B 3 Autonomous systems

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Using algorithms and methods of artificial intelligence, autonomous systems are able to solve complex tasks independently. They learn on the basis of data, and can act largely without human intervention even in unfamiliar situations.

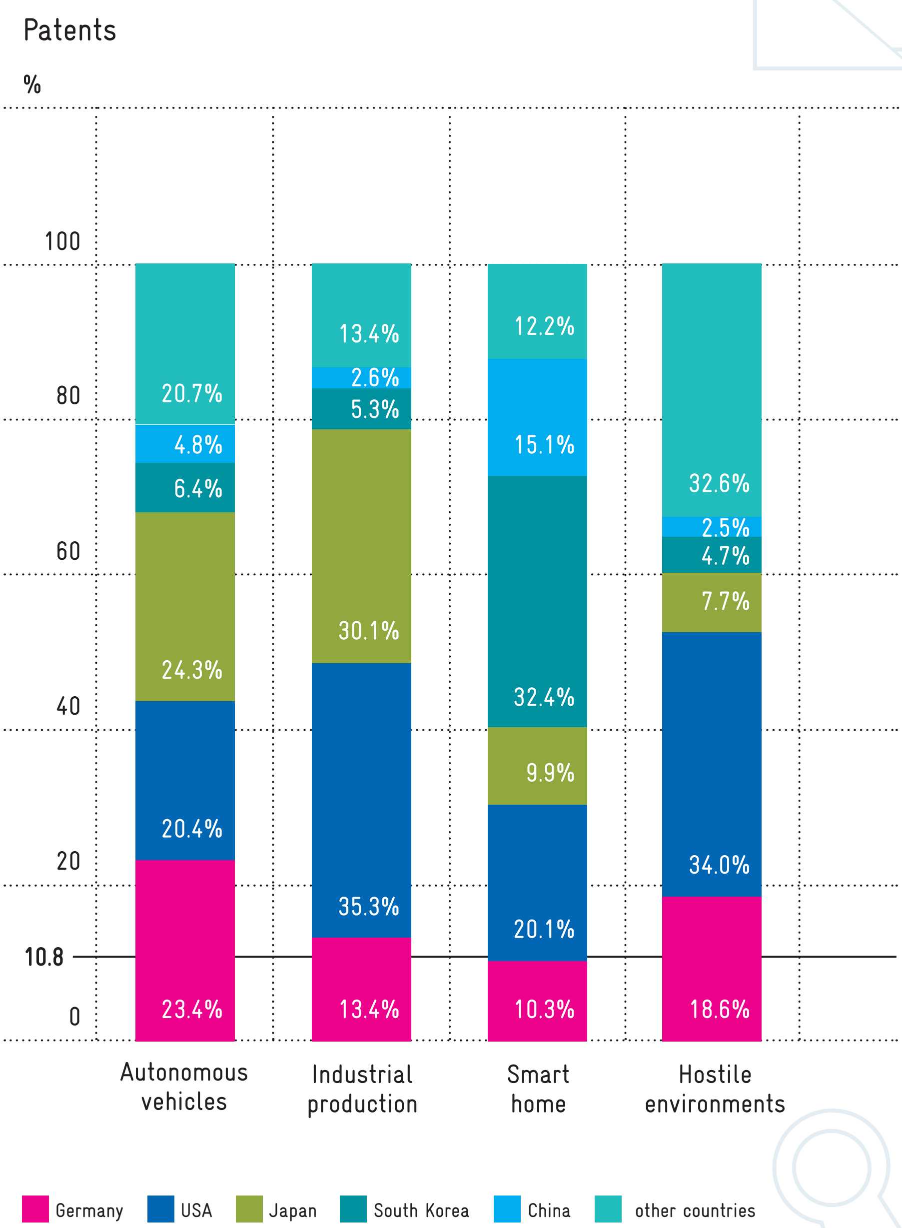
B

Autonomous systems are developed for many areas of application* – artificial intelligence forms a basis for this as a cross-cutting technology.

Source: *Dumitrescu et al. (2018).

Germany's share of transnational patents by international comparison for the four examined areas of application of autonomous systems, 2002–2016

Compared to the proportion of transnational patent applications by German inventors (horizontal line) in all sectors, Germany reveals a particular specialization in the application areas autonomous vehicles and hostile environments. Germany is a world leader here: about level with the USA and Japan in autonomous vehicles, and in second place behind the USA in the field of hostile environments.



Source: own calculations based on Pötzl and Natterer (2018) and Youtie et al. (2018). Cf. also table C 6-2.

B 3 Autonomous systems

B 3-1 Autonomous systems: a technology of the future

Autonomous systems can operate without direct human guidance, solve complex tasks, make decisions, learn independently, and react to unforeseen events. The potential economic and societal benefits of autonomous systems are considerable. Their use can help improve road safety, support people in work processes, make life more pleasant for the individual, and improve societal participation. For example, autonomous systems can be used in nuclear waste disposal or landmine clearance.[311] The integration of artificial intelligence (AI) can generate value-creation potential in a wide range of fields, particularly in areas other than industrial manufacture.[312]

A common example from the field of autonomous systems is autonomous driving. Human error is the cause of almost 90 percent of road accidents involving personal injuries.[313] Reliable estimates suggest that a massive reduction in personal injuries and material damage can be achieved by using autonomous systems.[314] Autonomous driving is made possible by the interplay of different technical components which register a vehicle's environment and, with this information, take driving decisions that solve problems in real-time. As the degree of automation rises, more and more driving decisions are transferred from humans to the system. In fully autonomous vehicles, humans only assume the role of a passenger who can spend their time in the car as they see fit. Among other things, this opens up new mobility possibilities for people who cannot drive a car themselves due to a disability.

At present, the use of autonomous systems is still in its infancy in many fields. Further progress will be required primarily in AI before there is a breakthrough at the technological level (cf. box B 3-1). Another important factor is shaping the framework conditions for the deployment of autonomous systems.

Germany is in a good starting position for reaping the potential benefits of autonomous systems in terms of added value and new applications. In basic research on AI, Germany can build on a solid foundation and has many strengths. Furthermore, the country has an internationally competitive basis for the development of autonomous vehicles. In other areas of application, however, Germany is lagging behind the market leaders in the development of autonomous systems. In addition, it is becoming apparent that other countries, above all the USA and China, but also the United Kingdom and France, are giving the topic of AI high priority in their research and industrial policy. In addition to designing a regulatory framework, therefore, German policy-makers must also increase their funding for research in the fields of both autonomous systems and AI.

B 3-2 Definition, components and technological development status

Based on algorithms and methods of artificial intelligence, autonomous systems are able to solve complex tasks independently. They learn on the basis of data, and can act largely without human intervention even in unfamiliar situations. The borderline between autonomous and automated systems is often defined by different degrees of automation.

Taking the example of automated driving, automation and autonomy can be divided into six levels and described as shown in figure B 3-2.[315] The starting

Box B 3-1

Artificial intelligence

The concept of AI was coined in 1956,[316] although the idea of machines mimicking aspects of human intelligence goes back much further. As long ago as 1950, Alan Turing described the possibility of a form of intelligence simulated by computers, and some of the components this would require, such as learning.[317] This was the beginning of an area of research dealing with artificial systems that are capable of solving complex problems rationally and can even reach their objectives in unfamiliar environments.[318]

In the following years, AI found application in a wide variety of fields. For example, heuristic search methods were developed, computer vision and computational linguistics (natural language processing) advanced, and initial progress was made in the field of machine learning.[319] However, difficulties in the practical implementation of AI in the late 1970s and early 1980s led to a decline in research interest.[320] Although the use of so-called expert systems led to the first successful applications of AI over the subsequent decade, these had the disadvantage of often being unable to cope well enough in unexpected scenarios; creating them was also cost-intensive.[321]

With more computing power becoming available and efforts focusing on specific, realistic tasks (e.g. image recognition), AI research has successfully become established since the mid-1990s.[322] The availability of large amounts of data has supported the development of AI and, in particular, machine learning over the last 20 years.[323] In the recent past, so-called 'deep learning' using neural networks has played a decisive role. This development has been made possible and accelerated by the use of graphics processors. In the field of image recognition, this progress particularly came to the fore in the 2012 ImageNet Competition.[324]

Results of AI research have already become part of commercial services, medical diagnoses and scientific research. By contrast, it seems that 'Artificial General Intelligence', which describes systems comparable to a human that are capable of carrying out a whole range of cognitive tasks with seemingly intelligent behaviour, will not be feasible in the foreseeable future.[325]

point is level 0, in which all processes are controlled by humans. As the degree of automation increases between levels 1 and 4, more and more functions are transferred from the driver to the system. The term autonomous driving is used for level 5 systems. There is no human vehicle guidance in such a vehicle. All driving functions are taken over by the vehicle. This classification can be transferred to other areas of application of autonomous systems.

The deployment of autonomous systems is possible in many areas of application. Apart from autonomous driving, these include hostile environments, the smart home, industrial production, agriculture, energy and health. In the following, the Commission of Experts concentrates on the application fields of hostile environments, the smart home, industrial production and autonomous vehicles.[326]

High complexity of autonomous systems

To be able to function without human intervention, autonomous systems must be able to solve a wide range of tasks reliably and independently. They must assimilate and process information, make and execute decisions, and communicate with other autonomous systems or human beings. A special challenge in this context is managing all this in unfamiliar situations or in environments that are not very structured – or not structured at all. Furthermore, systems operating at different degrees of automation must function both alongside each other and with each other (mixed operation).

Figure B 3-3 provides an overview of the components of autonomous systems. These components can be of two types: environment technologies or core technologies.

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Environment technologies – sensors, actuators, and man-machine or machine-machine communication – are required for environment recognition, communication and carrying out instructions.[327] Their concrete design depends essentially on the autonomous system's area of application. In the field of automated driving, for example, cameras, radar and laser-based sensors (LIDAR) can be used.[328]

The core technologies of autonomous systems include perception, learning, action and self-regulation. Starting with sensor technology to register the environment, an autonomous system uses perception technologies to process the data on its surroundings. The environment can be perceived on the basis of real-time images from a camera, which can be used to assign a designation such as 'stop sign' to an object that is in front of a vehicle. As a consequence, the autonomous vehicle will draft an action plan to 'come to a halt at the stop sign' on the basis of learning technologies. In order to implement this action plan, the action technologies specify concrete instructions. The vehicle's actuators then convert the instructions into steering movements and braking operations. To ensure that these functions also function reliably in new environments, the core technology of self-regulation continuously optimizes the vehicle's systems.[329]

Fig. B 3-2

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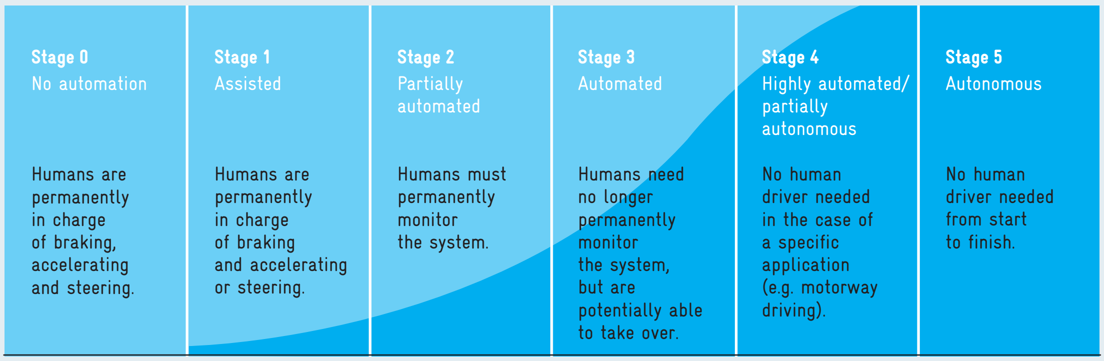
Degrees of automation in driving

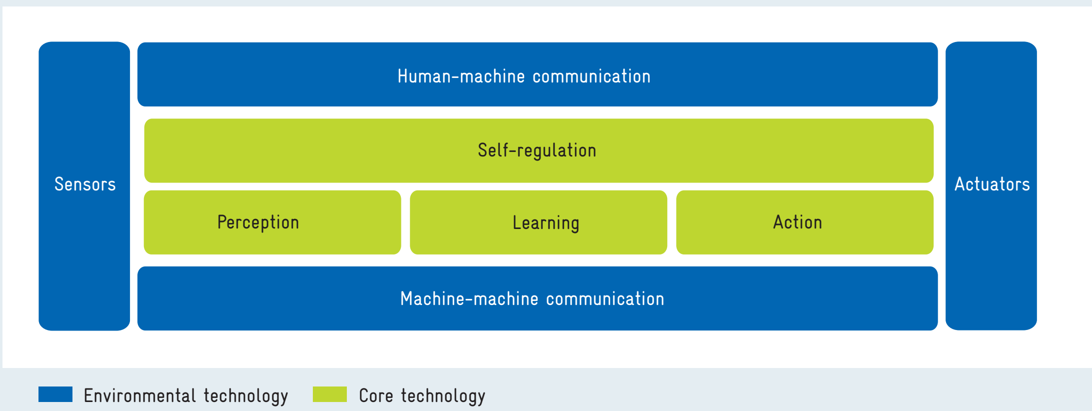


Source: own diagram based on Dumitrescu et al. (2018) and VDA (2015).

Fig. B 3-3

Download data

Environmental and core technologies of autonomous systems



Source: own diagram based on Dumitrescu et al. (2018).

As cross-cutting procedures, AI methods are very important for autonomous systems, since they make reliable operations possible even in relatively unstructured environments. Thus, the use of autonomous systems is highly dependent on progress in the field of AI. The deployment of AI is not limited to autonomous systems, but can already be meaningful in highly automated systems.[330]

Autonomous systems still require further development

A survey of experts has been carried out on behalf of the EFI to assess the international level of technological development in the field of autonomous systems.[331] The international technological development level of autonomous systems was evaluated by 37 national and 32 international experts; distinctions were made both according to the four areas of application selected for the study (hostile environments, the smart home, industrial production and autonomous vehicles) and according to the components of autonomous systems (environmental and core technologies).

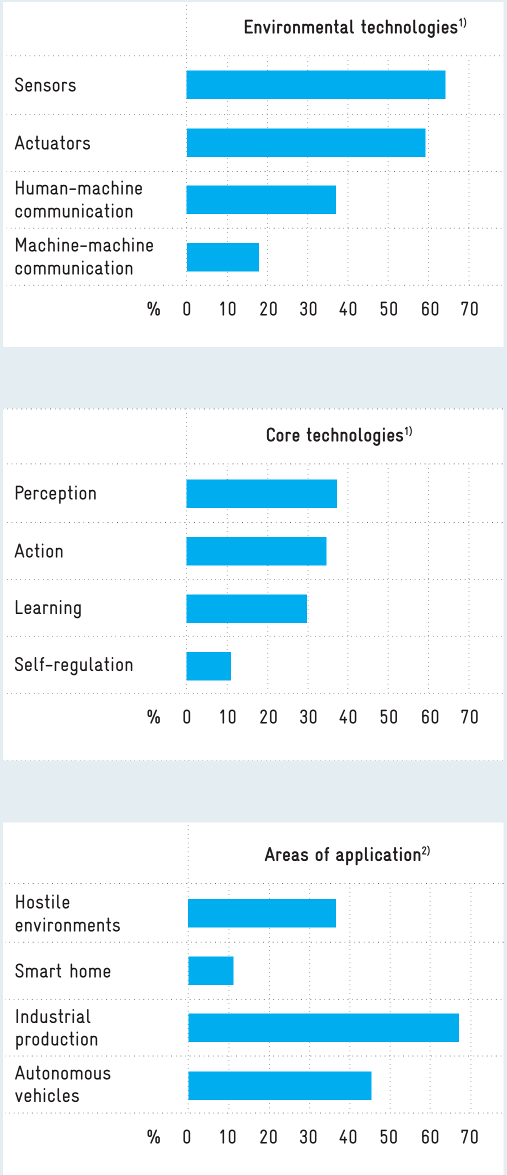
The international development level of the various environmental and core technologies of autonomous systems is assessed by the experts surveyed on the basis of a six-point scale ranging from 'undeveloped' to 'very highly developed'. On this basis, the percentage of respondents who assign one of the two highest levels on the scale to a technology is used as an indicator of a high level of development (cf. figure B 3-4).[332] The respondents see major differences in the development levels of the different environmental and core technologies. Nearly two-thirds of the experts assess sensors and actuators as being highly developed. The relatively low level of development in all other areas indicates a considerable need for research in these fields.

Differences in the level of development are also revealed in the areas of application of autonomous systems. Only in the field of industrial production do the majority of respondents believe that development has reached level 4 or 5 (cf. figure B 3-2). The majority of respondents expect level-5 systems to reach market maturity within the next ten years (cf. figure B 3-5).

Fig. B 3-4

Download data

State of development of autonomous systems by components and areas of application



Results of a survey of 37 national and 32 international experts.
1) Percentage of respondents who assign one of the two highest ratings to environmental and core technologies on a six-point scale between 'undeveloped' and 'very highly developed'.
2) Percentage of respondents who currently assign rating 4 or 5 to the areas of application (cf. figure B 3-2).
Source: own calculations based on Dumitrescu et al. (2018).

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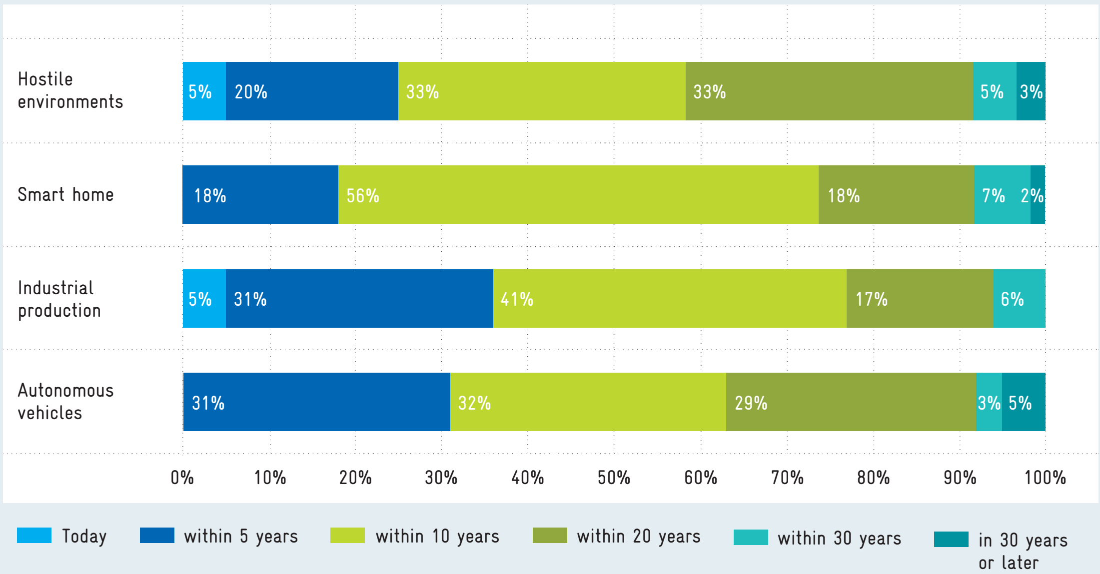
Fig. B 3-5

Download data

Duration until market maturity of autonomous systems (level 5) by area of application



Results based on the results of a survey of 37 national and 32 international experts.
Percentage of respondents expecting autonomous systems to reach market maturity during the period stated.
Source: own calculations based on Dumitrescu et al. (2018).

B 3-3 Potential and challenges

The use of autonomous systems promises a wide range of benefits, as exemplified in box B 3-6 for four application areas studied here: hostile environments, the smart home, industrial production and autonomous vehicles.[333] However, it also poses great challenges for citizens, companies and policy-makers. These must be quickly overcome in order to be able to tap into the potential benefits.

Need to tackle complex challenges

The increasing digitization of the processes used in autonomous vehicles, the smart home and industrial production is generating ever larger amounts of data. Many applications of AI and autonomous systems must have the ability to access many different kinds of data in real time.

The quality of automated learning processes – and the associated potential for innovative business models, as well as for more and better AI applications – essentially depends on access to and the quality of the available test data. Data can therefore be understood as essential facilities, as defined by competition economics,[334] control of which confers market power and thus needs to be regulated.[335] Moreover, state funding for the provision of data seems a good idea, since test data have the properties of public goods. If data management is in purely private hands, there is a risk of a shortage from society's point of view.[336]

Further need for regulation stems from the nature of the data that is generated. A distinction can be made here between personal data and data created in communication between things/objects (Internet of Things, IoT). The demands that must be made on data protection and data security vary in these two cases. Here, too, the Commission of Experts sees major challenges for policy-makers.

In industrial applications, aspects of data protection and privacy play a relatively minor role, and these must be clarified in the process of designing work processes; however, when it comes to applications related to individual persons, data protection plays a key role in autonomous systems. In industrial applications and the IoT, on the other hand, data security is of particular importance.

It is also yet to be decided how and to what extent autonomous systems and AI should be monitored in day-to-day operations – or perhaps pass through a registration process prior to their introduction.[337] In this regard, the Federal Government has taken an important step towards initiating a public discussion and clarifying the situation by creating the Ethics Committee on Automated and Networked Driving.[338] The debate on ethical aspects and data-protection issues is comparatively intense in Germany,[339] although not all relevant dimensions of autonomous systems are included in the discussion.

In order to tap into the benefits of autonomous systems, it will furthermore be key to reach a critical level of societal acceptance of such systems in the course of the societal discourse. In the assessment of the Commission of Experts, many people have positive associations with autonomous driving as an area of application. A social-media analysis conducted by the Commission of Experts draws a differentiated picture here.[340] Although scepticism is expressed in some cases, positive associations with autonomous driving prevail. There are three times more positive than negative German-language online posts about autonomous driving. By comparison, English-language contributions contain only about twice as many positive as negative comments on autonomous driving. Moreover, the societal discourse covers a broad range of topics, and the effects of autonomous driving are intensively discussed in a wide range of forums, blogs and media.[341]

An increasingly common question in discussions on the effects of AI and autonomous systems is their impact on the world of work. The ongoing adjustment of job profiles in many professions has accompanied technological progress continuously since industrialization. Similarly, the diffusion of autonomous systems will involve changes in the demand for existing occupations or perhaps change job profiles. At the same time, the use of autonomous systems can be expected to create possible ways of meaningfully complementing human work and transferring more and more repetitive tasks to technical systems. Such developments are usually associated with increases in the remuneration of labour. In the context of the diffusion of autonomous systems, the Commission of Experts believes there is no scientific justification for horror scenarios relating to the labour market.[342] However, far-reaching measures will have to be taken, above all in education, in order to tap the comprehensive potential benefits of autonomous systems (cf. chapter 2).

In addition to a stable and powerful internet connection, AI requires further complementary infrastructures. These include platforms on which data and algorithms can be stored, shared and re-combined, as well as powerful computer hardware. In addition to the physical input factors (computers, servers, buildings, high-performance internet), a significant part is played by complementary intangible input factors (development of data sets, company-specific human capital, implementation of new business processes, platforms). The reorganization of business processes requires not only purely technical adjustments, but also workforce-training measures.

In view of the foreseeable great importance of autonomous systems and the complexity of the tasks to be carried out, the Commission of Experts is in favour of setting up a Bundestag Committee of Inquiry to look closely at issues of ethics, data privacy, data security, military use and competition.

Germany's position by international comparison B 3–4

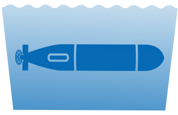
Germany's performance is measured and internationally compared using three indicators: the number of publications at the most important international AI conferences, publications in the areas of application of autonomous systems, and patent applications in the areas of application.

Basic research on AI well positioned in Germany

In order to assess the performance of German science in the AI field, the Commission of Experts consulted data on contributions to scientific research as recorded in the relevant conference proceedings (proceedings

Box B 3-6

Benefits for the economy and society

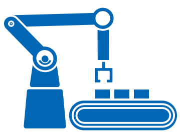


Hostile environments

In hostile environments – e.g. in outer space, underwater,[343] in the aftermath of earthquakes, after accidents in nuclear power plants or during their decommissioning – autonomous systems make it possible for work steps to be executed without endangering people. One advantage of autonomy in a system is that no permanent communication link with a human being is needed; another is that the system can plan parts of its deployment itself. For example, an autonomous robot can find its own way through a damaged nuclear power plant or a building in danger of collapse. Furthermore, in rescue or site-clearance work, robots can be deployed in situations that are too dangerous for people.[344]

The smart home

Autonomous systems can save energy and maximize comfort for the inhabitants by intelligently controlling heating and air-conditioning in buildings. Furthermore, intelligent energy management makes it possible to gear the operation of household appliances like washing machines to the time-related cost structure of the electricity supply (smart metering); in this way it can also react to fluctuating electricity generation from wind or solar energy. In addition, autonomous systems can be used in buildings to take over security functions and coordinate permanently installed monitoring systems with mobile units such as drones.[345] In future, the home, as the focal point of a person's life, could assume an integrating function for autonomous systems in different areas of life.[346] It would be conceivable, for example, to link smart-home functions with mobility solutions in which electric vehicles could be used to store locally generated energy; or the smart home itself requests an autonomous vehicle when a resident leaves the house.



Industrial production

In the field of industrial production, autonomous systems make it possible to both accelerate production and make it more flexible,[347] thus allowing a more individualized final product. For example, autonomous systems can be used in form of driverless transport systems for a company's internal logistics or in human-robot collaborations. The latter make it possible, among other things, to expand quality controls during the manufacturing process and to document work steps in real time.[348] Furthermore, autonomous systems reduce downtime by means of predictive maintenance. To do this, machine data are collected and analysed in real time to discover and report anomalies and initiate necessary measures before a defect occurs.

Autonomous driving

In road transport, autonomous systems will be used in the form of autonomous driving, among other applications. Autonomous driving promises a massive reduction in the number of accidents by avoiding human error, e.g. lack of attention. In addition, networked autonomous vehicles can make traffic more efficient with less congestion, since they can drive in a more proactive and coordinated way than people.[349] Time otherwise spent driving can be used for other purposes. Apart from autonomous vehicles, transport infrastructure, such as traffic lights, can also operate autonomously and in this way adapt dynamically to traffic situations. Parallel to this, different types of autonomous vehicles, such as buses and trains in a public transport network, offer a chance to develop new mobility concepts in combination with autonomous cars. Autonomous driving can also lead to changes in logistics, improve safety and reduce fuel consumption by means of driverless or digitally coupled trucks ('platooning'). At the same time, actors in the logistics industry hope to mitigate the looming shortage of truck drivers.[350, 351] However, a basic prerequisite for the effective operation of autonomous systems in the field of autonomous vehicles is unhindered, cross-border traffic, which ensures that vehicles are supplied with software updates across all national boundaries and, vice versa, that domestic manufacturers can retrieve data from vehicles that are currently abroad.[352]

contributions).[353] The conferences examined are regarded as especially important global forums for basic research on AI. These data were combined with bibliometric information to obtain information on the authors' respective location and on the citation balance of the publications.[354] The results of the evaluation are given in table B 3-7, which shows the countries and regions with the most publications.

The past decade is divided into two equally long time periods (2007–2011 and 2012–2016), which are compared. The choice of periods was influenced by the fact that there has been major progress in key AI components (e.g. neural networks) in recent years since the 2012 ImageNet Competition (cf. box 3-1), which led to a sharp reduction in AI research costs. At the same time, the number of disciplines in which AI is an important part of research is rising continuously. Publication activity has accelerated in the course of this development. The number of recorded proceedings contributions rose from 5,524 in the 2007-2011 period to 7,429 in the 2012–2016 period, a growth of about 35 percent.[355]

Almost half of the proceedings contributions were compiled at US research institutions. This US dominance of AI proceedings contributions is stable in both time windows. In addition to the number of proceedings contributions, their quality is important. To serve as a measure, we observed the ten percent of proceedings contributions that were cited most frequently, thus forming the group of highly cited proceedings contributions, or 'top publications'. Among the US proceedings contributions, these top publications accounted for 11.4 percent, slightly above the average of ten percent.

The gap between the USA and the group of countries made up of Germany, China, Canada, the UK and France is immense – these five countries together are responsible for only about half as many contributions (51 percent) as researchers from the USA. Taken together, EU countries reach a share of 22.8 percent during the period 2007–2011, and 21.6 percent between 2012 and 2016.

Researchers in Germany authored a similar number of contributions over the entire 2007–2016 period as researchers from other large EU countries (UK and France) or in China.

However, researchers from the UK and France increased the number of their proceedings contributions in the second five-year interval by more

Tab. B 3-7

Download data

Contributions to important AI conferences by country or region of author

Country (region)	Proceedings contributions 2007–2011	Share	Proceedings contributions 2012–2016	Share	Growth	Proceedings contributions 2007–2016	Share of highly cited proceedings contributions 2007–2015*
USA	2,729	49.4%	3,683	49.6%	35.0%	6,412	11.4%
EU	1,258	22.8%	1,607	21.6%	27.7%	2,865	
of which:							
Germany	336	6.1%	348	4.7%	3.6%	684	9.5%
United Kingdom	284	5.1%	430	5.8%	51.4%	714	10.7%
France	233	4.2%	367	4.9%	57.5%	600	9.1%
Other EU countries	405	7.3%	462	6.2%	14.1%	867	
Canada	318	5.8%	324	4.4%	1.9%	642	13.9%
China	283	5.1%	356	4.8%	25.8%	639	11.4%
Japan	160	2.9%	199	2.7%	24.4%	359	3.7%
Other countries	776	14.0%	1,260	17.0%	62.4%	2,036	7.4%
Total	5,524	100.0%	7,429	100.0%	34.5%	12,953	10.0%

Fractions are used to assign the authors to the countries of the research institutions with which they are affiliated. The percentage of highly cited publications is approximately corrected for distortions caused by the fact that the 90-percent percentile is stated in whole numbers. Authors are assigned to the group of frequently cited publications on the basis of citation distributions in the specific year of publication.
* Publications in 2016 were not taken into consideration when determining the share of highly cited publications, because the time period is too short for a reliable delimitation.
Source: calculations by the Max Planck Institute for Innovation and Competition on the basis of data from the Digital Computer Science Bibliography (DBLP) and Scopus.

than 50 percent (58 percent for France, 51 percent for the UK), while the number of German proceedings contributions virtually stagnated. Chinese proceedings contributions rose by approximately 26 percent, those by researchers in the USA by 35 percent. The number of Canadian proceedings contributions remained about the same. However, Canada has a very high proportion of highly cited proceedings contributions. The low share of Japanese researchers' proceedings contributions and their relatively low citation frequency is striking.

As in other leading reference countries, AI research in Germany is concentrated in a small number of locations and conducted by only a few scientists. 39.7 percent of the proceedings contributions analysed during the period 2007–2016 come from the Tübingen/Stuttgart (23.8 percent) and Berlin/Potsdam (15.9 percent) areas. Further particularly active regions or cities are Bonn/St. Augustin (6.9 percent), Saarbrücken (6.8 percent) and Munich/Garching (6.2 percent). These five locations thus generate 59.4 percent of the proceedings contributions recorded.

Relatively few publications on areas of application

In order to be competitive in the development of autonomous systems, it is essential to engage not only in basic research, but also in research and development (R&D) in the areas of application. Based on a study conducted on behalf of the Commission of Experts, this section looks at publication data in four areas of application: hostile environments, the smart home, industrial production and autonomous vehicles. The indicator for Germany's publication performance by international comparison is available for the period from 2002 to May 2017.[356]

From a global perspective, there was a marked increase in publication activities in the areas of application of autonomous systems over the last five years (2012–2016).[357] The most publication activity was recorded in the application area of autonomous vehicles. Here, there has been a substantial increase in publication activity since 2012 at an average annual growth rate of almost 19 percent.

In addition to the quantity of publications, their quality, as measured by the so-called top publications, is also an important indicator for assessing a country's scientific performance. Top publications are often identified by the frequency with which they are cited. In figure B 3-8, the top publications shown refer to the most highly-cited 10 percent of all publications in the relevant area of application.[358]

Figure B 3-8 shows the cumulated publication activities of selected countries in the individual areas of application over the last 15 years.[359] Figure B 3-8 visualizes the quantity indicator (i.e. the number of publications) on the horizontal axis. The quality indicator, i.e. the number of top publications, is plotted on the vertical axis.[360]

In the area of application of autonomous vehicles, the USA takes the leading position both in all publications and in top publications. Germany's publication output is just over one third (approximately 36 percent) of the USA's. This puts Germany slightly ahead of Japan and South Korea, but a long way behind China. However, in top publications Germany is ahead of China with about 26 percent of the US figure.[361]

China, the USA and South Korea are particularly strong in the area of application of the smart home. China is ahead of the USA and South Korea when it comes to total publications. However, the USA again dominates in top publications. Germany generates just under 36 percent of the leading nation China's output of total publications, and approximately 23 percent of the leading nation USA in top publications.[362]

In the area of application of industrial production, Germany is on a par with China and the USA in all publications. However, these two countries are ahead in top publications. China's strong position is striking, whereas Germany only accounts for about 31 percent of the USA's top publications in this category.[363]

The area of application of hostile environments is also dominated by the USA and, to a lesser extent, China. The dominant role of US researchers manifests itself particularly when it comes to top publications. Germany's publication performance relative to the USA is less than 17 percent for all publications and less than 11 percent for top publications.[364]

Good position in patents on autonomous vehicles

In order to be able to study patenting activities in the four areas of application, the Commission of Experts uses the results of two studies that it commissioned.[365] In the following discussion, the Commission of Experts refers to international patenting activities evidenced by transnational patent applications.[366] figure B 3-9 shows the distribution of the patent families determined in this way according to the inventor country. The results are shown explicitly for inventors from Germany, the USA, Japan, South Korea and China.

Patents of inventors from other countries are summarized (other countries). Patent families whose earliest application was in 2002 and thereafter are included. The figures mentioned here for inventors from Germany can be compared with the patents of German inventors as a percentage of total transnational patent applications. This percentage amounted to 10.8 percent in 2015 (cf. table C 6-2).

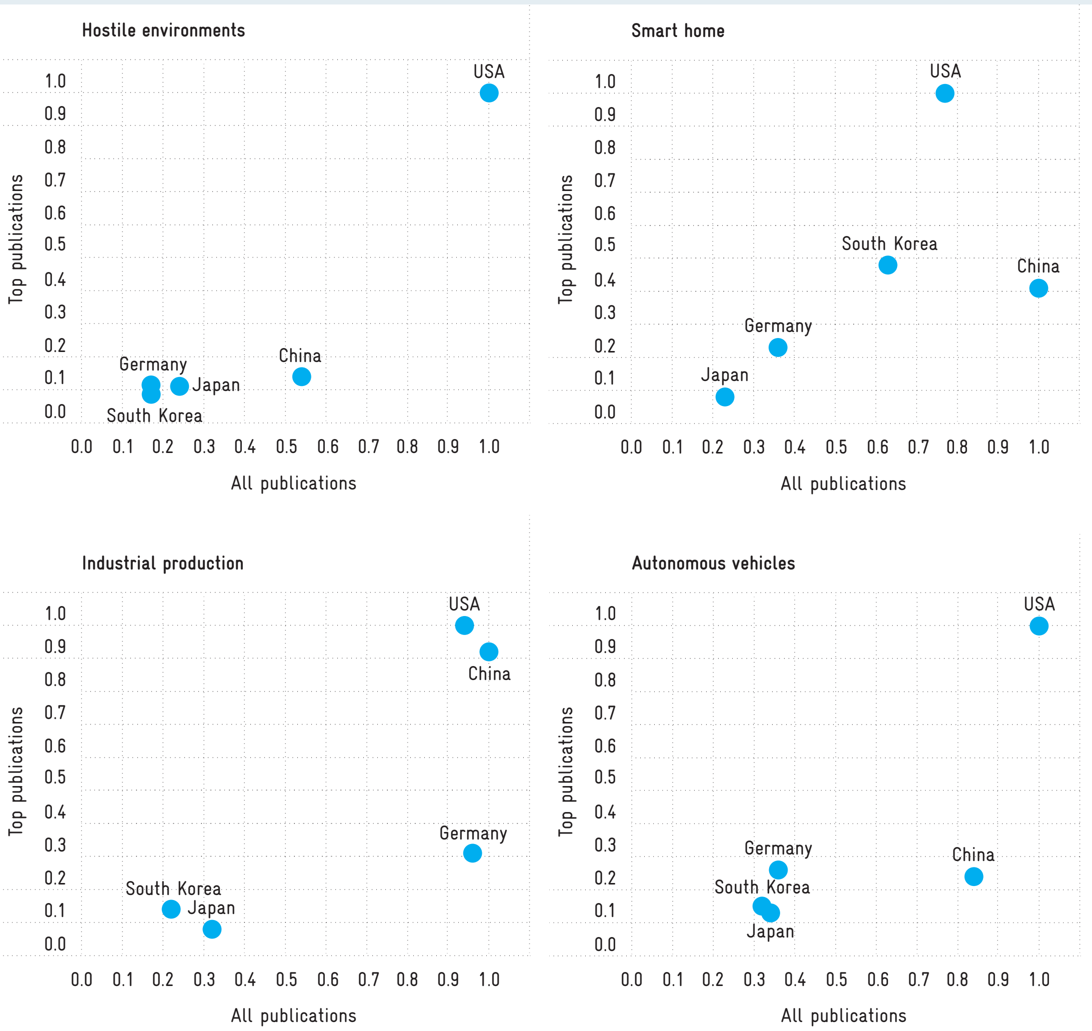
In the area of application of automated driving, 6,140 transnational patent families were identified. Application activity has accelerated: approximately one third of the identified patent families have been submitted since 2014. Inventors from Japan (24.3 percent), Germany (23.3 percent) and the USA (20.4 percent) have similarly high shares of the total number of patent families. South Korea (6.4 percent) and China (4.8 percent) follow some distance behind. In the remaining group (other countries), inventors from France (4.5 percent) and the UK (3.0 percent) record significant activities. Overall, these results indicate that Germany is very important as a location for R&D in the field of automated driving, and that German patent applicants have a competitive patent portfolio.[367]

In the area of application of industrial production, inventors from the USA (35.3 percent) and Japan (30.1 percent) hold the leading positions. Inventors active in Germany represent 13.4 percent of all the patent families considered here. South Korean (5.3 percent) and Chinese (2.6 percent) inventors reveal significantly lower patenting activities. Patenting in the area of application of the smart home is dominated by South Korean inventors, who make up 32.4 percent of the identified patent families. They are followed by inventors from the USA (20.1 percent), China (15.1 percent), Germany (10.3 percent) and

Fig. B 3-8

Download data

Publications and top publications* in relation to the leading country in the respective area of application for selected countries 2002–2017



Publications from 2017 are included up until May 2017. The numbers of all publications and top publications are shown below according to the following pattern: area of application (number of top publications by the leading country in this application area, number of all publications by the leading country in this area of application). Hostile environments (431, 2,733), smart home (135, 912), industrial production (118, 654), autonomous vehicles (947, 5,648).
* The top publications are defined as the top 10 percent of publications by citations. In the smart home area of application, this means that publications that were cited more than 60 times are taken into consideration. In the industrial production area of application, it is publications with more than 10, in autonomous vehicles more than 12, and in hostile environments more than 13 citations.
Source: own calculations based on Youtie et al. (2018).

Japan (9.9 percent). In the area of application of hostile environments, inventors from the USA (34.0 percent) again reveal particularly strong activities. German inventors follow with 18.6 percent.

Overall, these data suggest that Germany is in a particularly strong position in the area of application of automated driving and autonomous systems in hostile environments. Germany's position in the area of application of industrial production is slightly higher than German inventors' 10.8 percent share of all transnational patents. The position in the area of application of the smart home is roughly equivalent to that of German inventors for all transnational patents in 2015. So there is no particularly strong specialization here.

Assessment of the German position

The analyses of publication and patent activities reveal a mixed picture as regards Germany's position by international comparison. Germany holds a promising position when it comes to patents in the areas of autonomous vehicles and hostile environments. In publications, Germany is in a strong international position only in the number of publications on industrial production, but not among top publications. Up to now, Germany has also been strong in the field of AI basic research. However, activity among international competitors is much more dynamic here. Furthermore, China's strong position is striking; it has more publications than Germany in all the areas of application of autonomous systems; it also produces more top publications with the exception of the field of autonomous vehicles.

B 3-5 Funding measures and strategies

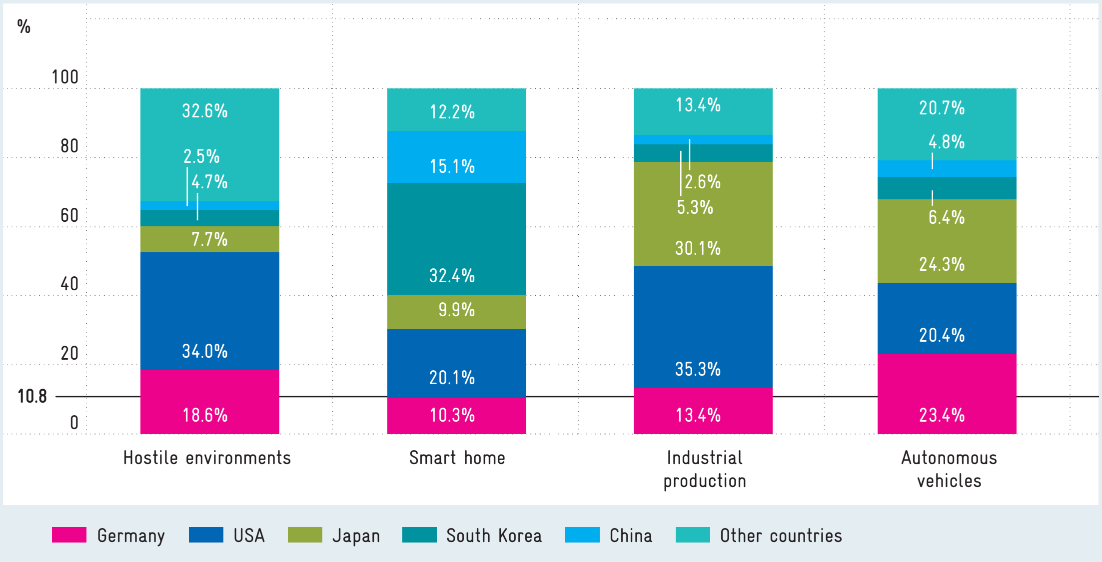
Autonomous systems and related individual technologies receive state funding at both the national and the international level. In Germany, different federal ministries are involved in the funding activities. The Federal Ministry for Education and Research (BMBF), for example, has introduced a platform called 'Learning Systems' and launched the 'Expert Forum on Autonomous Systems in the High-Tech Forum' together with the Federal Ministry of Economics and Technology (BMWi). Alongside many other funding programmes and projects of these ministries, there are also funding activities at other ministries such as the Federal Ministry of Transport and Digital Infrastructure (BMVI).[368] Overall, these measures[369] reveal a funding priority for autonomous driving as the current leading-edge application. Other priority topics include robotics and industrial manufacturing.[370] Autonomous driving is a priority at the European level, too. Most of the funding of autonomous systems in this field takes place within the framework of the 7th EU Research Framework Programme and Horizon 2020.[371]

In Germany, the German Research Foundation (DFG) also funds research into autonomous systems: e.g. the priority programmes 'Cooperatively Interacting Automobiles' (since 2015) and 'Autonomous Learning' (since 2012), as well as the Collaborative Research Centres/Transregio projects 'A Companion Technology for Cognitive Technical Systems' (2009

Fig. B 3-9

Download data

Germany's share of transnational patents by international comparison for the four areas of application of autonomous systems examined 2002–2016



The horizontal line shows patents from German inventors as a percentage of total transnational patent applications. This amounted to 10.8 percent in 2015. Cf. table C 6-2.
Source: own calculations based on Pötzl and Natterer (2018) and Youtie et al. (2018).

to 2017) and 'Cognitive Automobiles' (2006 to 2010).[372] In addition, the Volkswagen Foundation funds integrative research approaches in the social and engineering sciences in the field of AI with the programme 'Artificial Intelligence and the Society of the Future'.[373]

Furthermore, the 'Cyber Valley' research network was initiated by the state of Baden-Württemberg in 2016.[374] Various partners from science and industry in the Stuttgart/Tübingen region collaborate in this network to advance research and development of intelligent systems, ensure the transfer of technologies, and create a favourable environment for business start-ups.[375] The Commission of Experts welcomes this initiative, especially since it builds on the region's unequivocal leadership in basic research on AI (cf. section B 3-4).

An international comparison shows that other countries have announced massive funding efforts in the AI field. Many of these announcements have not yet been implemented. Nevertheless, they reveal an awareness of the importance of AI among Germany's international competitors. China, for example, aims to achieve a leading position in both technological developments and AI applications by 2030.[376] To this purpose, the state plans massive investments in AI start-ups, basic research and 'moonshot projects'.[377] The plan of the city of Tianjin near Beijing, announced in 2017, to set up a fund worth approximately €4.2 billion[378] to support the AI industry, deserves mention as an exemplary measure in China's AI-funding strategy.[379] In 2016, the government of South Korea also announced its intention of investing €780 million[380] in building an AI research centre by 2020 together with partners from industry, such as Samsung, LG Electronics and the Hyundai Motor Company.[381] In 2017, Japan published a strategy paper on AI technology which envisages R&D priorities in the fields of productivity, autonomous vehicles and health. The paper simultaneously supports collaborations between the government, industry and academic institutions and emphasizes the need for training in the field of AI. AI applications are also part of Japan's so-called Revitalization Strategy announced in 2017.[382] The USA also published several strategy papers in 2016 stressing the importance of AI for both the economy and national security, and presenting strategies for funding it.[383]

Despite a large number of individual measures, special institutions and platforms,[384] no strategy on the part of the Federal Government that sets comparably strong priorities on the funding of AI research can currently be seen in Germany.

Recommendations B 3–6

The Commission of Experts welcomes the fact that policy-makers became active at an early stage by setting up the Ethics Committee on Automated and Networked Driving, in order to promote a societal discourse on the ethical issues of autonomous systems. It also welcomes the fact that several ministries have incorporated the technological development of autonomous systems into their research-funding programmes. The platform Learning Systems set up by the Federal Ministry of Education can generate important new ideas for the future practice of funding and application.

Nevertheless, there is still a considerable need for action in various areas to put Germany in an advantageous position amidst the dynamic, international competition for innovation in the fields of AI and autonomous systems.

– The Commission of Experts therefore calls for the establishment of a Bundestag Committee of Inquiry on 'Autonomous Systems and Artificial Intelligence'. The key tasks of this 'Enquete Commission' should be:

  - to bundle the societal discourse on the design and use of autonomous systems,
  - to draw up development principles which ensure that autonomous or AI-based systems are monitored and adapted on the basis of socially recognized ethical principles,
  - to embrace relevant new technical, economic and social developments,
  - to link the debate in Germany with international and, in particular, European discussion processes,
  - to develop suitable indicators for regular reviews of both the framework conditions and Germany's performance by international comparison.

– The Commission of Experts calls for the development of a national strategy for AI with the aim of boosting Germany's scientific and technological competitiveness.

  - This strategy should be embedded in a European strategy, since Germany alone is unlikely to be able to keep pace with the ambitious plans of companies and research institutions in the USA and China in the foreseeable future. By contrast, a scientific and economic counterweight can be built up within the network of European actors.
  - The Commission of Experts recommends forging ahead with the already visible AI centres in Germany within the framework of this strategy. By ensuring competitive funding for basic research, the aim should be to encourage prolifically publishing researchers to stay in Germany, attract talent, and develop a good basis for the transfer of knowledge and the commercial use of AI.
  - In addition, the Commission of Experts recommends supporting such 'AI lighthouses' by conducting research in the humanities and social sciences, in order to address the societal implications of AI at an early stage, recognize areas where regulation is needed, and accompany the societal discourse.

– The Commission of Experts calls on the Federal Government to actively accompany and support the process initiated by the European Commission for the creation of a European single market for data. Only if a cross-border flow of data, unhampered by legal frictions, is possible, can the potential of increasingly data-based value-creation processes be realized.
– The Federal Government must ensure that companies cannot use data to build barriers to market entry that will obstruct competition in the long term. In this case, data should be treated by the competition authorities as essential facilities.[385]
– The Commission of Experts recommends funding the transfer of knowledge and findings between different actors via the Learning Systems platform. SMEs in particular should be included here. The budget allocated to the platform must be publicized and transparently kept separate from funds for ongoing projects.
– The fact that funding policy has hitherto been strongly focused on current strengths of the German economy could prove to be an obstacle to the development of new areas of application. The Commission of Experts advises incorporating all application fields of autonomous systems into funding.