CHAPTER 7

R&I ENABLING ARTIFICIAL INTELLIGENCE

KEY FIGURES

60 %
of all AI science is in fields other than computer science

22 %
EU share in global AI publications

19 %
EU28's share in world AI firms

8 %
EU28's share of global AI private investments

>€20 bn
per year of EU private and public investments over the next decade

What can we learn?

- **AI is a potential game changer for productivity and sustainability**, providing the right complementary skills, infrastructure and management culture are in place.
- **R&I solutions are needed to mitigate the environmental footprint of AI.**
- **AI is a vital tool in the fight against the new coronavirus**. At the same time, the use of AI tracking and surveillance tools in the context of this pandemic has shown the need for global ethical governance of AI.
- **Data explosion, stronger computational power, more sophisticated algorithms and open source software** have enabled breakthroughs in AI R&I.
- **'AI dynamics'**: exploring the boundaries of scientific fields beyond computer science, with intersectoral and intensified cross-country collaboration, EU included.
- **The EU ranks among global leaders in AI science but trails in AI innovation**, although it is in line with its share in global R&D.
- **A gender diversity gap in AI research persists** but is less pronounced in Europe than in other regions worldwide.
- **Private investments and acquisitions of AI startups are on the rise. EU investments remain insufficient**. The United States leads, followed by China.
- **AI talent is relatively scarce worldwide** and appears more predominant in the United States than in the EU.
- **AI is increasingly blending with digital technologies**, such as blockchain, **and with the physical world** in fields like advanced manufacturing and materials science.

What does it mean for policy?

- **AI can play a big role in the economic, social and ecological transition** Europe is undergoing.
- **The EU should capitalise on its scientific and industrial strengths to lead in AI development** and to foster technologies that both benefit and augment its potential.
- **The EU and Member States need to join forces** to raise the level of public and private investments in AI, deepen the Digital Single Market, move towards AI technology sovereignty, and diffuse AI practices across the Union.
- **The EU needs to promote AI talent** production and retention in the EU (while attracting foreign talent), **investments and capacity-building in related digital technologies**, such as high-performance computing, European cloud and microelectronics, and research and digital infrastructure, notably 5G.
- The EU's guiding principles of **trustworthy, human-centric, and ethical AI are a strength and not an obstacle to the EU AI innovation ecosystem**. These will also improve the 'trust in tech' and safeguard privacy.

1. Artificial intelligence: a potential game changer for productivity and sustainability

Artificial Intelligence (AI) as a field of study is already 70 years old. In 1950, Alan Turing put forward the so-called 'Turing test' as a way of determining if a computer is capable of thinking like a human. John McCarthy, a computer scientist, then coined the term 'artificial intelligence' during a conference in 1955. Between 1955 and 1997 – when IBM's Deep Blue defeated Gary Kasparov, world chess champion – there were periods of progress in the field, often restricted to highly specific applications and notably in natural language processing and neural networks. However, there were also periods known as 'AI winters', brought about by overly big expectations, a lack of practical applications of AI and, ultimately, reductions in AI research funding. In 2006, developments in deep learning generated further enthusiasm around AI. Importantly, the rise of big data allied to greater cloud and computing-processing capabilities boosted numerous developments in the field. Nowadays, AI is not only present as a tool in scientific research and industry activities but is also increasingly in everyday life.

Although there is currently no established global definition of AI, a recent definition put forward by the High-Level Expert Group on AI, set up by the European Commission[1], is presented in Box 7-1. It includes the sub-disciplines described in Figure 7-1, namely machine learning (and, within this category, deep learning and reinforcement learning), reasoning processes as well as intersections with robotics fields, for example, sensors.

BOX 7-1 Towards an AI definition

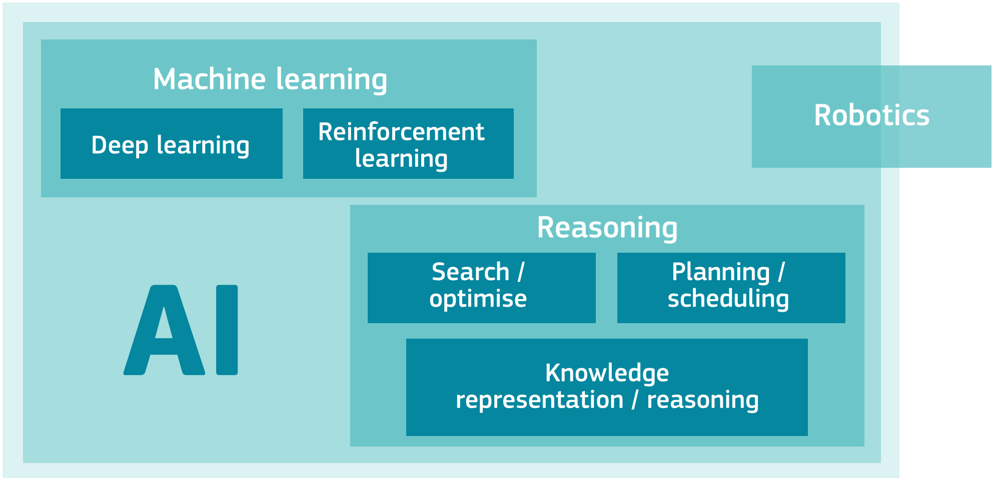
Artificial intelligence (AI) systems are software (and possibly also hardware) systems designed by humans that, given a complex goal, act in the physical or digital dimension by perceiving their environment through data acquisition, interpreting the collected structured or unstructured data, reasoning on the knowledge, or processing the information derived from this data and deciding the best action(s) to take to achieve the given goal. AI systems can either use symbolic rules or learn a numeric model, and can also adapt their behaviour by analysing how the environment is affected by their previous actions.

As a scientific discipline, AI includes several approaches and techniques, such as machine learning (of which deep learning and reinforcement learning are specific examples), machine reasoning (which includes planning, scheduling, knowledge representation and reasoning, search, and optimisation), and robotics (which includes control, perception, sensors and actuators, as well as the integration of all other techniques into cyber-physical systems) (see Figure 7-1).

Source: European Commission (2019), Report by the High-Level Expert Group on AI set up by the European Commission

1 Based on European Commission (2019), Report by the High-Level Expert Group on AI set up by the European Commission.

Figure 7-1 A simplified overview of AI's sub-disciplines and their relationship



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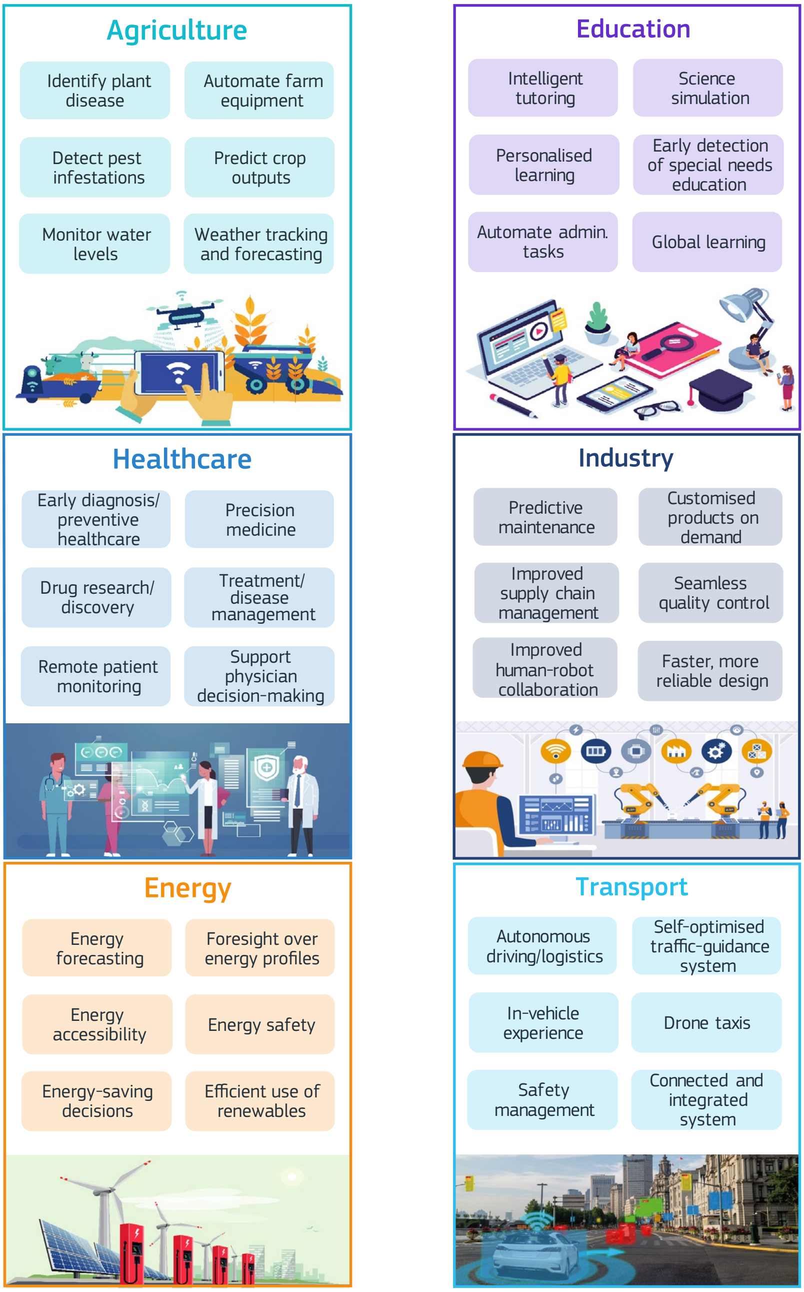
Source: European Commission (2019), Report by the High-Level Independent Expert Group on AI

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-1.xlsx

Achieving the full potential of AI for productivity depends on having in place the right complementary skills, infrastructure, and management culture. The fact that AI is seen by many as the 'new electricity' relates to its cross-cutting applications that make it a general-purpose technology capable of driving efficiency and productivity in virtually all sectors of the economy. By optimising operations and enabling accurate predictions, AI can also potentially be a powerful tool to help achieve the Sustainable Development Goals. However, while digital technologies such as AI hold a lot of promise for boosting growth and competitiveness, productivity growth remains lackluster. Chapter 3.1 - Productivity puzzle and innovation diffusion highlights potential explanations for this, notably the widening productivity gap between the most- and least-productive firms due to insufficient innovation diffusion and the rising market concentration around 'superstar firms'.

In the specific case of AI, Brynjolfsson et al. (2017) point to the time lag in implementing new technologies such as AI, or potential productivity mismeasurements following a 'J-curve' (Brynjolfsson et al., 2018). Moreover, AI investments depend on other complementary efforts and intangible investments that may take some time to materialise. These might include organisational and managerial changes and the need to acquire new skills or retrain staff, among others. The authors refer to the steam engine, electricity, and the internal combustion engine to argue that their impact also took some years (even decades) to be felt. Furthermore, AI can enable faster scientific discovery (OECD, 2018a) especially at a time when research productivity may be falling and new ideas seem harder to find, as highlighted by Bloom et al. (2017). Finally, AI can help increase productivity by helping humans use increased capabilities faster, and enabling more reliable forecasting, more flexibility in operations based on huge amounts of data, more precision, etc. On the other hand, automation entails risks as regards replacing many jobs and tasks as well as other issues related to the future of work, as addressed in Chapter 4.1- Innovation, the future of work and inequality.

Figure 7-2 Examples of cross-sector applications of AI as a general-purpose technology to optimise operations and increase efficiency



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Statista - AI report (2019), fao.org - State of food nutrition, futurefarming.com, Forbes - How Is AI Used In Education, European Commission (2018), PwC, Forbes with Intel – Sizing Up AI's Predictive Analytics Powers In Healthcare: Top Use Cases, softwebsolutions.com. Images © Ico Maker, #265312009, 2019; © Monopoly919, #188158746, 2019; © Francois Poirier, #209725591; © irinastrel123, #206006119, 2019; © mast3r, #180336886, 2019; © Mykola, #284569356, 2019; © petovarga, #166430109, 2019. Source: stock.adobe.com

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-2.xlsx

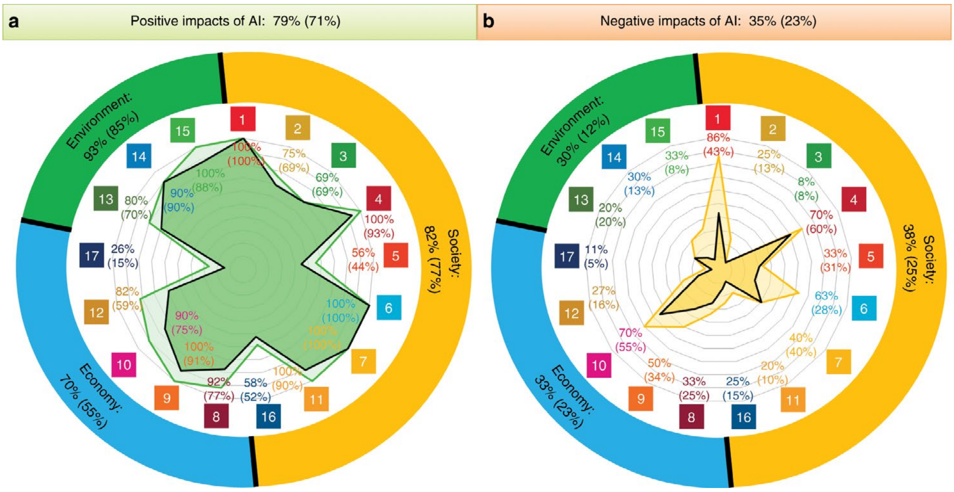
As a general-purpose technology, AI applications can boost productivity, improve predictions, and contribute to greater energy efficiency in virtually any sector of the economy. Figure 7-2 provides some concrete examples of AI applications across different sectors of the economy. For example, in agriculture, AI technologies can better predict crop outputs and detect pest infestations. In healthcare, AI can contribute to drug discovery and early diagnosis. In industry, operations such as supply chain management can be optimised and quality control improved. In energy, power-grid optimisation can rationalise energy supply based on demand. However, AI applications also pose some risks or face certain obstacles. OECD (2019a) stresses that in agriculture the lack of network connections in rural areas may undermine the use of sophisticated systems, and high-tech farms may require costly investments in automation tools and sensors. In addition, in healthcare the data privacy of patients must be taken into account.

The role of AI in tackling global challenges should not be underrated. In fact, AI and other digital technologies can be important channels towards cutting global greenhouse gas emissions. At the same time, AI itself may be a contributor to further emissions, namely due to greater energy consumption resulting from, for example, data centres and supercomputers. R&I can act as a mitigator by contributing to energy-efficient computing and 'greener' solutions. According to the Global Action Summit (2018), AI and digital technologies can contribute to cutting global emissions across sectors. For instance, annual emissions from the energy supply would be reduced via better grid flexibility and storage. Efficient shipping would also be an important channel for reducing the emissions from the transport sector, and precision agriculture could reduce the sector's footprint.

With growing digitalisation and ever-larger data flows, the need for both network capacity and computing power has increased enormously. As a result, energy demand from data centres and data-transmission networks could be on the rise. Andrae (2017) estimates that data centres could account for 10% of total electricity use by 2025. Fortunately, the International Energy Agency (2019) argues that to date technological progress in energy efficiency has contributed to limiting the growth of electricity demand and usage. In fact, accordingly, there has been a *shift away from small, inefficient data centres* towards much larger cloud and hyperscale data centres. Indeed, trade-offs may occur. As discussed in Vinuesa et al. (2020), while AI can act as an enabler in 79% of all SDG targets, the progress of 35% of them may be inhibited by AI, at least to some extent (Figure 7-3). As stated by the authors, this requires policies that help direct the vast potential of AI towards the highest benefit for individuals and the environment, as well as towards achieving the SDGs.

Thus, R&I can be a powerful ally by generating 'greener' solutions. At the EU level, the EuroHPC Joint Undertaking will develop a 'world-class supercomputing ecosystem in Europe' that will also use R&I to develop a low-power processor, for example. However, concerns over the environmental footprint of AI and data centres will remain in both the short and long run. According to Strubell et al. (2019), training a deep learning model could be equivalent to that of the lifetime of five cars, which calls for the greater mobilisation of R&I efforts to boost the energy efficiency of digital technologies, and eventually to replace the most-pollutant technologies with more energy-efficient or even carbon-neutral ones.

Figure 7-3 Summary of positive and negative impacts of AI on various Sustainable Development Goals (SDGs)



Source: Vinuesa, R., Azizpour, H., Leite, I. et al. (2020)
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-3.xlsx

AI-powered solutions can be important tools to help in the fight against a pandemic such as COVID-19. However, increased surveillance and tracking systems have also reinforced the need for global ethical governance of AI. Box 7-2 illustrates how AI and other digital technologies are being used to provide solutions that can help in the fight against COVID-19.

BOX 7-2 How artificial intelligence is used in the fight against the COVID-19 pandemic

AI, big data and other digital technologies are vital tools for helping to fight a pandemic such as COVID-19.

In just one week, scientists in China were able to recreate the genome sequence of the virus by using AI. The Canadian start-up BlueDot detected an outbreak[2] of pneumonia cases in Wuhan in December and identified the cities that were at the highest risk of facing their own outbreaks.

AI has been used to detect visual signs of COVID-19 on images from lung CT scans, monitoring changes in body temperature in real time, providing an open-source data platform to track and monitor the spread of the disease, and is increasingly being used to help identify potential treatments and cures. At the same

2 https://www.cnbc.com/2020/03/03/bluedot-used-artificial-intelligence-to-predict-coronavirus-spread.html

time, the use of AI tracking and surveillance tools in the context of this pandemic has clearly shown the need for a global ethical governance of AI.

AI solutions in the fight against COVID-19

All over the world, ambitious R&I projects and collaborations to track, monitor and contain the COVID-19 pandemic are increasingly being carried out, including AI-powered solutions.

AI-related applications have **enabled population screening, tracking the spread of the infection**[3]**, and the detection and diagnosis of COVID-19**. The new Pan European Privacy- Preserving Proximity Tracing initiative, compromising more than 130 members across eight European countries, is one of several endeavours to set up a tracking system using mobile phones and anonymised data in compliance with the European GDPR. An important challenge in this respect would be to ensure the compatibility of such national systems across the EU.

AI is also used to further speed up the drug-development process by modelling the efficacy of these drugs prior to clinical trials. In this context, AI could also optimise the process of clinical trials to discover new and effective drugs and vaccines.

As mentioned in Ting et al. (2020), 'the utilization of various AI-based triage systems could potentially alleviate the clinical load of physicians'. This includes, for instance, online medical 'chat bots' to guide patients in understanding their symptoms, providing guidelines for hand washing, and guiding patients through the next steps should their symptoms worsen. Another important use of AI is in fighting misinformation, for instance on social media channels.

An inventory of AI and robotics solutions to tackle COVID-19

The European Commission has launched an initiative to collect ideas about deployable AI and robotics solutions as well as information on other initiatives that could help us to face the ongoing COVID-19 crisis[4]. To date, this inventory has shown that the R&I community and enterprises have been very active in coming up with such solutions. For example, the Lucentia Lab in Spain has developed a platform for big data and AI for handling patients. In Belgium, KU Leuven has deployed therapeutics for the treatment of SARS-CoV infection, and there are many other examples.

Open data based on FAIR principles[5] *and high-performance computing*[6] *are key*

Openly accessible, machine-readable, inter-operable data is needed to track, monitor and forecast the spread of COVID-19. Key datasets include clinical, epidemiological and laboratory data. At the EU level, the **Action Plan - Research data-sharing platform for the SARS-CoV-2 and COVID-19 disease**, launched by the EMBL's European Bioinformatics Institute (EMBL-EBI) and the **European Open Science Cloud** intends to speed up and improve the sharing, storage, processing of and access to research data and metadata on the SARS-CoV-2 and COVID-19 diseases.

The goal is to start making these data available from the end of April through a new European data platform which is also connected to the European Open Science Cloud. This will allow the

3 https://www.bruegel.org/2020/03/artificial-intelligence-in-the-fight-against-covid-19/
4 https://ec.europa.eu/digital-single-market/en/news/join-ai-robotics-vs-covid-19-initiative-european-ai-alliance
5 Findable, Accessible, Interoperable and Reusable by both humans and machines, https://www.go-fair.org/fair-principles/
6 https://ec.europa.eu/digital-single-market/en/news/using-european-supercomputing-treat-coronavirus

scientific community to share, analyse and process them rapidly, openly and effectively **across the Member States** and worldwide in line with the relevant EU data legislation.

Three powerful European supercomputing centres – located in Bologna, Barcelona (Spain) and Jülich (Germany) – are participating in the EXSCALATE4CoV[7] project, along with a pharmaceutical company and several large biological and biochemical institutes. The project is now processing digital models of the coronavirus' protein and matching them against a database of thousands of existing drugs, aiming to discover which combinations of active molecules could react to the virus. The project has received EUR 3 million in funding from the EU's Horizon 2020 for research into COVID-19 vaccine development, treatment and diagnostics.

EU projects mobilised to forecast and model the pandemic[8]

The EPIWORK[9] project aimed to develop a set of tools and knowledge to design infrastructures that could forecast epidemics. It resulted in the Global Epidemic and Mobility Model project (GLEAM)[10] to deliver the analytic and forecasting power that could minimise the impact of potentially devastating epidemics. Researchers who worked on these projects are currently using the results to try to understand how the current pandemic may spread, how it may evolve over time and how containment and prevention measures may help.

AI solutions could also help to provide scenarios for a gradual exit from the lockdown by guiding the necessary social distancing and adapting the measures to the corresponding risks.

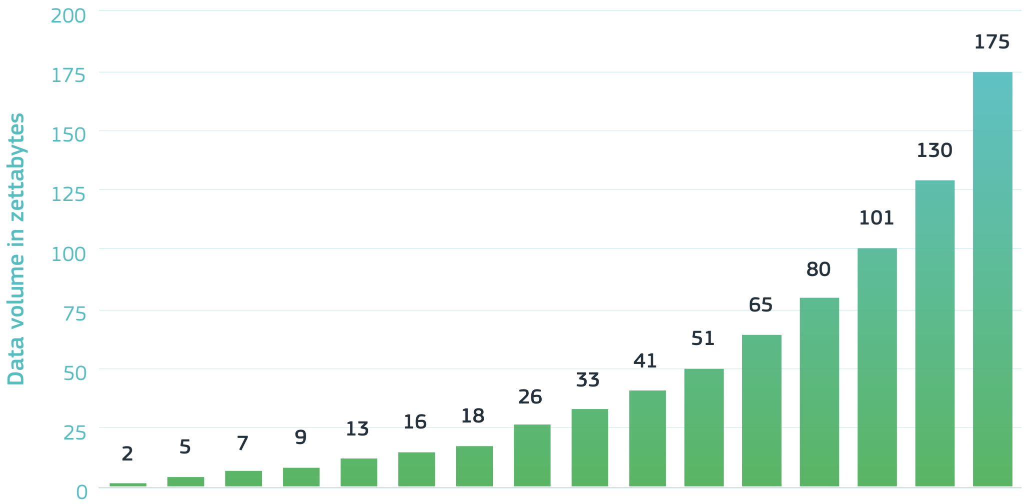
2. Global AI trends

Data explosion, stronger computational power, more sophisticated algorithms and open source software have fostered significant developments in AI R&I. The volume of data and information created has increased dramatically from just two zettabytes in 2010 to 26 in 2017 and is expected to reach 175 zettabytes by 2025 (Figure 7-4). This data explosion has been fuelled by the digital transformation of firms, economies and societies. Nowadays, the sources of data production include not only transactional and personal data, but also social interactions and machine-generated data. Indeed, the use of personal devices such as smart phones has boosted the number of interactions online through, for example, video views and engaging in social media platforms. In addition, greater cloud capacity has enabled the management and storage of big datasets. The connection of different Internet of Things (IoT) devices has also generated large amounts of new data. As a result, the increasing production of data combined with more sophisticated techniques to explore and analyse databases have enabled important developments in AI, notably in deep learning. However, not only huge amounts of data are needed for accurate predictions – the data must also be high quality. Moreover, important privacy and ethical issues related to data should also be taken into account, as highlighted later in this chapter.

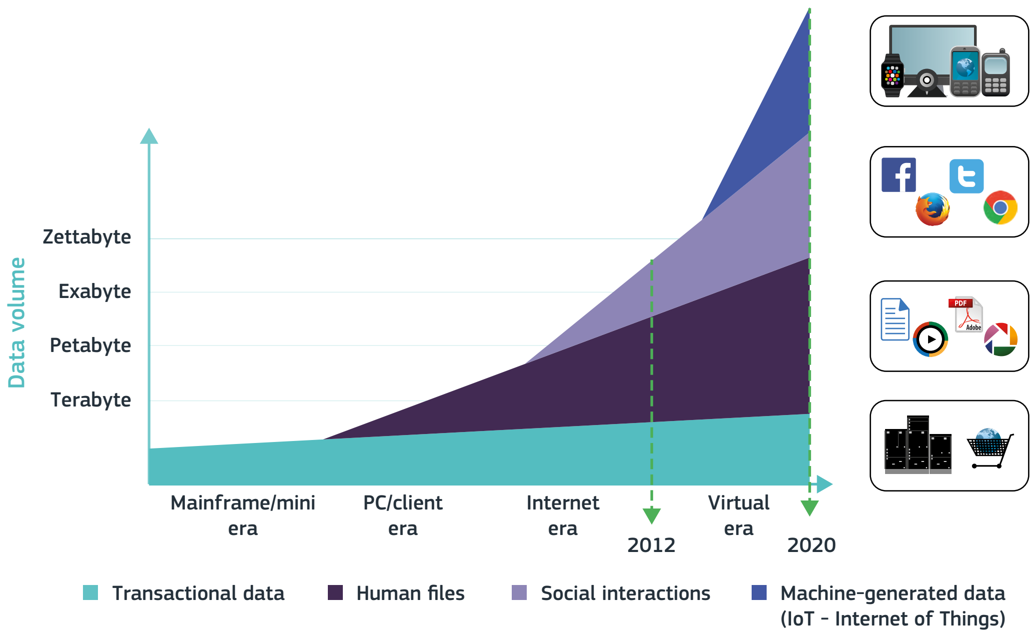
7 https://www.exscalate.eu/en/
8 https://ec.europa.eu/digital-single-market/en/news/forecasting-coronavirus-pandemic-help-eu-projects
9 https://cordis.europa.eu/project/id/231807
10 http://www.gleamviz.org/

Figure 7-4 The data explosion: sources and evolution over time

Volume of data/information created and forecast worldwide in zettabytes, 2010-2025



Evolution of data (main sources)



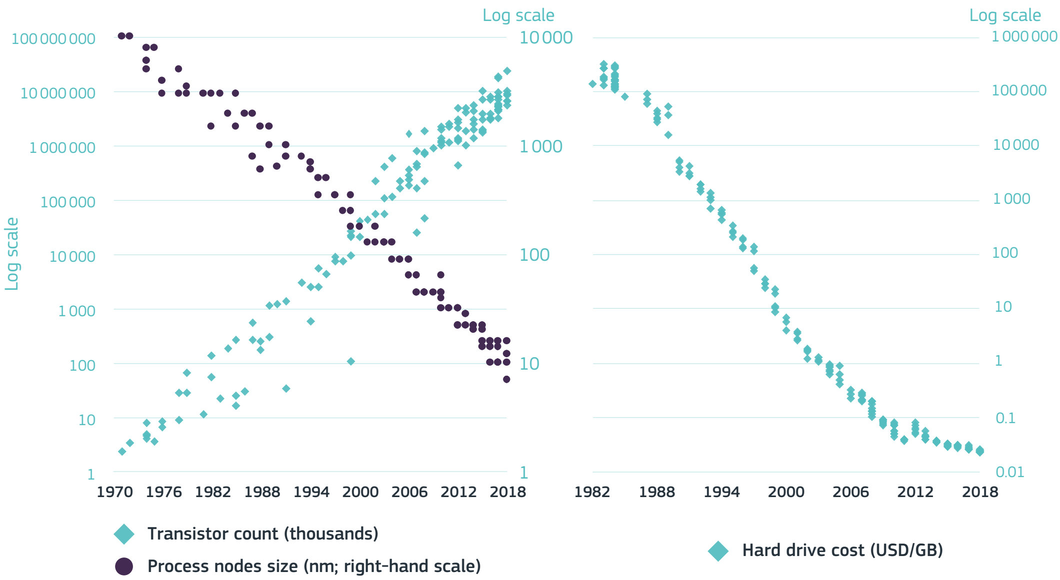
Source: https://medium.com/@melodyucros/ladyboss-heres-why-you-should-study-big-data-721b04b8a0ca, and IDC; Seagate; Statista estimates

Note: Values are estimated.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-4.xlsx

Breakthroughs in computing and the decrease in the cost of storage have contributed to greater and cheaper computing capacity to process large volumes of information (Figure 7-5). Indeed, using the number of transistors per chip as a proxy for computational power, the OECD (2019a) finds that capacity has doubled every two years since the 1970s. Greater speeds and energy efficiency have also been achieved thanks to the continuing miniaturisation of transistors.

Figure 7-5 Computing power and cost of storage[(1)], 1970-2018 and 1982-2018



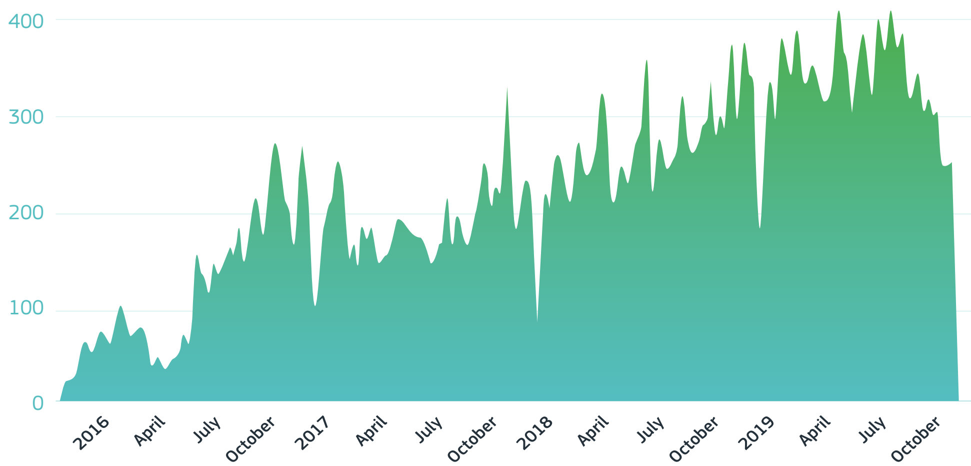
Source: OECD (2019a)
Note: [(1)]Number of transistors per central processing unit (CPU) microprocessor and process size (left-hand panel), cost of storage per GB (right-hand panel).
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-5.xlsx

Open-source software has enabled developments in AI and, in particular, in deep learning research. In fact, open-source tools have lowered the barriers to entry in the field of AI (CBInsights, 2019a) and are contributing to advancing research (and research productivity) in the AI field by sharing code among a community of users who can build their research upon already-existing code and can potentially improve it. Figure 7-6 shows that user traffic in one of the most popular open-source software tools – TensorFlow (a machine-learning library created by Google) – has increased remarkably since it became open and free-of-charge to the world in 2015. A year later, Google also made available to developers its DeepMind Lab training environment codebase on GitHub so that the community could use it to train AI systems on Google's code.

Sharing code is, however, not a practice specific to Google; on the contrary, it is also done by other organisations and

researchers[11]. Users benefit from these open and collaborative environments, as do the companies making it freely available as a community of contributors will be helping them in turn to accelerate their AI-related research. There are clearly important implications for new business opportunities, as companies can build on open source software and create new solutions, boosting innovation. On the other hand, this has important implications for cybersecurity. Also important in this context is the role of data – and data openness (data that are used for research questions but also for new solutions and business opportunities).

Figure 7-6 Number of users contributing to TensorFlow every month on GitHub, November 2015 - November 2019



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Source: GitHub, accessed on 19-11-2019
Note: Contributions to master, excluding merge commitments.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-6.xlsx

BOX 7-3 The vision of the Horizon 2020 project AI4EU, the AI-on-demand platform

The development and deployment of AI technologies in Europe are still being hindered by a number of gaps and challenges: a fragmented AI research landscape, difficulties in scaling up startups, limited uptake of AI technologies, instability of funding for AI research labs, and limited industrial investments. Among the projects funded under the European research and innovation programme (Horizon 2020), **AI4EU**[12] is aiming to tackle some of these issues.

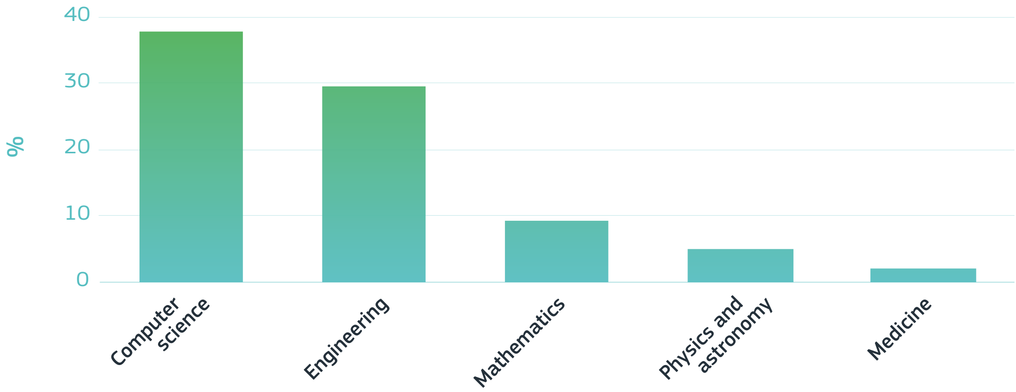
11 Other examples of open platforms include Amazon Machine Learning (AML), Microsoft Azure Machine Learning Studio, Microsoft CNTK, Caffe, etc.

12 https://www.ai4eu.eu/

AI4EU, the AI-on-demand platform, is gradually building a platform which allows the AI community to publish and exchange AI assets and skills. It will serve as a **channel** providing access to all **European AI resources** to all related communities, both researchers/developers and users, identifying synergies, avoiding fragmentation and sharing resources, expertise and skills. This platform will also collaborate with the network of Digital Innovation Hubs[13] distributed all over Europe which is helping local economies to take advantage of what technologies such as AI have to offer. In addition, as access to data in Europe is often in silos, with no standard data structures, the AI4EU on-demand platform can improve the facilitation of access to data and knowledge sources.

'Deep-tech' and, in particular, AI, are the result of the co-development of hard-core science and technology. AI is increasingly exploring the boundaries of scientific fields beyond computer science. Deep-tech innovations are typically very 'science-intensive' and allied to sophisticated technology. Using text-mining techniques, the OECD (2019) compiled the scientific fields underpinning AI-related documents between 1996 and 2016 (Figure 7-7). Although computer science has (as expected) made a major contribution to AI science, of almost 40 % to AI publications, 60 % of which actually refer to other scientific fields: engineering corresponds to 30 %, followed by mathematics (9 %), physics and astronomy (5 %) and medicine (2 %). The remaining 13 % are spread across a wide diversity of fields (Figure 7-8).

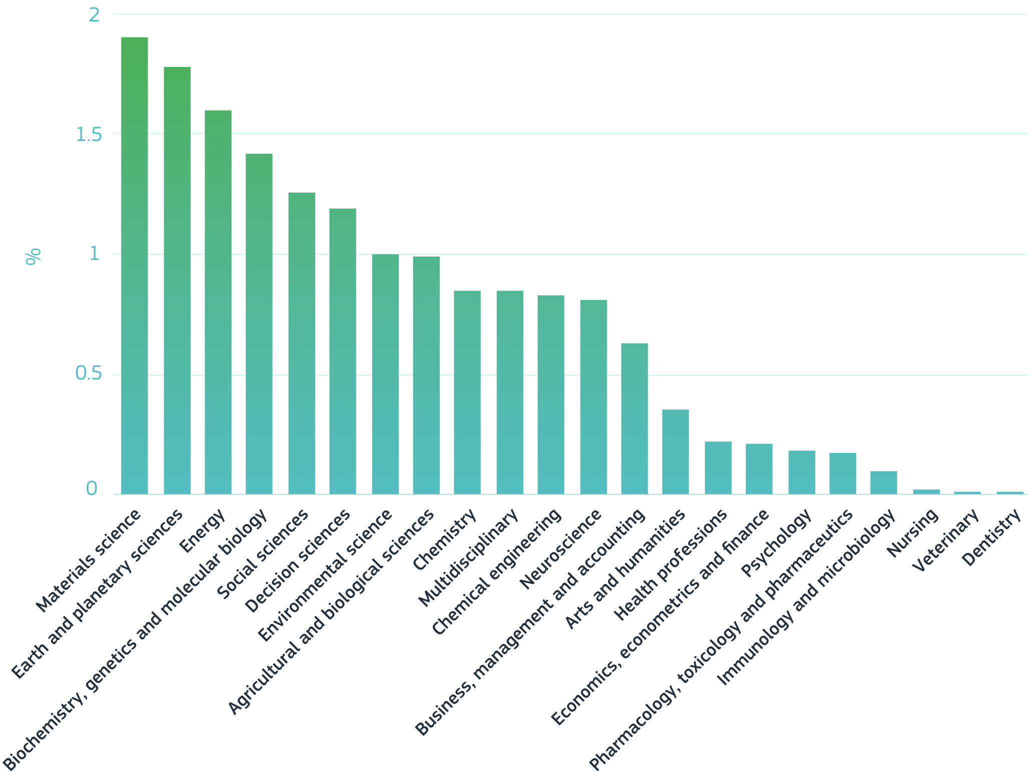
Figure 7-7 Top 5 scientific fields for AI-related scientific documents as a percentage of all AI-related documents, 1996-2016



Source: OECD (2019a), Measuring the Digital transformation
Note: Calculations based on Scopus Custom data, Elsevier, Version 1.2018, January 2019.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-7.xlsx

13 https://ec.europa.eu/digital-single-market/en/digital-innovation-hubs

Figure 7-8 Other scientific fields for AI-related scientific documents as a percentage of all AI-related documents, 1996-2016



Source: OECD (2019a), Measuring the Digital transformation
Note: Calculations based on Scopus Custom data, Elsevier, Version 1.2018, January 2019.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-8.xlsx

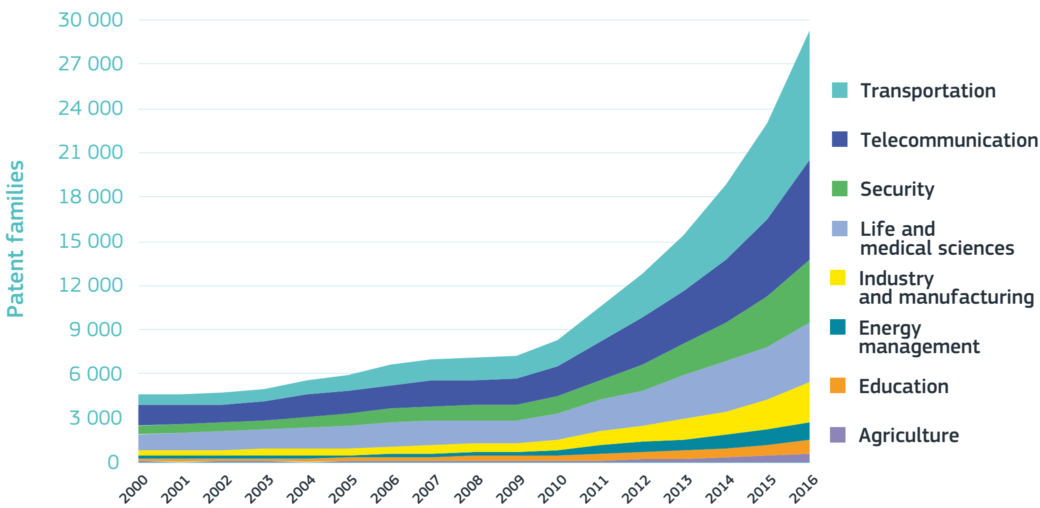
In the case of AI, Motohashi (2018) found that the co-development of science (proxied by research articles) and technology (proxied by patents) in AI has been fostered by the intersectoral mobility between academia and firms, i.e. 'those who had published AI-related publications in public research organisations later became involved in patenting activities at a private company (either through a joint appointment or by moving job)'. Hence, academia and public research organisations have an increasingly important role in AI-driven innovations which has been intensified by greater mobility.

The role of intellectual property (IP) in AI spin-offs also needs to be better understood. For example, it has been suggested that the standard technological discovery model does not apply in spin-outs based on machine learning that may rely instead on know-how on the part of the academic founders, which is central to the new business (Royal Society, 2017).

Since 2009, there has been a boom in AI patenting, notably in the fields of transportation, telecommunications, security, and life and medical sciences. Figure 7-9 depicts the evolution of patent families for the top selected AI application categories between 2000 and 2016. It can be seen that, since 2009, patenting activity has grown across all sectors identified in the graph, with the most pronounced increases in transportation, telecommunications, security, and life and medical sciences.

Acquisition of AI startups is increasingly regarded as a strategic move by acquirer companies to acquire data and absorb new AI knowledge and capacities. Cumulatively, CBInsights reports that between 2010 and 2019 (August) there were 635 acquisitions of AI companies. According to the WIPO (2019), most of the companies acquired are young startups with a median age of three years old. Accordingly, these companies tend to specialise in virtual assistants, big data analytics for recommendation systems, and image recognition, using machine learning as the main technology. From Figure 7-10 it is possible to conclude that acquisitions have become more common in recent years – in particular, around two thirds of all AI acquisitions occurred between 2017 and 2019. This is also in line with the general trend in the growing number of acquisitions worldwide, as described in Chapter 8 - Framework conditions. Moreover, the WIPO (2019) highlights that acquisitions in the AI sector can complement IP and development efforts since they may reduce the need for the acquirer to patent. The authors illustrate this argument with the example of Alphabet which has acquired a substantial number of AI companies 'while at the same time reducing its patent filing activity over the last several years'.

Figure 7-9 Patent families for top selected AI application patent field categories, by earliest priority year, 2000-2016



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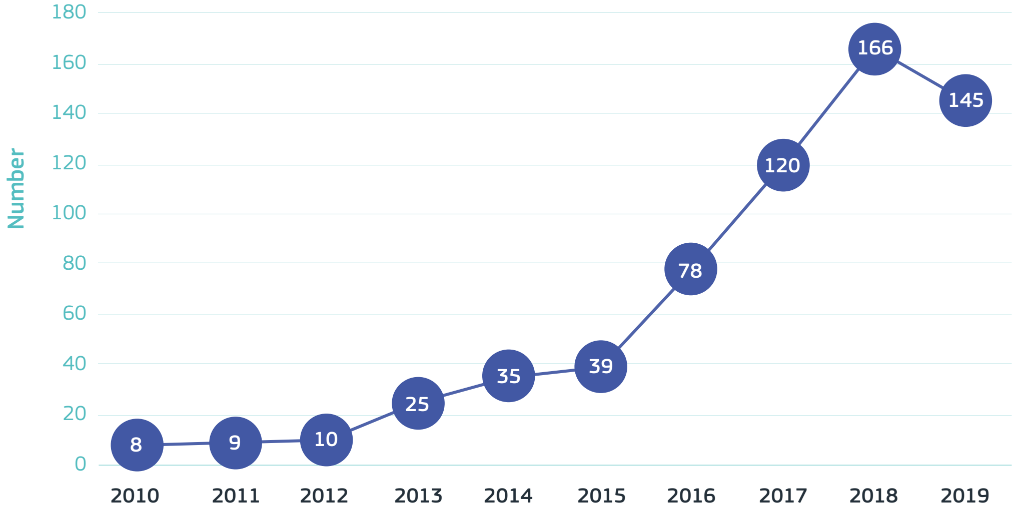
Source: WIPO Technology Trends 2019: Artificial Intelligence, based on Questel Orbit Intelligence, Fampat Database, March 2018

Note: A patent may refer to more than one category.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-9.xlsx

Figure 7-10 Number of AI acquisitions by acquisition year, 2010-2019[(1)]



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Source: CBInsights (2019), 'The Race For AI: Here Are The Tech Giants Rushing To Snap Up Artificial Intelligence Startups'

Note: [(1)]Data as of 31/08/2019 hence not covering the whole year.

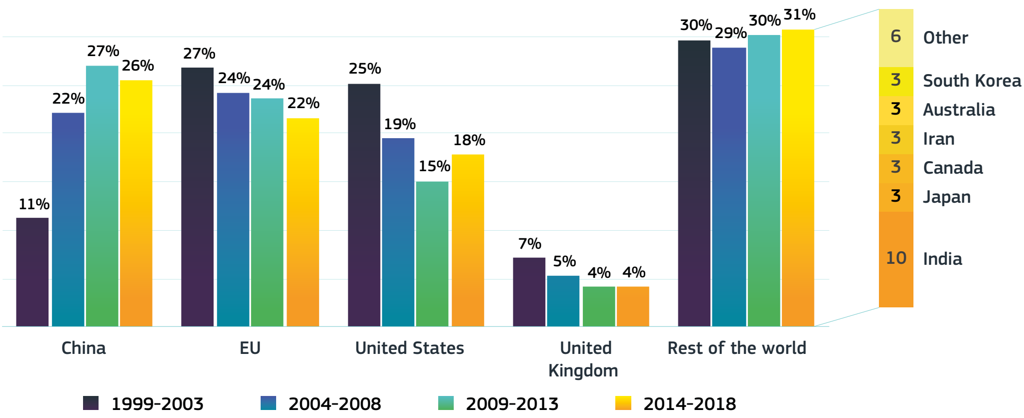
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-10.xlsx

3. EU ranks among global leaders in AI science

Although the EU ranks among global leaders in AI scientific production and excellence, its position has been deteriorating over time, while China has risen quickly. Globally, the weight of EU publications in AI has been on the decline since 2003, although it still ranks among the global leaders in AI scientific production (Figure 7-11). Indeed, between 2013 and 2017, the EU accounted for 22 % of world publications in AI, down from 27 % from 1999-2003. This compares with 26 % in China (up from only 11 %), and 18 % in the United States (down from 25 %). Thus, China has been emerging quickly as the global leader in scientific production in the AI domain. Other players, such as India (with a 10 % share) and the United Kingdom (with a 4 % share) have also been quite active in AI publishing.

Within the EU, Germany, France and Spain are the top producers of AI publications though the highest shares relative to national publications are in Luxembourg, Greece, and Cyprus. In the EU, Germany, France, Spain and Italy are the top producers of publications in AI (Figure 7-12). The United Kingdom also stands out as a major AI publishing nation in Europe. However, the size of these countries (e.g. GDP, population) is potentially correlated with the number of publications. For this reason, we have looked into the share of AI publications in relation to national publications. Having taken the size of the country into account, Luxembourg, Greece and Malta emerge as the EU Member States with the highest shares of AI scientific publications, corresponding to 3.7 %, 3.3 %, and 3.3 %, respectively, of all publications. The average citation impact is highest in the Netherlands, Austria, Belgium and Denmark. Switzerland's AI publications have the largest citation impact of the group of Associated Countries in the graph.

Figure 7-11 Share of world publications in artificial intelligence in selected regions (%), 1999-2018



Source: Elsevier (2018)

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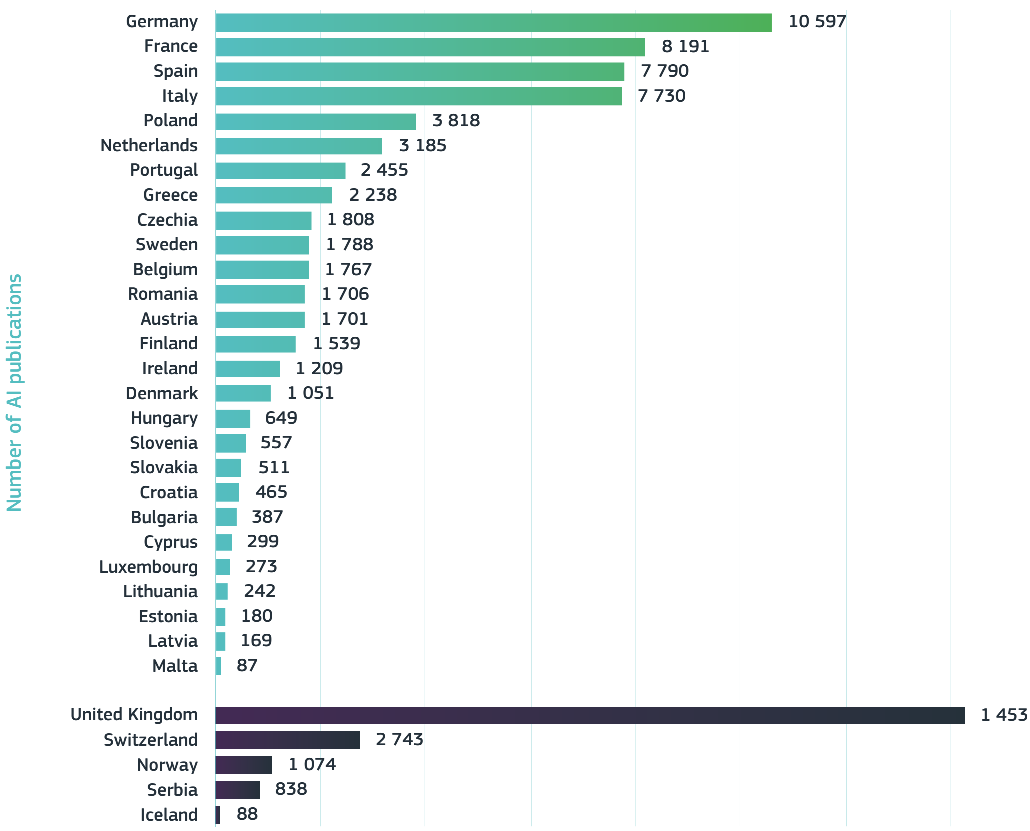
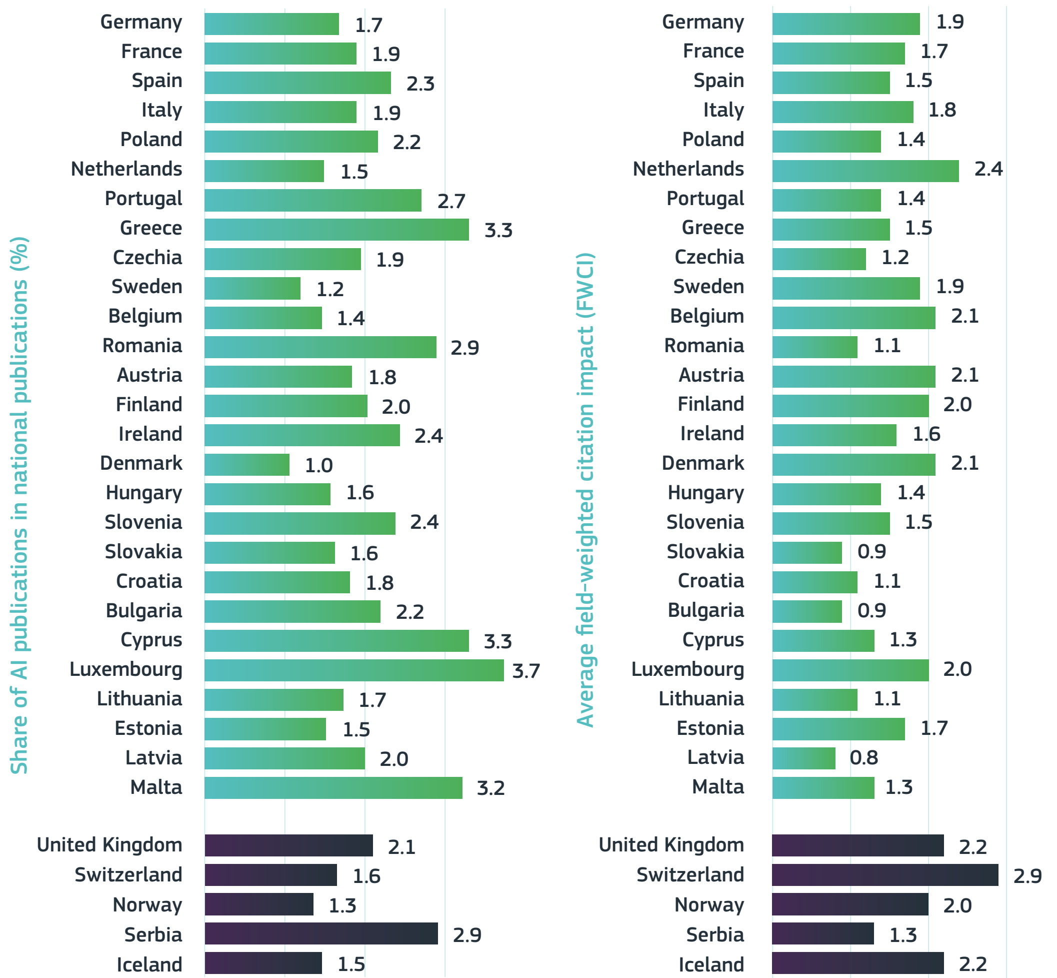
Figure 7-12 Number and share of publications in AI by country, and related field-weighted citation impact (FWCI) by country, 2015-2018



CHAPTER 7



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Elsevier (2018)

Note: Both the AI publications and the total publications used to compile the ratio of AI publications in all publications reflect only publication types, articles, reviews, and conference proceedings to ensure they are comparable.

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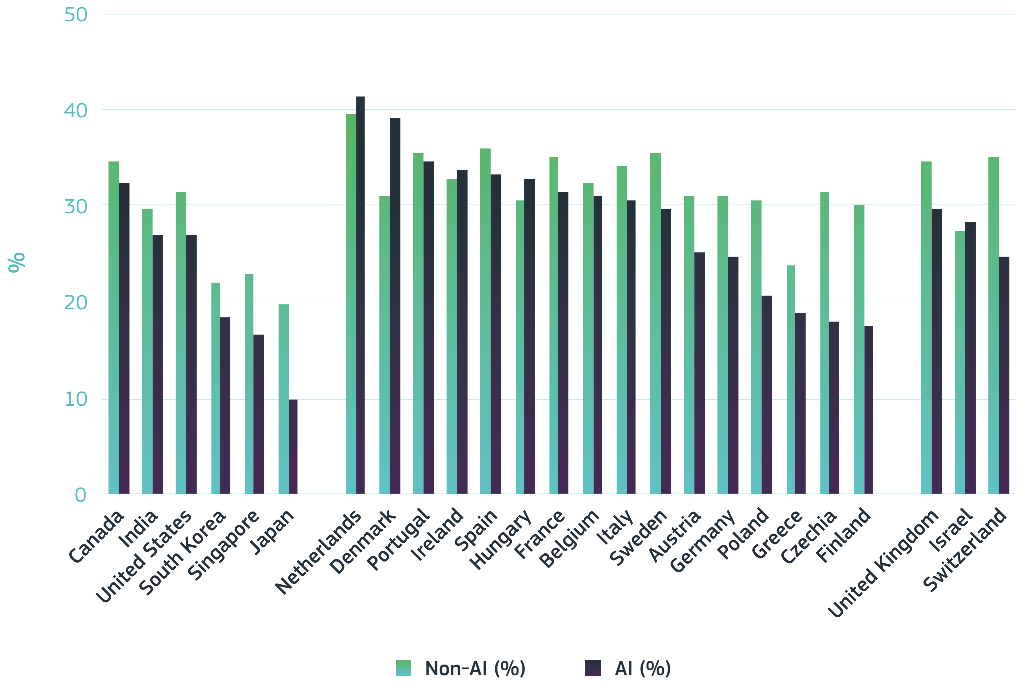
The lack of gender diversity in AI research persists, although there has been progress over time, notably in European countries. As reported by NESTA (2019), a gender diversity gap in AI research (using the arXiv repository) continues to be prominent (Figure 7-13). Within the EU, in 2018, the share of papers with at least one female author was highest in the Netherlands (42 %), Denmark (39 %) and Portugal (35 %). Moreover, in most EU Member States represented in the study, gender diversity was higher than in non-EU countries such as Canada, the United States, South Korea and Japan. It is also interesting to note that in the Netherlands, Denmark, Ireland and Hungary, the share of female authors in AI papers actually appears higher than in non-AI papers, contrary to the global picture. When looking at trends over time, the AI Index 2019 highlights the growth of female authorship between 2000 and 2018, with the most visible increases overall taking place in European

Figure 7-13 Percentage of AI and non-AI papers with at least one female author by country, 2018



Science, research and innovation performance of the EU 2020

Source: AI Index 2019, based on NESTA, arXiv, 2019

Note: Graph ranks countries based on the share of female co-authors in AI papers. NESTA (2019) uses author affiliations at the date of publication as a proxy of their location and focus on countries with at least 5 000 publications and more than 50 % of the authors gender-labelled with a high degree of confidence.

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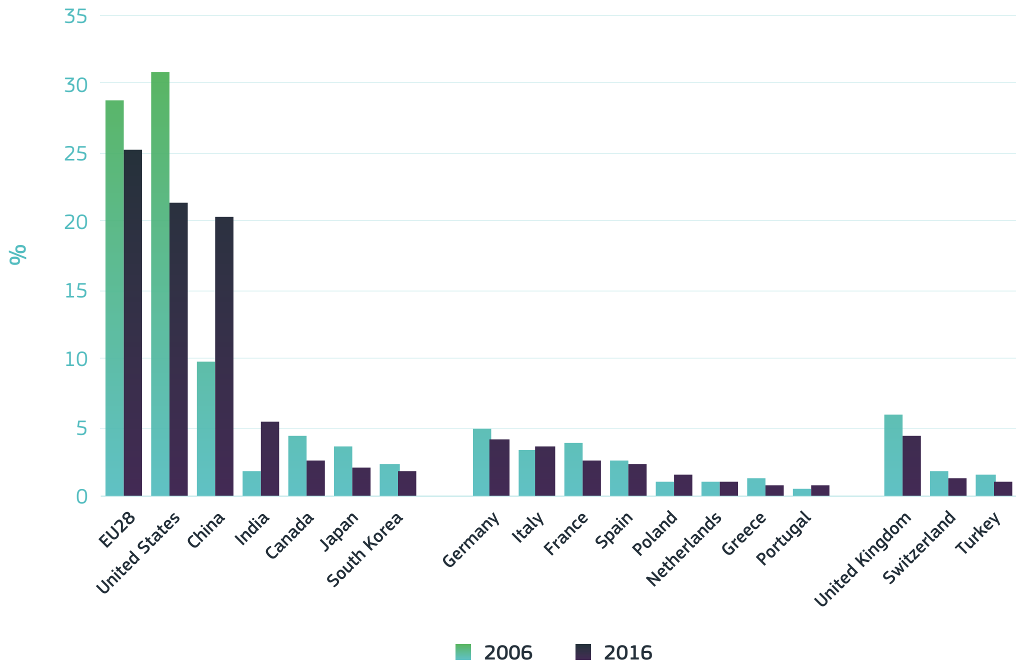
countries, namely in the Netherlands, Ireland, Hungary, France and Belgium. On the contrary, international economies, such as the United States and Japan, reported a decline over time in female authorship in AI.

The EU28 is a leader in scientific excellence in the AI field, as measured by the share of AI-related documents in the top 10 % most-cited publications worldwide (Figure 7-14). In 2016, the EU represented 25 % of the top most-cited AI publications, closely followed by the United States (21 %), and China (20 %). Both the EU and the United States saw a decline in their relative importance in AI excellence between 2006 and 2016, the EU down from 29 % and the United States down from 31 %. China, on the other hand, registered a remarkable increase in scientific excellence in the AI field, doubling its relative weight in just a decade. Within the EU, the German, Italian and French economies are the highest ranking in AI scientific excellence.

Figure 7-14 Top-cited scientific publications related to AI[1], 2006-2016



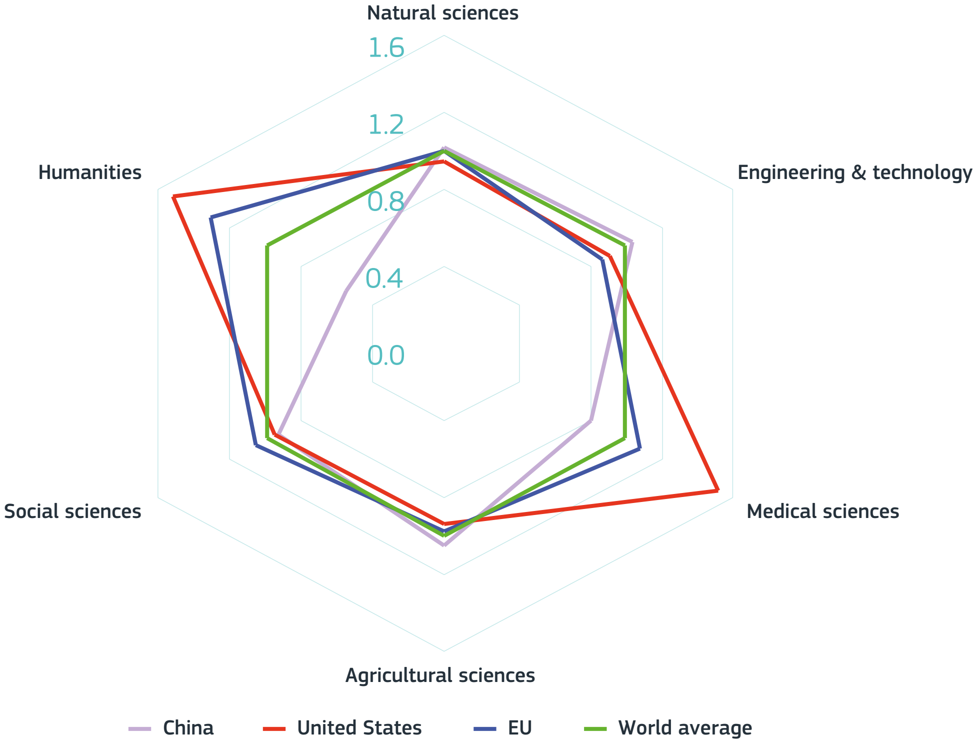
Science, research and innovation performance of the EU 2020

Source: OECD (2019), Measuring the Digital Transformation: a Roadmap for the Future
Note: [1]Selected countries with the largest number of AI-related documents among the 10% most-cited publications (%). OECD calculations based on Scopus Custom Data, Elsevier, Version 1.2018 and 2018 Scimago Journal Rank from the Scopus journal title list (accessed March 2018), January 2019. Fractional counting used.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-14.xlsx

Global AI specialisation profiles show that the EU's AI research is more oriented towards humanities and to a lesser extent also in medical sciences. China is more specialised in agricultural sciences and engineering and technology, and the United States in medical and health sciences as well as humanities. Figure 7-15 displays the specialisation profiles of AI publications by field and major economy relative to the world average. The EU's top specialisation appears to be in humanities, and the United States in both humanities, and medical and health sciences, and to a greater extent than in the EU. China exhibits a different orientation of AI research activity from both the EU and the United States, with AI publications more oriented towards agricultural sciences and engineering and technology. Elsevier (2018) explains that the apparent focus of the EU and the United States on the humanities could be driven by a 'very low number of publications and may be influenced by language'.

The top five entities contributing to AI publications in Europe appear to be from all universities or public research organisations in France, the United Kingdom and Spain. The same pattern applies to China. However, in the United States, the top five is a mix of contributors from both the public and private sectors.

Figure 7-15 Relative Activity Index[1] of AI publications (all document types) per FORD category per region, 2018



Science, research and innovation performance of the EU 2020

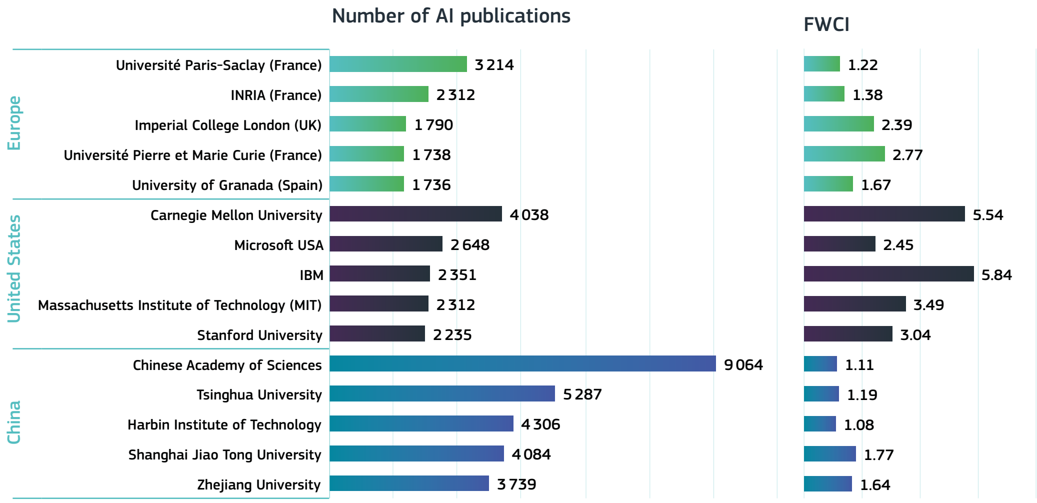
Source: Elsevier (2018)

Note: OECD Fields of Research and Development (FORD) categories show R&D expenditure and personnel by fields of research and development. A value of 1.0 indicates that a country's research activity in AI corresponds exactly with the global activity in AI; higher than 1.0 implies a greater emphasis, while lower than 1.0 suggests a lesser focus.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-15.xlsx

In Europe, the top contributors of scientific publications on AI are the Université Paris-Saclay, the Institut national de recherche en sciences et technologies du numérique (INRIA), the Université Pierre et Marie Curie (all three based in France), Imperial College London in the United Kingdom, and the University of Granada in Spain (Figure 7-16). Thus, the top five institutional contributors to AI research in Europe are universities and public research institutes. The picture is different in the United States where companies such as Microsoft and IBM also play a key role in producing AI publications. The US universities listed include Carnegie Mellon, the Massachusetts Institute of Technology (MIT) and Stanford University.

Figure 7-16 Top 5 institutional contributors per region by number of AI publications (all document types) and related field-weighted citation impact, 2013-2017



Science, research and innovation performance of the EU 2020

Source: Elsevier (2018)
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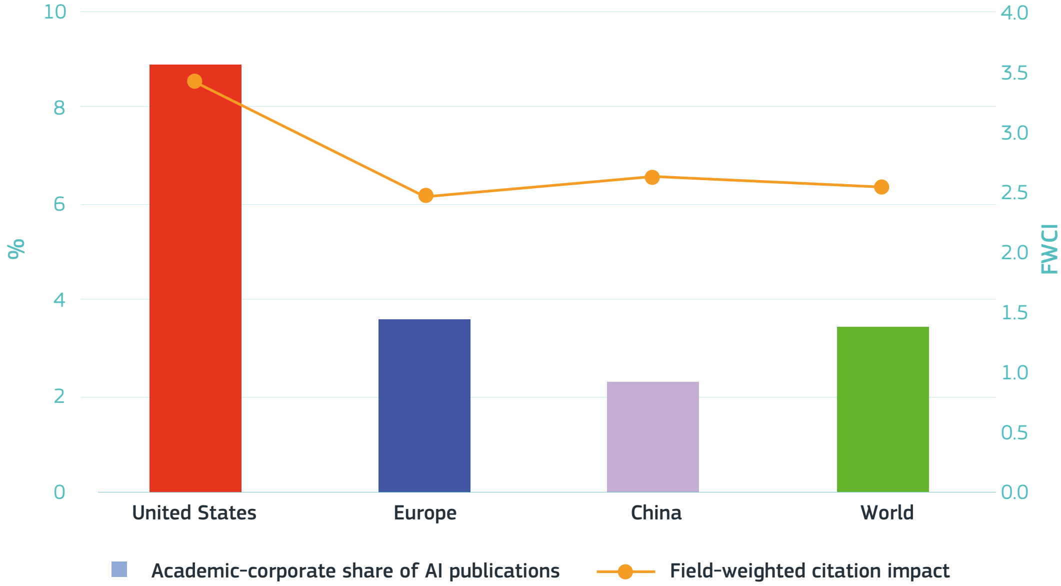
4. AI technological collaboration has intensified over time

Co-publications between academia and the private sector in the AI field are more common in the United States than in Europe. They also have a higher citation impact. Academic-corporate collaboration in AI is increasingly driving AI developments. It seems more apparent in the United States, where 9% of the AI publications involve academia and the private sector. It also has inherently a higher citation impact than in Europe or in China (Figure 7-17). In Europe, AI co-publications account for close to 4% of AI publications, which is similar to the share of scientific output resulting from public-private co-publications in the EU28[14]. This compares with only around 2% in China. However, Chinese AI co-publications appear to have a higher citation impact than Europeans.

14 The share of scientific public-private co-publications in scientific output was of 4.5% from 2000-2018 in the EU28 (full count). Data: Science-Metrix using data from the Scopus database.

Figure 7-17 Academic-corporate share of AI publications (% total AI publications by region) and related field-weighted citation impact, 1998-2017



Science, research and innovation performance of the EU 2020

Source: Elsevier (2018)

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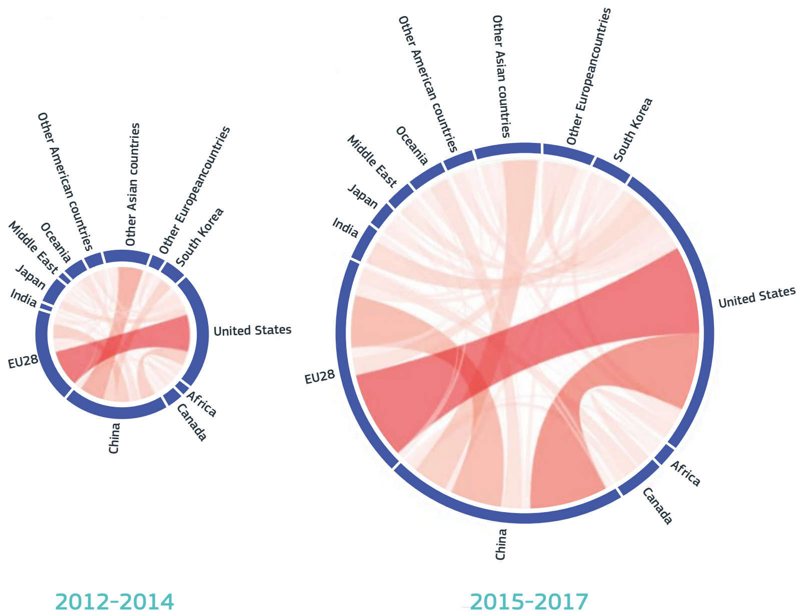
In recent years, international collaborations on AI technology around the world have intensified. In particular, EU28 players have significantly increased their collaboration with the United States and China in the AI domain. As shown in Chapter 6.2 - Knowledge flows, science is increasingly 'open to the world' in order to tackle global challenges and contribute to scientific advances/discoveries. In this context, international collaboration on AI between R&D players all over the world can also be beneficial to AI science and innovation. Figure 7-18 represents the evolution of the intensity of bilateral AI technological collaborations (namely co-publications and co-patents) across the globe, in three different periods. a bigger radius in the diagram means that collaboration was higher over that period. More recently, the level of international collaboration in AI has expanded remarkably. Furthermore, EU28 R&D players are not only collaborating more with the United States but with China, too.

Figure 7-18 AI technological collaborations between geopolitical areas[1], 2012-2017



Source: De Prato et al. (2019)

Note: [1]Number of bilateral collaborations (i.e. co-publications and co-patenting) between players active in R&D in the AI domains and located in different countries, in the indicated periods. The radius of the diagrams is proportional to the amount of external collaborations in the corresponding period of time.

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Countries are also collaborating at the EU and global level to agree on common principles governing AI. To date, the EU has taken the lead here. In its **Communication on 'Artificial Intelligence for Europe'** (April 2018), the European Commission identified the need to develop an ethical approach to AI, in accordance with core European values. a high-level expert group, representing academia, business and civil society, was set up to this end. Building on the group's ethical recommendations, the Commission issued a **Communication on 'Building Trust in Human-Centric Artificial Intelligence'** (April 2019) which confirms the European ambition to create trustworthy AI (Box 7-4). The Commission would like to bring this European approach to the global stage by opening up cooperation to all non-EU countries that share the same values.

BOX 7-4 Towards trustworthy, ethical and innovative AI in the EU

In itself, AI is neither good nor bad; nor is it neutral (Kranzberg, 1986). As with any impactful new technology, the way in which it is further developed and applied will determine either a positive or negative outcome. AI-powered cameras with facial recognition capabilities can make your neighbourhood safer but may also help oppressive regimes to identify and silence dissidents. Receiving targeted advertising based on the contents of your e-mails may be acceptable but having similar AI systems use your data for manipulating your voting behaviour is not.

For AI to have the positive impact we want, we should carefully reflect on the choices we make while developing and applying it. '**AI ethics**' is about identifying the core principles to guide us in our quest to maximise the technology's benefits while minimising its risks. Companies working with AI could use such principles to self-regulate their developments; governments could go a step further and enforce compliance through regulation.

For the Commission, **seven** key **requirements** define **trustworthy AI**:

1. Human agency and oversight
2. Technical robustness and safety
3. Privacy and data governance
4. Transparency
5. Diversity, non-discrimination and fairness
6. Societal and environmental well-being
7. Accountability

In order to operationalise these principles, the high-level expert group's ethical guidelines present an assessment list to check compliance with each of these requirements. During a piloting phase, stakeholders from a large range of sectors and types of organisations are currently testing and working with this assessment list. Their feedback will be used to optimise the list and turn it into a reliable and operational guide for the development of trustworthy AI in Europe.

The 'ethics-by-design' approach will play a key role in ensuring that ethical and legal principles are embedded at the very outset of system development. The European Commission has thus committed to exploring the opportunities for introducing the **ethics-by-design** principle in relevant calls for proposals under the EU-funded research programme.

The ethical principles for ethical, trustworthy AI may very well become the foundations on which a general European regulation for AI is built.

For AI 'made in Europe', the ethics-by-design approach will play a key role in ensuring that ethical and legal principles are embedded at the very outset of system development. Thus, the European Commission has committed to exploring the opportunities for introducing the ethics-by-design principle in relevant calls for proposals under the EU funded research programme[15].

15 https://ec.europa.eu/knowledge4policy/publication/coordinated-plan-artificial-intelligence-com2018-795-final_en

Following these important initiatives, in May 2019, 42 OECD member countries adopted a set of AI principles that ensure that AI fosters innovation while respecting human rights and democratic values (May 2019). As established in OECD (2019b), the guidelines are developed around five main principles, quoting:

- 'AI should benefit people and the planet by driving inclusive growth, sustainable development and well-being.
- AI systems should be designed in a way that respects the rule of law, human rights, democratic values and diversity, and they should include appropriate safeguards (...) to ensure a fair and just society.
- There should be transparency and responsible disclosure around AI systems to ensure that people understand AI-based outcomes and can challenge them.
- AI systems must function in a robust, secure and safe way throughout their life cycles, and potential risks should be continually assessed and managed.
- Organisations and individuals developing, deploying or operating AI systems should be held accountable for their proper functioning in line with the above principles.'

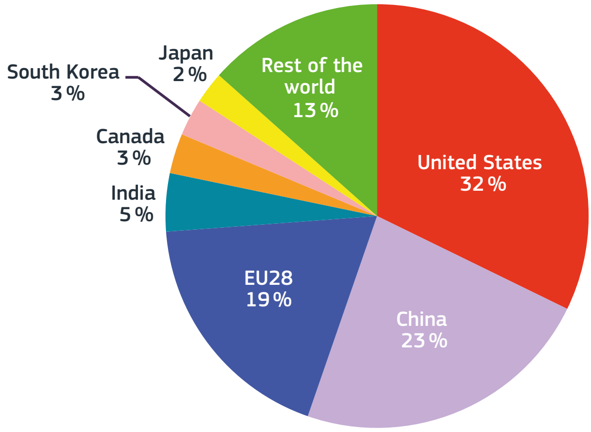
There are important privacy and ethical issues linked to AI. The EU is committed to building an AI ecosystem that spurs innovation within a clear and adequate legal and ethical framework.

5. EU trails in AI innovation

Despite ranking among global leaders on AI scientific excellence, the EU trails when it comes to AI innovation performance, both in the number of companies and patenting. However, the EU's performance is in line with its share in global R&D investments. Nearly one third of the world's AI firms can be found in the United States. China ranks second, with close to one quarter of AI companies. Hence, the two countries together account for slightly more than half of all AI startups. The EU28 represents 19% of firms active in AI worldwide (in accordance with the EU's approximate 20% share in global R&D investments), followed by India, Canada, South Korea and Japan (Figure 7-19). Today, AI applications are widespread across different industries. CBInsights' 2019 list of 'the most promising 100 AI startups' points precisely to the sectoral diversity of AI startups with 'high-potential' including in healthcare, finance, retail, cybersecurity, marketing and agriculture, among others (CBInsights, 2019c).

The EU's gap in AI innovation relative to the United States and China can also be observed in terms of the number of firms active in patenting in AI in each region. Indeed, outstandingly, Chinese AI companies account for almost 60% of all AI firms' patenting applicants. This compares with 14% in the United States but only around 7% in both South Korea and the EU28 (Figure 7-20) between 2009 and 2018.

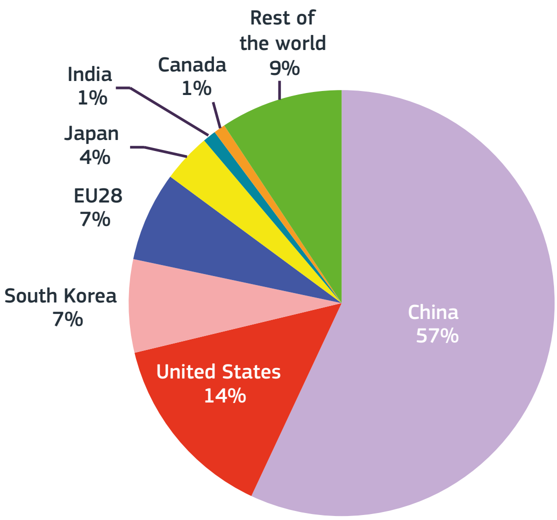
Figure 7-19 Distribution of AI firms worlwide (%), 2009-2018



Science, research and innovation performance of the EU 2020

Source: De Prato et al. (2019)
Note: Percentage over total number of firms active in the AI domain.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-19.xlsx

Figure 7-20 Share of firms' patenting applicants in the AI domain by region, 2009-2018

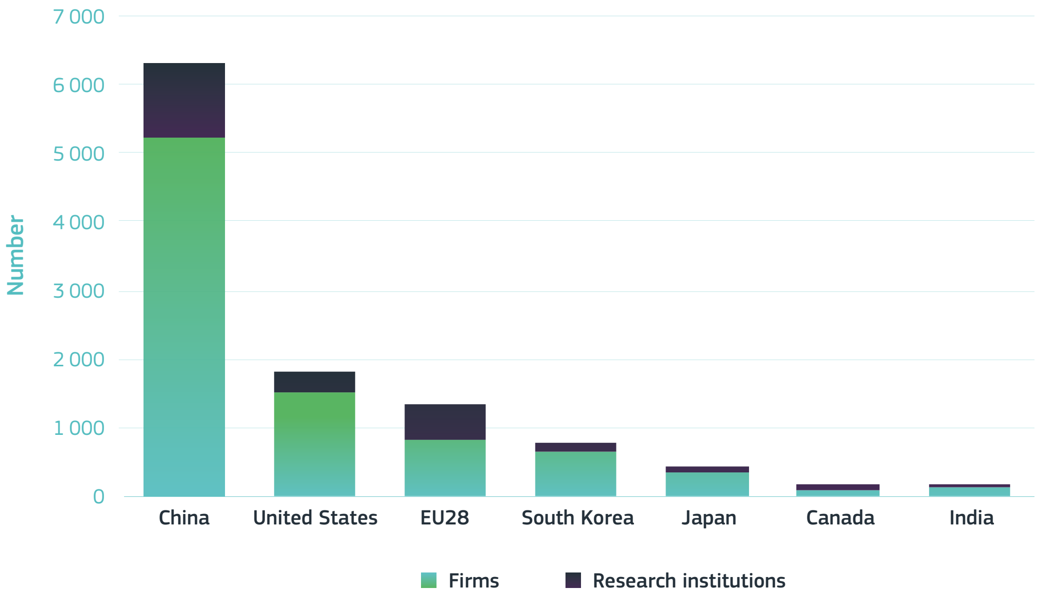


Science, research and innovation performance of the EU 2020

Source: De Prato et al. (2019)
Note: Percentage over total number of firms active in patenting activities in the AI domain.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-20.xlsx

China's striking leadership position is also visible in Figure 7-21 which shows the absolute figures for both firms and research institutions active in AI-related patenting activities. It is interesting to note that, in relative terms, EU28 research organisations account for almost 40% of AI patenting applicants in the EU28 and hence make the largest relative contribution to AI patenting when compared to the distribution among other nations.

Figure 7-21 Number of firms and research institutions active in AI-related patenting activities and frontier research in selected economies, 2009-2018



Science, research and innovation performance of the EU 2020

Source: De Prato et al. (2019)
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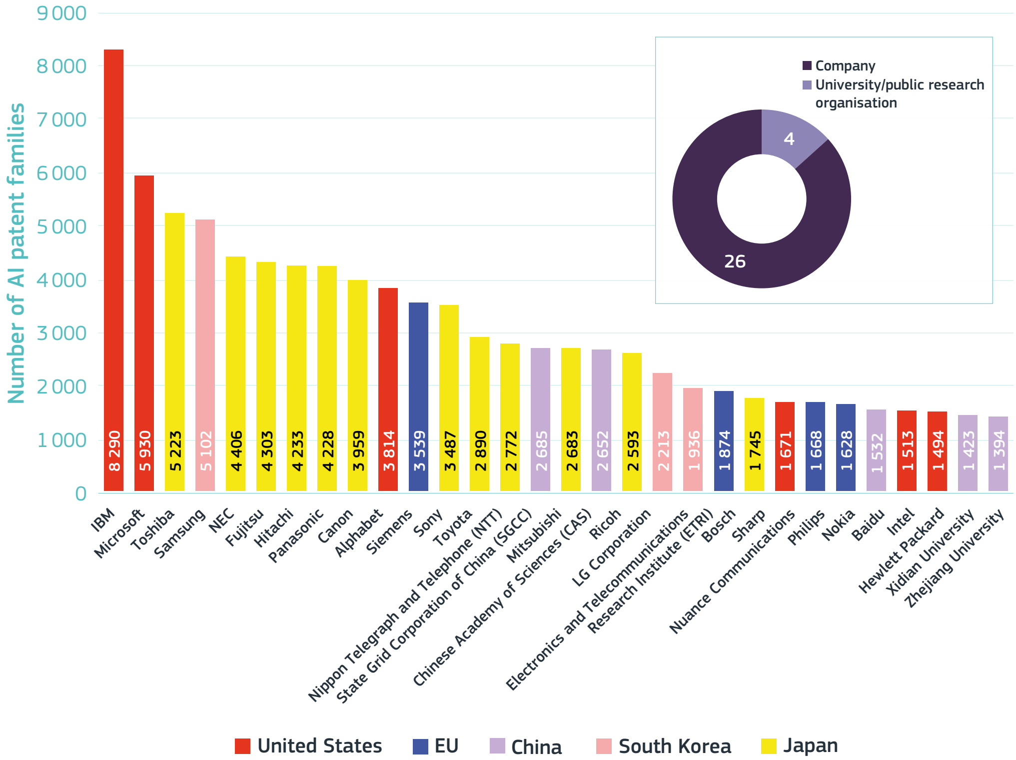
The majority of the world's top AI patent applicants are companies in IT, consumer electronics, electric power and automobile manufacturing. Almost half of the top patent applicants in the AI field are Japanese. The EU is represented by four companies – Siemens, Bosch, Philips and Nokia. Looking into patent applications in the AI field can provide an indication of who the global AI innovators are. Figure 7-22 shows that 26 of the top 30 applicants are companies, while only four are universities and public research organisations from China (three) and South Korea (one). Japan stands out as the nation with the largest number of companies (12) represented in the top 30, with Toshiba leading the Japanese group. The United States come next with six companies. In fact, IBM is the clear leader in AI patenting with a number of patent applications almost equivalent to the total sum of patents from Zhejiang University, Xidian University, Hewlett Packard, Intel, Baidu and Nokia. The EU has four companies in the list, namely Siemens, Bosch, Philips and Nokia, although none of them feature in the top 10. Finally, China has five companies, universities and public research organisations in the global top 30, while South Korea is represented by three entities.

Figure 7-22 Top 30 world patent applicants by number of AI patent families, region and type of organisation, 2018



Science, research and innovation performance of the EU 2020

Source: WIPO Technology Trends 2019: Artificial Intelligence, based on Questel Orbit Intelligence, Fampat Database, March 2018

Note: Fujitsu includes PFU; Panasonic includes Sanyo; Alphabet includes Google, Deepmind Technologies, Waymo and X Development; Toyota includes Denso; and Nokia includes Alcatel.

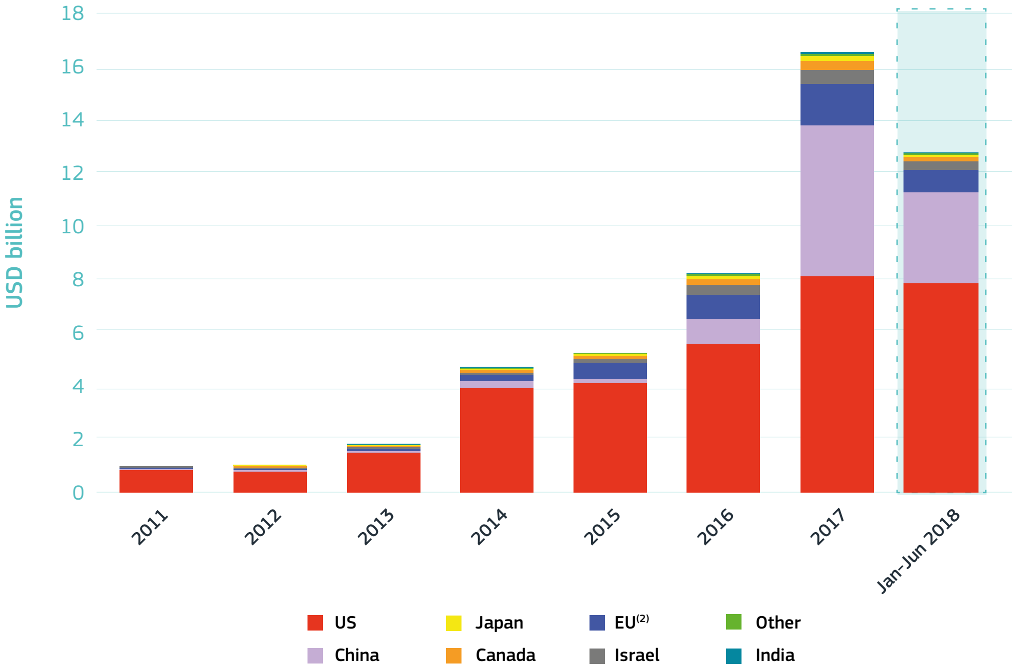
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-22.xlsx

6. Enabling AI: capital and people investments

With the unlocking of the potential of AI, private investments in AI startups are on the rise. The United States leads, followed by China. Although the EU has also made some progress in recent years to attract private capital, investments remain well below that of its main global competitors. Since 2016, private investments in AI startups have registered a significant boost worldwide, having doubled between 2016 and 2017 alone. Developments and breakthroughs in the AI field have attracted growing interest from private investors who are aware of the high potential of AI applications to disrupt several sectors. Indeed, OECD (2018) found that in the first half of 2018, 'AI startups attracted around 12% of all worldwide private equity investments, a steep increase from just 3% in 2011'.

Figure 7-23 provides evidence of the United States' global leadership in terms of equity investments in AI startups. According to the OECD (2018), US startups have attracted around two thirds of total private investments since 2011. However, more recently, China has rapidly increased its rate of private investments in AI companies, climbing from just 3 % in 2015 to 36 % of all AI private-equity investments worldwide in 2017. EU28 startups seem to be less attractive to private investors compared to US and Chinese AI startups, although it is important to note the substantial progress made in recent years – from only 1 % in 2013 to 8 % of global AI private investments in 2017.

Figure 7-23 Total estimated equity investments in AI startups[1] (USD bn) by startup location, 2011-2017 and first half of 2018



Source: OECD estimates based on Crunchbase (July 2018)

Notes: [1]AI startups are companies founded after the year 2000 and categorised in the 'artificial intelligence' technological area of Crunchbase, as well as companies that use AI keywords in the description of their activity. The sample is restricted to companies located in OECD and BRICS countries and for which sufficient information is reported. Numbers for 2018 are likely conservative due to possible delays in the input of new deals in the database. [2]EU includes United Kingdom.

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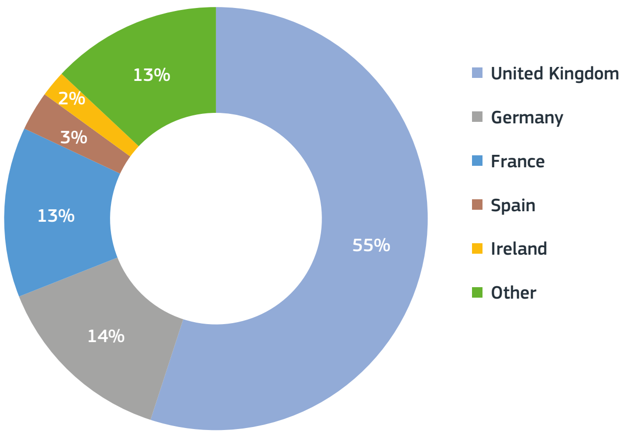
Within Europe, UK-based AI startups are the top recipients of more than half of all private equity investments targeted towards AI startups in the EU28. The United Kingdom has a sizeable attraction potential for AI private investments, attracting 55 % of all AI equity investments in the EU28 (Figure 7-24). German AI startups rank second and account for 14 % of AI private investments, followed by France (13 %), Spain (3 %) and Ireland (2 %).

Figure 7-24 Share of private equity investments in AI startups based in the EU28, 2011 to mid-2018, % total amount invested in EU-based startups over the period



Science, research and innovation performance of the EU 2020

Source: OECD estimates based on Crunchbase (April 2018)
Note: AI startups are companies founded after the year 2000 and categorised in the 'artificial intelligence' technological area of Crunchbase, as well as companies that use AI keywords in the description of their activity.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-24.xlsx

The focus areas of AI startups that have received funding in recent years point to the rise of AI as a general-purpose technology along with some geographical differences. Between 2018 and 2019, the EU AI startups that received most funding focused on fashion and retail tech (5.7 %), medtech (4.4 %), text analytics (4.4 %), marketing and adtech (4.3 %), autonomous vehicles (4.0 %), data tools (4.0 %) and energy management (4.0 %). This distribution and ranking is somewhat different in the United States and China (Figure 7-25). In particular, the top five focus areas for those US startups receiving funding were data tools (8.1 %), medtech (5.3 %), fashion and retail tech (4.7 %), text analytics (4.7 %) and chatbots (3.9 %). In China, top-funded AI startups focused on automation, oil and gas (12.0 %), facial recognition (8.8 %), edtech (8.0 %), autonomous vehicles (6.4 %) and mental health and wellness (5.0 %). In addition, the AI Index 2019 reports that both the United States and Europe have a very diverse range of AI applications, *each with some representation across all 36 sectors* identified in the study.

Figure 7-25 Top 15 focus areas of AI Startups in the EU28, the United States and China that received funding over July 2018-July 2019

Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on AI Index 2019, CAPIQ, Crunchbase and Quid data, 2019

Note: The top 5 focus areas for the three regions are coloured purple (#1), lighter blue (#2), green (#3), yellow (#4) and darker blue (#5).

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-25.xlsx

It is likely that the recent upsurge in AI capital has enabled the growth of more AI startups into the next unicorns. This is particularly the case in the United States and China. Figure 7-26 shows that the number of new AI startups becoming the next unicorns has increased remarkably especially since 2017, having more than doubled between 2017 and 2018 alone (see Chapter 3.3 - Business dynamics and its contribution to structural change and productivity growth for more on unicorn companies). Between 2015 and 2019, 46 new AI-related unicorns came into the picture (11% of the current total number of private unicorns), with half (or 23) being US-based. China accounts for slightly more than a quarter of all AI unicorns, followed by the United Kingdom with four, Israel with two, and France, Japan, Canada and Singapore with one each. Hence, only one unicorn in the AI field was found in the EU over the period 2015-2019 (Figure 7-27). However, UiPath, an 'AI unicorn' with headquarters in the United States, has 'EU DNA' as the company's founders are Romanian and the headquarters were initially based in Bucharest. Considering that the amount of funding received is a key component of private valuations, this increase could be partly explained by greater interest on the part of private investors in AI technologies due to their potential to boost innovation and productivity.

Figure 7-26 Number of new private unicorns in AI, 2015-2019

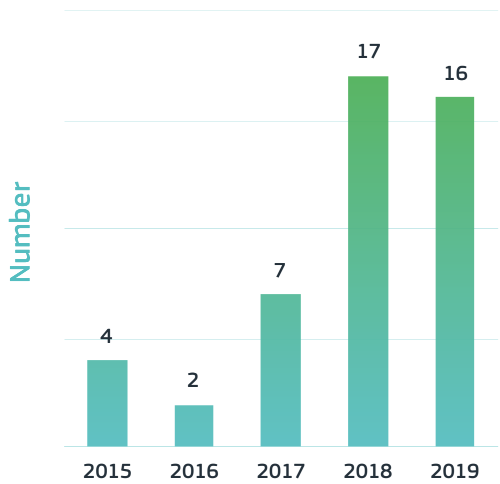
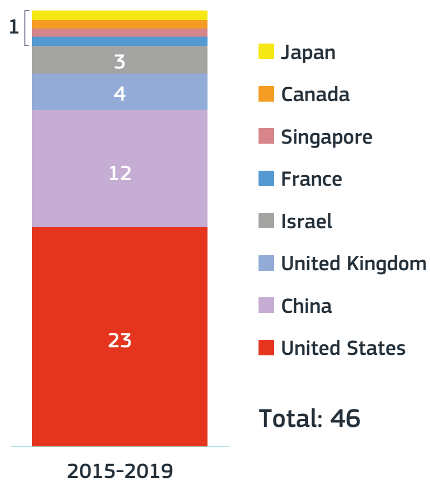


Figure 7-27 Number of AI unicorns by country, 2015-2019



Science, research and innovation performance of the EU 2020

Source: CBInsights Unicorn Tracker, accessed on 11/12/2019
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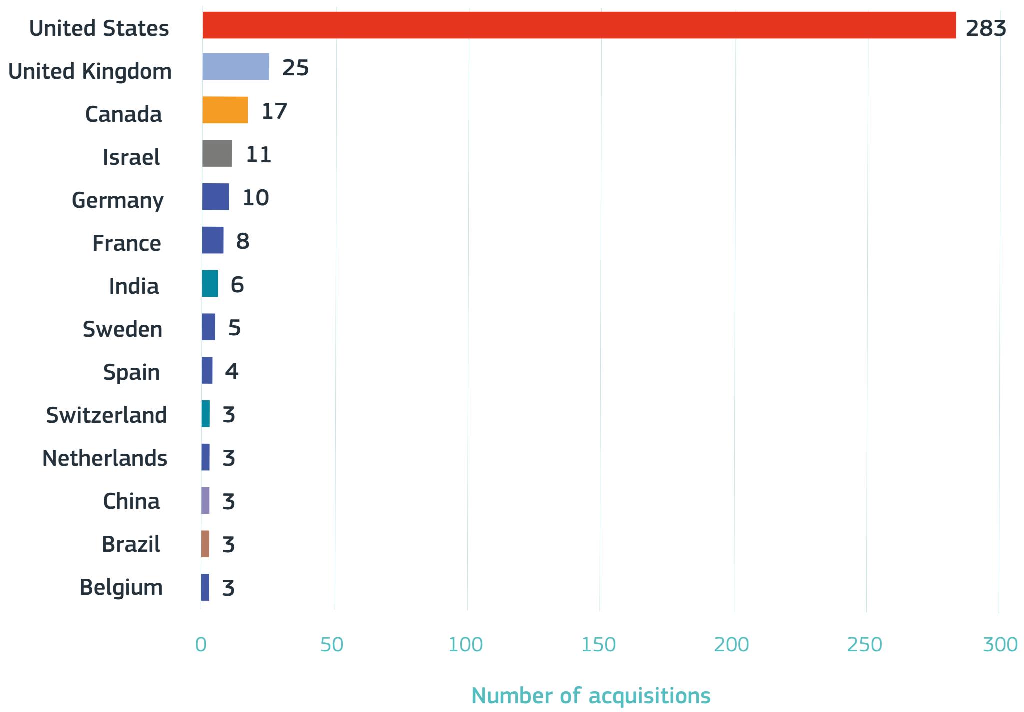
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-27.xlsx

Acquisitions are on the rise. Around two thirds of acquisitions in the AI sector were in the United States, where one third of all AI firms are located, too. The United Kingdom comes next with 25 British startups acquired over the same period. In the EU, there were AI-related acquisitions of by 10 German, 8 French, 5 Swedish, 4 Spanish, 3 Dutch and 3 Belgian AI companies (Figure 7-28).

Figure 7-28 Acquisitions in the AI sector by country of acquired company, 1998-2018



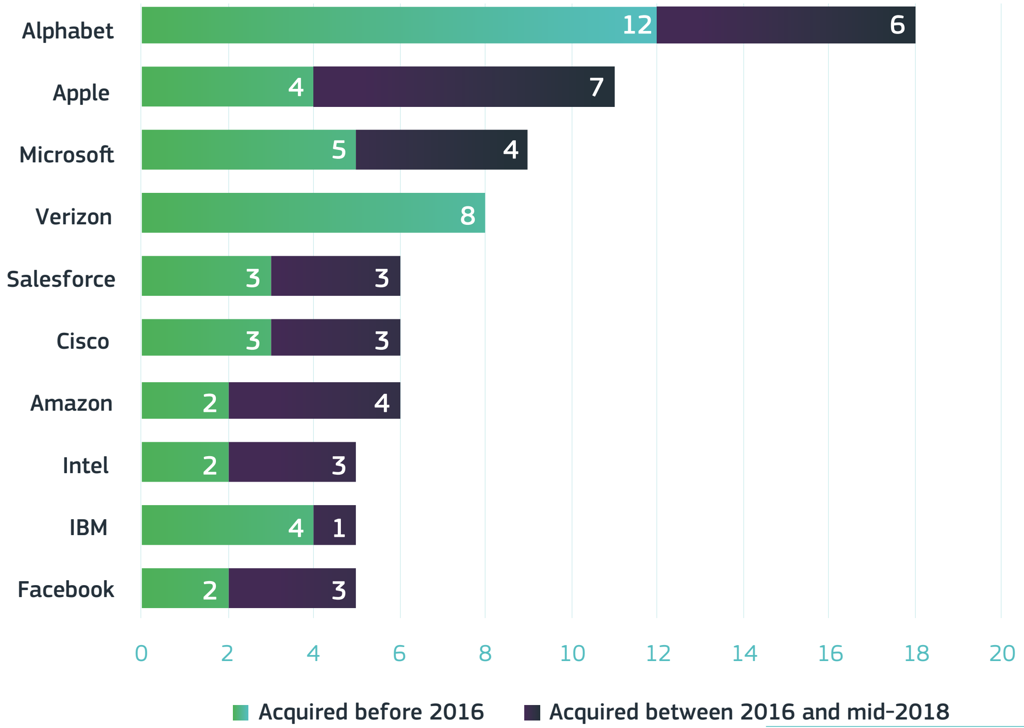
Science, research and innovation performance of the EU 2020

Source: WIPO 2019 report, based on CrunchBase database, May 2018

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-28.xlsx

The top 10 acquirers of AI companies are mainly 'tech' or 'digital giants' from the United States. Together they account for almost 20% of all AI-related acquisitions, and their pace of acquisitions has accelerated since 2016. Figure 7-29 shows the number of AI-related companies acquired by a top acquirer, both before and after 2016 (up to May 2018). Most of the top 10 acquiring companies are US multinationals in tech, which also have high market capitalisation. Alphabet leads the list with 18 acquisitions, Apple ranks second with 11 and Microsoft comes third with nine. Cumulatively, up to mid-2018, the top 10 acquirers made 79 AI acquisitions. Furthermore, the number of acquisitions has accelerated since 2016 as companies increasingly perceive AI as a technology to boost their R&D and innovation capacities, productivity and competitiveness. The overall state of play of acquisitions worldwide is further discussed in Chapter 8 - Framework conditions.

Figure 7-29 Number of AI companies acquired by top acquiring companies, before and after 2016 up to mid-2018



Science, research and innovation performance of the EU 2020

Source: WIPO 2019 report, based on CrunchBase database, May 2018

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-29.xlsx

Besides acquisitions, 'tech giants' are also adopting a set of different strategies to lead in AI development, from investing heavily in R&D labs for AI to programmes designed to attract overseas talent. Although acquisitions are one of the top strategies used by top tech companies to gain 'AI superiority' relative to their competitors, there are certainly others, as indicated in Figure 7-30. These include investing heavily in R&D labs to foster AI research, initiatives to attract top talent, democratising access to AI, and gaining public trust around how AI is built and used, among others.

Figure 7-30 Examples of efforts in a selection of US and Chinese tech giants to lead the AI race

Company	Company efforts to promote AI - examples

Alibaba (China)	▸ USD 15 billion investment into R&D
	▸ The DAMO (Discovery, Adventure, Momentum and Outlook) Academy:
	  ▸ programme to set up research and development labs world in 7 different locations worldwide[(1)]
	  ▸ focus on foundational and disruptive technology research in areas such as data intelligence, natural-language processing, quantum computing, and machine learning

Tencent (China)	▸ AI research lab in Seattle, United States ▸ Open platform to drive AI projects in other companies
Baidu (China)	▸ Collaborative projects with telecom, smart home-appliance-maker companies ▸ Collaboration with top Chinese universities ▸ Campus recruiting campaigns in top US universities to work in company´s HQ in Beijing
Alphabet (United States)	▸ Open-source TensorFlow library for machine-Learning computations ▸ Google AI Principles for responsible AI, and People + AI Research (PAIR) for human-centred AI ▸ Google AI Residency Program, mentoring ▸ Quantum AI, to develop quantum algorithms to accelerate machine learning
Microsoft (United States)	▸ Microsoft Ventures: new fund for startups ▸ Microsoft Research AI, focused on AI R&D ▸ Microsoft AI School ▸ Initiatives within the 'AI for Good' program
Apple (United States)	▸ Overton AI development tool ▸ 'Hiring the competition' - hired Google's chief of search and artificial intelligence, to run its ML and AI strategy

Science, research and innovation performance of the EU 2020

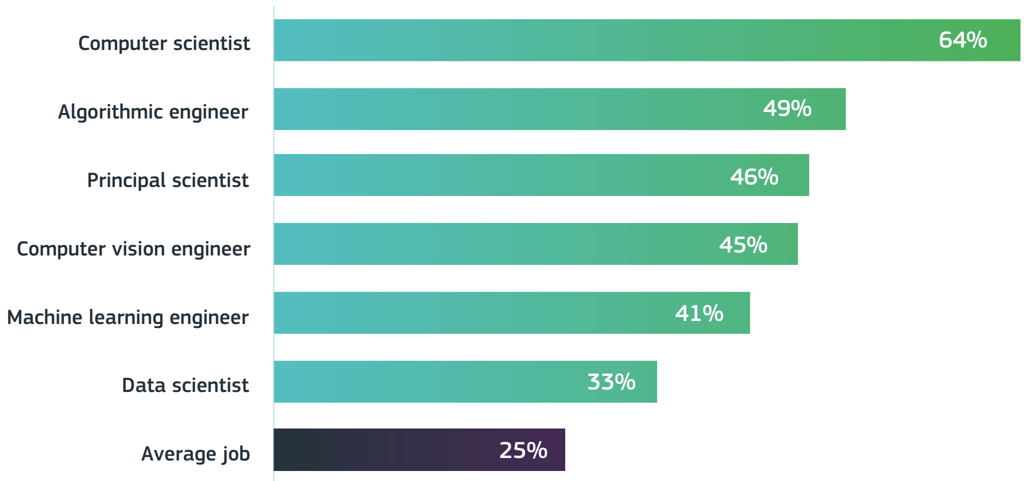
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on multiple media and company websites´ sources: https://qz.com/1099535/alibaba-is-plowing-15-billion-into-rd-with-seven-new-research-labs-worldwide, https://damo.alibaba.com/labs/, https://www.cnbc.com/2017/05/02/tencent-ai-research-lab-seattle.html; https://blog.aimultiple.com/baidu/, https://www.scmp.com/tech/big-tech/article/2164765/tencent-releases-open-platform-help-drive-ai-projects-other-companies, https://www.popsci.com/google-ai/, https://ai.google/research/teams/applied-science/quantum/, https://www.forbes.com/sites/jonyounger/2019/01/16/googles-ai-and-ml-research-priorities-freelancers-take-note/#36a9b4a8344c, https://www.techworld.com/picture-gallery/data/tech-giants-investing-in-artificial-intelligence-3629737/, https://venturebeat.com/2019/09/13/apple-details-overton-ai-development-tool-whose-models-have-processed-billions-of-queries/

Note: [(1)]The locations include Beijing and Hangzhou, Singapore, Moscow, Tel Aviv, Seattle and Silicon Valley, hence none in the EU, according to the article. All the examples listed above are merely illustrative and not exhaustive.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-30.xlsx

The race for AI talent is on. Currently, AI talent is relatively scarce worldwide but appears more predominant in the United States. The EU faces a shortage in AI professionals which could undermine its ambition to galvanise its AI innovation landscape. AI-related jobs seem harder to fill compared to the 'average job' (Figure 7-31) which hints at a limited pool of AI talent worldwide. In particular, the profiles of computer scientists, algorithmic engineers and principal scientists are proving to be the hardest AI-related vacancies to be filled. For example, in the Indeed portal – a job-search portal – 64% of the computer scientist vacancies were still open after 60 days of being published on the portal.

Figure 7-31 Percentage of AI-related jobs on Indeed open after 60 days, and comparison with average job



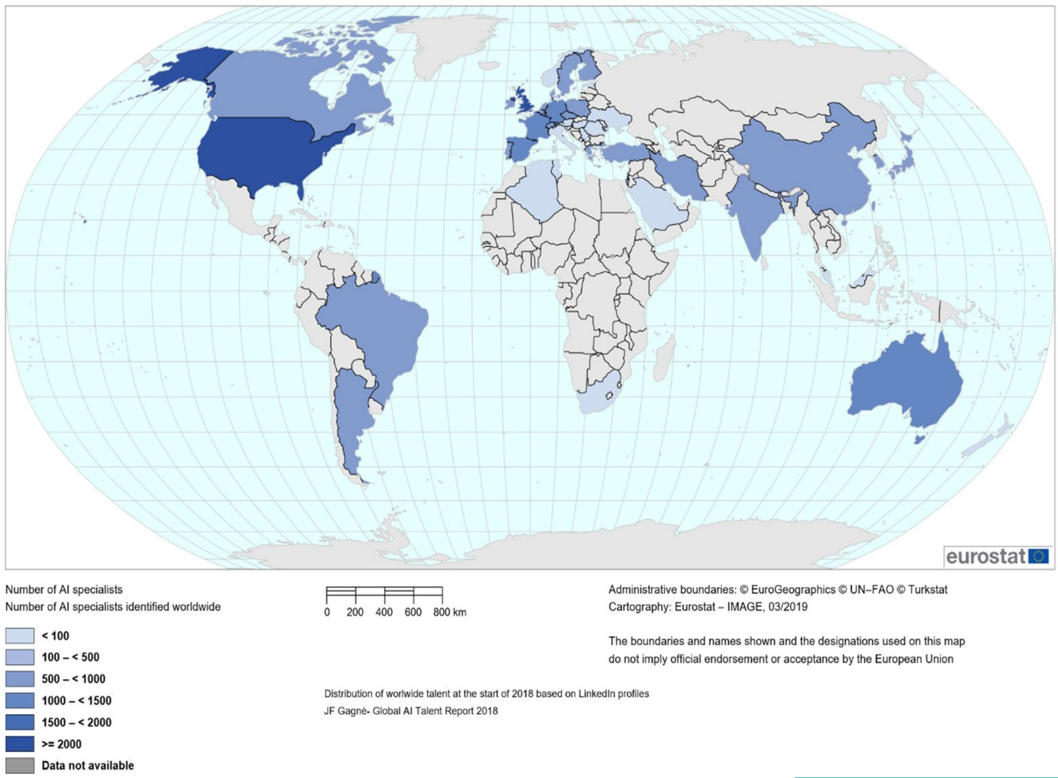
Science, research and innovation performance of the EU 2020
Source: Priceoconomics data studio – Which Industries are investing in Artificial inteligence (18 November 2018) based on Indeed data
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-31.xlsx

Official statistics on the existence and production of AI talent are still lacking. However, certain external efforts have provided some indication of the geographical distribution of AI specialists worldwide. J.F. Gagné (2018) used the LinkedIn job platform to identify AI specialists all over the world (Figure 7-32). One caveat of the analysis is that the use of LinkedIn is more common in the West, so there may be a bias in the data collected which may underestimate the presence of AI specialists, for example, in China. The United States appears to have more AI talent available than, for example, the EU or China. In addition, most tech giants are based in the United States. In light of the scarcity of AI talent, these multinationals offer highly competitive salaries and alluring benefits to attract and retain top talent.

For the EU, this means that, on the one hand, it is important to increase the number of students and professionals with an AI-related academic background

and/or AI technical competences and skills acquired, for instance, in trainings that also reflect the potential risks of AI technologies. On the other hand, the EU should enable the right environment for them to work in the EU (i.e. to retain AI talent) and attract more talent from abroad, as highlighted in the 2018 European Commission Communication on 'Artificial Intelligence for Europe', for example through the 'Blue Card scheme'.

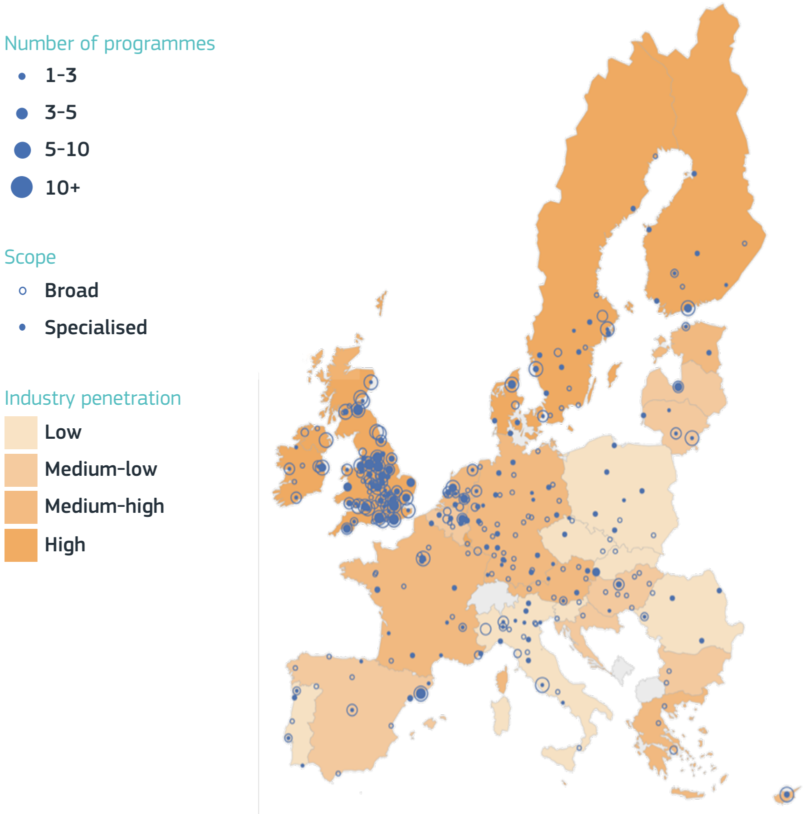
Figure 7-32 **Global AI talent pool based on AI Specialist LinkedIn profiles, 2018)**



Source: J.F. Gagné - Global AI Talent Report 2018
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-32.xlsx

Within Europe, AI industry is more dense in Malta, the United Kingdom, Denmark, Ireland, Finland, Luxembourg and Sweden. The AI academic offer is concentrated in top urban centres. Four of the top five European cities offering specialised programmes on AI are in the United Kingdom. Figure 7-33 combines data on industry penetration by AI (i.e. the number of AI enterprises in total enterprises) with an academic offer on AI (i.e. the number of bachelor and master's programmes) in Europe. Malta, the United Kingdom, Denmark, Ireland, Finland, Luxembourg and Sweden stand out as the European countries with the highest industry penetration rates. The top five cities in terms of the supply of AI academic programmes are London, Southampton, Edinburgh, Barcelona and Manchester, which means four of the top cities are in the United Kingdom.

Figure 7-33 Industry penetration of AI[1] and AI academic offer[2] in the EU28



Science, research and innovation performance of the EU 2020

Source: De Prado et al., 2019

Notes: [1]The number of AI enterprises over total number of enterprises. [2]Total number of programmes (bachelor's and master's degrees) identified as AI-specialised.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-33.xlsx

7. AI can lead to public-sector innovation but not all EU Member States are embracing it

It is time for the public sector to embrace the opportunities created by AI. While some EU Member States rank high internationally in 'government AI readiness', in others a greater effort is needed to roll-out AI capabilities. AI-related technologies can also lead to greater efficiency in the public sector, enhancing the quality of public services and enabling better techniques to process and analyse data, as well as acting as a support tool for policy evaluation. In the EU, the public sector is one of the most data-intensive sectors. Clearly, the reuse of open data can contribute to the development of AI. For this reason, many countries worldwide, including EU Member States, are embedding public sector AI innovation into their national AI strategies. The OECD (2019c) describes some of the main elements of public sector-focused AI strategies, including, for example:

- ‘Experimentation with AI in government and the identification of specific AI projects currently under way or that will be developed in the near future;
- Collaboration across sectors, such as through public-private partnerships;
- Fostering of cross-government councils, networks and communities to promote systems approaches;
- Automation of routine government processes to enhance efficiency.

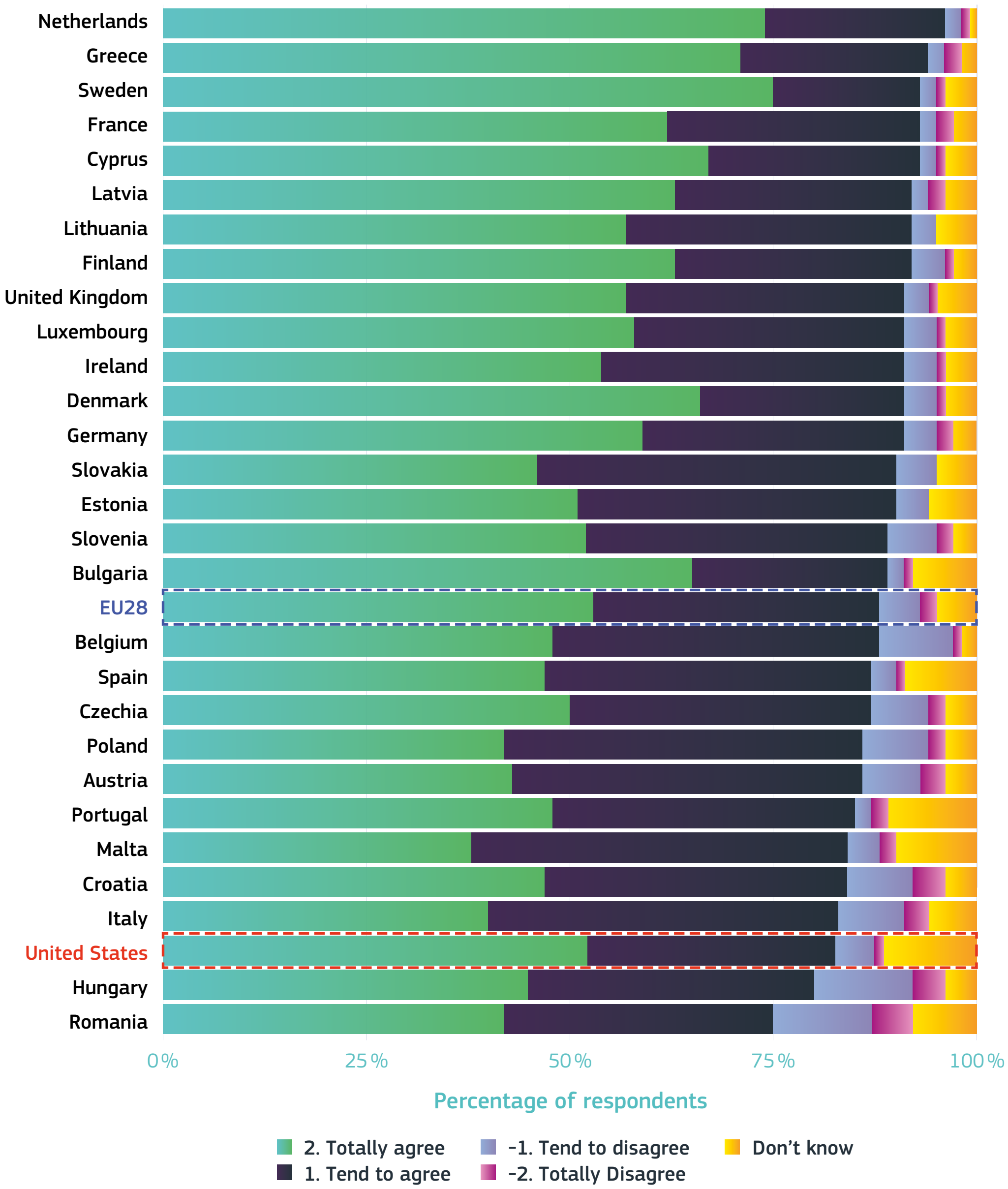
Despite these benefits, there are also concerns about bias, privacy, transparency and the overall complexity of data accessibility and usability. The ‘Open Data Directive’ (Directive (EU) 2019/1024)[16], which entered into force on 16 July 2019, provides more guidance and clarity on the use of open data in the public sector. Under the new rules:

- All public sector content that can be accessed under national access to documents rules is in principle freely available for reuse. This could allow more SMEs and startups to enter new markets in providing data-based products and services.
- A particular focus is placed on high-value datasets such as statistics or geospatial data.
- Public undertakings in the transport and utilities sector generating valuable data when providing services in the general interest will have to comply with the principles of transparency, non-discrimination and non-exclusivity set out in the Directive, and ensure the use of appropriate data formats and dissemination methods. They will still be able to set reasonable charges to recover the costs of producing the data and of making it available for reuse.
- Publicly-funded research data enters into the scope of the Directive: Member States are required to develop policies for open access to publicly funded research data while harmonised rules on reuse will be applied to all publicly funded research data which is made accessible via repositories.

Building trust and broad social acceptance around AI is key for its success. Most Europeans agree that robots and AI require careful management (Figure 7-34), while the same applies to the United States. As a result, policies to foster AI should follow a human-centric, transparent and trustworthy approach in order to promote public trust in this field.

16 https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1561563110433&uri=CELEX:32019L1024

Figure 7-34 Agreement with statement that robots and AI require careful management[1], in the EU28 and the United States



Source: Centre for the Governance of AI and Eurobarometer

Note: [1]EU28 data from 2017 Special Eurobarometer #460.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-34.xlsx

The 'Government AI Readiness Index' ranks the governments of 194 countries and territories based on their 'preparedness to use AI in the delivery of public services' based on four clusters covering aspects linked to governance, infrastructure and data, skills and education and, finally, government and public services. Figure 7-35 shows the 2019 results. Germany, Finland, Sweden, France and Denmark rank in the top 10 governments well-prepared to embrace AI opportunities to improve their efficiency. However, in other EU Member States such as Hungary, Greece, Cyprus, Romania and Croatia, considerable efforts are still needed to support the uptake of AI in the public sector.

Figure 7-35 Overall rankings for Government AI Readiness 2018/19[1]

Top 10 and rank of EU Member States

Rank	Country	Score
1	Singapore	9.186
2	United Kingdom	9.069
3	**Germany**	8.810
4	United States	8.804
5	**Finland**	8.772
6	**Sweden**	8.674
7	Canada	8.674
8	**France**	8.608
9	**Denmark**	8.601
10	Japan	8.582
(...)		
14	Netherlands	7.659
15	Italy	7.533
16	Austria	7.527
23	Estonia	6.968
24	Belgium	6.859
25	Luxembourg	6.857

Rank	Country	Score
27	Poland	6.835
30	Portugal	6.693
31	Czechia	6.673
33	Latvia	6.548
34	Ireland	6.542
36	Spain	6.332
37	Lithuania	6.288
38	Slovenia	6.232
43	Malta	5.961
45	Slovakia	5.923
47	Bulgaria	5.806
48	Hungary	5.794
49	Greece	5.760
53	Cyprus	5.668
55	Romania	5.540
62	Croatia	5.273

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Source: Government Artificial Intelligence Readiness Index 2019 – Oxford Insights and International Development Research Centre

Note: [1]The overall score is comprised of 11 input metrics, grouped under four high-level clusters: governance; infrastructure and data; skills and education; and government and public services. The data is derived from a variety of resources, ranging from desk research into AI strategies, to databases such as the number of registered AI startups on Crunchbase, to indices such as the UN eGovernment Development Index.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-35.xlsx

Box 7-5 The EU Digital Package: European Strategy for Data & White Paper on AI

On 19 February 2020, the Commission published a White Paper and two Communications pertaining to the Digital Single Market, together referred to as the '**Digital Package**'.

In '**Shaping Europe's digital future**'[17] , the Commission presents its overall vision and goals for the development and use of digital technologies in Europe, as well as a roadmap for future actions, Communications and regulatory initiatives.

The aim of '**A European strategy for data**'[18] is for Europe to have a genuine single market for data so that the EU's share of the data economy could correspond to its economic weight. The strategy includes setting up a governance framework (including regulatory action), increasing investment, and creating sector-specific common European data spaces. Data spaces for industry (manufacturing), the Green Deal and health data, are among those being proposed, as well as the European Open Science Cloud.

The '**White Paper on Artificial Intelligence – A European approach to excellence and trust**'[19] outlines the Commission's vision for a European approach to AI, building on its existing strengths (research, robotics, manufacturing, EU research funding, coordinated plan with the MS), respecting European values (ethics, privacy protection) and presenting the main challenges. In order to overcome these challenges, the White Paper describes actions to build an 'ecosystem of excellence' to encourage investment, on the one hand, and an 'ecosystem of trust' through a regulatory framework, on the other.

An **ecosystem of excellence** is required to support the development and uptake of AI across the EU economy and public administration. The proposed actions are focused on:

1. revising the existing coordinated plan between the Member States;
2. extending and creating new excellence and testing centres;
3. investing in advanced skills and higher education;
4. expanding Digital Innovation Hubs with a focus on AI, and providing equity financing (a pilot in 2020 which can be scaled up in 2021);
5. creating public-private partnerships under the new Horizon Europe framework programme, including one on 'AI, data and robotics'; and
6. facilitating public procurement.

The **ecosystem of trust** would consist of an appropriate regulatory framework providing legal certainty and trust in AI and addressing its significant risks. An initial basis has been developed by the high-level expert group on AI, in the form of seven key requirements for trustworthy AI, operationalised in an assessment list, which is under review following extensive stakeholder consultation (see Box 7-4).

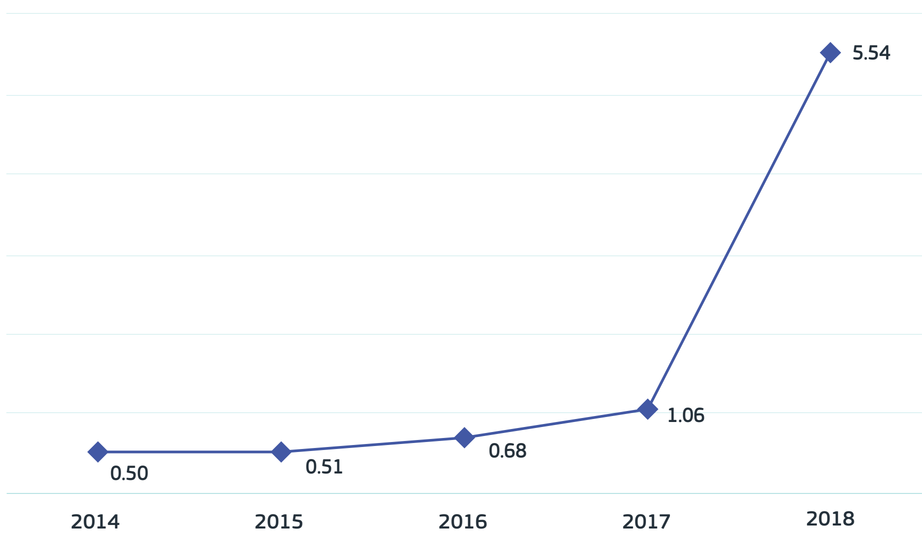
17 https://ec.europa.eu/info/sites/info/files/communication-shaping-europes-digital-future-feb2020_en_3.pdf
18 https://ec.europa.eu/info/sites/info/files/communication-european-strategy-data-19feb2020_en.pdf
19 https://ec.europa.eu/info/sites/info/files/commission-white-paper-artificial-intelligence-feb2020_en.pdf

8. ‘Digital meets digital’: how other digital technologies can augment the potential of AI

Blockchain technology has attracted a lot of interest lately, as regards applications that go beyond bitcoin and cryptocurrencies. Blockchain is a technology that allows for sharing and exchanging data in a peer-to-peer way, i.e. without the need for an intermediary. Data in the blockchain are stored in blocks that are linked with each other using cryptographic methods. Multiple copies of the blockchain will then circulate in a blockchain network, making it difficult to alter the data because if someone wanted to alter an entry she/he would need to alter the entire blockchain and then get consensus in the network that his/her version of the blockchain was the correct one rather than those held by the others.

The interest around AI is particularly true in the financial sector, but increasingly so in other sectors of the economy. Indeed, data is increasingly becoming a key element across many sectors of the economy. With the introduction of the Internet of Things (IoT) in areas like manufacturing, mobility, health, logistics, etc., managing the amount of data produced in a secure way will require new innovative technologies like blockchain. The interest around blockchain is reflected in Figure 7-36 which shows the exponential increase in venture capital investment in blockchain technologies between 2017 and 2018.

Figure 7-36 Global venture capital invested in blockchain companies in USD bn, 2014-2018



Source: MIT Technology Review 2 April 2019 based on Pitchbook data
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This interest is also reflected in the job market. Figure 7-37 gives an indication of this in the US market. In particular, it is possible to see that blockchain developer was the top 'emerging job' on LinkedIn between 2014 and 2018, with job postings growing 33 times over that period.

Figure 7-37 Emerging jobs on LinkedIn by growth over 2014-2018

	2018 Top 5 emerging jobs	Growth (2014-2018)
1	**Blockchain Developer**	**33x**
2	**Machine Learning Engineer**	**12x**
3	Application Sales Executive	8x
4	**Machine Learning Specialist**	**6x**
5	Professional Medical Representative	6x

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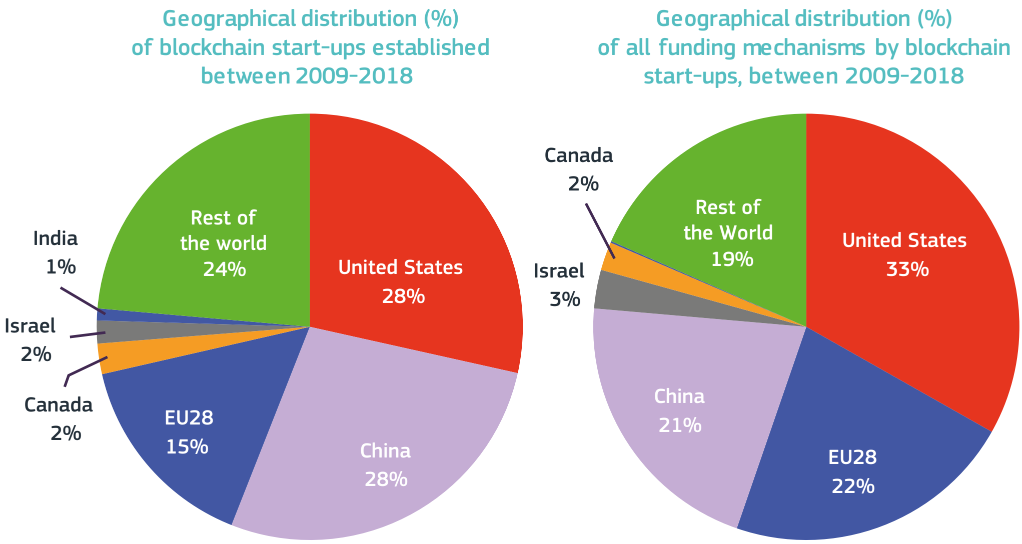
Source: LinkedIn 2018 Emerging Jobs in the US Report
Note: Analysis of LinkedIn Economic Graph data between 2014-2018.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-37.xlsx

Blockchain and other distributed data technologies could provide technical solutions that guarantee the authenticity of the data to be used in machine-learning algorithms. The success of machine learning is based on the availability of data – not just any data but data that can be trusted. In this respect, verifiable provenance of data used in ML algorithms is essential. Data protection of private data requires the consent of data subjects for its use. In that sense, blockchain could provide technical solutions that give control of the data to those to whom the data belong. For example, the research project DECODE[20] funded by Horizon 2020 is using blockchain to offer tools that give individuals control over their personal data.

The United States and China lead in terms of blockchain startups, while the EU28 only account for 15% of all blockchain startups. **Funding for blockchain startups also appears more readily available in the United States than in the EU**. Figure 7-38 shows the geographical distribution of both blockchain startups (left-hand chart) and the funding received by these startups (right-hand chart). The United States and China both account for 28% of all blockchain startups worldwide, and in total for almost 60% of all startups in the field. The EU28, however, only represents 15% of the global blockchain startup ecosystem, followed by Canada and Israel (both with a 2% share), and India (1%). US blockchain startups appear to have raised more funding than EU or Chinese startups: the United States represents one third of all funding mechanisms, compared to 22% in the EU28, 21% in China, 3% in Israel and 2% in Canada.

20 https://decodeproject.eu/

Figure 7-38 Blockchain: startups and funding, 2009-2018



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Source: Anderberg et al. (2019) based on Venture Scanner – Dow Jones

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-38.xlsx

Horizon 2020 supports the development of blockchain applications. Through Horizon 2020, around EUR 200 million have already been allocated to blockchain-related projects in areas such as managing and controlling access to medical and personal data, IoT, smart homes and grids, cybersecurity, transport, energy, environment and social media. The 2019 'Blockchain for Social Good' Horizon 2020 prize awarded five prizes of EUR 1 million each to the best decentralised social innovations leveraging on distributed ledger technologies such as blockchain.

The EU wants to be at the forefront of blockchain policy action globally, by monitoring, regulation and governance of blockchain technologies. The Commission is monitoring the development of blockchain technologies and assessing the need for regulation. It has set up an EU Blockchain Observatory and forum[21] to monitor trends, developments and use cases in blockchain across sectors. In 2018, the Commission had already adopted the FinTech action plan[22] Communication in which it identifies blockchain, distributed ledger technologies, AI and other digital technologies as those that are changing the financial services. The action plan sets out a number of actions to assess the regulatory framework and to set up regulatory sandboxes.

The European Blockchain Partnership (EBP) agreement between all Member States plus Norway and Lichtenstein aims to cooperate in putting in place the European Blockchain Services Infrastructure (EBSI) for the use of blockchain technologies by the public sector initially and later the private sector, too. The EBSI is expected to be operational in 2020-2021, with the first cross-border digital public services.

21 https://www.eublockchainforum.eu/

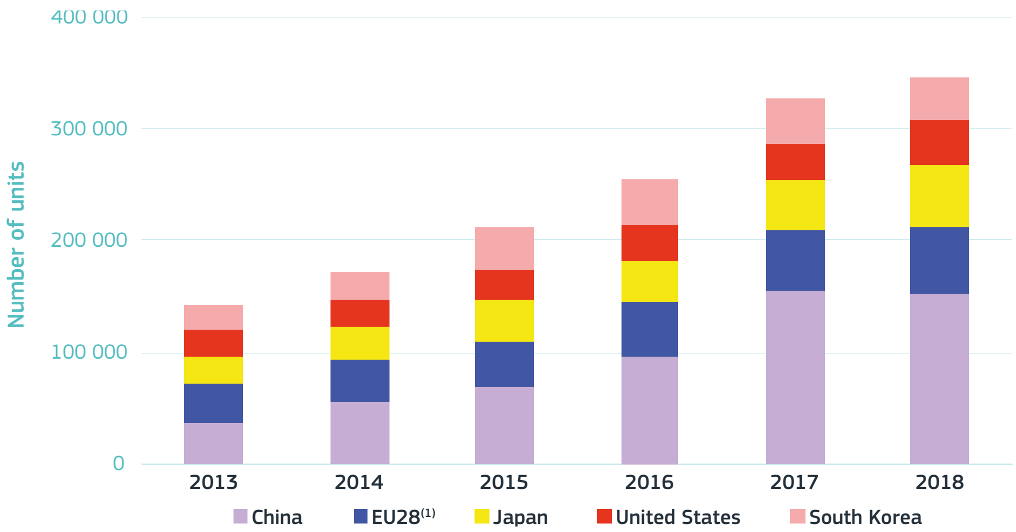
22 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52018DC0109

Finally, in 2019, the European Commission supported the launch of the International Association for Trusted Blockchain Applications (INATBA)[23]. This public- private sector association, with members from around the world, is working on issues relating to interoperability, sector deployment guidelines and governance of blockchain technologies.

9. 'Digital meets physical': AI and advanced manufacturing

Two of the top 10 industrial robot manufacturers are in the EU. Worldwide, the number of industrial robots keeps growing. China has the largest market, followed by the EU and Japan. a German company (KUKA) and the Italian company Comau are in the world's top 10 robot manufacturers[24]. The World Robotics Report shows that a record number of 422 271 industrial robots were shipped globally in 2018, a steady increase of 6 % compared to 2017 (IFR, 2019). As mentioned in Chapter 4.1 - Innovation, the future of work and inequality, worldwide robot density is highest in South Korea, followed by Japan, the United States and then the EU. In absolute terms, the Chinese market is by far the largest, followed by the EU, and it has been growing rapidly (Figure 7-39).

Figure 7-39 Annual installations of industrial robots - number of units, key world players, 2013-2018



Science, research and innovation performance of the EU 2020

Source: International Federation of Robotics (2019)

Note: (1)The EU28 values were obtained by subtracting from Europe's total the number of non-EU countries, 'others not specified' and 'other European countries'.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-39.xlsx

23 https://inatba.org/

24 https://www.marketresearchreports.com/blog/2019/05/08/world's-top-10-industrial-robot-manufacturers

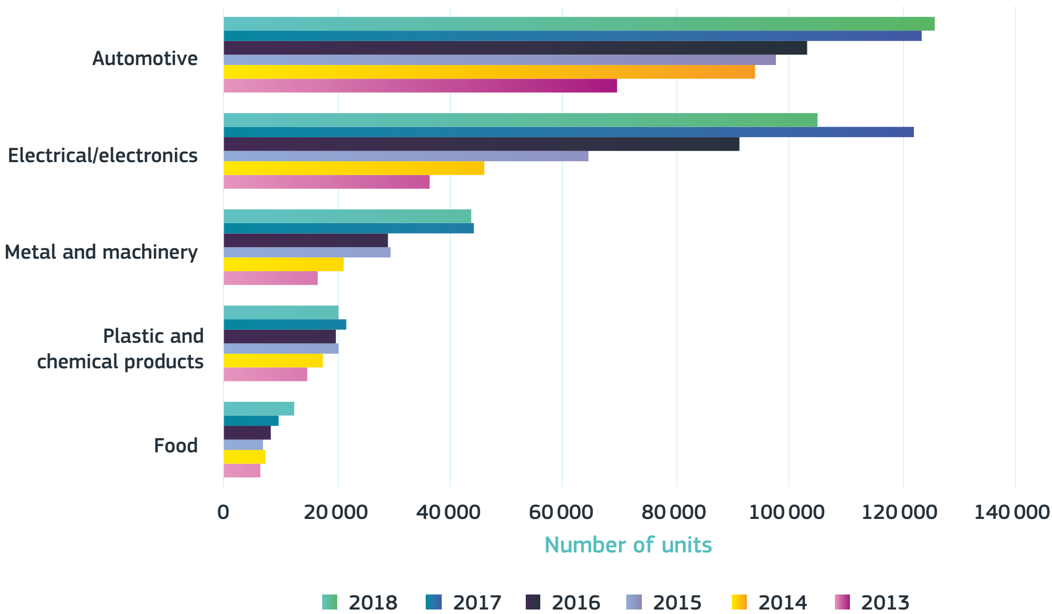
The automotive and electronics sectors are still the drivers although they are no longer growing. The food sector has registered a 32 % increase in robot deployment (Figure 7-40).

There are a number of examples of AI in current and potential application areas in manufacturing, such as cognitive automation, learning machines and robotics, intelligence monitoring (for anomaly detection and inspection) and predictive maintenance, process optimisation, sensors development, production ramp-up commissioning, task planning and scheduling, energy management, and logistics and value chains. **Overall, AI will have a major impact on how a factory will be run and which tasks workers will have to carry out**[25].

Another example where AI is expected to make a significant impact concerns the capabilities of industrial robots, making them smarter and enabling their deployment in tough and unstructured environments. Eurofound (2019) identifies advanced industrial robotics as *one of the five game-changing technologies in manufacturing*.

Factories of the future will feature advanced robots that will be able to roam around a site autonomously, recognise objects and humans, predict their movements and intentions, inspect products and assess quality. Robots will be able to learn from gestures and voice commands. All of these features will enable a true human-robot collaboration.

Figure 7-40 Annual installations of industrial robots at year-end worldwide by industries, 2016-2018



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Source: International Federation of Robotics (2019)

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-40.xlsx

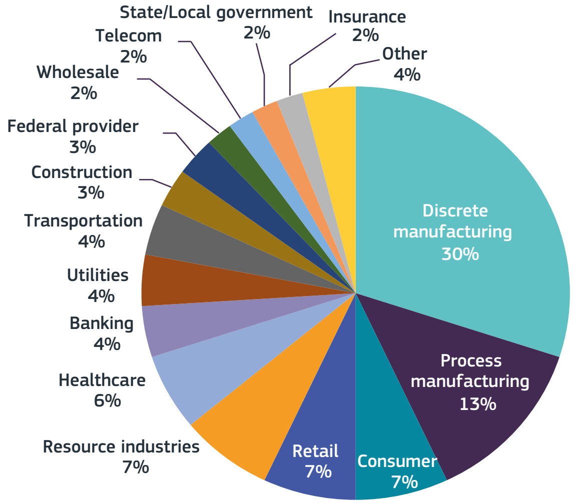
25 See JRC, The changing nature of work and skills in the digital age, September 2019.

In 2018, *Science Robotics* listed the 10 grand challenges in robotics[26]. They identified the need for further research on new materials and fabrication schemes, new batteries and power sources for mobile robots, robot swarms, new navigation systems, AI technologies, social interaction and security. For example, further research is needed to overcome the limitations of techniques such as SLAM (Simultaneous localisation and mapping) to allow for the navigation and exploration of unmapped, time-varying and dynamic environments. This would enable an effective deployment in unstructured environments, such as construction sites. AI is still far from giving robots the capability to learn on-the-fly, adapt to dynamic settings or recover from failure. Despite great advances in sensing technologies, robots have underdeveloped social abilities. Today, robots are not able to interpret social clues such as gaze direction, facial expression or vocal intonations, which are key to unlocking the full potential of human-robot collaboration.

Europe is leading the way in collaborative robots. According to the International Data Corporation (IDC), discrete manufacturing and process manufacturing are expected to attract 30 % and 13 %, respectively, of global investment in AI estimated at EUR 32.7 billion in the world and EUR 4.6 billion in Europe (Figure 7-41).

AI in manufacturing, which relies mainly on a B2B business model, is fundamentally different from AI in the B2C world as it utilises less, but very heterogeneous, data from a variety of sources often implemented on edge devices rather than in the cloud. Manufacturing also has higher requirements regarding reliability, while the adoption of autonomy comes with safety, security and ethical issues. For business-to-business applications, Europe is still a champion.

Figure 7-41 Expected distribution of financial investments in AI systems, robotics and drones in Western Europe, 2019



Science, research and innovation performance of the EU 2020

Source: https://www.eu-robotics.net/cms/upload/downloads/ppp-documents/AI_PPP_SRIDA-Consultation_Version-June_2019_-_Online_version.pdf

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-41.xlsx

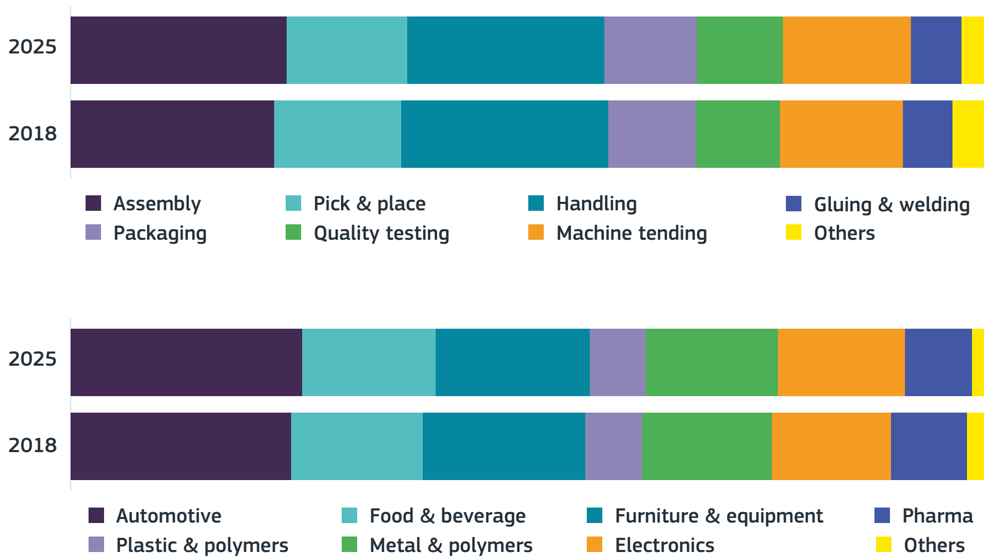
26 Yang et al., Science Robotics 3, eaar7965 (2018).

Three of the world's largest producers of industrial robots are European and 20% of industrial robots are produced in Europe.

Industrial robots were introduced decades ago to carry out repetitive, dull and tedious tasks better and faster than humans. Normally, such robots are caged behind fences for safety reasons and need to be carefully pre-programmed to do a specific task. Reconfiguration and flexibility are minimal. Factories of the future will feature advanced robots that will be able to roam around the site autonomously, recognise objects and humans, predict their movements and intentions, inspect products and assess quality. Robots will be able to learn from gestures and voice commands. All these features will enable a true human-robot collaboration. Nevertheless, although several advances have been achieved on smart grippers, connectivity and programming, in order to make advanced industrial robotics a reality on the shop floor the further development and integration of AI technologies, such as machine learning, computer vision, connected automatic vehicles, speech recognition and neural networks is required.

Currently, Europe as a whole is the key market for collaborative robotics, accounting for a significant share of around 37% in 2018 (Grand View Research, 2019). The material handling and assembly application segments are currently the strongest in the collaborative robot market with end use in the automotive, plastic and polymers, metal and machine, electronics, pharma food beverage and furniture and equipment industries. As illustrated in the figure below, assembly application is expected to undergo steady growth over the forecast period thanks to the ability of combining both repetitive and easy work along with more complex assembly processes in industries such as inspection, logistics and electronics.

Figure 7-42 Collaborative robots: market size and growth prospects

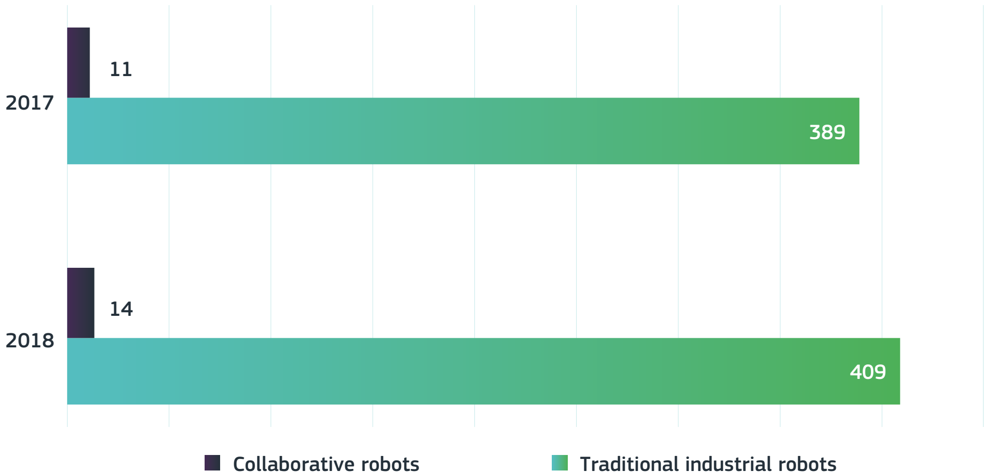


Source: Grand View Research (2019) based on RIA, IFR, Factor-tech and Discover Magazine. Hoover's, Primary interviews, Company Annual reports

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-42.xlsx

Despite the constant growth of the robotics market, market-advanced collaborative robots can be still be considered as being relatively small, as only 14 000 collaborative robots were sold in 2018 worldwide (Figure 7-43) as against 409 000 traditional models.

Figure 7-43 Collaborative and traditional industrial robots, 2017 and 2018



Science, research and innovation performance of the EU 2020

Source: International Federation of Robotics (2019)

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-43.xlsx

On the other hand, the global market share for collaborative robots is on the rise supported by investments in Industry 4.0, showing a 23 % increase from 2017 to 2018, with the overall market for robotics increasing by 6 % during the same period. China is expected to grow at a faster pace in the coming years, becoming the largest market for collaborative robots by 2025 (Figure 7-44).

Figure 7-44 Regional market place for collaborative robots

Region	Revenue 2018 (USD mn)	Revenue 2025 (USD mn)	Notable markets
Europe	241	241	UK, Germany
North America	193	193	United States, Canada
South America	23	23	Brazil, Mexico
Asia-Pacific	183	183	China, India

Science, research and innovation performance of the EU 2020

Source: Grand View Research (2019) based on RIA, IFR, Factor-tech and Discover Magazine. Hoover's, Primary interviews, Company Annual reports

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-44.xlsx

Box 7-6 Supporting human-robot collaboration in manufacturing within Horizon 2020

Under Horizon 2020, the EU has invested more than EUR 220 million in human-robot collaboration in manufacturing and related technologies. In 2018, 5 new collaborative projects on human-robot collaboration were funded, for around EUR 37 million, under the contractual public and private partnership Factories-of-the-Future. a large number of sectors are being targeted, from aeronautics to white goods production, and from electronic-waste recycling to food packaging.

The EU-funded THOMAS project is developing a new reconfigurable industrial shop floor where AI provides mobile robots with cognitive abilities that enable them to detect other robots and thereby to calculate collision-free trajectories, share and reallocate work in case of unexpected events, whilst also detecting people in the work space and understanding their intentions. THOMAS is validating its new concept with end-users in the automotive and aeronautics sectors, estimating a market potential of at least 300 factories in Europe.

AI and material discoveries

AI is providing ways to speed up discoveries in materials science. 'From the Stone Age through the Bronze and Iron Ages to today's Silicon Age, every major advance in human civilisation has been driven by a fundamental development in materials science.' Professor Spaldin from ETH Zürich quotes and argues that without new materials we are stuck with our existing concepts for information technology and have an energy bottleneck in human progress.

The traditional pipeline through which new materials are discovered, designed, developed, manufactured, and deployed remains slow, costly, and highly inefficient (Himanen et al., 2019). AI applications (computational data science and machine learning) are significantly speeding up both fundamental and applied materials research (Schmidt et al., 2019). Current machine learning applications in materials science are rich and diverse, ranging from catalyst design, exploring the mechanisms of high-temperature superconductivity to predicting excitation spectra. Researchers are using computer modelling and machine-learning techniques to generate libraries of candidate materials by the tens of thousands to shortlist, for example, how well they will work as a conductor or an insulator, whether they will act as a magnet, and how much heat and pressure they can withstand (Nosengo, 2016).

It takes a lot of trial and error as well as lab experimentation to identify new materials, particularly high-performance materials for next-generation applications. Researchers are combining AI and machine learning models to find the optimal material to fit any given criteria in order to reduce the time and cost spent moving from lab to market. The use of machine learning and ab initio calculations are presented to guide strain engineering whereby material properties and performance could be designed (Shi et al., 2019).

Nanomedicine design also benefits from the application of AI by optimising material properties according to predicted interactions with the target drug, biological fluids, immune system, vasculature, and cell membranes, all affecting therapeutic efficacy (Adir et al., 2019). Such machine learning tools are increasingly being incorporated directly into material data infrastructures (Himanen et al., 2019).

Box 7-7 Snapshot of EU-funded projects using AI to accelerate material discoveries for green solutions

The large-scale **Battery 2030 project**, with 17 partners from academia and industry, wants to design batteries of the future by using ultra-high-performance materials and structures from the atomic level up, using advanced approaches like density functional theory calculations in combination with AI.

The **Moldesign project** uses computational material design by combining material simulation methods with AI to enable large-scale material screening for the next generation of organic solar cells.

The **CoMManD project** is developing a computational approach using AI to accelerate the discovery of molecular materials targeting applications in molecular separations, sensing, (photo) catalysis and photovoltaics.

The **DYNAPOL project** is studying bio-inspired properties such as the ability of various supramolecular materials to self-heal, adapt or reconfigure dynamically by using AI and massive multi-scale modelling.

Accelerating the discovery of new materials, and the associated research required for real deployment, will require a radical departure from traditional forms of discovery and a multidisciplinary and international effort. Computation and design are simply the first step in bringing novel materials to market. Materials synthesis and characterisation have yet to benefit from automation and accelerated learning on a large scale[27]. Even if the use of AI in materials science is still in its early days in Europe, it will enable unforeseeable and revolutionary impacts across nearly the entire spectrum of materials and structures, processes, and multi-scale modelling and simulation over the next two decades (Dimiduk et al., 2018). To establish data-driven materials science as a true paradigm in materials research, joint eco-system efforts are necessary between research, industry and public and governmental organisations (Himanen et al., 2019).

27 http://mission-innovation.net/wp-content/uploads/2018/01/Mission-Innovation-IC6-Report-Materials-Acceleration-Platform-Jan-2018.pdf

10. Conclusions

The EU ranks among global leaders when it comes to AI science. However, there is an AI innovation gap when compared to the United States and China. This includes, for instance, the number of AI firms and the share of firms active in AI patenting. Most unicorn companies in the AI field are also based in the United States and China.

In terms of 'AI dynamics', worldwide academia-business and cross-country collaborations have intensified over time. The EU collaborates strongly with the United States, then China, in research and patenting in the AI domain. Likewise, **AI science is no longer confined to fields such as computer science. In the EU, AI research is more oriented towards humanities and social sciences**. Moreover, in the global AI race, top companies are investing highly in AI. This is illustrated by the **rapid pace of acquisitions of AI startups (notably by tech giants)**, especially in recent years, **in order to access data and top AI knowledge**, with implications for the EU's future positioning in AI, market-concentration dynamics, data protection and competition policy.

Worldwide, major economies have put forward ambitious AI strategies. China was first to launch a comprehensive AI strategy in 2017 with the 'Next Generation Artificial Intelligence Development Plan' followed by the industry-targeted 'Three-Year Action Plan for Promoting Development of a New Generation Artificial Intelligence Industry (2017)'[28] with the aim of becoming the global AI leading nation by 2030. With the **Declaration on Cooperation on Artificial Intelligence** (2018) and the **Coordinated Plan on Artificial Intelligence 'Made in Europe'** (2018)[29], the EU and the Member States demonstrated their ambition to align priorities and maximise the impact of public and private investments in AI to enable innovation and collectively ensure that the EU as a whole can compete globally. The EU **Digital Strategy**[30] wants to ensure not only that Europe is a global digital player but also that the EU leads in making sure that technology works for all, and that we live in an open, democratic and sustainable digital society. The United States followed with a national strategy for AI, the American AI Initiative (2019)[31] which identifies R&D as a top priority for maintaining global leadership in AI.

AI can play a big role in the economic, social and ecological transition that Europe is undergoing. In the context of the current productivity slowdown, AI can be a powerful tool to improve the efficiency of operations throughout the economy. As a result, the EU should capitalise on its industrial strengths to lead in AI development. This includes, for instance, manufacturing as well as new areas of early application such as material science. In order to achieve **technology sovereignty in the field of AI as well as to diffuse it** across sectors and regions, the combination of efforts at the EU and Member State level is paramount.

28 http://www.gov.cn/zhengce/content/2017-07/20/content_5211996.htm, http://www.miit.gov.cn/n1146295/n1652858/n1652930/n3757016/c5960820/content.html
29 https://ec.europa.eu/digital-single-market/en/artificial-intelligence
30 https://ec.europa.eu/digital-single-market/en/content/european-digital-strategy
31 https://www.whitehouse.gov/ai/

Although AI, like any technology, does not automatically make the world a better place, it can. In the fight against climate change, AI can make a significant contribution across different fields. By enabling automatic monitoring through remote sensing (e.g. pinpointing deforestation, and assessing damage after disasters), accelerating the process of scientific discovery (e.g. by suggesting new materials for batteries and carbon capture) and optimising systems to improve efficiency (e.g. by consolidating freight, designing carbon markets, and reducing food waste)[32]. In addition, AI can also help to improve public services (e.g. traffic management, healthcare delivery and processing tax forms). While some EU Member States have a high international ranking in 'government AI readiness', more efforts to roll-out AI capabilities are needed in other countries.

AI and other digital technologies have reached a stage of technological maturity that makes them important tools to help in the fight against a pandemic such as COVID-19. All over the world, ambitious R&I projects and collaborations to track, monitor and contain the COVID-19 pandemic are increasingly being carried out, including AI-powered solutions. AI-related applications have enabled population screening, tracking the spread of the infection, and the detection and diagnosis of COVID-19. Openly accessible, machine-readable, interoperable data is needed to track, monitor and forecast the spread of COVID-19. At the EU level, the Action Plan - Research data-sharing platform for the SARS-CoV-2 and COVID-19 diseases launched by the EMBL's European Bioinformatics Institute (EMBL-EBI) and the European Open Science Cloud intends to speed up and improve the sharing, storage, processing of and access to research data and metadata on the SARS-CoV-2 and COVID-19 diseases. At the same time, the use of AI tracking and surveillance tools in the context of this pandemic has clearly shown the **need for the global ethical governance of AI.**

AI also requires investing in a set of complementary assets. These include fostering talent production and retention in the EU (while attracting foreign talent from other parts of the globe), investments and **capacity-building in related digital technologies**, such as high-performance computing, European cloud and micro-electronics, and **research and digital infrastructure**, notably 5G networks, for Europe to remain competitive and ensure technological sovereignty. Both the EC's **Horizon Europe and Digital Europe Programmes** will be instrumental in achieving this. Furthermore, **advancing market integration** in Europe with a complete Digital Single Market is vital for AI startups and scale-ups to succeed, including simpler and quicker patent rights.

In addition, one of the most important considerations is to ensure that the economic and social benefits of AI are broadly shared across society. Thus, building 'trust in tech' and social acceptance around AI is essential. For example, open source and open data have important implications for boosting innovation, although there are also concerns relating to privacy and cybersecurity. In the EU, the General Data Protection Regulation (GDPR) is a major step towards building trust and ensuring legal clarity in AI-based applications. Also, AI predictions and decision-making capabilities are only as good as the quality of the underlying data. Concerns over AI bias based on gender, race and other factors due to 'inherited' bias in historical data or missing observations may lead to discriminatory decisions.

32 Tackling climate change with machine learning: https://arxiv.org/abs/1906.05433

All in all, although Europe has a rich history in AI research and continues to lead in that area, it is clear that the early implementers of recent breakthroughs in machine learning, big data analytics, and cloud computing are situated mainly in the United States and China, predominantly in the B2C market. In years to come, the application of AI will increasingly be the subject of concerns about its long-term impacts on privacy, technological sovereignty and the future of work. Europe is currently carving out a position to lead in a more thoughtful, ethical approach to AI with a clear and adequate legal and ethical framework to build an AI ecosystem that spurs innovation: **Europe is designing its own way**. By seeking out opportunities in the business-to-business market, investing in the development of privacy-preserving and transparent AI, rethinking existing paradigms (e.g. edge vs. cloud-based AI), putting an emphasis on the environmental impact of information technologies, and by introducing targeted regulation (of which GDPR could be seen as an onset), **Europe is positioning itself for a self-designed, AI-infused future**.

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