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Focus on Economics

Artificial intelligence in Germany: Status quo, opportunities and options for economic policy measures

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Looking at Germany's position in the field of artificial intelligence (AI), we find a mixed picture. Germany's main weakness here is that it is not established as a provider of AI solutions. It lags behind leading countries by a considerable margin. The share of leading countries in global AI patent applications is nearly five times higher than that of Germany. With respect to foreign trade, Germany has clear trade deficits in artificial intelligence. At the same time, academic research into artificial intelligence in Germany is regarded as being of high quality and German businesses are at the front of the field in Europe in the use of artificial intelligence.

Efforts aimed at improving Germany's position appear worthwhile because AI has great potential for Germany in a wide range of areas. It provides opportunities for increasing productivity and generating additional growth. Artificial intelligence can also provide valuable help in capitalising on Germany's traditional strengths despite the digital transformation, in managing the impact of demographic change or meeting the climate targets.

In order to realise the existing opportunities which artificial intelligence holds for Germany, it would be useful to promote the broad adoption of artificial intelligence in businesses in the short term. In the long term, they should establish themselves as providers of AI products and services of high technological quality.

The key starting points for putting artificial intelligence to use in businesses quickly are the digital skills and the degree of digital maturity of enterprises. In order to make inroads in this respect, it is necessary to address the shortage of IT specialists and improve digital skills on a broad front. What is also important is to eliminate financing obstacles, create more awareness of the strategic significance of digitalisation and further improve the digital infrastructure. Businesses must achieve a high level of digitalisation in order to be able to use artificial intelligence profitably.

The key approaches for Germany to rise up to become an international provider of high-quality AI solutions in the long term consist in further intensifying research, developing an AI industry, improving computing infrastructure and providing adequate access to training data. From an overarching perspective, there is also a need to strengthen acceptance and trust in German and European AI solutions.

Thanks to advances in computing power and the increasing availability of large quantities of data, the development and application of artificial intelligence has experienced an upswing for some years now.[1] Last year, ChatGPT demonstrated the power of artificial intelligence to the general public and triggered a broad debate about its qualities as a game changer and the opportunities and risks involved. It currently occupies the most prominent position among the technologies linked to the digital transformation.

Artificial intelligence has a wide range of uses as a cross-cutting technology. It thus has the potential to expand the possibilities for production in many sectors, overcome shortages of skilled workers and qualifications, and increase aggregate prosperity. The high potential of artificial intelligence is undisputed.

Various scientific studies confirm the productivity-enhancing impact of artificial intelligence.[2] What has also been found is that businesses that use artificial intelligence are more innovative than others.[3] Most market observers anticipate enormous growth of AI markets in the coming years. Market studies predict strong growth effects and increases in aggregate productivity. A recent study predicts that artificial intelligence will generate additional global growth of around 7% and annual productivity growth of 1.5% in the next decade.[4]

So far, however, there is no generally accepted definition of artificial intelligence. In very general terms, AI systems can be understood as machines or instruments that understand and are capable of performing tasks that normally require human intelligence.[5] The EU Parliament defines artificial intelligence as 'the ability of a machine to display human-like capabilities such as reasoning, learning, planning and creativity. AI enables technical systems to perceive their environment, deal with what they perceive, solve problems and act to achieve a specific goal. […] AI systems are capable of adapting their behaviour to a certain degree by analysing the effects of previous actions and working autonomously."[6]

The present study provides an overview of Germany's position in the field of artificial intelligence, the opportunities and challenges as well as possible economic policy measures for strengthening the country's position and speeding up the adoption of artificial intelligence by businesses.

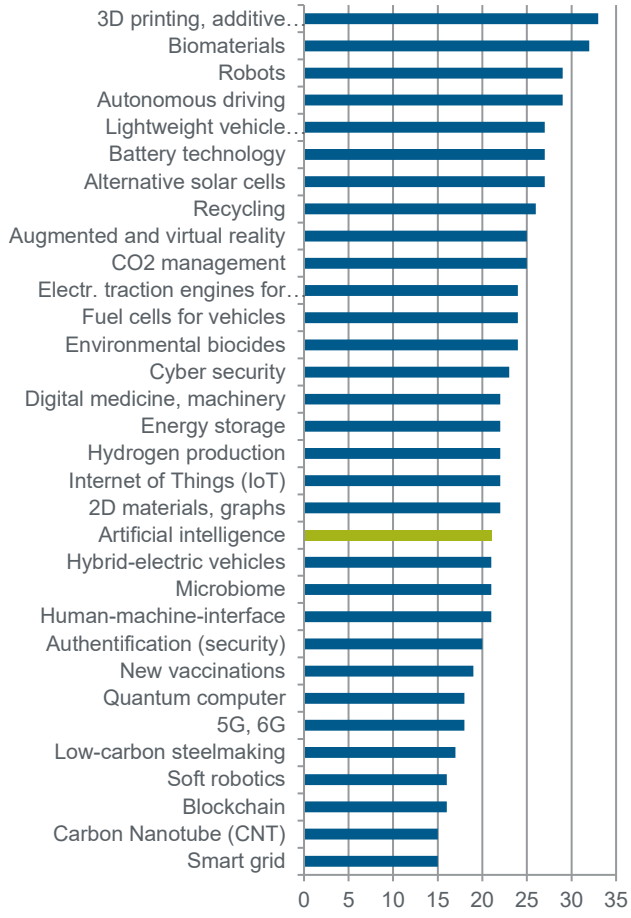
Where does Germany stand in artificial intelligence?

Information technologies are not one of Germany's strengths

Germany is not a pioneer in the adoption of digital technologies. It achieves only mean scores compared with other European countries for many of the indicators of the 'DESI 2023 dashboard for the Digital Decade' developed by the EU Commission.[7] These extend from the use of enterprise resource planning (ERP) systems through electronic invoicing to social media, cloud computing and e-commerce, for example. When this indicator was calculated for the previous year, in which the individual indicators were still combined into an overall ranking, Germany ranked only 13th. In fact, the country only ranks 16th in integrating digital technologies into business processes.[8]

Figure 1: Ranking of technologies of the future by technological indicators from a German perspective

In index points



Source: Schmoch et al. (2021)

Among the technologies of the future, AI sits in the back of the field in Germany

The development of digital technologies is not among the strengths of the German innovation system either. A study carried out by the Fraunhofer Institute for System and Innovation Research (ISI) on behalf of KfW Research in 2021 identified technologies that constitute technologies of the future from a German perspective.[9] The main criterion for selecting the technologies was that they should gain high market relevance in the medium term, in other words, in a period of around five to ten years. That meant technologies that were already starting to be used commercially at that time and hold significant potential.

The analysis of these technologies was based on 12 key indicators for patent applications, scientific publications and trademark registrations in the relevant technology. These indicators were combined into a composited indicator that enabled the technologies to be ranked. In order to take the medium-term perspective into account, patent indicators were weighted most heavily.[10] This ranking reflects how promising a technology is from a German perspective based on the dynamics of its development worldwide and Germany's participation in it.

Information technologies generally do not occupy the top positions in this ranking (Figure 1). Artficial intelligence is merely in 20th place, even behind other information technologies such as cybersecurity (14th place) and the Internet of things (18th place). Among the technologies of the future, artificial intelligence therefore is not among Germany's prime disciplines.

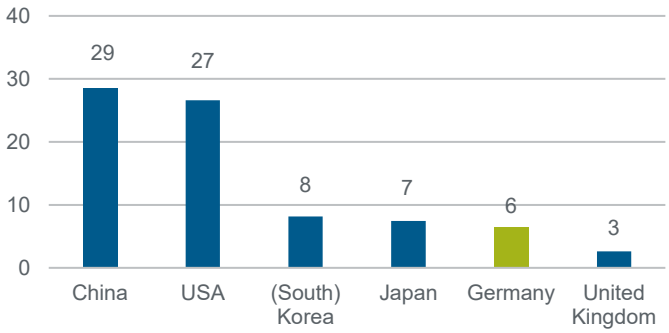
Germany lags far behind in AI patents

As was already suggested in the aforementioned section, Germany's weak position in artificial intelligence is deeply rooted in the limited patent registration activities. Patents are legal documents that protect technical inventions such as new products or procedures from undesired imitations. Thus, they reflect to a high degree how often companies (in particular) develop technological innovations with economic potential that deserve to be protected.[11]

Germany's share in the number of global AI patent registrations sits at 6% (Figure 2).[12] That puts it well behind leading countries such as China and the US (with 29% and 27%).

Figure 2: Shares of selected countries in AI patents around the world

In per cent



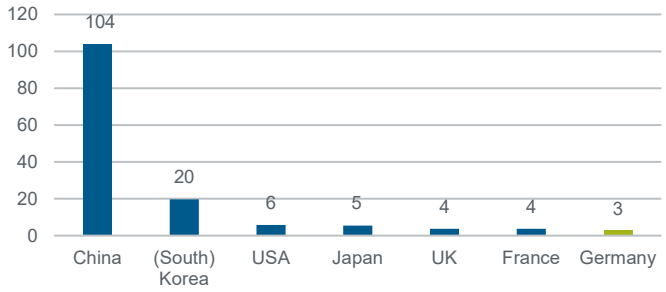
Note: transnational patent applications, i.e. patent applications submitted to the European Patent Office for European countries or as a Patent Cooperation Treaty (PCT) registration for non-European countries.

Source: Expert Commission on Research and Innovation (2024): 2024 Report

Patent registrations also exhibit much weaker growth in Germany than in the leading countries (Figure 3). In China, the number of patent registrations has increased more than 100-fold since the beginning of the 2000s. In countries such as South Korea, the US and Japan, registrations have at least grown by factors of 20, six and almost five. In Germany, on the other hand, the number of patent registrations merely tripled in the same period.

Figure 3: Variation in number of AI patents

Variation factor between the mean values of the years 2000–2002 and 2017–2019



Source: Expert Commission on Research and Innovation (2022): 2022 Report

The gap between Germany and the leading countries in AI patents is wide and has thus widened noticeably in the past almost two decades. In the medium term it will be more than difficult for Germany to catch up quickly as a provider of AI solutions of high technological quality.

Germany has a pronounced external trade weakness in AI

A country's strength in a particular technology can also be measured on the basis of its specialisation in external trade. It measures how well technological expertise can be transformed into successes in the domestic and international market. It reflects how successful domestic businesses are in positioning themselves over foreign competitors.

The metric often used for this is the RCA value (Revealed Comparative Advantage). It determines a country's export-import ratio in a particular group of products in relation to its overall export-import ratio. It thereby provides insight into a country's specialisation in international trade. An RCA value greater than zero suggests that the country has a (relative) advantage in the group of goods in question, whereas a value less than zero indicates a disadvantage.

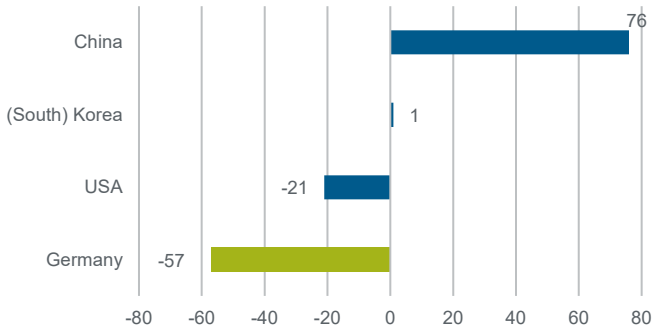
The RCA value for artificial intelligence for Germany is clearly negative at -57 (Figure 4). Thus, Germany has a (relative) disadvantage in external trade in artificial intelligence. It is therefore not one of Germany's strengths in terms of market success either.

Germany has strong AI research

This comparatively weak performance in patents and trade specialisation contrasts with strong AI research activity. It is true that Germany also lags behind the leading countries in the number of research publications on artificial intelligence, and the gap to the leading countries has also widened in publications over time.[13] Nonetheless, the quality of the publications is deemed to be high. Germany's research landscape is well connected internationally and hosts top international researchers. Among the top 50 research facilities for artificial intelligence are several German institutions such as the Technical University of Darmstadt, the Technical University of Munich, the KIT in Karlsruhe, the universities of Bonn and Nuremberg and the Max-Planck Institutes in Saarbrücken and Tübingen.[14] International AI talents, particularly from Asia, are often attracted to German universities as students and PhD candidates.[15]

Figure 4: Specialisation in external trade in artificial intelligence

In index points



Note: The hyperbolic tangent of the logarithm multiplied by 100 of this relation has been removed for ease of presentation

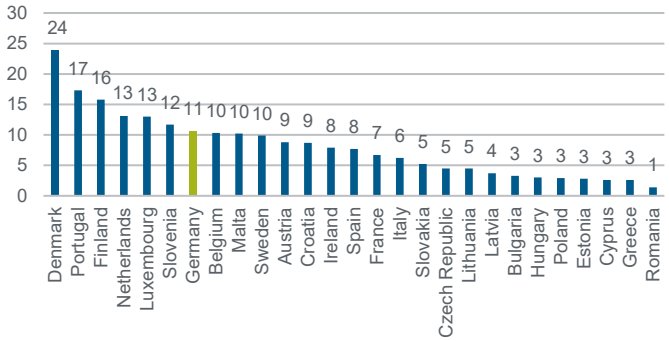
Source: Expert Commission on Research and Innovation (2022): 2022 Report

Diffusion of AI in German businesses compares well with other EU countries but can be improved

Another positive is that in international comparison, German enterprises are at the front of the field in the use of artificial intelligence. Germany ranks seventh in the digitalisation indicator of the EU Commission (Figure 5). This places it well ahead of other large EU countries such as France, Italy and Spain, and ahead of Sweden and Ireland, which count among the leaders in digitalisation in Europe. In order to make a comparison based on uniform EU criteria, we draw on a data collection that covers only companies with ten or more employees. The actual values for Germany and the other EU countries are thus likely to be overstated.

Figure 5: Companies that use artificial intelligence in an EU comparison

Share in per cent



Note: Only enterprises with 10 or more employees

Source: EU Commission (2023) DESI 2023 Dashboard for the Digital Decade, last retrieved on 9 April 2024

What is the importance of artificial intelligence for Germany?

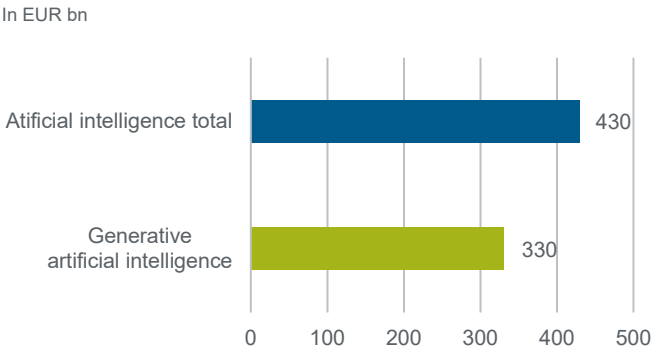
High value-added potential of AI in Germany

The first thing to consider is that artificial intelligence can contribute to more efficient production in broad areas of the economy.[16] Scientific studies have identified the productivity-enhancing impact of artificial intelligence.[17] It makes companies more competitive and thereby contributes to securing prosperity in Germany.

Besides, as we mentioned at the beginning, AI markets are viewed as attractive markets that will grow in the coming years and are expected to generate significant growth impetus for the aggregate economy. The market for artificial intelligence in Germany is forecast to grow at an annual rate of around 15% in the coming years. The volume of this market is expected to grow to EUR 27 billion by 2030.[18]

Market studies predict a high potential of artificial intelligence for the aggregate economy as well (Figure 6). One of the studies concluded that Germany's gross domestic product will grow by 11.3% or EUR 430 billion purely as a result of the penetration of artificial intelligence by the year 2030.[19] A current study quantified the value-added potential that can be realised with artificial intelligence alone[20] at an additional EUR 330 billion if more than 50% of German enterprises use it.[21]

Figure 6: Growth of value added through artificial intelligence



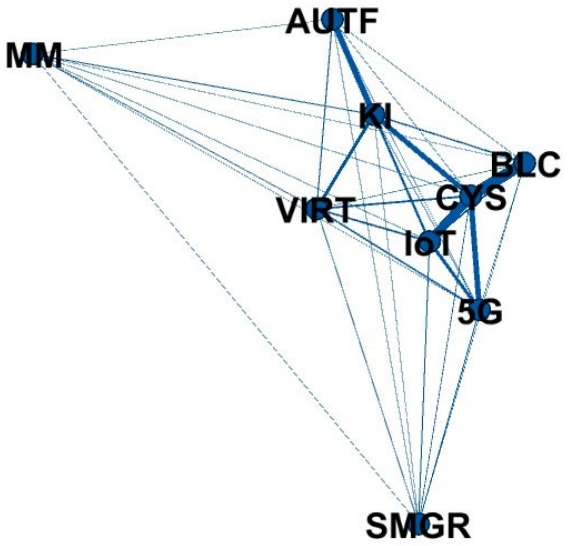
Source: PWC (2018); IW Consult (2023)

AI is a key building block for a successful digital transformation

Artificial intelligence also has an important role to play for a successful digital transformation. Thus, a special characteristic of information technologies is the phenomenon known as 'convergence of information technologies'. This refers to the coming together of multiple information 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. This means that weaknesses in individual technologies also slow down the further development of other information technologies.

Figure 7 illustrates these correlations on the basis of patent applications.[22] It visualises the overlaps of multiple technological fields in individual patent applications. The connecting lines in the network diagram show what different technologies are addressed in a patent. Technologies mentioned together with many other technologies in a patent are illustrated at the centre of the network. The thickness of the lines expresses the intensity of the overlaps between two technologies.

Figure 7: Network of information technologies



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

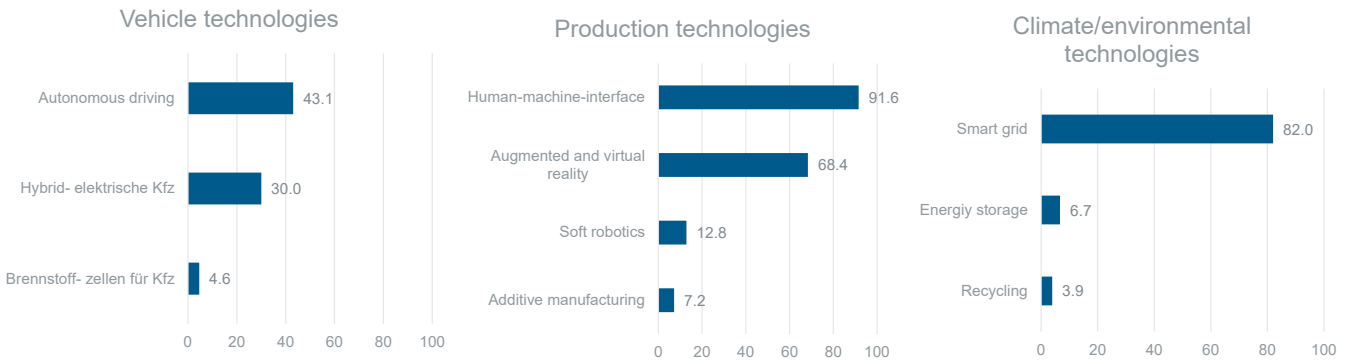
Source: Schmoch et. al (2021)

Figure 6 shows that artificial intelligence occupies one of the central positions among information technologies. Close links exist to other key technologies such as augmented and virtual reality, Internet of things and cybersecurity but also to other technologies.

Thus, there is a close connection between information technologies that has intensified in recent years. And these links are expected to continue to grow stronger in the future. On the one hand, this means that having strengths in a specific information technology alone is not very helpful as they have to be supplemented by capacities in other information technologies. It therefore generally does not appear to be helpful to focus on individual information technologies while neglecting other technologies. On the other hand, progress in the digital transformation overall is at risk if there are weaknesses in individual technologies. This applies in a particular way to technologies that occupy a key position, such as artificial intelligence.

Figure 8: Share of patents with information technology in other technological fields

In per cent



Source: Schmoch et al. (2021)

Information technologies are increasingly relevant in other technological fields as well

Another development of the past years is that information technologies are of increasing importance for other economic sectors and technological fields as well, such as automotive engineering, production technologies and climate and environmental technologies. 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 relate to information technologies (Figure 8). In production technologies, information technologies at the human-machine interface even account for nearly 92% and 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%.[23]

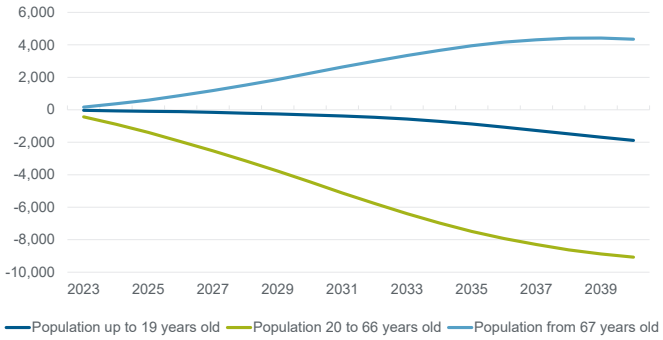
The foregoing underscores that it is hardly possible for Germany to harness new value creation potential or capitalise on its existing strengths in the future unless it develops adequate capacities in the area of digital technologies. The success of the digital transformation is of high importance for many segments of the economy and must not be jeopardised by any weaknesses in artificial intelligence.

AI is a lever for mitigating the impact of demographic change in Germany

The demographic trend in Germany is having a strong impact on the number of working-age people. The number of school graduates has been on the decline for some time now. In the coming years, more and more workers from the baby boomer generation will be leaving the workforce. The insufficient availability of skilled workers is therefore becoming a tightening bottleneck for businesses.[24] According to the most recent KfW-ifo Skilled Labour Barometer, 39% of the businesses surveyed reported that their business activity was disrupted by a shortage of skilled workers.[25]

By 2040, the number of working-age German inhabitants will shrink by a further 9 million, while retirement-age workers will grow by a good 4 million (Figure 9). According to calculations by the Institute for Employment Research (IAB), the skilled labour shortage will peak at 7 million people in the year 2035.[26] Productivity gains are urgently needed to address this shortage. Artificial intelligence can be expected to be able to make a substantial contribution to this.

Figure 9: Demographic trend by age group



Cumulative change in number of inhabitants by age class in 1,000 per year
Note: Results of the 15th coordinated population projection (basis: 31 December 2021) in a net zero immigration scenario
Source: Federal Statistical Office, own calculation

AI as a tool for the ecological transformation

The productivity surge expected to be triggered by artificial intelligence also means a more resource and energy-efficient production. Using artificial intelligence is therefore also predicted to contribute towards achieving the sustainability goals. One example is the energy transition, where artificial intelligence can support the control of electricity grids.[27]

How can Germany make progress in artificial intelligence?

German economic policymakers are aware of the high importance of artificial intelligence. They have set the ambitious goal of making Germany a global leader in the research, development and application of artificial intelligence. The strategies for artificial intelligence from the years 2018 and 2020, the 2023 Action Plan and numerous initiatives provide a wide array of promotional approaches. The AI strategy is to be further developed as well.

The Federal Government promotes AI centres of competence which form a network of eleven AI locations, AI professorships and junior researcher groups. There are also promotional programmes that focus on small and medium-sized enterprises, along with support schemes for AI start-ups. These activities are supplemented by initiatives at state level, such as the Cyber Valley in Tübingen.

A dual strategy is necessary in order to realise the opportunities of AI

What would generally need to happen for Germany to make progress in artificial intelligence? In order to realise existing potentials for Germany, economic policy can run a dual strategy that pursues both short-term and long-term goals.

As set out above, in the short term Germany appears unlikely to be able to catch up on leading countries in the development and marketing of AI products and services of high technological quality. Other countries are too far advanced, as illustrated by the number of patents, for example. In the short to medium term, the aim must therefore be to establish artificial intelligence applications in enterprises in order to build AI application skills and avoid falling behind. Without outside support, however, diffusion across the business community will be slow to occur. That is why speeding up the diffusion of AI is an important option for economic policy.

From a long-term perspective, it makes sense to build on Germany's good position in academic research on artificial intelligence. Academic research must be further strengthened, and the transfer of findings to high-quality and internationally competitive products and services must be ensured.

Remove barriers to the use of AI in businesses

In order to achieve the aforementioned productivity gains across the aggregate economy it is important to spread the use of artificial intelligence across the business community.[28] The findings of business and expert surveys describe the barriers that exist in this regard.[29] Both surveys consistently identified human and skills-related barriers such as a shortage of specialists, lack of in-house skills or lack of time as well as a lack of underlying data and security concerns as key barriers. From a more overarching perspective, the findings give the degree of digital maturity of a business high importance for the use of artificial intelligence.

Improve skills, ease skilled labour shortages

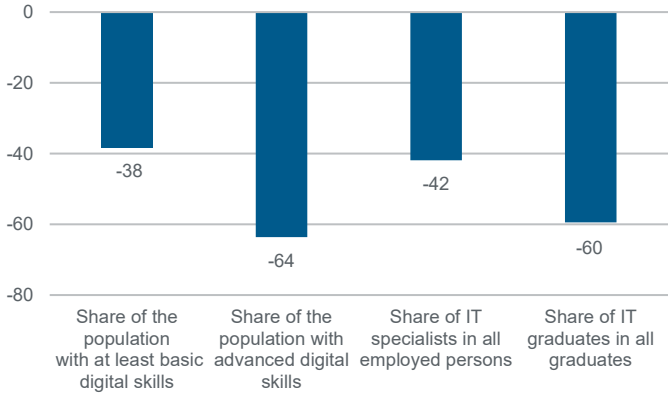
The high importance of skills-related obstacles as a stumbling block for the use of artificial intelligence is not really surprising. Shortages of digital skills and IT specialists are among the main barriers identified by SMEs in digitalisation.[30] The lack of IT experts is the greatest skilled worker shortage in the German labour market.[31] Digital skills across the broad workforce play a major role particularly for small and medium-sized enterprises, as companies are often too small to employ specific IT specialists.

Germany has digital skills deficits in international comparison as well. The country lags well behind the EU leaders in the availability of human capital relevant for digitalisation. Compared with the leading EU countries, Germany is far behind particularly with respect to advanced digital skills (Figure 10). Especially in the field of artificial intelligence, as a comparatively new technology that so far has little standardisation, workers are likely to require in-depth skills to manage its application in businesses. A study from the year 2020 has concluded that two fifths of businesses that use AI have themselves developed at least part of the artificial intelligence they use.[32] Germany lags well behind the leading countries with regard to not just the availability of digital skills but also the supply of IT specialists as a share of the workforce and young professionals.

In order to improve digital education in Germany, greater efforts must be undertaken at all levels of the educational system. It is important to increasingly integrate IT skills not just in vocational and academic education but also in school curricula. Germany is lagging well behind other European countries in the teaching of digital skills in schools.[33] While a good half of the federal states of Germany offer information technology as an elective subject at best, countries such as Japan are planning to teach artificial intelligence and data science as a foundation subject at all schools and universities.[34] With respect to continuing education and training, there is a need to realise the guiding principle of 'lifelong learning' in Germany.

Figure 10: Germany's deficit in digital skills and IT specialists

Gap to leading EU country, in per cent



Note: basic and advanced digital skills: Self-assessment of the survey participants; leading countries in Europe: basic digital skills: Finland; advanced digital skills: The Netherlands; share of IT specialists in the workforce: Sweden; share of IT graduates in all graduates: Estonia

Source: EU Commission (2023), DESI, own calculation, last retrieved on 27 March 2024.

The particular challenge around artificial intelligence consists in developing and attracting specialists with suitable expertise who would be available for both cutting-edge research and the application of artificial intelligence in businesses. To this end, the availability of degree places and PhD places in the disciplines of information technology, statistics and ethics[35] have an important role to play. More young people need to be motivated to study information technology, and the dropout rate needs to be reduced. One approach is to attract more female students, since the share of female students of information technology still sits at only just under one fifth.[36] What is equally important is to attract top researchers by offering competitive conditions.[37]

Raise the level of digital maturity of enterprises

In order to be able to successfully implement and use applications of artificial intelligence, the appropriate conditions must be in place within an enterprise. These conditions are often summarised under the buzzword 'digital maturity'. It is an indicator of the extent to which different areas of the business are digitally linked and processes within the enterprise are already digitalised. Both are preconditions for automation or autonomation with the use of artificial intelligence.[38] For example, comprehensive data storage, efficient data management and intelligent data use are indispensable in order to use AI successfully.[39] Thus, the level of digital maturity reflects how

easily an AI application can be integrated into the business structure.

In order for more enterprises to use AI applications, digitalisation must be advanced across the broad front of the entire business community. Small and medium-sized enterprises in particular require support because of their limited capacities. After all, the majority of SMEs is still preoccupied with comparatively simple stages of digitalisation. Digitalising interactions with customers and suppliers remains the most common type of project being implemented. Ambitious, more in-depth projects such as digitalising workflows, linking IT systems within the business or digitalising the product assortment are much less common and implemented by just under one third to one fourth of businesses with digitalisation projects.[40]

Various starting points are possible for stimulating digitalisation activities in the SME sector. Besides addressing digital skills, these include removing funding obstacles, raising awareness of the strategic importance of digitalisation and expanding digital infrastructure in the country.[41] Across the broad SME sector, a higher level of digitalisation must be reached before artificial intelligence can be used.

Establish Germany as a provider of high-quality AI solutions
In order to establish Germany as a provider of high-quality AI products and services, there is a need to further expand the country's good position in research into artificial intelligence and simplify the transfer of new findings to commercial application. Since it is so far behind in commercialisation, this will require a great deal of patience.

Further intensify academic research
Research into artificial intelligence is developing at a rapid pace in other countries as well.[42] In order to maintain and, where possible, further expand Germany's position, more research in this area is also necessary. The creation of 150 additional AI professorships[43] in Germany is an important step in this direction. It can be expected to provide impetus not just for research but for educating AI experts for German enterprises.

In order to develop an AI ecosystem, it appears advisable to step up research into AI and contribute to the development and expansion of AI infrastructure in the form of data and computing capacity.

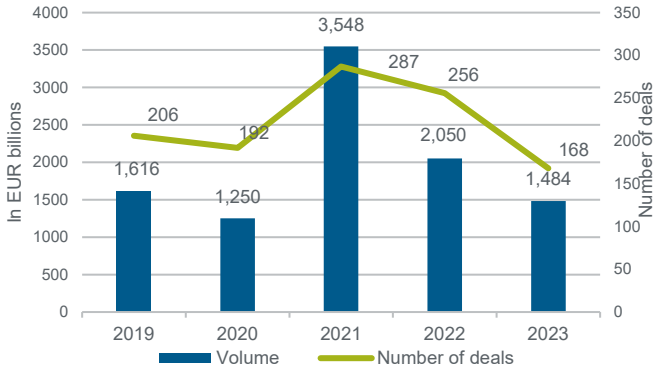
Expand computing infrastructure
In order to generate marketable products and services from AI models, academia, business and government must have the ability to fine tune and use them. This requires high-powered computing infrastructure – for example for language models – as such development work requires a great deal of computing power and places specific demands on computing hardware.[44] The demands on this computing infrastructure will continue to grow as an AI industry increasingly gains a foothold in Germany. Providing an adequate computing infrastructure is therefore a major prerequisite for establishing an AI industry in the country. Experts therefore regard the further expansion of computing capacity in Germany as a matter of urgency.[45]

Improve technology transfer
A smooth transfer of successful research to commercial applications generally constitutes one of the strengths of Germany's innovation ecosystem.[46] The transfer of research must be supported with economic policy measures in artificial intelligence as well. A cornerstone of technology transfer is the development and marketing of offerings from start-ups that are based on new technologies and business models. As Germany is not yet an established provider of AI solutions, it is precisely here that start-ups have a particular role to play in the development of an AI industry.

Funding for start-ups primarily comes from venture capital (VC) and financing arrangements that resemble VC. The availability of these sources of funding therefore represents a major lever for establishing an AI industry in the country.

Last year, EUR 1.5 billion in funding was made available for AI start-ups in the German VC market (Figure 11). In the previous years, deal volume was EUR 2 billion and EUR 3.5 billion. With the interest rate turnaround that began in early 2022, the VC market entered a cooling phase which is reflected in both the volume and the number of deals. In the course of the interest rate turnaround, fundraising in particular became increasingly difficult. In the past years, AI start-ups accounted for around one fifth of annual VC deal volume. That share was roughly the same as in the United Kingdom and France.

Figure 11: VC market for artificial intelligence in Germany



Source: KfW Research

A key building block for promoting the VC market in Germany is the Future Fund, which reliably provides funding as anchor investments through different components. So, it is an important support for the market to further develop the VC ecosystem.

Create a more enabling environment
Not least, improving the conditions for the use of artificial intelligence will be conducive to promoting its dissemination in the business community. Besides the aforementioned aspects, this includes, for example, building trust in the new technology and sufficient competition between stakeholders. Among other things, users will need to be able to choose which forms and providers of artificial intelligence they wish to use.[47] It could be helpful in creating acceptance if the state administration emphasised the beneficial aspects of the use of artificial intelligence. As an anchor client, the state can also contribute to the development of an AI industry by using new

technologies early as a pioneering client and thereby generating cash flow for young businesses.

Furthermore, it must not be forgotten that in addition to expertise and computing infrastructure, the development of artificial intelligence also needs to rest on a foundation consisting of huge quantities of training data. A more restrictive use of data in Germany and Europe can result in competitive disadvantages in the development of AI models and applications when existing data is not allowed to be used. Against this background, improving the availability of data also appears to be an important prerequisite for the success of artificial intelligence in Germany.[48]

Conclusion

The present study examines the status quo, opportunities and challenges of artificial intelligence in Germany and available economic policy measures for harnessing these opportunities.

Germany has a mixed position in AI

Looking at Germany's position in the field of artificial intelligence, we see a mixed picture. Among the technologies of the future, artificial intelligence is not one of Germany's strengths. One of the main reasons for this is that Germany lags behind the leading countries in patent applications – which can be used as a measure of the implementation of technological innovations in marketable applications that deserve to be protected. What is concerning here is that this gap has actually widened in recent years. This weakness is also reflected in Germany's weak external trade performance in artificial intelligence.

By contrast, academic research in the field of artificial intelligence is deemed to be of high quality. Moreover, German enterprises are at the front of the field in the use of artificial intelligence in Europe. Therefore, there are starting points for improving Germany's position.

AI has potential in a wide range of areas in Germany

Artificial intelligence has great potential for Germany in a wide range of areas. Besides aspects such as productivity increases and additional growth, which apply to many countries, artificial intelligence can also address specific challenges facing Germany. This includes, for example, the role of artificial intelligence in advancing the penetration of information technologies in traditional German industries, demographic change and the achievement of climate targets.

It therefore appears worthwhile to make efforts aimed at improving Germany's position in the development and use of artificial intelligence. After all, it can make an important contribution to economic development particularly in Germany.

Possible starting points for economic policy measures to improve Germany's position in artificial intelligence

One measure for realising the existing opportunities which artificial intelligence holds for Germany could be to encourage the broad use of artificial intelligence in businesses in the short term. This can prevent the country from falling behind in the use of artificial intelligence. In the long term, what is needed is to build skills in the development and marketing of ambitious AI products and services of high technological quality and to catch up with the current leaders as a provider of such solutions.

In order to speed up the application of artificial intelligence in enterprises, it would be advisable to address the obstacles to its dissemination. The digital skills shortfall, for example, is a major bottleneck in digitalisation. To enable artificial intelligence to be used by businesses to their benefit, what is also of key importance is that businesses achieve a higher degree of digitalisation. Removing funding obstacles, raising awareness of the strategic importance of digitalisation and expanding the digital infrastructure are important starting points for raising the level of digital maturity.

In order for Germany to become an international provider of high-quality AI solutions in the long term, key starting points consist in further intensifying research, developing an AI industry, improving computing infrastructure and providing adequate access to training data. From an overarching perspective, there is also a need to strengthen acceptance and trust in German and European AI solutions.

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

[2] Cf. e.g. Damioli, G., van Roy, V. and Vertesy, D. (2021), The Impact of Artificial Intelligence on Labor Productivity, Eurasian Business Review 11, p. 1–25.; Cockburn, I. Henderson, M. R. and Stern, S. (2019), The Impact of Artificial Intelligence on Innovation: An Exploratory Analysis, in: Agrawal, A., Gans, J. and Goldfarb, A. (eds.), The Economics of Artificial Intelligence, University of Chicago Press, 115–148 or Brynjolfsson, E., Rock, D. and Syverson, C. (2019), Artificial Intelligence and the Modern Productivity Paradox: A Clash of Expectations and Statistics, in Agrawal, A., Gans, J. and Goldfarb, A. (eds.), The Economics of Artificial Intelligence: an Agenda, National Bureau of Economic Research conference report, The University of Chicago.

[3] Cf. Czarnitzki, D., Fernández, G. P. and Rammer, C. (2023), Artificial Intelligence and Firm-level Productivity, Journal of Economic Behavior & Organization, 211, 188–205, or Rammer, C., Czarnitzki, D. and Fernández, G. P. (2022), Artificial Intelligence and Industrial Innovation, Research Policy, 51(7).

[4] Cf. Goldman Sachs (2023), Generative AI: Hype, Or Truly Transformative?, Global Macro Research 120.

[5] Cf. Russel, S. J. and Nordvig, P. (2021), Artificial Intelligence – A Modern Approach, 4th ed. Pearson.

[6] Cf. European Parliament (2023), 'What is artificial intelligence and how is it used?' Available at: https://www.europarl.europa.eu/topics/en/article/20200827STO85804/what-is-artificial-intelligence-and-how-is-it-used. Last retrieved on 9 April 2024.

[7] Cf. European Commission: [https://digital-decade-desi.digital-strategy.ec.europa.eu/datasets/desi/charts, last retrieved on 19 January 2024.

[8] Cf. European Commission: https://digital-strategy.ec.europa.eu/en/policies/desi, last retrieved on 9 April 2024.

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

[10] Cf. Zimmermann, V. (2021): Information technologies are not one of Germany's strengths but of vital importance as technologies of the future, Focus on Economics No. 322, KfW Research.

[11] It must be noted here that the use of patents as an indicator of innovations has weaknesses. Other indicators of innovation activity, however, such as research and development expenditure, are not recorded with enough detail for individual technologies in Germany, so that we use patents as an indicator here. Cf. Blind, K. et al. (2006): Motives to Patent: Empirical Evidence from Germany, Research Policy 35(5), p. 655–672.

[12] The analysis was based on transnational patent registrations. Transnational patents have the advantage that as patents that are relevant for international markets, they are of greater relevance than merely national patents. The registration numbers are also more readily comparable internationally.

[13] Cf. Expert Commission on Research and Innovation (2024): 2024 Annual Report, and Expert Commission on Research and Innovation (2022): 2022 Annual Report.

[14] Cf. Brühl (2023): Artificial intelligence – where do we stand in Germany? Wirtschaftsdienst 103(8), p. 521–524.

[15] Cf. Maslej, N. et al. (2023): The AI Index 2023 Annual Report.

[16]Cf. Bertschek, I. (2023): Jetzt bloß nicht den Anschluss verlieren! – Status quo, Potenziale und Herausforderungen von Künstlicher Intelligenz (*Just don't fall behind now! – Status quo, potentials and challenges of artificial intelligence* – our title translation, in German); Wirtschaftsdienst 103(8), p. 518-520 and Vöpel, H. (2023): Die „unmenschliche" Revolution – Künstliche Intelligenz als Schicksalstechnologie für Deutschland und Europa (*The 'inhuman' revolution – artificial intelligence as a vital technology for Germany and Europe* – our title translation, in German), Wirtschaftsdienst 103(8), p. 513–517.

[17] Cf. e.g. Damioli, G., van Roy, V. and Vertesy D. (2021), The Impact of Artificial Intelligence on Labor Productivity, Eurasian Business Review 11, p. 1–25.; Cockburn, I. M., Henderson, R. and Stern, S. (2019), The Impact of Artificial Intelligence on Innovation: An Exploratory Analysis, in: Agrawal, A., Gans, J. and Goldfarb, A. (eds.), The Economics of Artificial Intelligence, University of Chicago Press, 115–148, or Brynjolfsson, E., Rock, D. and Syverson, C. (2019), Artificial Intelligence and the Modern Productivity Paradox: A Clash of Expectations and Statistics, in Agrawal, A., Gans, J. and Goldfarb, A. (eds.), The Economics of Artificial Intelligence: an Agenda, National Bureau of Economic Research conference report, The University of Chicago.

[18] Cf. Statista (undated): https://de.statista.com/outlook/tmo/kuenstliche-intelligenz/deutschland, last retrieved on 4 September 2024.

[19] Cf. PWC (2018), https://www.pwc.de/de/pressemitteilungen/2018/pwc-studie-beziffert-potenzial-kuenstlicher-intelligenz-auf-430-milliarden-euro.html, last retrieved on 4 September 2024.

[20] Generative artificial intelligence is defined as a form of artificial intelligence that can produce texts, images and various other content based on its training data.

[21] Cf. IW Consult (2023): Der digitale Faktor. Wie Deutschland von intelligenten Technologien profitiert (*The digital factor. How Germany benefits from intelligent technologies* – our title translation, in German).

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

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

[24] Cf. Müller, M. (2023): Skills shortage marks a turning point: The times of guaranteed growth are over, Focus on Economics No. 414, KfW Research, or for example Hickmann, H. and Malin, L. (2022): Fachkräftereport März 2022 – offene Stellen und Fachkräftelücke auf Rekordniveau (*Skilled Labour Report March 2022 – vacancies and skills shortages on record level* – our title translation, in German). KOFA Kompakt 4/2022, Kompetenzzentrum Fachkräftesicherung, Cologne Institute for Economic Research.

[25] Cf. Müller, M. (2023): Weak business cycle reduces skilled labour shortages – challenge remains, KfW-ifo Skilled Labour Barometer, December 2023, KfW Research.

[26] Cf. IAB (2022): https://www.iab-forum.de/wie-sich-eine-demografisch-bedingte-schrumpfung-des-arbeitsmarkts-noch-abwenden-laesst/, *(How the demographically induced labour market contraction can still be averted – our translation)* last retrieved on 9 April 2024.

[27] Cf. Vöpel, H. (2023): Die „unmenschliche" Revolution – Künstliche Intelligenz als Schicksalstechnologie für Deutschland und Europa (*The 'inhuman' revolution – artificial intelligence as a vital technology for Germany and Europe* – our title translation, in German), Wirtschaftsdienst 103(8), p. 513–517.

[28] Cf. Bertschek, I. (2023): Jetzt bloß nicht den Anschluss verlieren! – Status quo, Potenziale und Herausforderungen von Künstlicher Intelligenz (*Just don't fall behind now! – Status quo, potentials and challenges of artificial intelligence* – our title translation, in German); Wirtschaftsdienst 103(8), p. 518–520.

[29] Cf. Feike, M., et al. (2023): Künstliche Intelligenz aus Sicht von Unternehmen (*Artificial intelligence from a business perspective* – our title translation, in German), Fraunhofer-Institut für Arbeitswirtschaft und Organisation IAO; Lundborg, M. et al. (2023): Künstliche Intelligenz im Mittelstand. Mit welchen Anwendungen sind kleine und mittlere Unternehmen heute schon erfolgreich? (*Artificial intelligence in SMEs. What applications are small and medium-sized enterprises already using successfully?* – Our title translation, in German) WIK Consult and Lundborg, M. and Märkel, C. (2019): Künstliche Intelligenz im Mittelstand. Relevanz, Anwendungen, Transfer (*Artificial intelligence in SMEs. Relevance, applications, transfer* – our title translation, in German), WIK Consult.

[30] Cf. Zimmermann, V. (2022): Vielfältige Hemmnisse bremsen die Digitalisierung im Mittelstand (Various obstacles hamper digitalisation in SMEs – in German), Focus on Economics No. 380, KfW Research.

[31] Cf. Hickmann, H. and Koneberg, F. (2022): Die berufe mit der höchsten Fachkräftelücke (*The occupations with the greatest shortage of skilled workers* – our title translation, in German) , IW-Kurzbericht 67/2022.

[32] Cf. Rammer, C. et al. (2020): Einsatz von Künstlicher Intelligenz in der Deutschen Wirtschaft (*The use of artificial intelligence in German business* – our title translation, in German), German Federal Ministry for Economic Affairs and Energy.

[33] Cf. Suessenbach, F. et al. (2023): Informatikunterricht: Deutschland abgehängt in Europa (*IT skills teaching: Germany is left behind in Europe* – our title translation, in German), Policy Paper edition 1 /January 2023, Stifterverband and Heinz Nixdorf Stiftung.

[34] Cf. Government of Japan (2022): AI Strategy 2022.

[35] In addition to the risk that AI systems may generate misinformation, other risks include racist outcomes or use for the surveillance of citizens, discrimination and persecution of minorities or the operation of autonomous weapons systems. Cf. https://github.com/daviddao/awful-ai last retrieved on 22 April 2024.

[36] Cf. https://de.statista.com/statistik/daten/studie/732331/umfrage/studierende-im-fach-informatik-in-deutschland-nach-geschlecht/, last retrieved on 10 April 2024.

[37] Cf. Bertschek, I. (2023): Jetzt bloß nicht den Anschluss verlieren! – Status quo, Potenziale und Herausforderungen von Künstlicher Intelligenz (*Just don't fall behind now! – Status quo, potentials and challenges of artificial intelligence* – our title translation, in German); Wirtschaftsdienst 103(8), p. 518–520.

[38] Cf. Engels, B. (2023): Künstliche Intelligenz in der deutschen Wirtschaft: Ohne Digitalisierung und Daten geht nichts (*Artificial intelligence in the German business community: Nothing works without digitalisation and data* – our title translation, in German), Wirtschaftsdienst 103(8), p. 525–529.

[39] Cf. Büchel, J. and Engels, B. (2022): Digitalisierung der Wirtschaft in Deutschland. Digitalisierungsindex 2022, Kurzfassung der Ergebnisse des Digitalisierungsindex im Rahmen des Projekts „Entwicklung und Messung der Digitalisierung der Wirtschaft am Standort Deutschland" (*Digitalising the German economy. Digitalisation index 2022, abridged version of the results of the digitalisation index under the project 'Development and measurement of the digitalisation of the economy in Germany'* – our title translation, in German).

[40] Cf. Zimmermann, V. (2024): KfW SME Digitalisation Report 2023. Digitalisation activities are defying the economic slowdown, KfW Research.

[41] Cf. Zimmermann, V. (2024): KfW SME Digitalisation Report 2023. Digitalisation activities are defying the economic slowdown, KfW Research.

[42] Expert Commission on Research and Innovation (2024): 2024 Annual Report, and Expert Commission on Research and Innovation (2022): 2022 Annual Report.

[43] Cf. Federal Ministry for Education and Research (2023): Artificial Intelligence Action Plan. Neue Herausforderungen chancenorientiert angehen (*Rising up to new challenges with an opportunity mindset* – our title translation, in German).

[44] Cf. Expert Commission on Research and Innovation (2024): 2024 Annual Report.

[45] Cf. Expert Commission on Research and Innovation (2024): 2024 Annual Report and KI Branchenverband (2023) Large AI models for Germany. Feasibility study.

[46] Cf. Zimmermann, V. (2023): Wo steht Deutschland bei Innovation und Digitalisierung im internationalen Vergleich? (Where does Germany stand in innovation and digitalisation in an international comparison? – in German only), Focus on Economics No. 412; KfW Research.

[47] Cf. Vöpel, H. (2023): Die „unmenschliche" Revolution – Künstliche Intelligenz als Schicksalstechnologie für Deutschland und Europa (*The 'inhuman' revolution – artificial intelligence as a vital technology for Germany and Europe* – our title translation, in German), Wirtschaftsdienst 103(8), p. 513–517.

[48] Cf. Expert Commission on Research and Innovation (2024): 2024 Annual Report.