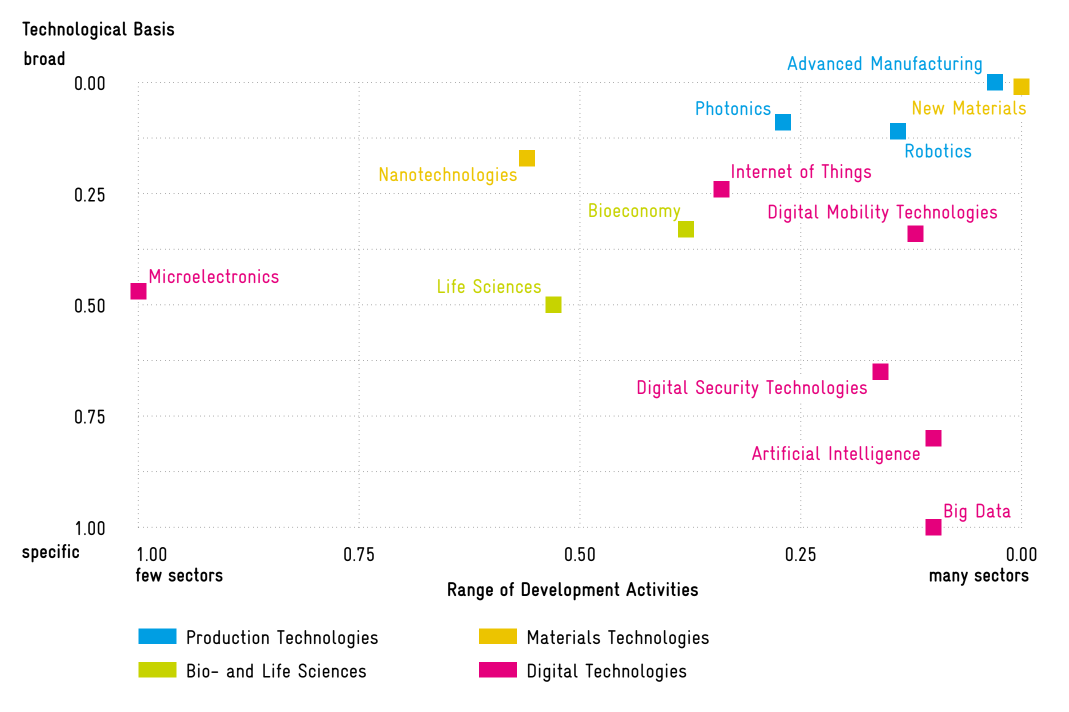


Illustration of the 13 individual technologies based on the breadth of development activities and the technological basis. Legend: With a value of 0.1, Big Data has a relatively broad range of development activity (corresponding technologies are being developed in many sectors). With a value of one, Big Data has a very specific technological basis. Source: Own representation based on Kroll et al. (2022).

behind another in absolute publication numbers but had a higher change factor, the lagging country could narrow the scientific gap over time or possibly even overtake the initially leading country. However, if the change factor of the leading country is greater than that of the lagging country, then the scientific gap between the two countries has widened.

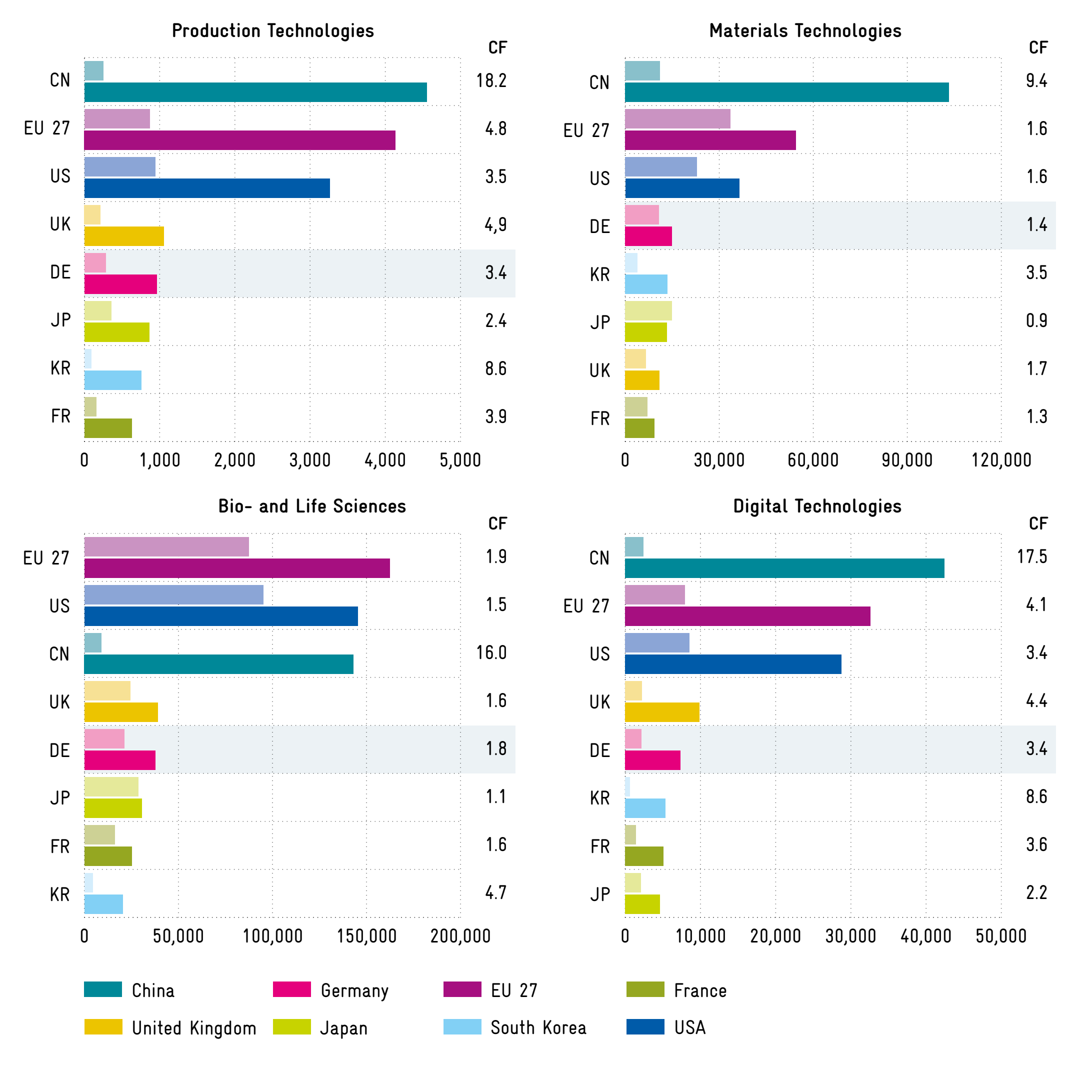
Figure B 1-2 demonstrates that China,[154] the USA and the EU 27 dominate publication activities in all four key enabling technology areas at the current margin. The rapid increase in publication activity in China stands out. Although Germany and other countries have also significantly increased their publication volume, none have done so to a comparable extent. In the area of digital technologies, for example, Germany was able to increase its publication volume by a factor of 3.4, but China by a factor of 17.5. In less than 20 years, China has thus succeeded in overtaking the USA and the EU 27 in the fields of digital technologies, materials technologies and production technologies, and in catching up in the field of bio- and life sciences.[155]

Germany occupies a position in the midfield in all key enabling technology areas that is commensurate with its size. In terms of the change factor, it is generally on par with the European countries and the USA. Compared to South Korea and China, which have significantly higher change factors, Germany's initially advantageous position deteriorates or turns into a following position. A strong position at the top is only possible for Germany together with the other EU 27 countries.

The six individual technologies in the field of digital technologies are presented below. This detailed analysis is justified by the special role of digital technologies. They are increasingly having an impact on almost all other technology areas. As a driving force, they have a pronounced cross-sectional effect, they initiate or accelerate development processes in other technology areas.

According to the change factor, publication activity in Germany is developing at a similarly dynamic pace in all individual digital technologies (see figure B 1-3) as in the other Western countries of

Fig. B 1-2 Mean value of publications in key enabling technology areas for selected countries and regions 2000–2002 and 2017–2019



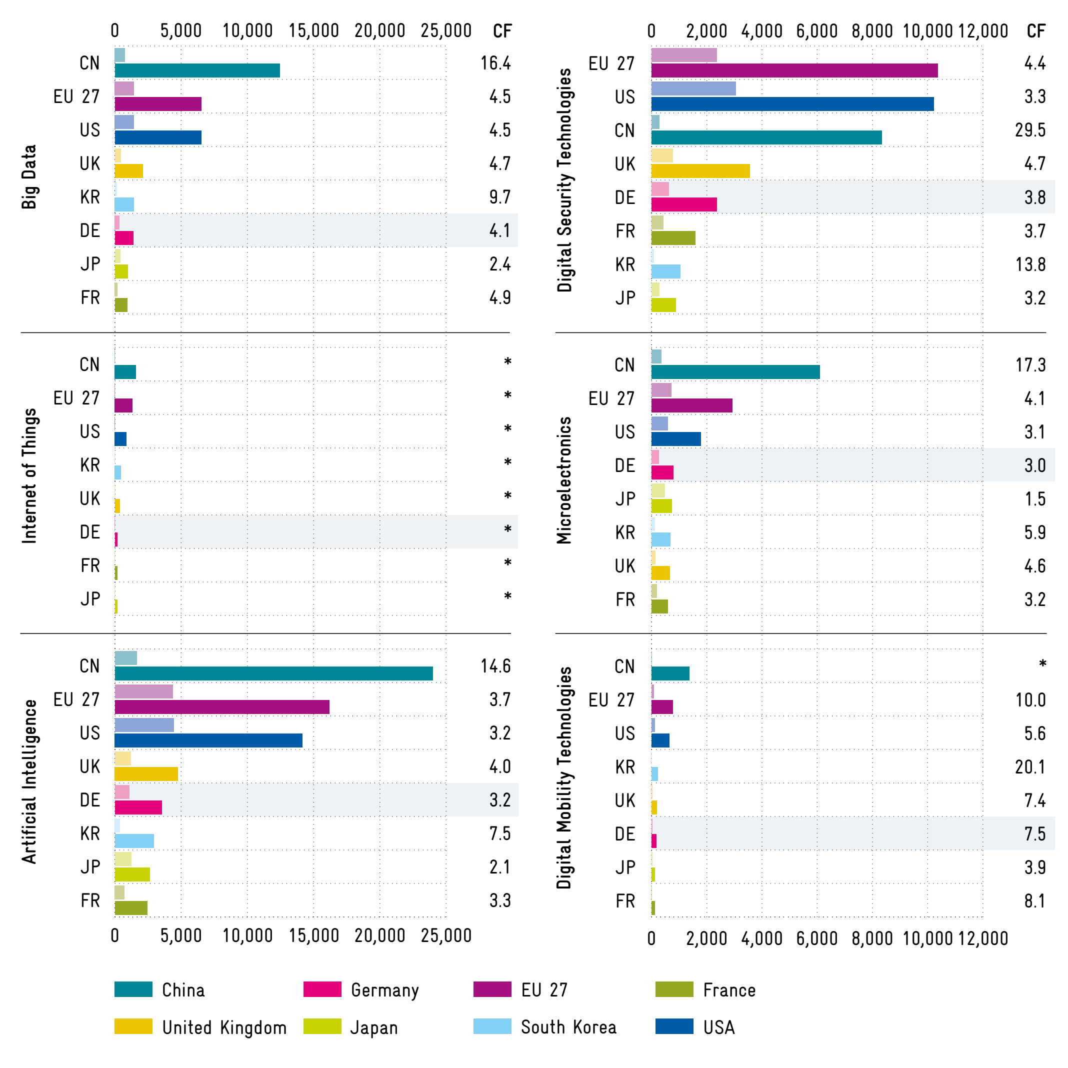
The lighter shade of colour shows the average number of publications for the years 2000 to 2002, the darker shade that for the years 2017 to 2019. The sorting and thus the order of the countries within each key enabling technology area follows the mean values from 2017 to 2019. The change factor (CF) indicates how publication figures for the last three years relate to publication figures for the first three years. A change factor smaller than one means a decrease and a change factor larger than one means an increase in publication numbers in the period under consideration. A change factor of one means that the publication numbers have not changed between the periods under consideration.
Source: Own representation based on Kroll et al. (2022)

comparison. In this detailed analysis, China's strong position is once again noticeable, as it is the leading nation in all digital technologies, with the exception of digital security.

Patent Applications: Mixed picture in Germany

Transnational patent applications[156] in the period from 2000 to 2018 can be used as an indicator for innovations in the application of key enabling technologies.[157] Here, too, the mean values of the first three years of the period under consideration (2000-2002) and those of the last three years (2016-2018) were calculated and compared. The change factor indicates how the patent numbers of the last three years relate to the patent numbers of the first three years. As with the change factor for publications, this can be used in country comparisons to interpret the development of technological gaps based on patents.

Fig. B 1-3 Mean value of publications in digital technology areas for selected countries and regions 2000–2002 and 2017–2019



The lighter shade of colour shows the average number of publications for the years 2000 to 2002, the darker shade that for the years 2017 to 2019. The sorting and thus the order of the countries within each technology area follows the mean values from 2017 to 2019. A single publication can be assigned to several individual technologies for reasons of content. The change factor (CF) indicates how the publication figures of the last three years relate to the publication figures of the first three years. A change factor smaller than one means a decrease and a change factor larger than one means an increase in publication numbers in the period under consideration. A change factor of one means that the publication numbers have not changed between the periods under consideration. * are used when the change factor takes on extreme values due to a minor initial value.
Source: Own representation based on Kroll et al. (2022).

The overview shows that especially in the Asian countries (Japan, China, South Korea) patenting activities have increased strongly, while they have decreased in some Western countries (see figure B 1-4). In Germany, this concerns the key enabling technology areas of materials technologies as well as bio- and life sciences.

Germany's patent applications in the key enabling technology areas of production and materials technologies as well as bio- and life sciences are in the middle of the field. Japan, the EU 27 and the USA top the list. China follows in fourth place and also shows a very dynamic development here. In terms of the change factor, Germany is again at a similar level to the other Western countries; however, the significantly higher factors for China, Japan and South Korea show that Germany is increasingly lagging behind in terms of technology. In production technologies and, to a lesser extent, in the bio- and

Fig. B 1-4 Mean value of transnational patent applications in key enabling technology areas for selected countries and regions 2000–2002 and 2016–2018

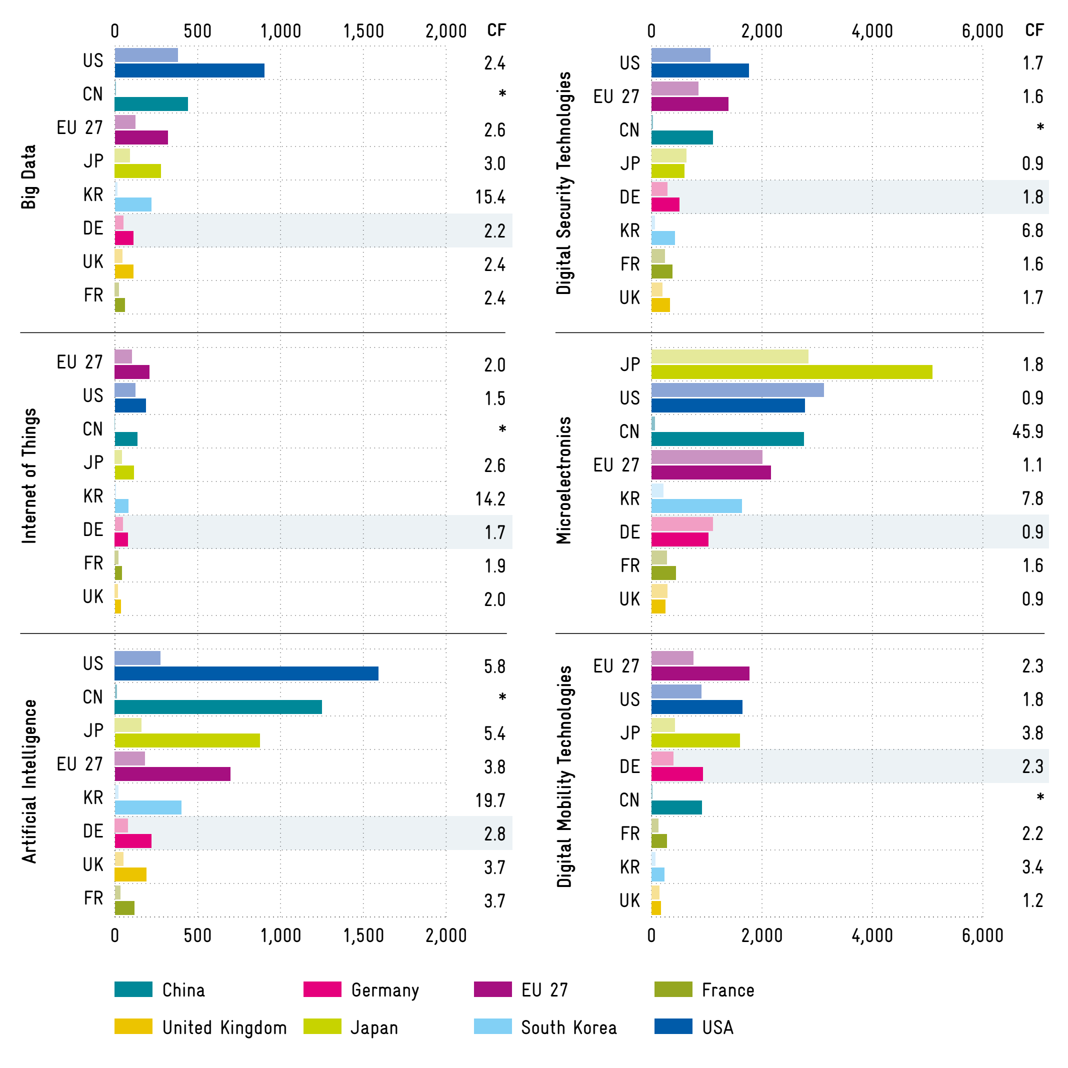
The lighter shade of colour shows the average number of patent applications for the years 2000 to 2002, the darker shade that for the years 2016 to 2018. The sorting and thus the order of the countries within each key enabling technology area follows the mean values from 2016 to 2018. The change factor (CF) indicates how patent application figures for the last three years relate to patent application figures for the first three years. A change factor smaller than one means a decrease and a change factor larger than one means an increase in patent application numbers in the period under consideration. A change factor of one means that the patent application numbers have not changed between the periods under consideration.
Source: Own representation based on Kroll et al. (2022).

life sciences, Germany is still doing quite well in this respect.

In the key enabling technology area of digital technologies, China and South Korea have developed particularly dynamically. Japan and the USA are in the lead, followed by China.

A detailed examination of the individual digital technologies (see figure B 1-5) shows that German patent applications increased moderately in all individual technologies except microelectronics. There was a slight decline in microelectronics. A comparison of the change factors shows that Germany has lost its technological lead to China, South Korea and to some extent also Japan, or that the gap to these countries has widened. The rise of China is striking in this context. China is to be found in the top three places in all individual technologies, with the exception of digital mobility,

Fig. B 1-5 Mean value of transnational patent applications in digital technology areas for selected countries and regions 2000–2002 and 2016–2018



The lighter shade of colour shows the average number of patent applications for the years 2000 to 2002, the darker shade that for the years 2016 to 2018. The sorting and thus the order of the countries within each technology area follows the mean values from 2016 to 2018. A single patent can be assigned to several individual technologies for reasons of content. The change factor (CF) indicates how patent application figures for the last three years relate to patent application figures for the first three years. A change factor smaller than one means a decrease and a change factor larger than one means an increase in patent application numbers in the period under consideration. A change factor of one means that the patent application numbers have not changed between the periods under consideration. * are used when the change factor takes on extreme values due to a minor initial value.
Source: Own representation based on Kroll et al. (2022).

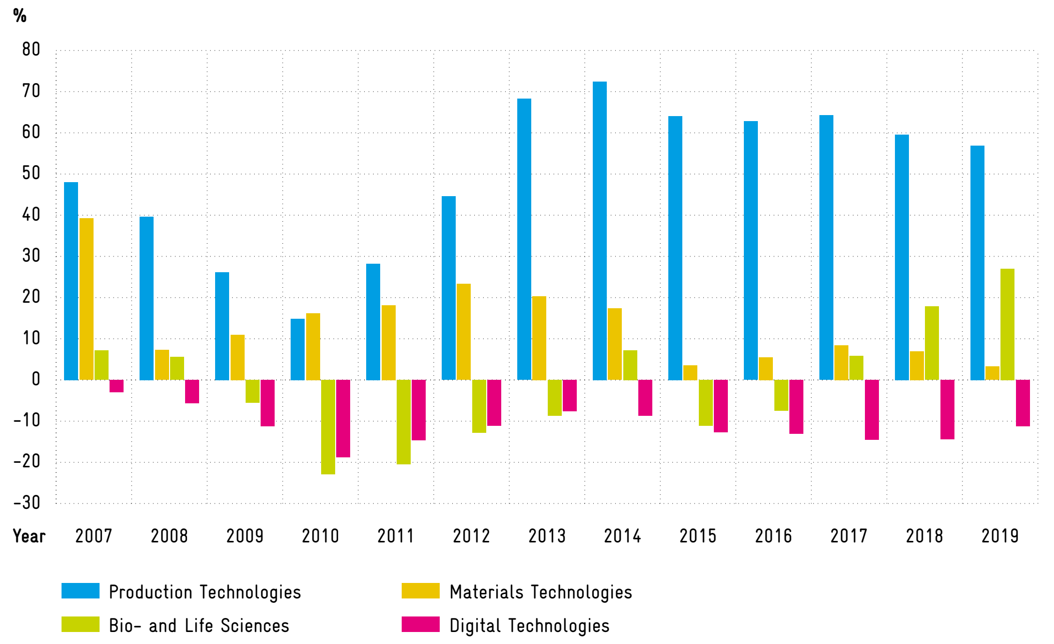
although it has the lowest initial values compared to the other countries.

Relative Trade Balance: Germany Weak in Digital Technologies

The trade balance provides insights into the export strength of an economy. A positive trade balance occurs when exports exceed imports. Figure B 1-6 shows the relative trade balance[158], defined as the percentage surplus of exports over imports, for Germany from 2007 to 2019 in the four key enabling technology areas.[159]

This indicator shows that Germany has relative export strength in the key enabling technology areas of production technologies and materials technologies over the entire period under study, i.e. it is a net exporter. This relative export strength is most pronounced in production technologies. In the key

Fig. B 1-6 Germany's relative trade balance in the key enabling technology areas 2007–2019 in percent



Source: Own representation based on Kroll et al. (2022).

enabling technology area of bio- and life sciences, the relative trade balance is at times negative and at times positive during the period under review but has been clearly positive since 2017. In the area of digital technologies, Germany has a negative relative trade balance over the entire period under review, i. e. it is a net importer.

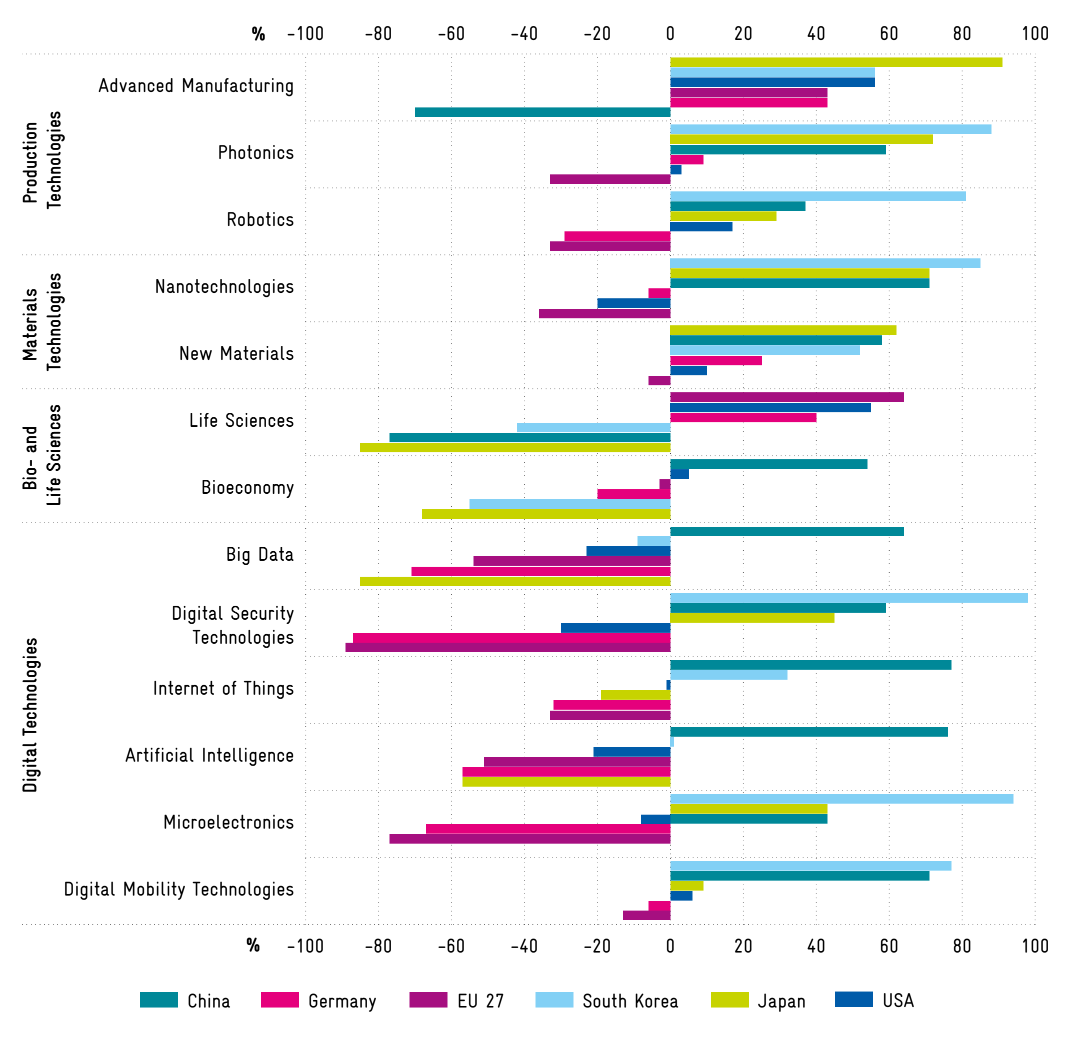
Trade Specialization: Germany and EU 27 with Weaknesses

The trade specialization of an economy and its position in international comparison can be described using the revealed comparative advantage (RCA). Here, the RCA describes the export share of a key enabling technology in a country in relation to the share of this key enabling technology on the world market.[160] If the RCA is positive, the country has a comparative trade advantage in the respective key enabling technology. If, on the other hand, the RCA is negative, this indicates a comparative trade disadvantage.

Germany has both comparative trade advantages and disadvantages in the key enabling technology areas of production technologies, materials technologies and the technologies of the bio- and life sciences (see figure B 1-7). Germany's trade advantages lie in the individual technologies of photonics, advanced manufacturing, new materials and in the life sciences. Trade disadvantages for Germany can be seen in robotics, bioeconomy and nanotechnology, but above all in the entire area of digital technologies. The comparative disadvantages are particularly pronounced in the individual technologies of digital security, big data, microelectronics and artificial intelligence.

The EU 27 have similar comparative advantages and disadvantages as Germany. This applies in particular to the area of digital technologies, in which the EU 27 consistently display comparative disadvantages. In contrast, China has pronounced comparative trade advantages in all digital technologies, which are even surpassed by South Korea in microelectronics, digital security and digital mobility.

Fig. B 1-7 Mean value of revealed comparative advantage in individual technologies for selected countries and regions 2016–2018 in percent



A positive value indicates a comparative advantage, a negative value a comparative disadvantage.
Source: Own representation based on Kroll et al. (2022).

Most Important Countries of Origin of German Imports: China Dominant

One indicator of Germany's direct dependence on another country for a key enabling technology is the import share. This indicates what percentage of German imports of a key enabling technology derives from another country. A high value indicates a possible dependence.[161]

The analysis of the import shares for the years 2015 to 2019 shows that China leads the ranking of the most important countries of origin of German imports in nine of the 13 individual technologies. The high importance of Chinese imports is particularly evident in the area of digital technologies, as China is the most important country of origin in five out of six individual technologies. The European countries play a subordinate role as countries of origin of German imports compared to China except in the individual technology of life sciences.[162]

Standard Setting: Digital Technologies Neglected in Germany

Global and European technological standards are a key factor for the development and dissemination of key enabling technologies. Representatives from science and industry discuss and agree on these standards in international standardization committees.

Unlike Germany and many Western countries, China does not leave the setting of standards to the individual responsibility of the companies and organizations concerned but relies on centralized and controlled state action.[163] China has massively expanded its involvement in standardization organizations in recent years. By contrast, German companies and organizations do not seem to succeed in making a significant contribution to forums for negotiating future standards in the particularly dynamic key enabling technology area of digital technologies.[164]

Cooperation with Asian Countries Insufficient

An analysis of Germany's scientific and technological cooperation patterns with other countries shows that they still reflect the structures of the 1980s and 1990s. While German science organizations and companies have close cooperation structures with European and North American partner countries, which are reflected in pronounced co-publication and co-patenting activities, comparable links have not been established with the technologically leading companies and organizations in Asian countries.[165]

In the case of Japan and South Korea, this shortcoming could be related to the traditionally low propensity of the corporate sectors there to cooperate internationally.[166] In the case of China, the reason for this can also be seen in the increasing state control and supervision of the science and business sectors, as well as in the unequal conditions of competition and cooperation (unlevel playing field) for German and Chinese stakeholders.[167] In addition, the growing systemic competitive relationship between the Western world and China contributes to German organizations perceiving long-term cooperation with China as risky.[168] There is a risk that the availability of key enabling technologies and related knowledge will be increasingly limited as a result.

B 1-3 Promotion of Key Enabling Technologies as a Political Task

The danger of an economy falling behind in key enabling technologies in international competition and thus having to accept losses in prosperity and welfare development as well as in its self-reliance leads to the topics of key enabling technologies and technological sovereignty being placed high on the political agenda in many countries.

Measures for Safeguarding Technological Sovereignty

From the conceptual considerations in section B 1-1, political approaches can be derived that can in principle be addressed with the following presented R&I policy measures. These measures are used in different combinations and intensities in political practice.

With regard to the mastery of key enabling technologies, measures to build up knowledge and skills in the field of key enabling technologies are of help in the medium and long term. Here, the promotion of science and research, vocational and continuing education and training as well as academic education should be considered. In addition, knowledge and technology transfer to the economy and society as well as key enabling technology-specific innovation activities should be promoted.

Industrial and foreign trade policy measures can also ensure in the short term that the generation, further development and above all the production of key enabling technologies remain in an economy. Subsidies for selected key enabling technologies, protectionist measures for the import of key enabling technologies and measures to promote exports can help to reduce the problem of limited availability and insufficient mastery of a key enabling technology. Measures of this kind can have the effect that key enabling technologies are produced and further developed domestically (increasing availability) and that learning effects can be generated and used in the process (improving mastery).

The use of industrial policy measures should be limited in time and should take place at an early stage, when a key enabling technology is still young and the exploitation of its technological and economic potential is still in its infancy. The risk of losing touch with international developments is particularly great especially in the early phase of a new key enabling technology. This is where the argument of infant industry protection or infant technology protection comes into play. It states that new industries or technologies should be protected from international competition until they are mature and strong enough to face this competition.

Industrial policy support can also be designed in such a way that R&I activities are not supported across the entire breadth of a key enabling technology, but only in selected sub-areas of this technology. This would amount to a structure of intra-technological specialization in which several national economies are leaders in a given key enabling technology, but each in different sub-areas or niches. Through international trade, these economies would complement each other.

In this way, unequal power relations in conflict situations could be balanced. Should a trading partner try to use its position of strength in a way that limits the technological sovereignty of other economies, these in turn could use existing strengths in (complementary) technological sub-areas as a means of counter-pressure.

Germany: Technological Sovereignty Through Own Competences

The debate on the control and availability of key enabling technologies to safeguard technological sovereignty is comparatively young in Germany. The COVID-19 pandemic and the disruption it caused to value chains has drawn increased attention to the limited availability of technological components. Against this background, there is now also increased discussion in this country about how independent Germany and the EU need to be with regard to certain technologies.[169] The establishment of a Council for Technological Sovereignty in September 2021 by the Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung, BMBF) illustrates the increased importance of the topic in the political arena.[170]

According to the BMBF's ideas, technological sovereignty should be secured primarily by building up and strengthening Germany's own scientific and technological competencies.[171] Reinforcing the German R&I system in cooperation with European partners should ensure that science and industry are able to 'shape the development and application of key enabling technologies internationally on an equal footing and in line with our values.'[172]

Only recently have industrial policy interventions in the market mechanism been brought into the discussion. For example, in its impulse paper on technological sovereignty, the BMBF formulates that it may be necessary to 'develop key enabling technologies and technology-based innovations in Europe independently and to build up own production capacities for them if this is necessary to maintain the state's ability to act or to avoid unilateral dependencies'.[173] In doing so, the BMBF is moving in the direction that the then Federal Ministry for Economic Affairs and Energy (BMWi) had already taken earlier with its Industrial Strategy 2030 and the tightening of investment control.[174, 175]

To boost scientific and technological competencies, the Federal Government has formulated and pursued various strategies in recent years to promote technologies, including key enabling technologies.[176] The High-Tech Strategy 2025 also focuses on promoting key enabling technologies in particular by building scientific and technological capabilities.[177] Beyond its own national initiatives, the Federal Government is also active at the EU level to promote selected key enabling technologies and thus to secure Germany's and Europe's technological sovereignty in the sense of maintaining competencies.[178]

European Union: Technological Sovereignty Through Support

The promotion of key enabling technologies (KETs) in industrial policy was already considered by the EU in 2009.[179] Initially, the focus was on strengthening industrial manufacturing, and only then was the target dimension of technological sovereignty added.[180] Prominent examples of the promotion of key enabling technologies and the growing importance of technological sovereignty within the European funding portfolio are the European Partnership Initiatives[181] and the Important Projects of Common European Interest (IPCEI).[182] So far, three IPCEI initiatives have been launched, for the promotion of microelectronics, for the development and production of battery cells and for the production of hydrogen.[183] Further projects are planned.

The European Industrial Strategy, presented in 2020 and renewed just one year later, aims, among other things, to strengthen Europe's open strategic autonomy[184] and to create the conditions for investment in key enabling technologies.[185] As part of this update, the EU Commission also presented an instrument to monitor the EU's strategic dependence on non-European products and technologies[186] as well as a revision of its competition law to combat the competition-distorting effects of foreign subsidies on the European internal market.[187] In addition, the Commission announced a European standardization strategy to safeguard European interests in standardization inside and outside the EU.[188] The measures make it clear that both the question of mastery and the question of availability of key enabling technologies are of increasing importance for the EU.

China: Technological Sovereignty Through Open Industrial Policy

The Chinese understanding of technological sovereignty is strongly shaped by the goal of mastery and availability. With its industrial policy, China not only wants to be the world leader in a large number of technologies, including key enabling technologies, but also to dominate entire value chains and successively replace foreign technology providers with domestic ones.[189]

In the long term, the Chinese state is promoting the development of numerous key enabling technologies with massive investments[190] and is pushing the involvement of Chinese organizations in international standardization bodies.[191] Moreover, the state not only assumes a central guiding, framing and supporting function. As a quasi-entrepreneur and provider of capital, it is itself significantly involved in the implementation of its own technical-economic specifications.[192]

In addition, the state pushes industrial capacity and competence building at home and restricts access to domestic markets for foreign competitors. Examples include the Cybersecurity Act of 2017 and the Export Control Act of 2020.[193]

USA Technological Sovereignty Through Covert Industrial Policy

For the USA, its claim to global political leadership is closely linked to a claim to technological leadership. To assert a leading position in as many key enabling technologies as possible, the USA, in contrast to China, pursues a rather covert industrial policy.[194] To this end, the development and application of selected key enabling technologies is supported in the long term by formulating favourable framework conditions and targeted funding programmes. Examples of these support programmes are the national initiatives on AI, nanotechnology and robotics as well as on advanced manufacturing.[195]

Moreover, especially since the global financial and economic crisis of 2008/09, state intervention and approaches of explicit industrial policy have become increasingly popular in US-American industrial policy.[196] Also under the Biden administration, an industrial and trade policy can be observed that regulates China's access to the US-American market and restricts exports and international technology transfer.[197] The USA thus pursues the approach of not only promoting the mastery of key enabling technologies, but also securing its dominant position in individual technologies by restricting the availability of key enabling technologies to competing states.

B 1-4 Recommendations for Action

In terms of publications, patents and foreign trade, Germany shows strengths in the key enabling technology areas of production technologies as well as bio- and life sciences in an international comparison. In the area of digital technologies, on the other hand, Germany, like the EU 27, shows clear weaknesses. This means that they are not only losing touch in a technology area that is becoming more and more important economically but are also jeopardizing their existing strengths in other key enabling technology areas such as production technologies and the bio- and life sciences, which are increasingly being penetrated by digital technologies. This problem is exacerbated by the fact that Germany is dependent on imports from China, especially in digital technologies.

Establishing a Monitoring and Advisory Body for Key Enabling Technologies

Unlike in China and the USA, the strategic promotion of key enabling technologies in Germany is still in its infancy. The focus of German funding efforts is on knowledge building. Strategic monitoring of key enabling technologies and concerted capacity building for the development and use of key enabling technologies in the pre-market and market sector have hardly taken place so far. The Commission of Experts therefore recommends the following measures:

- Key enabling technologies and derived key enabling technology portfolios must be defined using clear and operationalizable criteria to ensure that their selection is not determined by assertive individual interests.

- Key enabling technologies should be systematically kept under review through continuous foresight analyses and monitoring processes. To this end, the Federal Government should set up a monitoring unit, preferably with a European composition, consisting of several independent research institutions. The aim of these monitoring processes must be to record current, emerging and potential key enabling technologies and to assess them in terms of their technological, economic and societal potential.

- In addition, the Federal Government should establish an independent strategic advisory committee for key enabling technologies. This committee has the task of evaluating the information from the European monitoring unit and compiling it into a continuously updated key enabling technology portfolio. In addition, the committee should formulate recommendations for action on how to deal with selected key enabling technologies for the Federal Government at regular intervals.

Thinking About Support in European Terms and Shaping Market Interventions Catalytically

The EU 27 and Germany are in danger of losing the ability to master important digital key enabling technologies. The availability of these technologies on international markets is also at risk. This can lead to massive restrictions on technological sovereignty not only in the area of digital technologies, but also in the other key enabling technology areas whose development increasingly depends on and is driven by digital technologies.

- In key enabling technology areas where technological leaps are emerging, funding should be provided not only for contributions to basic research, but also for application-oriented pilot projects. It is important to initiate the accompanying development of corresponding competences in academic education as well as in vocational and continuing education and training at an early stage.

- As a reaction to changes in the world trade system and the ideal of a level playing field, which is coming under increasing pressure, the Federal Government should not only focus its promotion of key enabling technologies on the pre-market sector. To promote potential key enabling technologies (infant technologies), subsidising interventions can also be made in the market, provided they have a catalytic character, i. e. they have a knock-on effect and are then withdrawn again.

- To reinforce key enabling technologies and their own technological sovereignty, Germany and the EU must take stronger joint action to achieve a critical mass of capacities and activities.

- Germany should become more involved in existing European programmes such as the IPCEI initiatives and set priorities through co-financing and content-related contributions.

- In view of the great importance of digital technologies, especially for the development of other key enabling technologies, solutions for new application contexts at the intersection of digital and other key enabling technologies should be specifically promoted.

Increasing Engagement in Standardization Committees

German involvement in the standardization committees, especially for digital technologies, is low.

- Appropriate incentives to participate in the international standardization committees should be set. The costs incurred by companies in connection with standardization projects could be subsidised through the research allowance.

- Companies and scientific institutions should be made more aware of the topic of standardization.

Improving Framework Conditions for Cooperation with Asian Partners

The scientific and technological cooperation of German organizations has so far focused mainly on European and US partners; suitable framework conditions can support the opportunities for cooperation with East and Southeast Asian countries, which are particularly strong in digital technologies.

— The Federal Government should improve the framework conditions for cooperation with Asian partners, especially in digital technologies. To this end, a competence centre, as already proposed by the Commission of Experts in 2020, should systematically collect and evaluate information on experiences and problems in cooperation projects and make it available to research institutions and companies. Furthermore, a level playing field with equal competitive conditions and prerequisites for action must be established for all stakeholders involved.