McKinsey & Company

How nine digital frontrunners can lead on AI in Europe

Harnessing the opportunity of artificial intelligence in Europe’s digital frontrunners

October 2020

Table of contents

The purpose of this report is to provide a fact base on the topic of artificial intelligence in the European group of nine “digital front-runners,” namely Belgium, Denmark, Estonia, Finland, Ireland, Luxembourg, the Netherlands, Norway, and Sweden, in order to enable a discussion on what the what the “region” can do to advance on AI and to inspire the DF9 and broader European public and private sector actors to succeed, with reference to the characteristics of leading countries.

The material herein is based on extensive primary research and secondary sources. We would also like to thank the many experts from the public, private, and social sectors who provided insights and helped advance our thinking. In particular, we would like to thank Google for its contributions.

1. What is AI?

At a glance

Artificial intelligence (AI) is a game-changing technology that has the potential to impact almost every sphere of human activity. The technology's power arises from its ability to process huge data sets quickly, enabling it to mimic aspects of human intelligence, including perception, learning, reasoning, planning, and decision making.

Around the world, researchers are working on thousands of applications for AI, ranging from innovations in marketing to breakthroughs in agriculture, transport, and healthcare. Much of the activity is located in tech clusters, in particular in the US and China. Europe is also seeing rising levels of AI engagement, but not on the same scale. The onus is now on European companies and policy makers to put in place the frameworks to ensure that the continent keeps pace and realizes AI's potential.

Amid a dynamic development landscape, it is incumbent on Europe to pick up momentum in AI investment, policy, and experimentation. The key will be to grasp the many facets of the technology – from its commercial potential to its impact on labor markets – and to formulate a strategic response that serves the best interests of business, the public sector, and the public at large.

If Europe is to make the most of AI, it must find a way to leverage skills from across the continent. One potential source of leadership is the continent's nine digital frontrunners, namely Belgium, Denmark, Estonia, Finland, Ireland, Luxembourg, the Netherlands, Norway, and Sweden. These "DF9" are ahead on AI infrastructure and policy environment and have the potential, given the right conditions, to become Europe's AI locus, driving adoption and maximizing the technology's impact.

This report is divided into five chapters. The first explores the essence of AI, explaining what the technology is and how is can be used in a variety of settings. Chapter 2 describes the race to develop AI around the globe, highlighting key clusters and setting out the current state of play in Europe, including in the DF9. Chapter 3 focuses on the economic opportunity, which is significantly greater than that of early robotics and web technologies. We expect to see GDP uplifts in all economies, with AI becoming the key driver of economic growth in some. In Chapter 4 we disaggregate AI's potential into individual sectors and highlight key verticals that may see the biggest impacts, namely healthcare, sustainable activities, and the public sector. We believe special efforts should be made to ensure SMEs reap the benefits. Finally, in Chapter 5 we set out some ideas for focus areas going forward.

The future role of AI remains uncertain, but all the signs are that it will play a significant role in numerous aspects of our lives.

Source: Gareth et. al.: An Introduction to Statistical Learning, 2019; Trevor et. al.:The Elements of Statistical Learning, 2019

COVID-19 and AI

The COVID-19 outbreak is first and foremost a human tragedy, affecting hundreds of thousands of people, but it has also had a significant impact on business and people's daily lives. As the volume of data around the virus accumulates, governments and companies are turning to artificial intelligence to analyze its various impacts. Indeed, based on the experience of previous pandemics and emerging use cases, the crisis could accelerate the adoption of technology (and in this case AI), both in combatting the disease and supporting business activities.

It is difficult to predict how COVID-19 will evolve, or the exact impact it will have on digital adoption. However, previous disease outbreaks may provide some indication of the potential. The 2003 SARS epidemic in China had a similar effect on behaviors as COVID-19, with people staying away from public places. As a result, retail sales growth fell to the lowest level in the last two decades, prompting some retailers to switch towards more digital business models.[1] To avoid bankruptcy, the founder of JD.com was forced to close 11 of his 12 physical stores. Instead, he started selling online, and eventually scrapped his ambition to open 500 physical stores and moved to an online-only model. Today, JD.com has a net revenue of US$83 billion. Similarly, tech-giant Alibaba launched its consumer-to-consumer website Taobao during the SARS outbreak and saw immediate success. In 2005 Taobao had 59 percent market share.

The COVID-19 crisis is having global impacts that are unprecedented in modern times. Given widespread quarantine measures, consumers are using digital more than ever. Almost half of Chinese consumers have started or increased use of video chat, while European use of online grocery delivery has risen by 10 to 30 percent (April, 2020).[2,3] Businesses are seeing the same shifts. In one international survey, two of three digital business managers said they expect COVID-19 to accelerate the pace of digital transformation, which will have a direct impact on AI adoption.[4]

AI's ability to process data much faster than conventional methods means it may play an important role in combatting the current pandemic. Among recent use cases, two sister companies in the Netherlands, trained an algorithm to detect COVID-19 via X-ray scans in more than a hundred hospitals in the Netherlands. Similarly, academics in Finland have started testing AI models to make reliable predictions on the contagion dynamics of the virus. In the business environment, the technology is being used to solve both operational and commercial challenges. A US tech startup is using an AI algorithm to predict the volatility in energy consumption during the pandemic. With other channels closed, a large Indian FMCG player is employing AI-powered chatbots to sell via WhatsApp.

As the number of use cases proliferate, it is becoming increasingly apparent how significant a difference the technology can make.

1 National Bureau of Statistics China, 2020
2 McKinsey & Company, 2020d
3 McKinsey & Company, 2020b
4 DMEXCO Trend Survey 1-2020, 2020. Survey asking 305 digital managers from around the globe

What is AI

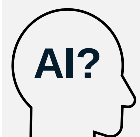
Artificial intelligence (AI) is a general-purpose technology that is set to transform our lives to the same extent as previous game-changing innovations such as electricity or the internet.[1] AI mimics functions typically associated with human intelligence, including perception, learning, reasoning, planning, and decision making. It allows computers to function "intelligently," meaning they can analyze and take action – with a degree of autonomy – to achieve their goals.

AI has significant potential because of three core characteristics: it can be rolled out pervasively across industries and sectors; it becomes more effective and efficient over time; and it is a driver of innovation, leading, for example, to better diagnoses of health conditions, deeper analysis of agriculture yields, and more personalized customer services.

The learning algorithms associated with AI work on the basis that inferences that were correct in the past will likely be correct in the future. They range from simple logical progressions – if A then B – to complex decisioning networks that – for some tasks – provide insights beyond human capabilities. The practical applications of most AI algorithms are limited at present, but they are starting to prove themselves in a variety of business, social, and policy situations.

Much of the work of AI is based on so-called machine learning, by which computers perform tasks based on predefined inputs. Machine learning comprises three common techniques: supervised learning, unsupervised learning, and reinforcement learning (Exhibit 2). Supervised learning uses a data set to "train" algorithms, while unsupervised learning employs a trial and error process to arrive at the right answer. Unsupervised learning is focused on finding patterns in large, unstructured data sets. Currently, reinforcement learning is the most sophisticated subset of machine learning, as it can process a larger volume of data, outperform humans in decision making, and produce more accurate results than the other approaches. It is currently being used to develop applications, including driverless cars and industrial robots. AI systems can be purely software-based, acting in the virtual world (for example, voice assistants, image analysis, search engines, speech and facial recognition systems) or embedded in hardware devices such as robots, autonomous cars, drones, or the Internet of Things.

EXHIBIT 1: Definition of AI in this report



In this report, only artificial narrow intelligence ("weak" AI) is considered

Weak AI, based on machine learning, is designed and trained to perform a single task and operates within a predetermined, predefined range, i.e., analyzing input data that yields valuable insights to perform a task

Moreover, when assessing the value opportunity of AI, we consider the incremental value of current (known) AI technologies over traditional analytics

To clearly distinguish from traditional analytics, we generally estimate the value impact from use cases utilizing currently deployable deep-learning techniques, specifically "feedforward neural networks", "recurrent neural networks", and "convolutional neural networks"

1 For a definition of general-purpose technology, see Jovanovic and Rousseau, 2003.

Source: Gareth et. al.: An Introduction to Statistical Learning, 2019; Trevor et. al.:The Elements of Statistical Learning, 2019

EXHIBIT 2: Overview of AI technologies

Goal	Machine learning technology and underlying algorithms		Example applications[1] (AI can be embedded in software and or hardware)	
Use data to find optimal response	**Supervised learning**	Uses a labeled training dataset with input and output variables to learn/estimate the relationship between input and output; expected output (and in simple cases optimal response) is known I.e., is first trained by being presented with multiple inputs, e.g., images of a cat with associated output variables "Cat", to later be able to identify cats based on the training images Example models/algorithms include: (Deep) neural networks, random forest, Naïve Bayes, generalized linear models (GLM), LASSO	**Speech recognition**	**Corti's patient triage** – analyzing dispatcher's patient interviews and logging real time questions and answers in text to aid detection and prevent misdiagnosis[2]
			Image recognition	**Medical imaging** – trains AI to identify health concerns e.g., diagnosing signs of skin cancer in skin lesions with performance on par with certified dermatologists
	Reinforced learning	Uses data through a trial and error process to make a sequence of decisions based on rewards/penalties Optimal response is not known, and goal is to continuously find the optimal response based on the available data that maximizes rewards and minimizes penalties E.g., a chess playing AI algorithm will decide its moves based on opponents' moves, while taking into consideration all possible outcomes to determine optimal move Example models/algorithms include: deep Q neural network/deep-learning, actor-critics, deep deterministic and policy gradient	**Industrial automation**	**Google's Bonsai** – offers a wide range of solutions to industrial manufacturing using reinforced learning, e.g., a machine cutting metal with spinning tools being rewarded for speed and precision
			Interactive computer software	**Computer software AlphaGo** – plays the board game "Go" by optimizing moves based on a neural network algorithm
			Autonomous vehicles	**Wayve's self-driving car** – learns to drive with the use of reinforced learning and computer vision by being rewarded for staying in a lane. Autonomous cars require complex multi-layer systems, but reinforced learning may be part of their training
Use data to find patterns	**Unsupervised learning**	Uses data to identify hidden structure from unlabeled data; rather than predicting the right output it draws inferences from the data Common approaches are clustering, identifying commonalities between input data and grouping accordingly, and association rule mining, identifying association rules e.g., people buying X tend to buy Y Example models/algorithms include: Apriori, hierarchical clustering, k-means and local outlier factor	**Customer segmentation**	**E-commerce target strategy** – makes user-specific recommendations based on purchase history that is identified as similar through clustering algorithms
			Anomaly Detection	**Credit card fraud detection** – identifies typical and nontypical instances of transactions to predict/prevent credit card fraud. This output may be fed to a supervised learning dataset that makes fully automated decisions

1 The different types of AI/machine learning algorithms are often used in combination, e.g., running an unsupervised anomaly detection algorithm, manually exploring and using the output to train a classification model in a supervised setting. Example applications are thus simplified for illustrative purposes

2 The output text from these interviews are analyzed through more complex AI (e.g., natural language processing) to provide suggestions and guide dispatchers through the interview and detect critical incidents

Source: James et. al.: An Introduction to Statistical Learning, 2019; Hastie et. al.: The Elements of Statistical Learning, 2019; Esteva et.al.: Dermatologist-level classification of skin cancer with deep neural networks , 2017, Nature 542 (7639): 115-118.

AI has started to surpass human accuracy

Though the concept of AI is half a century old, interest in the technology has grown rapidly over the past decade. This has been driven by increased data availability and computing power, the declining cost of data processing, and new advanced mathematics, allowing for significantly lower costs of prediction and analytical capacity. These developments mean organizations can use the technology's ability to interpret large volumes of data, enabling them to perform more complex and targeted calculations.

In most environments, AI's abilities remain inferior to those of humans. For example, an AI-powered car has trouble interpreting the movements of pedestrians. However, in some cases, it surpasses humans, and its abilities are accelerating as research and funding increase (Exhibit 3). There has been particularly fast growth in three areas:

Image recognition. One of the most common uses of AI is image recognition. The modern smartphone user – always connected to the internet and equipped with a high-quality camera – produces and consumes large quantities of image and video content every day. AI image recognition technology surpassed the human accuracy level of 95 percent in 2015 and can be used to categorize, edit, and parse this data. Applications building on this technology are being rolled out at scale on social media, for instance, where facial recognition is used for tagging. Applications extend beyond our browsers into the physical world, despite regulatory uncertainty. For example, Alibaba's grocery venture Freshippo uses it to verify payments, and Shanghai's Hongqiao Airport employs a facial-recognition-based check-in system.

Speech recognition. AI can also be used to translate spoken words into text. AI speech recognition surpassed the human accuracy level of 95 percent in 2017 and some of the world's leading tech companies use it on devices such as Google Home, Amazon Echo, and Siri. While the technology is still in its infancy, it has significant potential. Research firm Gartner predicts that 30 percent of web browsing
will be without a screen in 2020.[1] Another use case is for emergency services, which incorporate algorithms to identify callers' symptoms by listening to a person's breathing, voice, and words.

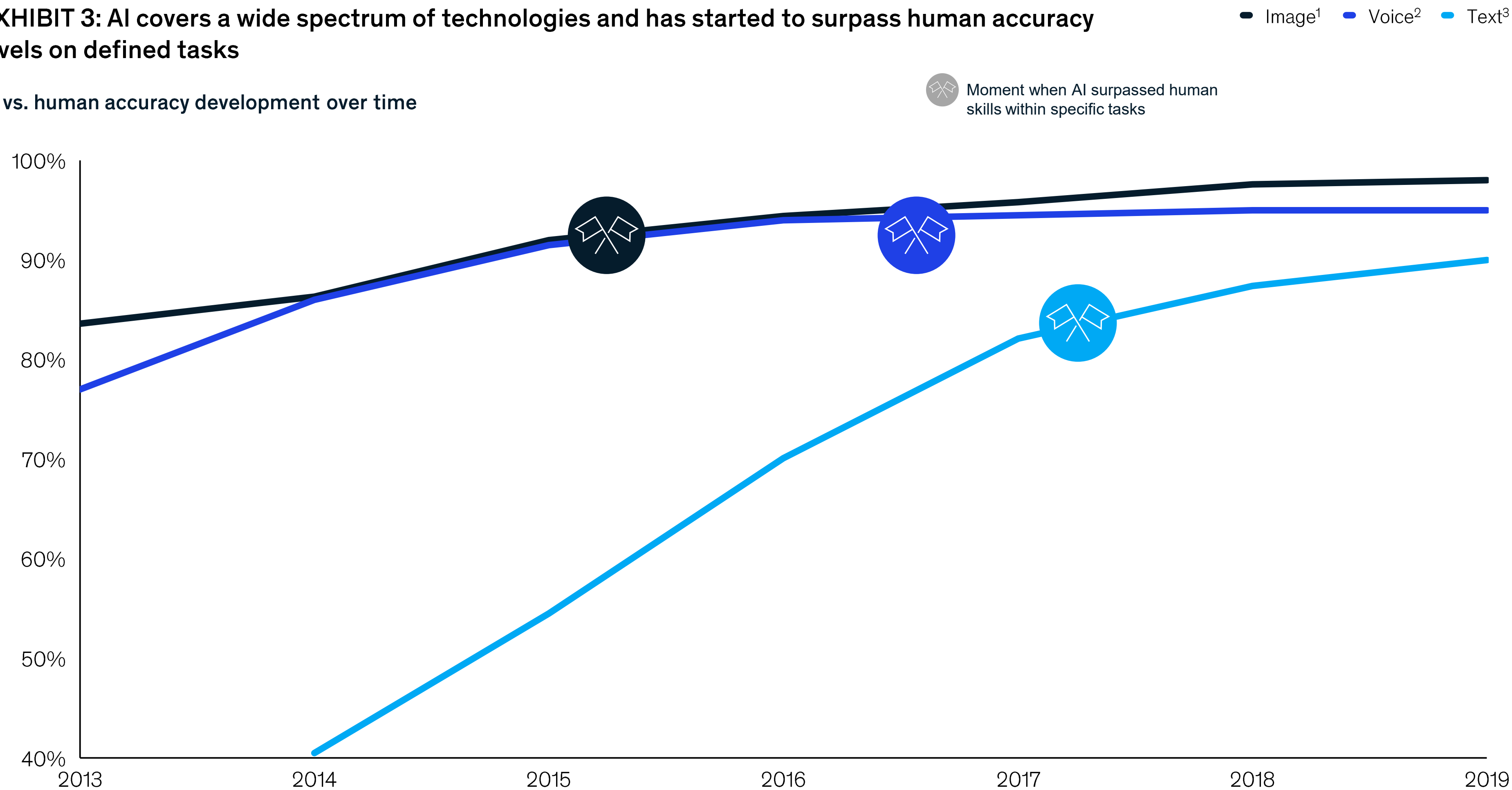
Natural language processing. There is a vast amount of information in text. Natural language processing (NLP) can contribute to recognition, understanding and generation of language and has been shown to exceeded the average human score in reading comprehension tests of 86 percent in 2018. NLP can be combined with speech recognition to process the meaning from speech or with image recognition to analyze handwriting[2]. NLP AI can help businesses make smarter decisions, governments deliver better services, or simply make peoples' lives easier!

In some areas, AI is moving beyond image, speech, and text to abilities considered even more uniquely human. A bourgeoning field of study is affective computing, which seeks to equip AI with the ability to recognize, interpret, and replicate human emotions. A 2018 Ohio State University experiment found that AI could recognize some emotions more accurately than humans by going beyond interpretations of facial expressions alone, to include skin color, body posture, and cultural context.[3]

1 Gartner research, 2017
2.. The conversion from e.g., handwritten to machine encoded text is known as Optical Character Recognition (OCR)
3 Web page of The Ohio State University
Source: Stanford University HAI, 2019; ImageNet; Kleiner Perkins, 2018; Stanford Questions Answering Dataset; CodaLab

EXHIBIT 3: AI covers a wide spectrum of technologies and has started to surpass human accuracy levels on defined tasks

AI vs. human accuracy development over time



1 Top-5 accuracy score on ImageNet; whether the correct label was present among top 5 predicted labels for each image for a single model
2 Word accuracy rate using speech recognition by Google machine learning
3 Score on Stanford Question Answering Dataset Challenge 1.1

Source: Stanford University HAI, 2019; ImageNet; Kleiner Perkins, 2018; Stanford Questions Answering Dataset; CodaLab

AI is gaining momentum across society

Just as the internal combustion engine was the basis for the car, the airplane, and eventually modern transport systems, AI is likely to have a profound impact on our societies and economies. If the next wave of innovation is in line with the past innovations of a similar nature, AI will make large amounts of analytical capacity affordable and widely available within the budgets of even relatively small organizations. On that basis it will present a compelling value proposition for a wide range of stakeholders, including those looking to solve some of society's biggest challenges.

Although the COVID-19 outbreak is likely to spur interest in AI, the technology has been picking up momentum for several years. Over the past decade there has been increasing research, education, employment, and investment. The ratio of published AI papers doubled from 2010 to 2018, while AI patent applications tripled. Enrollment in AI and related studies expanded rapidly, both at the university level and online, and AI became the most popular specialization among computer science PhDs. The majority of AI PhD graduates now get hired to industry rather than academia, with leading companies offering researchers up to ten times their academic salaries.

Start-ups are at the forefront of AI innovation – some of the most valuable companies today did not exist a few years ago. Global investment in AI start-ups grew at an average annual rate of almost 50 percent from 2010 to 2018, from EUR 1.2 billion to 36.7 billion. The number of AI-related job postings grew twelvefold over the same period. High tech services and manufacturing were the primary drivers of demand.

EXHIBIT 4: AI experienced massive momentum across all areas of society from 2010 – 2018

- **3x** — **AI patent applications worldwide**
  From 27,000 to 78,000
- **4x** — **AI course enrollment** in US universities
  From 900 to 3,600
- **3x** — Ratio of **AI PhD's being hired to industry**
  From 20% to 62%
- **12x** — **AI-related job postings** in the US
  From 4,400 to 51,800
- **2x** — **Published AI papers** as a share of total papers
  From 0.9% to 1.7%
- **2x** — **PhD graduates in AI** out of all PhD graduates
  From 13% to 22%
- **31x** — **Investment in AI startups**
  From EUR ~1.2 to 36.4 billion

Source: Stanford University HAI, 2019

Several countries have published AI strategies

AI brings with it the potential for economic and social welfare gains, and various governments are engaged in developing or rolling out strategies. These are also reflections of the challenges presented by AI in relation to, for example, accountability for decisions made by algorithms, data protection, and potential shifts in labor markets.

The comprehensiveness of government efforts differs across regions. Some offer strategic guidance without a defined roadmap, while others have published detailed initiatives and invested millions or even billions of euros in research and talent development. Finland, for example, offers a free online AI course, Elements of AI, with the goal of teaching 1 percent of the population the basic concepts.[1]

Strategies in the EU often focus on areas of strategic importance, such as core industries or ethics. By contrast, China's strategy emphasizes fast growth across all sectors of its economy and achieving global AI leadership. Most strategies are public sector led but several have been built through public-private partnerships (Exhibit 6). Some, such as the US strategy, are predicated on the private sector taking a leading role.

The European Commission has published a Europe-wide plan aimed at ensuring competitiveness and sharing knowledge. It also recently published a strategy to create a single European market for data and has asked individual countries to develop national AI strategies. However, more than ten countries in the 27-country bloc are still to deliver. In addition to defining country-level priorities, there is broad consensus that cooperation should be increased across Europe to achieve scale benefits.

EXHIBIT 5: Examples of elements in AI strategy of DF9 countries

Launched a national customer service robot network, the Aurora assistant, that creates a platform for people to seamlessly connect with public and private service providers

Introduced a new digital agency, with open government data as one of the core areas of work

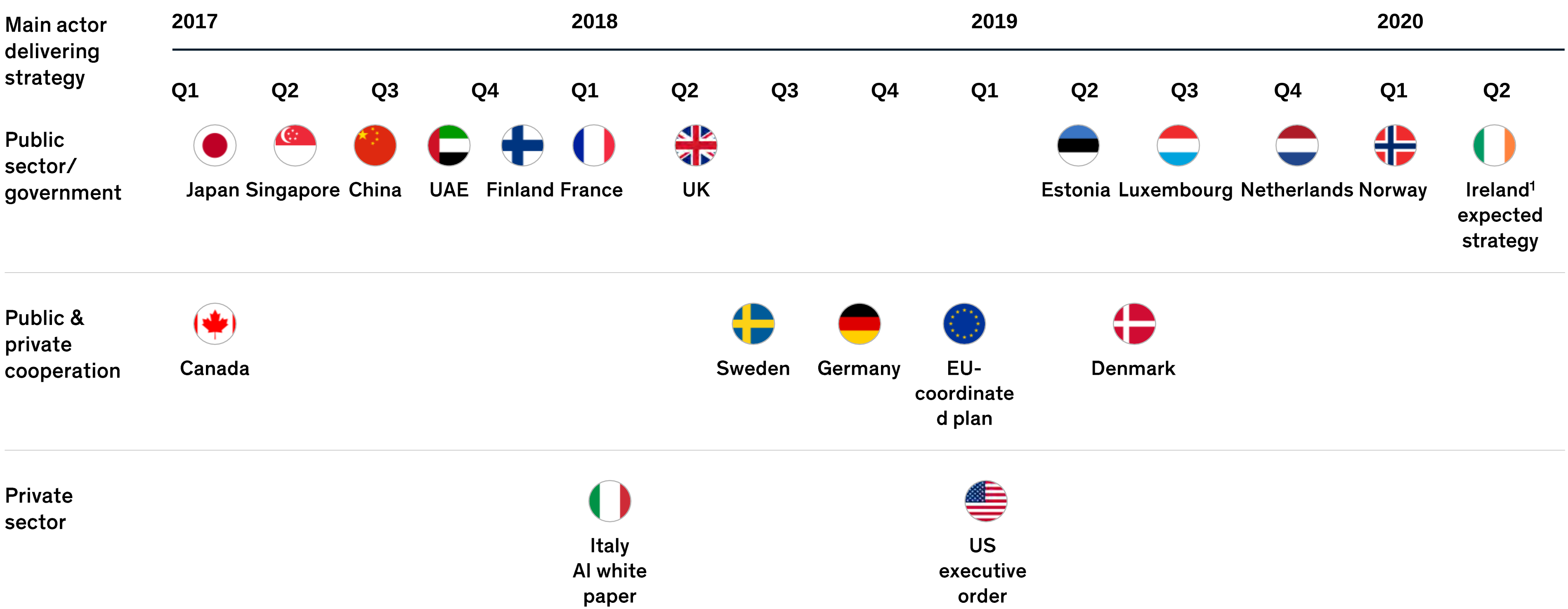
Established a R&D project to finance research on the implementation of automatic AI-based decision-making to support Estonian state institutions

Initiated the Dutch AI Coalition between parties from government, business and research institutions with the purpose of stimulating AI activities

1 www.elementsofai.com.

Source: National AI strategies; governmental websites

EXHIBIT 6: With AI receiving increasing attention, several countries have released strategies on AI



1 Expected in early 2020

Source: National AI strategies; governmental websites

2. The global AI race

2. The global AI race

US and China focused on leading

The US and China have adopted a broad approach to AI focused on leadership and are leading on metrics such as investment. Although their approaches differ in many ways, both build on three pillars: early mover strategies, significant private and public investment, and large technology sectors and talent pools fostering AI clusters.

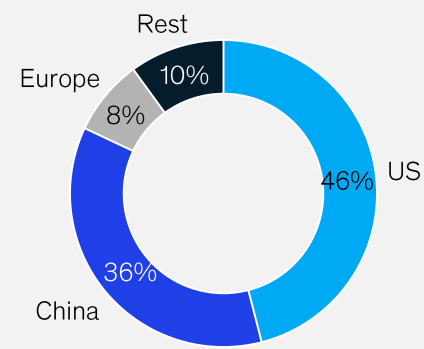
Since 2013, China has launched several initiatives, including a 2017 AI strategy focused on ensuring global leadership by 2030.[1] The US first issued a national AI report in 2016 and followed up with an executive order in 2019 that emphasized maintaining leadership.[2] Both the US and China aim to lead across all sectors, rather than focusing on specific strengths. However, while the Chinese government is closely involved in driving the AI agenda, the US places more emphasis on the role of the private sector.

On a governmental level, both the US and China are investing significantly in R&D and prioritizing AI in their national budgets. The US government has budgeted around EUR 4.5 billion for 2020, after assigning the same amount the previous year. While China does not disclose its national budget, the cities of Shanghai and Tianjin have said they plan to invest around EUR 13.5 billion over the next decade. By comparison, the EU invested around EUR 275 million per year from 2014 to 2017 under its Horizon 2020 program.

The scale of private sector investment in the US dwarfs that in most other regions. Between 2012 and 2018, the country invested 20 times more in AI and big data than Europe.[3] In 2018, the US attracted 46 percent of total private investment in AI, while China drew 36 percent and Europe 8 percent (Exhibit 7). Still, Chinese investment has grown more rapidly than in the US or Europe in recent years. Europe, including the DF9, has generally smaller venture capital (VC) markets than its continental peers. In addition, it can be challenging for European start-ups to access cross-border funding.

During the COVID-19 crisis, the US and China have taken a lead in using AI for automated diagnosis, exploring vaccines and treatments, and predicting disease development in society and individuals. For example, MIT developed a machine learning algorithm to predict when infections will slow down in each country and quantify the impact of quarantine measures.[4] In China, an AI system was developed to accurately predict disease progression in COVID patients, which clinicians can use to manage medical resources and ensure that patients at the highest risk are monitored closely.[5]

EXHIBIT 7: Private investments in AI, 2018



1 The State Council of China, 2017.
2 The US government, 2016 and 2019.
3 PitchBook: VC, PE, and M&A investments in AI and big data companies
4 Dandekar and Barbastathis, 2020
5 Dong et al, 2020.
Source: Pitchbook

The US is home to some of the world's largest tech companies, with Google, Facebook, Apple, Microsoft, and Amazon leading the way in building AI infrastructure and developing new applications. Chinese innovation, meanwhile, is led by its own tech giants (including Alibaba, Tencent, and Ant Financial).The prevalence of tech giants and large companies is important; some 70 percent of AI investment is conducted by private companies, which reflects the distribution of talent and innovation.[1] Large tech clusters are often centered around leading tech universities, of which Europe has fewer than the US. Some 16 percent of scientists working in the US come from outside the country, while just 3 percent of scientists working in the EU come from outside the region.[2]

The US is home to the world's top AI clusters

Around the world, technology innovation is often centered around a limited number of urban environments or clusters that offer access to talent, opportunities for funding and industrial collaboration, and excellent supporting infrastructure. The key stakeholders are academia, enterprises, start-ups, and government. London, for example, is a cluster with a ready supply of capital and close ties between academia and industry.

To assess the performance of 294 cities as AI clusters, we created an index based on seven key drivers. These included prominent researchers in AI, and relevant talent and financial conditions, which were assessed via 20 data proxies (e.g., number of AI start-ups and AI patents).[3] The index shows the US is home to 18 of the top 25 clusters; these naturally drive innovation and increase competition between stakeholders. Only three European and four Asian cities, meanwhile, rank in the top 25 (Exhibit 8).

Europe's top cluster in London is no longer part of the EU due to Brexit. Europe, including the DF9, has clusters outside London, but none currently rival top-performing ecosystems. Ideally, therefore, Europe should focus on expanding nascent AI clusters as a catalyst for AI adoption and innovation.

Clusters are responsible for an outsized proportion of innovation, entrepreneurial activity, and economic growth, and the effect is self-reinforcing; better research through more talent and capital improves commercialization, which fosters investment in research and in turn attracts new talent (Exhibit 9). San Francisco's greater Bay Area cluster in 2018 received 46 percent of all VC funding in the US and was responsible for 52 percent of VC-backed exits.[4]

1 McKinsey Global Institute, 2017.

2 The Observatory on Borderless Higher Education, 2019.

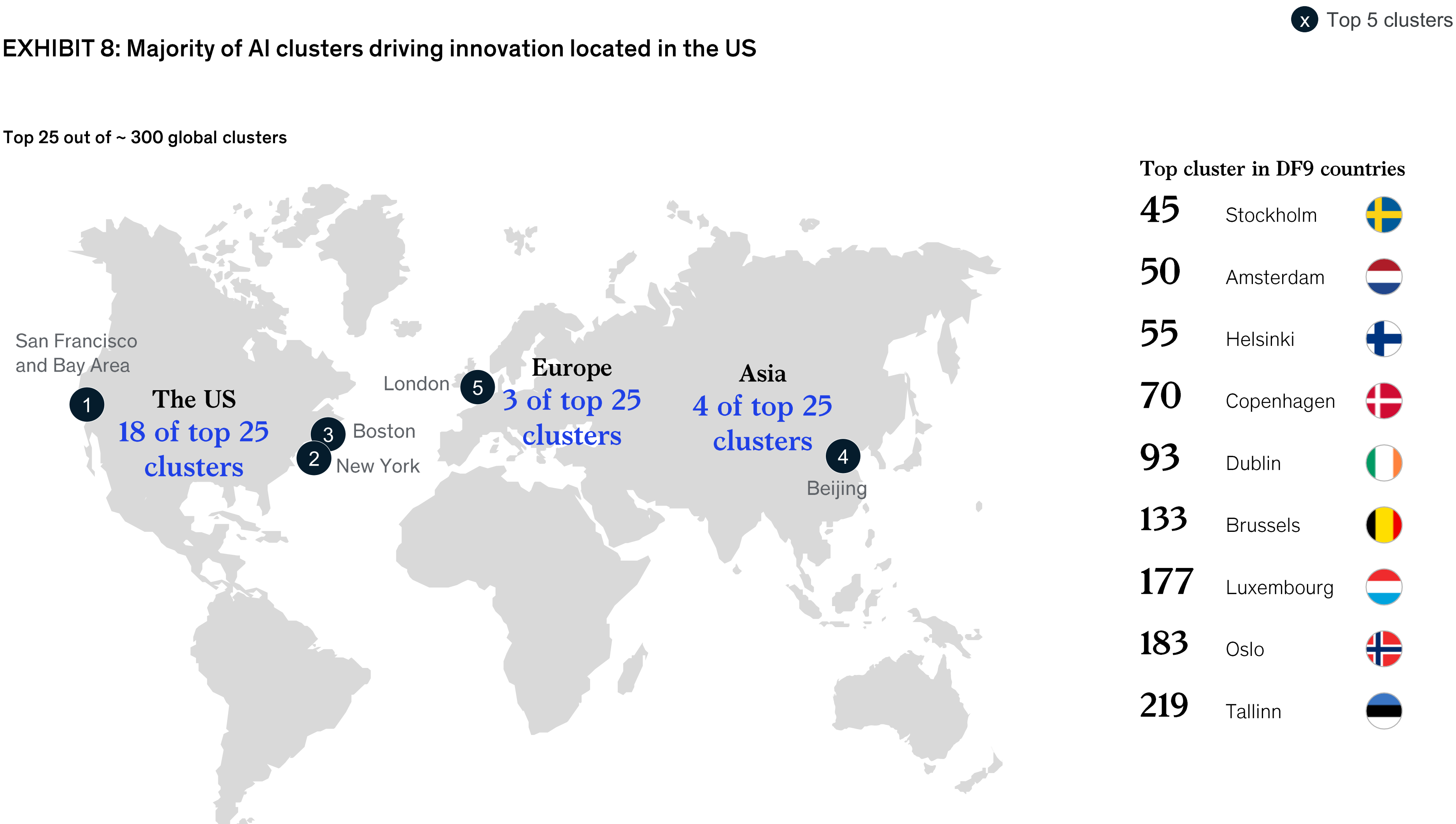
3 Details of methodology can be found in methodology appendix..

4 Startup Genome, 2019 Global Startup Ecosystem Report; Bloomberg, 2019: https://www.bloomberg.com/opinion/articles/2019-01-08/venture-capital-still-flowing-to-silicon-valley-and-bay-area and PitchBook, 2018: https://pitchbook.com/news/articles/18-charts-to-illustrate-us-vc-in-2018.111111

Source: Interviews; Press search for successful AI clusters; Scott, Hughes & Kraus, 2018; Lehmann & Menter, 2018; Isaksen, 2016; Eisingerich, Bell & Tracey, 2009; Han & Chen, 2018; Pan, Song, Zhang, Zhou , 2018; Piątyszek-Pych, 2013; Porter,1990 and1998

EXHIBIT 8: Majority of AI clusters driving innovation located in the US

Top 25 out of ~ 300 global clusters



Top cluster in DF9 countries

45	Stockholm
50	Amsterdam
55	Helsinki
70	Copenhagen
93	Dublin
133	Brussels
177	Luxembourg
183	Oslo
219	Tallinn

Source: Times Higher Education and QS World Universities; Cornell SC, Insead, and WIPO, 2019; World Economic Forum 2017-2019; OECD; Pitchbook; Asgard, 2019; Crunchbase; Innography

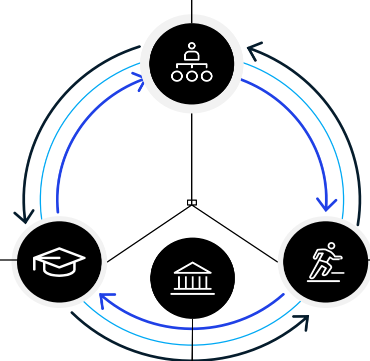
EXHIBIT 9: Key AI cluster participants

Enterprises

- Provides data and business problems to AI developers
- Financial support and manpower to private and public research labs
- The possibility of working with MNEs and well-known brands attracts talent
- Guidance, support and access to network (mostly relevant for startups)
- Exit option (mostly relevant for startups)

Academia

- Superstars develop pioneering AI solutions, which attracts talent, enterprises and startups/entrepreneurs
- Develop talent and act as recruitment channel
- Provide training possibilities for companies
- Sense of community and network for alumni (mostly relevant for startups)



Start-ups

- AI solutions developed by startups act as an eye-opener to the possibilities of applied AI
- Successful AI startups create a pull for AI talent and capital, fostering ecosystem growth
- Successful startups reinvest in research community and next generation of startups
- Startup environment is an opportunity for researchers to commercialize

Government

- Possible support for all interactions in ecosystem
- Defines underlying conditions for each of the actors
- May act as a large enterprise by representing local demand for AI and/or providing financial support

Source: Interviews; Press search for successful AI clusters; Scott, Hughes & Kraus, 2018; Lehmann & Menter, 2018; Isaksen, 2016; Eisingerich, Bell & Tracey, 2009; Han & Chen, 2018; Pan, Song, Zhang, Zhou , 2018; Piątyszek-Pych, 2013; Porter,1990 and1998

The status of AI across Europe

Although the US and China are moving forward at pace and are in a strong position to harness the AI opportunity, Europe has the necessary tools to excel. The continent has a high number of strong incumbent industries, the world's largest single market area, a sturdy legal framework, excellent public services, and many companies and SMEs that are leaders in their field. Europe also has high-quality education and research and is the source of many of the most influential academic papers on AI. It has been the most prolific publisher of AI papers over the past 20 years.[1]

On a policy level, the EU is leading coordination among its member states for investment, data sharing, and developing an ethical and legal framework. The EU's "Coordinated Plan on Artificial Intelligence" encourages the use of AI to solve some of the world's most pressing challenges, from diseases, to climate change, and cross-border crime. The EU's February 2020 "White Paper on Artificial Intelligence" supports a regulatory- and investment-oriented approach, with the twin objectives of promoting uptake of AI and addressing the risks associated with certain uses.[2]

Across Europe's diverse economies, some countries have recently ramped up investment in AI, while others are playing catch-up. The UK, Germany, and France are home to Europe's largest tech hubs, supported by dedicated policy and fiscal initiatives such as R&D tax credits. With the help of an effective AI strategy, the UK has become the world's fourth largest market for investment, after the US, China, and Israel, and is home to some of the biggest names in the business, including DeepMind, SwiftKey, and Babylon.[3] Germany, meanwhile, is seeing a wave of innovation, with industrial giants leading the world in patent applications in some categories. France has developed a national strategy called AI for Humanity, with ambitions that include wider access to big data, deeper research, and the development of plans to cater to the impact of AI on labor.

While Europe's larger economies are making significant progress on AI, some of the continent's smaller economies have yet to fully commit. Some regions in Southern and Eastern Europe have fewer resources and suffer from talent migration to larger areas. Innovation and adoption are more limited in the private sector than in other countries and there are few tech hubs, amid relatively low levels of science and technology employment.[4]

Still, the dispersion of strengths across Europe indicates that countries can borrow best practices from each other to create a more favorable and enabling AI environment.

EXHIBIT 10: Facts on AI in Europe

Europe has over 6 million professional developers vs 4.3 million in the US

Europe accounts for 32% of all published AI papers and was the largest publisher for last 20 years

Europe has 3.1 AI companies per million workers vs 10.5 in US and 0.3 in China

Europe has 50% more AI researchers than the US and 2x more than China

1 Stanford University HAI, 2019.
2 European Commission, 2018, 2020
3 Estimated from PE, VC, M&A investments in AI and big data companies from PitchBook.
4 The concept of adoption has been used in various contexts under various names, e.g., AI diffusion, absorption. In this research, we only use the word adoption. We define adoption as when an economic entity – notably a company – chooses to invest in one of the five generic AI technologies (computer vision, natural language, virtual assistants, robotic process automation, and advanced machine learning).

Source: Stanford University HAI, 2019; European Commission 2018a, 2018e; Atomico, 2019; Center for Data Innovation; Tufts University, 2017

The nine digital frontrunners could play a leading role in Europe

A proportion of European AI activity is associated with the continent's nine digital frontrunners, namely Belgium, Denmark, Estonia, Finland, Ireland, Luxembourg, the Netherlands, Norway, and Sweden. The group boasts a high level of tertiary education, advanced digital infrastructure, populations that are amenable to new technologies, and strong corporate buy-in – some 62 percent of large companies in the nine countries have adopted AI in their daily operations, although they are mainly at the exploratory stages in their AI journeys.[1] The DF9's history of collaboration, based on their strong cultural and business ties, are a good fit for the kind of concerted efforts required to turn AI algorithms into useful solutions (Exhibit 11). Together they have the potential to become Europe's AI locus, driving adoption, encouraging research, and maximizing the technology's impact.

To provide a holistic view of countries' abilities to harness the AI opportunity – independent of size – we have evaluated the top 29 countries based on seven key indicators:[2]

- Quantity and quality of available talent
- Level of private AI investment
- AI research activity
- Innovation activity
- Private sector technology adoption and future adoption potential
- Level of support from policy environment
- Quantity and quality of available data and underlying tech infrastructure[3]

AI readiness is a strong predictor of the ability to generate employment and growth through AI. On the basis of the analysis, Singapore shows the strongest performance across key AI indicators, followed by the UK and US. The DF9 all have a solid position (Exhibit 12). One of the best positioned countries of the DF9 is Finland, which has embraced digital through multiple private and public initiatives and was the first European country to implement a national AI strategy. Finland is well positioned across all key indicators, while Sweden, Denmark, the Netherlands, Norway and Luxembourg are all strong on three or more. This strong representation suggests that together the DF9 have the potential to become Europe's AI hub, driving adoption, encouraging research, and maximizing the technology's impact.

EXHIBIT 11: Common characteristics of the DF9

- **~50%** of population with **tertiary education**
- **~90%** of population using internet compared to 87% in the US and 54% in China
- All on **top 10** on European Digital Economy and Society Index (DESI) ranking
- **~40%** employment in knowledge-intensive services compared to 33% in rest of Europe
- **~60%** of large companies using or piloting use of AI technologies
- **~75%** of inhabitants with a positive **attitude towards AI** compared to 61% in rest of Europe

1 McKinsey Global Institute, 2019c.
2 To adjust for size, variables are measured relative to GDP and population where possible.
3 Refer to the methodology appendix for definitions and rationale for the AI-readiness dimensions.
Source: World Economic Forum 2017; McKinsey & Company 2019c; European Commission 2018-2019; Tufts University, 2017

EXHIBIT 12: DF9 are well positioned globally on AI readiness when accounting for size

DF9 countries in bold

Indicators of AI readiness

Using key proxies for indicators of potential to harness the AI opportunity (“AI readiness”) and adjusting underlying measures for scale, the global top 29 countries can be ranked with respect to AI readiness

Ranking of 29 top global countries on AI readiness

Adjusting for population size/GDP

Quartile		
Top quartile: Leading performance across most indicators	Singapore, UK, US, Switzerland	**Finland**, Japan, Germany
2nd quartile: Strong performance across several indicators	**Sweden**, **Denmark**, Canada, **Netherlands**	Israel, **Norway**, **Luxembourg**
3rd quartile: Strong performance for at least 1 indicator	**Ireland**, Australia, France, UAE	**Estonia**, Austria, **Belgium**
4th quartile:	Spain, Russia, Portugal, Italy	India, Brazil, South Africa

China[1]

1 China is not included in the quartile rankings as the adverse effect of correcting for scale draws up an incorrect picture of its position, placing them in the 3rd quartile; when assessed in absolute terms, China is ahead of most other nations, along with the US

Source: World Bank; UN data; ILO; Innography; IDC; World Economic Forum; UNCTAD, 2019; Pitchbook; McKinsey Global Institute 2018b-2018d; Tortoise media, 2019; Stanford University HAI, 2019; Oxford Insights, 2019; OECD; European Commission 2017-2019; Capgemini, 2018; Asgaard, 2019

The DF9 can harness the AI opportunity

The DF9's key strengths in terms of AI readiness are high levels of technology adoption potential, a solid digital infrastructure and data availability, and a policy environment supporting AI development (Exhibit 13).

Technology adoption potential

AI has wide-ranging applications that will impact competitiveness across industries. However, to reap the full economic benefits, mass adoption is important. A good indicator of a country's ability to achieve mass adoption is its private sector adoption capability. Here the DF9 are in an overall strong position and four countries are among the global top ten. In addition, the DF9 are expected to have a higher ratio of companies adopting AI by 2030 than the global average, most likely due to the investment made by the DF9 in the first wave of digital.[1] One DF9 initiative that aims to accelerate corporate adoption is CeADAR, Ireland's national center for AI and applied data analytics. CeADAR provides companies with prototypes, analytical tools, and best-practice methodologies and processes.

The potential is significant, and COVID-19 will likely accelerate adoption. In a survey of global digital managers, two thirds say that COVID-19 will speed up the pace of digital transformation.[2] This is an enabler of AI adoption, because a strong digital core is a prerequisite of harvesting the benefits of AI.[3] Furthermore, there is huge unlocked value potential from AI across the DF9, and the financial impact of the crisis might make it even more urgent for companies and governments to act.[4] We see early signs of this, with DF9 countries launching several AI-based initiatives to fight the virus (Exhibit 14).

1 McKinsey Global Institute, 2017
2 DMEXCO Trend Survey 1-2020, 2020. Survey asking 305 digital managers from around the globe
3 McKinsey & Company, 2018b
4 Exhibit 16

Source: World Bank; UN data; ILO; Innography; IDC; World Economic Forum; UNCTAD, 2019; Pitchbook; McKinsey Global Institute 2018b-2018d; Tortoise media, 2019; Stanford University HAI, 2019; Oxford Insights, 2019; OECD; European Commission 2017-2019; Capgemini, 2018; Asgaard, 2019

EXHIBIT 13: DF9 could build on its strengths to take a leading position in AI

Strengths per country on AI readiness in order of rank, DF9 and selected global peers

DF9	UK	US	Singapore	Israel	Germany
1 **Technology adoption**	Data/digital infrastructure	Innovation	Policy environment	Investments	Talent
2 **Data/digital infrastructure**	Policy environment	Data/digital infrastructure	Investments	Innovation	Innovation
3 **Policy environment**	Investments	Investments	Research	Research	Technology adoption

Source: World Bank; UN data; ILO; Innography; IDC; World Economic Forum; UNCTAD, 2019; Pitchbook; McKinsey Global Institute 2018b-2018d; Tortoise media, 2019; Stanford University HAI, 2019; Oxford Insights, 2019; OECD; European Commission 2017-2019; Capgemini, 2018; Asgaard, 2019

EXHIBIT 14: Examples of how DF9 countries have used AI to combat Covid-19

Diagnosis

Two sister companies have used data from all over Europe to train an AI algorithm to diagnose COVID-19 via X-ray scans. The technology is used in 100+ hospitals, and it is being made free to use as it is believed it can help poorer countries ramp up testing capacity much faster.

Belgian healthcare company Icometrix collaborated with hospitals and organizations globally to build an AI algorithm that is trained on CT scans to detect type, pattern, and extent of lung pathology in COVID-19 patients.

A university is training an AI tool to quickly and accurately discriminate between patients that have COVID-19, other pneumonia, or are healthy. In the long term, it is planned that the tool shall be part of a larger project in Luxembourg using other biomarkers for disease staging.

Prevent further spread

Hospitals are testing AI-powered cleaning robots to prevent spread. The robot radiates ultraviolet light that can kill bacteria and viruses, and it is clinically proven to be effective on COVID-19.

A public-private partnership is developing an app to prevent spread. The app uses AI to analyze location data from infected peoples' phones and detect who they have been in close contact with.

The government developed an AI-based chatbot for government websites, taking pressure off emergency phones, and preventing further spread by being able to answer common questions and directing citizens to the information they need.

Forecast

Hospitals are developing an AI-model that can analyze newly-diagnosed patients health journals to predict disease development, including the risk that the patient will need intensive care.

The startup, My Telepscope, uses an AI algorithm to predict how the COVID-19 spread will evolve on a country-by-country basis, using a range of behavioral people data (e.g. internet searches, YouGov polls, SoMe).

Academics are testing different modeling approaches and available data to make reliable predictions on the spread dynamics of COVID-19 in Finland. The project also dives into the social, economic, and healthcare aspects of the new coronavirus by analyzing the effects of government interventions and mobility restrictions.

Source: Press research

Digital infrastructure and data availability

Reliable digital infrastructure, from basic internet access to digital public services, are required to facilitate digital transformation and incorporate new AI technologies. The DF9 have invested in digital infrastructure and all rank in the top ten in the European Digital Economy and Society Index. From basic measures, such as internet distribution and broadband speeds, to digital public services, the DF9 are in a strong position.

Data availability can help accelerate research and innovation. Vast amounts of data are required to train algorithms, so the availability and standardization of data is a key indicator of a country's AI readiness.

Digitally advanced nations typically have significant amounts of available data. However, it is not always accessible or in a consistent format. Furthermore, in terms of private sector data availability, Europe is currently at a disadvantage, as much of the world's data is stored in data centers controlled by non-European operators.

The DF9 have high levels of accessible data in their public sectors, and in particular areas such as health and education. Moreover, they have initiatives in place to increase usable data. These include Sweden's Data Factory and Finland's MyData initiative, which centralize citizen data and give companies access where citizens are willing to share.

Policy environment

Policy can have a significant impact on the pace of AI adoption and innovation. Key components are regulatory certainty, including whether policy addresses broader societal concerns raised by AI, the extent to which regulation is adapted to match the demands of new technologies, and whether relevant incentives are in place.

The DF9 are characterized by stable and effective governments that are aware of the importance of technology. In Estonia, the government has gone so far as to amend traffic regulation to enable an Estonian company to use delivery robots with AI technology. However, the DF9 overall are behind global peers in providing incentives for AI investment.

In addition to building on strengths, the DF9 could address AI readiness development areas

Key development areas might include talent availability, private sector AI investment, AI innovation, and research activity.

Talent availability

One of the biggest hurdles in harnessing the AI opportunity worldwide is developing, acquiring, reskilling, and retaining the right AI talent, and a country's ability to do that will be a key differentiator for future AI adoption and performance. However, AI development requires advanced skills that are in short supply in the DF9, across academia, and the public and private sectors.

The DF9 currently trail global peers on the number of STEM graduates per capita and in their appeal to foreign talent. Furthermore, much European AI talent is being attracted to study and work in the US. On a positive note, Finland has the highest share in Europe of enterprises offering reskilling for IT experts. Going forward, it is important that the DF9 increase efforts to bridge the talent gap.

AI investment levels

There is a large gap between the DF9 and leading peers when it comes to private AI investment, even when adjusting for GDP. Private equity, venture capital, and M&A investment in AI are dwarfed by levels in the US. Investment is the ultimate factor in determining a country's ability to innovate, attract talent, adopt, scale up, and develop AI technologies as well as build AI ecosystems. Increasing both public and private investment will be key for AI development in the DF9.

AI innovation activity

Relatively few start-ups are building AI solutions in the DF9. There are no top AI clusters, and R&D spend as a percentage of GDP is less than that of peers. These are important factors for future commercialization. A strong innovation environment is a key factor in how likely a country is to develop innovative AI solutions and products. Meanwhile, best-in-class innovators are more likely to attract a higher share of AI investment and talent. Countries that lead on innovation will potentially also reap higher overall economic benefits because they could become the locus for the emergence of entirely new economies and ecosystems, leading also to significant employment gains (as seen with the cloud infrastructure in the US). The DF9 will not realize these benefits if they only adopt existing AI technology and do not innovate, which would leave them increasingly dependent on foreign technology.

AI research activity

Although certain countries among the DF9, such as Finland, boast high levels of AI research output per capita, the number of AI patents is relatively low overall, and there are very few leading AI researchers in the region. A high number of citations or high rankings of leading researchers on global indexes indicate quality of research. However, on both these dimensions, the DF9 are behind when compared with peers, especially the US and the UK.

As the development of new technologies is driven by scientific research, and given that AI is still a nascent technology, research, including basic research, is especially important. By investing significantly in research, the DF9 could attract more talent, and countries leading in research might gain a first mover advantage when it comes to commercialization.

The DF9 have unique strengths, but must solve key challenges

The DF9's key strengths in terms of AI readiness are high levels of digital adoption (and adoption potential), a solid digital infrastructure and a policy environment conducive to technological development (refer back to Exhibit 13). Readily available data and a strong digital infrastructure are critical enablers, and initiatives such as Sweden's Data Factory, designed to feed the country's AI ecosystem, and Finland's MyData program mean the DF9 are in great shape to seize Europe's AI opportunity (Exhibit 15).

Still, to build a more mature AI-driven economy, the DF9 must tackle a number of challenges. No single sector or individual firm in the DF9 economies has the scale to drive game-changing innovation. There is a need, therefore, for greater collaboration between sectors, companies, and policy makers, echoing the situation in the US and China, which also have scale advantages.

Moreover, with the rules for the digital economy being defined by the US and China, Europe must decide on an approach that works for Europe and will reduce its dependence on foreign technology.

Finally, Europe must navigate the pitfalls and challenges that accompany any disruptive phenomena. That means effectively addressing concerns over data privacy, catering to AI's potentially disruptive impact on the labor markets, and ensuring that citizens have the skills required to live and work in a world in which AI is part of their daily lives. These challenges mean that Europe and the DF9 should accelerate their efforts to prepare for the impact of AI. If they fail to do so, they risk missing out on some of the benefits in terms of economic and social welfare. Finally, given the demographic pressures in Europe, with the labor force set to shrink and the proportion of older citizens set to grow, AI may become an essential tool in supporting output while sustaining living standards.[1]

1 ESPAS, 2019

EXHIBIT 15: Examples of initiatives within the DF9 strongholds

Data/digital infrastructure

Lack of data and costly infrastructure are some of the major obstacles to AI innovation

Sweden has established a “Data Factory” supplying the private sector with infrastructure and data to overcome these barriers

Data has been made sharable and available to all partners, which represent industry, public sector and academia

Data protection concerns can similarly hinder data sharing needed for developing AI use cases

Finland’s “MyData” movement1 aims to simultaneously tackle these obstacles by centralizing all citizen data under 1 data management structure and giving companies access to large amounts of data

But each citizen has full transparency and control over what data can be shared with companies

Tech adoption

AI use cases aimed at solving very concrete challenges can help accelerate adoption

Matching profiles to occupations can be a difficult task; the employment service of Flanders, maps competences of individuals and uses AI to match them with relevant roles

This approach improves match quality as well as jobseekers’ chances in the job market

Slow adoption of AI across companies is often due to a lack of tools and talent

Ireland’s national centre for AI and applied data analytics, CeADAR, accelerates development, deployment and adoption of AI technology and innovation for their member companies

The primary outputs are industry prototypes and demonstrators along with data analytics technology, tools, best-practice methodologies and processes

Policy

Achieving advancements in AI requires policies that foster a solid digital infrastructure

Denmark’s Digital Growth Strategy aims to maximize value from a digital future building on 38 initiatives that help prepare for future tech adoption

Largely thanks to these initiatives, great progress has been made and Denmark leads the EU rankings for connectivity and use of internet services

Governments around the world are trying to balance a focus on adequate safeguards with respect to AI on the one hand, while avoiding making regulation a roadblock for innovation on the other

In 2017, the Estonian government amended the Estonian Traffic Act to accommodate technological changes and enable an Estonian company to use delivery robots with AI technology

Source: DF9 National AI strategies; press search

3. The economic opportunity provided by AI in the DF9

3. The economic opportunity provided by AI for the DF9

The potential economic impact is substantial

If the DF9 adopts AI at scale, the potential impact could be up to around EUR 42 billion annually (or 1.4 percent of GDP) (Exhibit 16). This would far exceed the impact of early robotics (around 0.4 percent annually globally from 1993 to 2007) and early web technologies (0.4 percent annually in the EU from 2004 to 2008). AI's potential is high because of three core characteristics: it can be rolled out pervasively across industries and sectors; it tends to become more effective and efficient over time; and it can be a driver of innovation, leading to an array of tangential products and services.

There is some regional variation on the projected GDP effect. Leading AI economies such as the US and China will likely see a GDP uplift of around 1.5 percent, while European countries such as Germany, France, and Italy will see an approximate 1.2 percent GDP gain. This is especially important in an environment in which many economies are heading toward recession due to the COVID-19 outbreak. In that context, AI can be instrumental in helping businesses and governments accelerate recovery and build a platform for economic growth.

How we calculate the numbers: an AI impact model.

The AI impact model simulates the incremental impact of companies adopting AI and automation technologies. It provides point estimates of AI's impact on GDP and employment. It breaks down the overall estimate into a set of channels, allowing for a more in-depth understanding of the ways in which AI generates both positive and negative effects. However, as with any simulation, the model is necessarily a simplification of reality and may not capture all channels. It is therefore designed to inform understanding of relative dynamics and orders of magnitude, rather than to forecast precise values.

The economic boost will be delivered through a combination of increased workforce productivity and higher economic demand, surpassing the costs associated with AI. Specifically, we consider the impact of AI on GDP along nine channels clustered into three categories: domestic production, trade effects, and spill over effects on the economy. These nine cover a broad spectrum of the ways in which AI may impact the economy. They include direct productivity effects, where machines and algorithms may substitute or augment humans in certain tasks; indirect effects such as cross-border commerce (such as tools that reduce supply chain and logistic friction); and increased wage premium for digital and nonrepetitive jobs against their nondigital, repetitive counterparts.

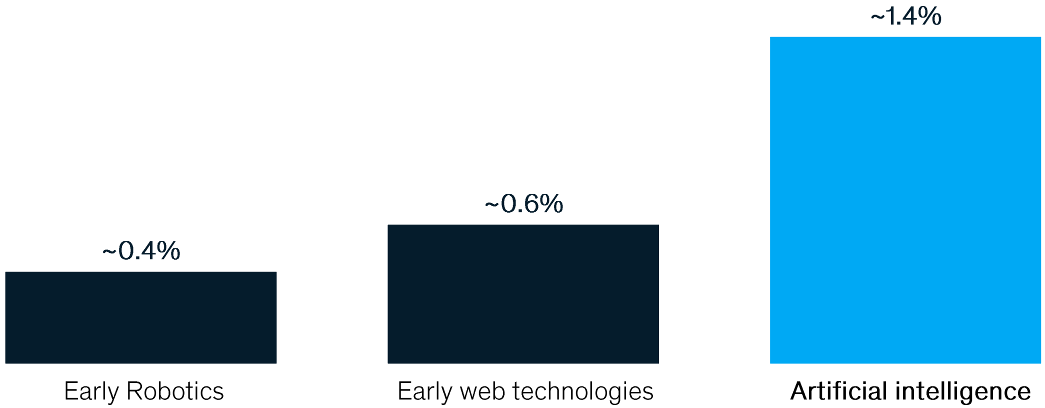
Labor substitution and innovation are likely to be the primary drivers of AI growth in the DF9, accounting for around 70 percent of the uplift. The high-level labor substitution stems from the fact that AI could realize a substantial share of automation potential in the DF9. Tasks with potential to be automated represented 44 percent of working hours in 2017.[1] Innovation is the net outcome of new (tech-enabled) products and services from the use of AI and a competition effect – in which the emergence of new offerings can shift gains from nonadopters to frontrunners that embrace AI.

Meanwhile, AI may fuel demand for some products and services. As open and digitally advanced economies, the DF9 are likely to benefit from increased data flows and reinvestment of income generated by AI-enabled wealth creation.

1 McKinsey & Company, 2017.

EXHIBIT 16: The potential economic impact for the DF9 from AI is substantial; 1.4% in additional annual GDP growth

Estimated GDP impact from technological waves[1]
Annual percentage points



Period	**1993 - 2007**	**2004 - 2008**	**2018 - 2030**
	~0.4%	~0.6%	~1.4%
	Early Robotics	Early web technologies	Artificial intelligence
Scope	Worldwide	27 EU countries	DF9
Contribution to GDP growth	~16%	~40%	~60-70%[2]

Potential economic impact amounts to **~EUR 42 bn** annually for DF9

Further, AI is likely to have a **neutral impact on long-term employment in** the DF9; while some jobs will be automated, others will arise as a result of AI[3]

1 Impacted through, e.g., labor substitution, innovation
2 Estimate based on Europe as a whole
3 McKinsey & Company: Shaping the future of work in Europe's digital frontrunners (2017)

Source: Ezell, Stephen, 2016; Graetz and Michaels, 2015; McKinsey Global Institute analysis

Still, AI adoption may lead to negative impacts. As the DF9 economies transition to new ways of working, both companies and employees could suffer. Firms will need to hire the right employees, ensure proper data management, and introduce new technological infrastructures. During the transition, employees may need reskilling, which can entail temporary unemployment. Still, in the longer run, we expect AI will have a neutral effect on employment, with as many jobs created as are destroyed. Lastly, AI may create a wage premium for people with relevant skills.

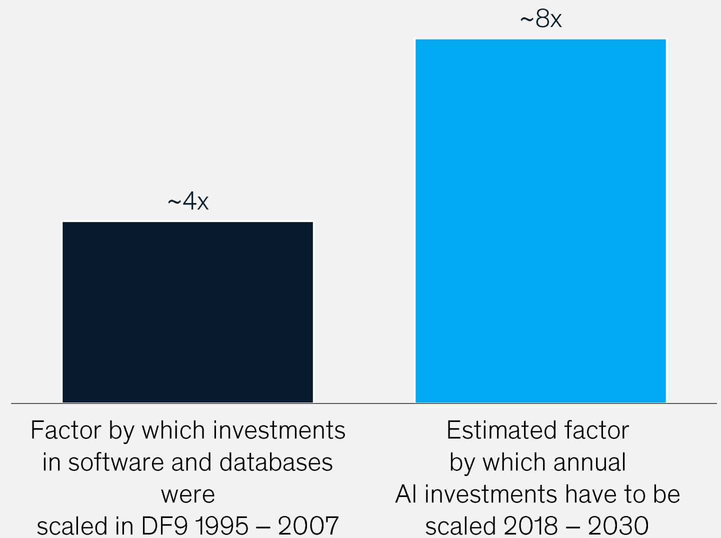
Capturing the economic impact will likely take time and require significant investments

Patience and commitment will be required because capturing the upside from AI adoption will require time and significant investment. There will be lags and transition costs associated with deploying technologies, especially where major shifts in skills are required and labor markets are fluid. Furthermore, the size of the potential will depend on how the private and public sector prioritize investment.

The DF9 can rightly boast about having invested in the software and databases that were key underlying technologies for the first wave of digital, but these investments will not be sufficient to support the rollout of AI. In the first digital wave from 1995 to 2007, the group scaled up investment by a factor of four. The AI wave, however, will likely produce twice the economic potential up to 2030, so we believe scaling up will be required in the order of eight times (Exhibit 17).

EXHIBIT 17: DF9 scaled investments by 4x in previous technology wave, while the AI wave will likely require ~8x

Required DF9 AI investment in 2018 – 2030 to achieve full AI economic impact potential



Source: Pitchbook; McKinsey Global Institute analysis; IHS Markit

AI has the potential to deliver social and welfare benefits in the DF9

AI has the potential to become a force for good and deliver welfare benefits, with possibilities ranging from increased environmental sustainability to more meaningful jobs focused on creativity and social skills.[1] It is already starting to have an impact, with many use cases being developed across the United Nation's 17 Sustainable Development Goals (Exhibit 18). The COVID-19 outbreak has served to demonstrate AI's potential to deliver healthcare and safety benefits, with DF9 countries using it for diagnosis, disease control, and forecasting (refer back to Exhibit 14).

Within the DF9, some of the most promising areas of potential are healthcare and the work environment. There are a significant number of AI applications in both and the potential for many people to benefit. To get a sense of the impact, a useful metric is "GDP equivalent," which incorporates factors such as whether the impact drives welfare or can be modeled robustly. Preliminary results on this basis quantify the GDP-equivalent impact as 0.4 percent of GDP annually (Exhibit 19). Benefits include better health, fewer working hours, and increased leisure time, while drawbacks may include stress, inequality, and unemployment.

Healthcare effects are pronounced, which is a particular benefit in the face of rising healthcare costs. AI-related technologies may ease access to low-cost healthcare through telemedicine solutions, and remote healthcare services such as virtual consultations may become a realistic alternative to physical consultations.[2]

Indeed, the COVID-19 outbreak has increased pressure on state budgets, which is likely to encourage governments to use AI to reduce healthcare costs. The economic potential of improved health and increased longevity could amount to 1 percent of GDP annually. However, AI-induced stress in relation to job security, for example, could deduct 0.2 percent of annual GDP impact.

Real-life examples are emerging. A leading hospital in the Netherlands in 2018, for example, adopted an EarlySense AI-enabled system, which analyzes patients' risk of falling and alerts personnel before patients leave their beds. The Estonian government, meanwhile, has rolled out a machine learning algorithm that matches individuals with employers.

Of course, stakeholders also need to guard against potential misuses of AI that include disinformation campaigns, cyberattacks, and cyber-fraud. There also may be unintended impacts of implementation, such as increases in inequality. As AI develops, policy frameworks will be required to protect users and the wider public. Policy makers should also move to tackle public concerns over privacy and work with the private sector to ensure sensitive personal information is not misused or made public.

Stakeholders in both the private and public sectors in the DF9 have essential roles to play in ensuring that AI can achieve its potential for social good, supported by tools such as model validation techniques and "human in the loop" quality checks. In perfecting these approaches, the DF9 could set the benchmark in Europe, particularly in sensitive areas such as criminal justice and data dissemination.

1 McKinsey Global Institute, 2018b.
2 PwC, 2018.

EXHIBIT 18: AI applications supporting the UN SDGs emerging in the DF9

AI impact on UN's Sustainable Development Goals

3. Good health and well-being

Preparing questions prior to consultation through Bingli app to ensure higher quality as general practitioners are better prepared

Supporting clinical decisions at hospitals through Anzyz AI-based support system to identify and classify allergies of concern for anesthesia during surgery by analyzing health records

Diagnosing brain tumors based on a molecular marker by the National Center for Pathology that uses AI for tumor classification

4. Quality education

Personalizing learning by Claned Group that first uses AI to understand how individuals learn and then optimizes learning efficiency by creating personalized learning plans incl. appropriate tasks, materials, and study colleagues

Incubating research through Open AI Lab, that drives general and applied AI research and connects small businesses and large corporations on the topic

6. Clean water and sanitation

Optimizing drinking water system by Project CHAIN that uses AI in Aarhus municipality

7. Affordable and clean energy

Monitoring and controlling energy consumption at residential homes by AI startup Watty that uses AI algorithms to detect and identify individual appliances in real time

8. Decent work and economic growth

Reducing labor-intensive processes through computer vision by Van Oord that uses computer vision AI technology to scan and intelligently process documents

Increasing employment through ML matching process, where laid-off workers are fed into a ML-system which matches their skills with employers

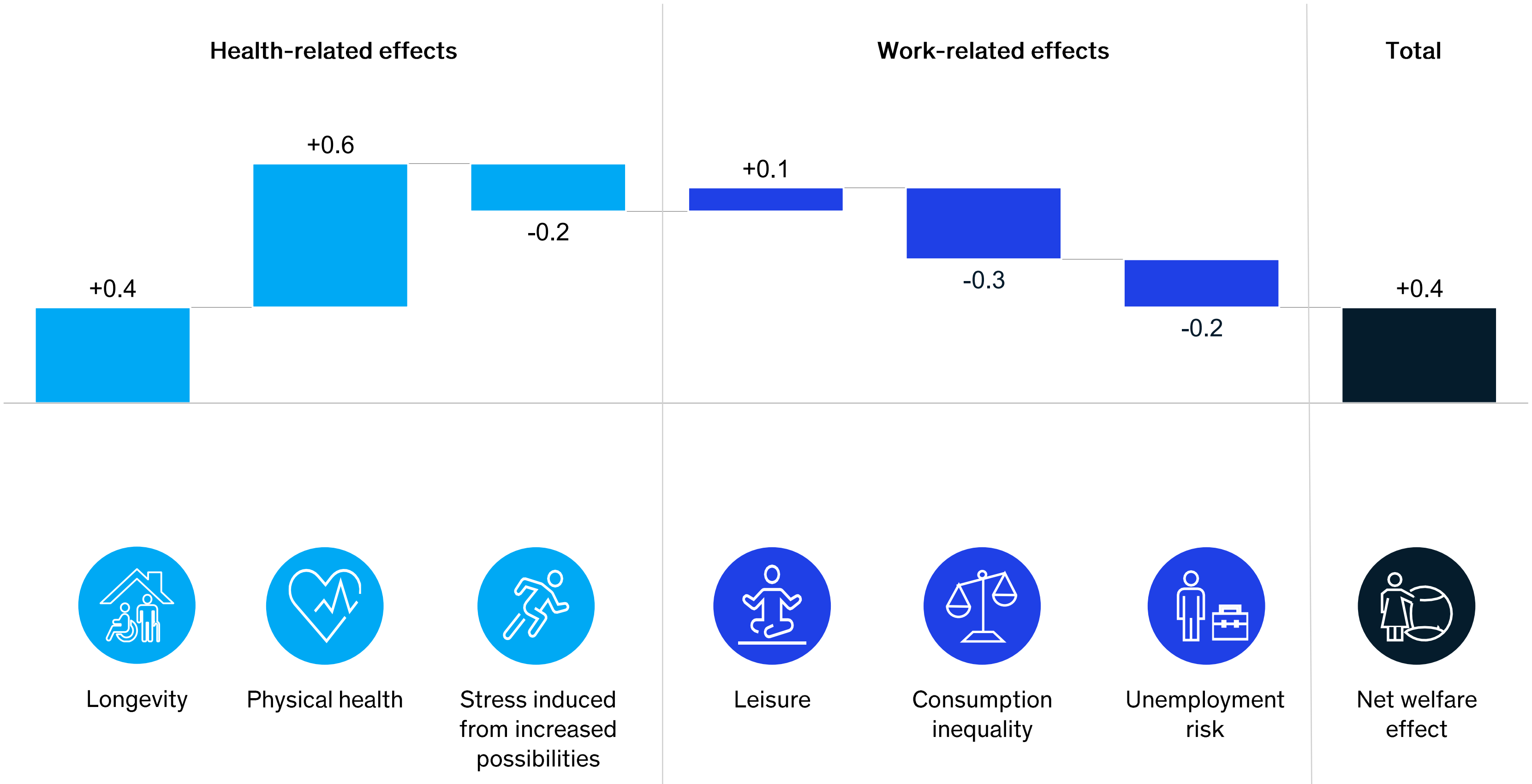
13. Climate action

Reducing carbon emission of enterprises energy data which is analyzed by EnergyElephant through AI

Source: UN; OECD; press search

EXHIBIT 19: Beyond GDP growth, AI could deliver significant welfare benefits for the DF9

Potential welfare gains in GDP equivalents[1]



1 Based on welfare methodology proposed by two economists at Stanford University (e.g., Jones and Klenow, 2016)

Source: McKinsey Global Institute analysis

4. The impact of AI across sectors

4. The impact of AI across sectors

Potential to unlock EUR 170 bn of value in the DF9 economies

Current AI technologies have the potential to unlock EUR 170 billion of value in the DF9 economies, based on McKinsey research (Exhibit 21).[1] Importantly, this value potential only constitutes the direct impact from currently known AI techniques. All industries are expected to benefit substantially, but retail and travel have the highest potential relative to industry size. Other promising applications include price optimization in finance, yield enhancement in manufacturing, next-product-to-buy in retail, and predictive maintenance in energy. AI techniques may provide value above and beyond traditional analytics techniques ranging from 30 to 128 percent, depending on the industry.[2]

As with any disruptive phenomena, there will be winners and losers. Frontrunning companies could achieve double the cash flow from the impact of AI by 2030 than nonadopters. However, there is work to be done in establishing data and obtaining the necessary organizational capabilities, so it will pay to be bold and invest early.

While adoption levels in most DF9 industries are generally low at present, there is some variation. The sectors that lead on digital, including high tech, banking, automotive and assembly, are most enthusiastic.[3] Sweden's automotive industry is a global leader and has adoption levels above those of auto industries in China, Germany, France, and Italy.[4]

Although current adoption levels are low, COVID-19 will likely accelerate AI take up in some industries. Retail, travel, and transport and logistics have been significantly impacted by the pandemic and are likely to prioritize tools that can help them get back on track.[5] Many retail players have already made changes, employing AI tools to replace locked-down call services, support logistics, and speed up distribution. In travel and transport and logistics, the imperative to control costs suggests there will rising appetite for AI adoption.

EXHIBIT 20: Examples of where and how value is created by applying AI

Retail – anticipate demand trends in fruit and vegetable sales with **1–2% EBIT improvement** through real-time forecasting

Transport and logistics – determine timing of goods' transfers to increase material **delivery time by 30%** with reinforced learning algorithms

Healthcare Systems and Services – tailoring drugs and treatment would lead to **savings of 2 – 9 EUR trillion** by adapting therapies and drug formulations to patients

Public and social sector – optimize education systems with virtual teaching assistants which can answer **40% of students' routine questions**

1 Full value potential from AI without considering the time it takes to realize the potential; based on an analysis of 400 use cases across industries where the annual value potential of applying AI is estimated for each case. This potential is smaller than the macro economic impact (1.4%) as it does not take macro-economic effects into account (e.g., wealth creation, trade effects).
2 McKinsey Global Institute, 2018c.
3 McKinsey Global Institute, 2017.
4 Capgemini, 2019.
5 McKinsey & Company, 2020a

Source: McKinsey Global Institute analysis; McKinsey Global Institute 2018c

EXHIBIT 21: AI could hold significant value potential of ~EUR 170 bn across all sectors in DF9[4]

	Gross output for DF9, EUR bn	AI annual value potential for DF9[2], EUR bn	Current AI adoption/maturity[3]
Transport and logistics	391	20	Low … High
Retail	170	18	
High tech	243	17	
Healthcare systems and services	587	16	
Public and social sector	1000	14	
Travel	138	13	
Consumer packaged goods	270	10	
Pharmaceuticals and medical products	190	9	
Banking	208	8	
Automotive and assembly	252	8	
Other[1]	1164	36	
Total	4611	170	

1 Others include media and entertainment, insurance, basic materials, oil and gas, telecom, advanced electronics/semiconductors, chemicals, agriculture, aerospace and defense
2 Full value potential from AI without taking into account the time it takes to realize the potential; estimated by the use of 400 use cases across 19 industries. AI is defined as 'feedforward neural networks', 'recurrent neural networks', and 'convolutional neural networks'. The value potential in this research is only based on AI use cases. In other research larger numbers might be referenced because of a broader scope that includes the impact from both traditional advanced analytics and AI. AI techniques make up 25%-55% of the total value potential from traditional advanced analytics and AI depending on the industry
3 Based on global numbers and results are weighted by firm size. AI adoption is measured in terms of share of firms which are adopting 1 or more AI technologies at scale or in business core
4 Numbers have not been adjusted for the impact of Covid-19

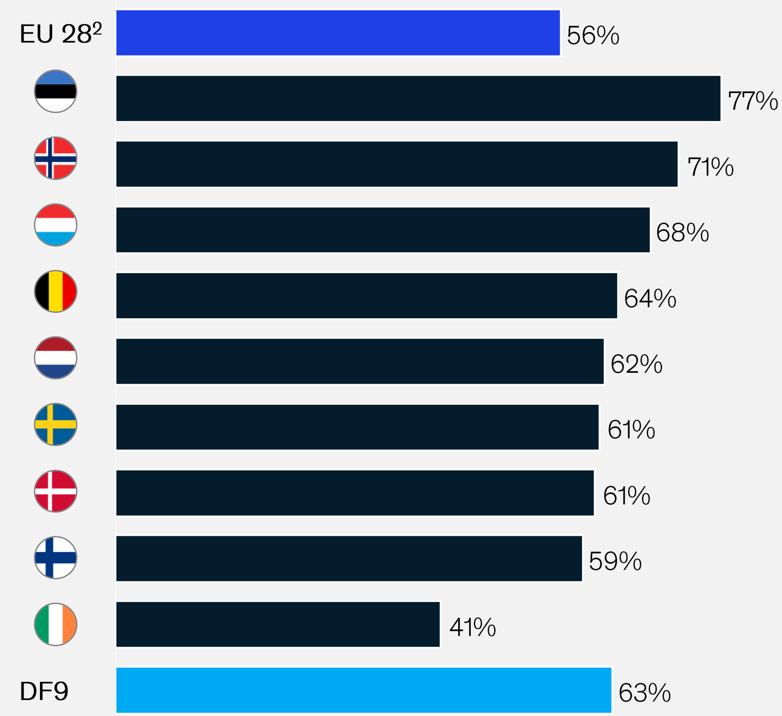
Source: McKinsey Global Institute analysis; McKinsey Global Institute 2018c

The SME segment must embrace AI for the DF9 to reap the full benefit

SMEs are critical elements of DF9 economies, accounting for 63 percent of value added in 2019, compared with 56 percent on average in the EU 27 (Exhibit 22). SMEs account for between one and three quarters of value creation in most industries, with the highest shares in construction, professional services, and food services. However, SMEs are slow adopters of AI. Across Europe, just 20 percent use the technology in a significant way, compared with 60 percent of larger companies. This is due to SMEs facing particular challenges in using AI, including limited access to capital and talent, which may slow adoption and ultimately limit the impact potential of AI in DF9.

Low AI adoption levels among SMEs might significantly undermine future growth in GDP per capita or living standards.

EXHIBIT 22: SME share of DF9 value added in business economy[1,2], 2019



SMEs represent almost two-thirds of value creation and 68% of employment in the DF9 business economy

1 Survey of > 300 SMEs across 10 European countries (includes both established SMEs and start-ups

2 Due to limited data availability, SME distribution only includes business economy e.g., industry, construction, trade, and services (NACE Rev. 2 sections B to J, L to N), but not enterprises in agriculture, forestry, and fisheries and the largely non-market service sectors such as public administration, defense, social security, education, and health – Norway data estimated from 2014 levels, as later data not available

Source: Structural Business Statistics from Eurostat; OECD; McKinsey Global Institute analysis

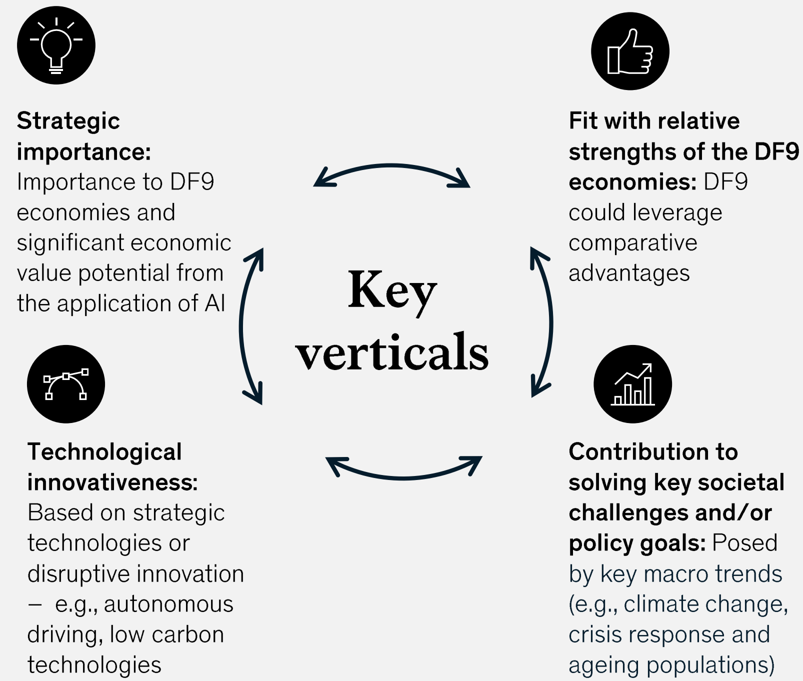
The DF9 could focus on key verticals

The international AI race is highly competitive and leading nations are using their scale to invest more than the DF9. One way to maximize the economic and social impact in the DF9 would be to focus efforts on key verticals across sectors where the DF9 have a strong starting point. This in turn may create momentum that could drive innovation more broadly.

We define key verticals as sectors or value chains in which there is significant economic or social potential and where it is likely that the DF9 could play a leading role in Europe. We identify the verticals based on four parameters: strategic importance, technological innovation, fit with relative strengths of DF9, and contribution to solving key societal challenges (Exhibit 23). On the basis of these, the three most promising verticals are the public sector, the intersection between manufacturing and the Internet of Things, and sustainability.

The public sector could elicit significant value from AI through more effective interrogation of large data sets in areas such as longevity and disease prevention and treatment. Relatively powerful public sectors and strong digital health cultures in the DF9, as well as high levels of education, accentuate the potential in this area.

EXHIBIT 23: Identification of key verticals based on overall assessment across 4 elements[1]



1 Long list of key verticals that are of strategic importance, technological innovative, and contribute to solving key societal challenges are based on the identified "strategic value chains" by the European Commission: Strategic Forum for Important Projects of Common European Interest: "Strengthening Strategic Value Chains for a future-ready EU industry". From long list, examples of key verticals which fitted with relative strengths of DF9 economies were identified

Source: European Commission, 2019b; McKinsey Global Institute analysis

Among current efforts, Finland, launched a free AI course online in 2018, which was first only for Finnish citizens but in 2019 was opened to students globally.[1] The Estonian government, meanwhile, has rolled out AI across public services. One application is an AI-driven job matching service, which lifted the retention rate after six months from 58 percent to 72 percent.[2] More recent efforts have been aimed at combating COVID-19. Danish hospitals are developing an AI-model to predict disease development based on patients' health journals.[3] In Norway, a public-private partnership is building an AI-powered app to trace chains of infection using mobile location data.[4]

The DF9 are global leaders in manufacturing, with seven companies among the 20 largest public industrial equipment makers globally.[5] Ireland has a world-class life sciences manufacturing industry and is the largest per capita employer of MedTech professionals in Europe. All of the world's top ten pharmaceuticals companies have operations in the country.[6] Belgium is a leader in chemicals and plastics manufacturing and posts the highest chemicals and plastics sales per capita globally. Antwerp is the second-largest petrochemical hub in the world, and clusters such as Catalisti and Essencia comprise more than 100 companies.[7] Sweden is home to leading industrial equipment and advanced automotive manufacturers, both of which have received support from the government to adopt AI. Specifically, the Swedish government supports AI initiatives in the industrial sector, committing EUR 300 million to part of the country's largest industrial research program ever. The success of these companies suggests the foundations are in place for AI development in areas such as robotics and the Internet of Things; for example, in development of solutions for predictive maintenance.

EXHIBIT 24: DF9 could play a defining role within sustainability, public sector and industrial AI solutions

	Observations on strategic importance
Public sector solutions	Ageing populations and prevalence of lifestyle diseases Large public sectors in DF9 with ~20% higher healthcare spending (per capita) and education spending (as percentage of GDP) compared to Europe Public sector has a key role within education to bridge current tech skill gap (e.g., currently +750,000 unfilled jobs in the European ICT sector[a])
Sustainability solutions	Global economy facing pressure to shift towards more sustainable modes of production and consumption EU aims towards a climate-neutral economy by 2050 Sustainable solutions in high demand
Industrial/ manufacturing solutions	The next phase of automation/industrial 4.0 has begun incl. use of robotic solutions combined with (industrial) IoT If industrial IoT is **not implemented successfully, European manufacturing expertise and a high number of jobs could be lost** to international competition (e.g., 15% of DF9 employment[b])

a The European Commission: E-Skills and Jobs in the Digital Age (2017)
b Based on estimates from EU28

1 Finland has the highest ranking on the European Digital Economy and Society Index (2019).
2 For this and further examples of AI being implemented in governmental services, please see www.e-estonia.com
3 Halim, 2020
4 Simula, 2020
5 Based on 2,000 of the biggest public companies from Forbes, 2019.
6 MedTech Europe, 2019.
7 Flanders Investment & Trade; CEFIC, 2020.

Source: Eurostat; OECD; European Commission, 2019b; Forbes, 2019; Yale and Columbia University, 2019

Deep dive: sustainability

In relation to sustainability, Europe needs to accelerate reduction of greenhouse gasses to achieve its 2030 target of an around 20 percent reduction from today.[1] Key CO2-emitting sectors include energy, manufacturing, construction, and transport. However, sustainability extends far beyond these sectors. A broader aim is to create a circular European economy, which is defined as an economy that eliminates waste and encourages reuse, sharing, repair, and refurbishment. Only around 12 percent of material is currently recycled, while 20 percent of food is lost or wasted.[2]

How can AI help? AI models are designed to boost the efficiency of analysis, which leads to benefits including better energy forecasting and usage, new mobility solutions, smart waste management and recycling, precision agriculture, and a more informed approach to water conservation (Exhibit 25).

Across energy, transport, agriculture, and water it is estimated that AI applications could lead to an around 17 percent reduction in greenhouse gas emissions by 2030.[3] In terms of economic potential, those four industries alone could spur growth that will add 5 percent to GDP by 2030 and 2.3 million jobs (around 1 percent of Europe's total).

EXHIBIT 25: AI offers solutions across key sustainability themes[a]

Decarbonization
Increased efficiency of renewables, incl. hyperlocal weather modeling to monitor and adjust the positioning of solar panels and wind turbines
Energy prediction to better forecast energy needs balancing supply and demand

Land and agricultural sustainability
Agricultural robotics carry out agricultural tasks autonomously with optimal timing e.g., tractor picking fruit only when ripe
Precision monitoring of environmental conditions incl. use of intelligent field sensor to optimize yield

Future mobility
Autonomous vehicles including eco-driving features
Traffic optimization to monitor traffic flow to, e.g., decrease congestion

Plastic and waste management
Smart waste sorting to identify and process waste based on the type of garbage
Intelligent trash bins fitted with computer vision sensors to identify the type of garbage being thrown in them

Water scarcity
Water demand prediction to track actual water use on industrial and household level allowing suppliers to pre-empt water demand, reducing both wastage and shortages

Material efficiency
Optimal operating HVAC strategy in large building structures based on weather forecast, occupancy levels and energy price

a Microsoft and PWC: How AI can enable a Sustainable Future (2019)

1 Climate Action Tracker organization, 2019
2 European Commission, 2019d.
3 Climate Action Tracker organization, 2019; Microsoft and PwC, 2019.

The DF9 are sustainability frontrunners in multiple dimensions and therefore well-positioned to play a critical role in promoting the use of AI to pursue environmental, social, and governance factors (Exhibit 26).

Eight countries of the DF9 are global leaders in sustainability (Exhibit 26). The share of energy consumption from renewable energy is almost twice that in the DF9 than the EU average (29 percent versus 18 percent).[1] Five DF9 countries have 2030 ambitions that go beyond the EU target of 32 percent.[2] They are supported by regulation and initiatives such as Denmark's ambitious wind farm agenda and the VAT exemption for zero-emission vehicles in Norway.

Seven of the top 15 companies for environmental governance are in the DF9, and the DF9 collectively have 21 companies in the top 100 most sustainable globally (Exhibit 26). Good environmental governance comprises protecting and preserving the climate and natural resources through policies, regulation, and cooperation. Some companies in Denmark have started to acquire and integrate AI solutions. In the Netherlands, agriculture accounts for 15 percent of exports, making it the second-largest agricultural exporter after the US.[3] On the key metric of yield per square meter, it operates at 1.5 to 2 times the average efficiency of global peers, largely due to the implementation of advanced technologies.[4] Amsterdam-based Connecterra supports farmers through AI that has made some dairy farms 20 to 30 percent more efficient and has reduced antibiotic use in animals by up to 50 percent.[5] In the recycling area, Finland's ZenRobotics has developed an AI-enabled solution to optimize waste sorting through real-time analysis of waste streams (Exhibit 27).

In addition, governments in the DF9 are enthusiastic adherents to the global environment agenda and have been active in multilateral efforts toward climate change solutions. Sweden, for example, has a strong record of exceeding international requirements, including the Kyoto Protocol and Paris Agreement. Norway, in which 99 percent of electricity comes from hydropower, is experimenting with AI solutions to improve allocation of water resources, helping create what may become the first AI algorithm to optimize energy production.[6]

Given strong corporate and public sector commitment to sustainability, the DF9 are set to play a critical role in promoting the use of AI to pursue environmental, social, and governance targets.

1 Share of renewable energy in gross final energy consumption, from Eurostat.
2 Denmark, Finland, Sweden have ambitions of having a 50 percent share of energy consumption from renewable energy in 2030, Estonia 42 percent, while Norway in 2015 already had an ambition of 67.5 percent in 2020.
3 Growth Lab at Harvard University, 2017.
4 FAOSTAT, 2019.
5 Connecterra's web page.
6 University of Agder.

EXHIBIT 26: The DF9 are frontrunners on sustainability

DF9 country/company

Overall country performance

Most sustainable countries measured by Global Environmental Performance index[1]

1. Switzerland
2. France
3. Denmark
4. Malta
5. Sweden
6. UK
7. Luxembourg
8. Austria
9. Ireland
10. Finland
14. Norway
15. Belgium
18. Netherlands
48. Estonia

Environmental policies

Ranking of environmental governance by Bertelsmann Stiftung[2]

1. Sweden
2. Switzerland
3. Denmark
4. Norway
5. Finland
5. Lithuania
7. Estonia
7. Luxembourg
9. UK
10. France
10. Germany
14. Ireland
19. Netherlands
24. Belgium

Private sector performance

Most sustainable corporations globally by Corporate Knights[3]

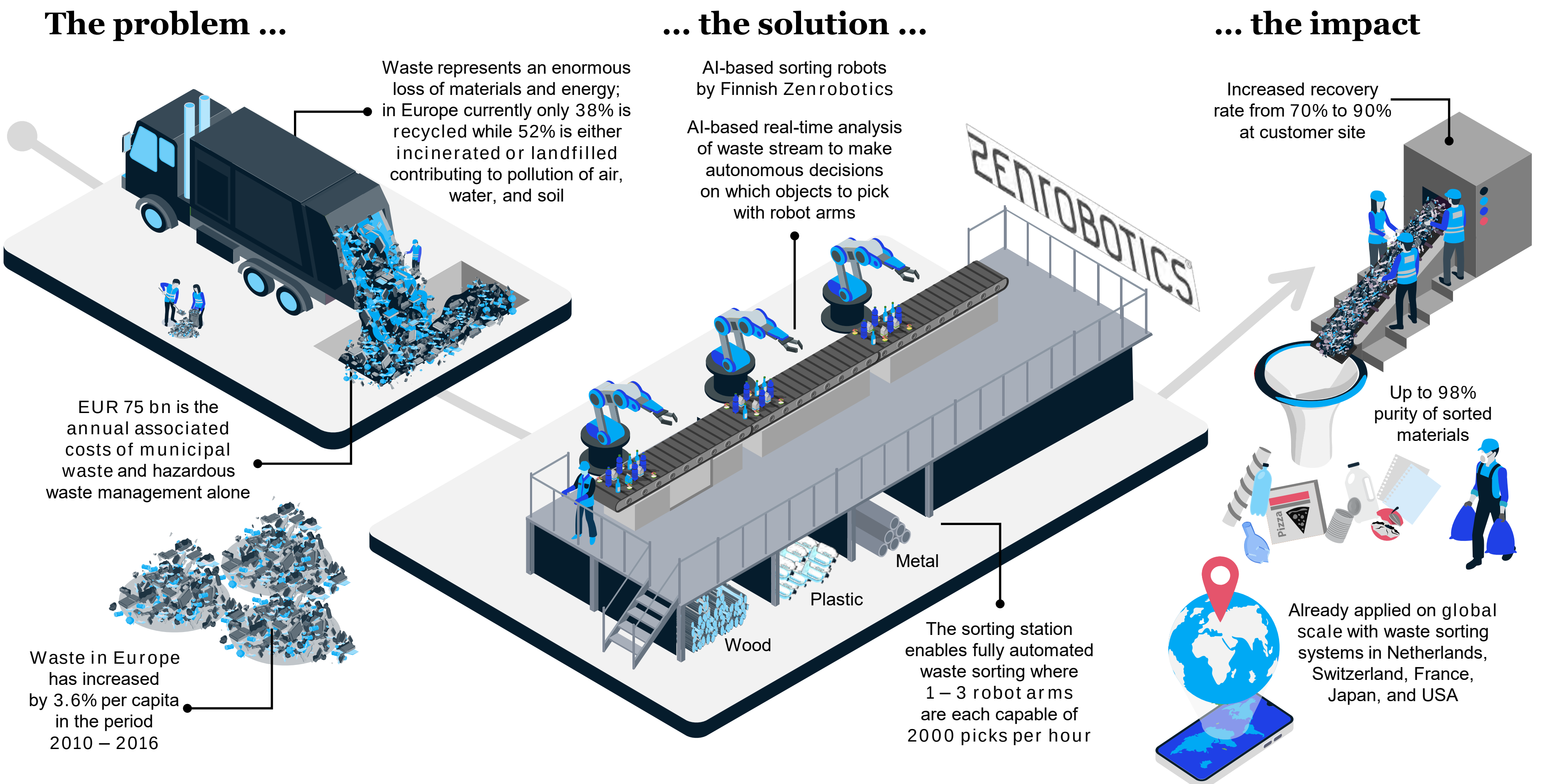
1. Ørsted A/S
2. Chr. Hansen Holding A/S
3. Neste Oyj
4. Cisco Systems Inc.
5. Autodesk Inc.
6. Novozymes A/S
7. ING Groep NV
8. Enel S.p.A
9. Banco do Brasil S.A.
10. Algonquin Power & Utilities Corp.

21 DF9 companies within global top 100 – being almost 4x the fair share of 6%[4]

1 Based on 10 sub indexes measuring climate and energy, biodiversity and habitat, forests, fisheries, air pollution, water resources, agriculture, air quality, water and sanitation and heavy metals
2 Based on two underlying indexes with 50% weight each measuring; 1) how much the environmental policy preserve and protect resources and environment and 2) how much the government participate in global collective activities to protect the climate
3 Annual ranking of corporate sustainability performance amongst all publicly-listed companies with gross revenue of a minimum of $PPP-currency USD 1 bn
4 Fair share is estimated as share of DF9 companies of top 2000 global public companies - where 97% has reported gross revenue above USD 1 bn

Source: Yale and Columbia University, 2019; Bertelsmann Stiftung, 2019; Corporate Knights, 2019; Forbes Global, 2019

EXHIBIT 27: AI solution for waste management increases recycling rates



Going forward the industry is expected to grow significantly at a rate of 17% in the period 2019–2023

Source: Eurostat; Zenrobotics; Press search

5. Potential focus areas for the DF9

5. Potential focus areas for the DF9

Europe is at risk of falling behind in the race on AI, which may have a knock-on effect on its relative productivity performance in the years ahead. However, the DF9, which are European leaders on key readiness dimensions, may provide a boost to Europe's standing. The group scores highly on AI readiness, which could help accelerate efforts to adopt AI across Europe. A key ingredient of getting there is increased investment. First, however, the DF9 must take steps to lay the foundations, which we believe could mean focusing on five key priorities:

— Collaborate to innovate

— Adopt AI at scale

— Offer thought leadership on regulation

— Promote data access

— Ensure the necessary talent is in place

The proposed priorities reflect DF9 strengths and development areas as well as areas in which the DF9 could use collaboration and the EU AI policy agenda. Furthermore, they reflect topics for which there is evidence that stakeholders (business, public, and academia) broadly acknowledge the need for intervention. The priorities are mutually reinforcing and could ensure that the DF9 not only consume, but also supply AI – especially in verticals where DF9 countries have a competitive advantage.

In addition, the five areas of focus are conceived with the intention of helping the private sector overcome barriers to adoption. These include a lack of technical and managerial capabilities, regulatory uncertainty (for example, relating to data privacy), challenges in identifying an AI business case and related strategy, competing investment priorities, and a shortage of high-quality, unbiased data and supporting infrastructure.

It is hoped the priorities will feed into and support existing initiatives at EU and national levels and act as a potential spur to cross-country partnership while respecting the division of competences between the EU and its member states. One way for the DF9 to contribute to ongoing EU-level efforts is by taking the lead on the national level and experimenting with cooperation on a regional level to inspire the rest of the EU to further action.

The discussions below should not be viewed as policy blueprints or recommendations; rather they are intended to serve as a starting point for discussion on how the DF9 could harness the opportunity of AI and, where it makes sense, deepen research into the legal, financial, and operational implications

Collaboration to innovate

DF9 economies do not individually have the financial scale to drive significant AI innovation in key verticals. However, their strong geopolitical ties and cultural similarities mean they are positioned to collaborate to generate the momentum they need.

Source: 1) Official AI strategies for 15 countries; 2) Government and key private stakeholder reports and white papers: AI 4 Belgium, 2019; Future Jobs Ireland, 2019; IDA Ireland, 2017; Innovationsfonden, McKinsey & Company, 2019; Vinnova 2018; Teknologirådet, 2018; Finnish Ministry of Economic Affairs and Employment, 2017; Estonian Ministry of Economic Affairs and Government Office, 2019b; Cairn, 2018; 3) Other sources: McKinsey & Company 2019; World Economic Forum, 2019, WIPO, 2018; European Commission, 2018a; Microsoft, 2018; OECD ,2017; Tufts University, 2019; Cambrian AI Index 2019; Stanford University HAI, 2019; Cornell SC, Insead, and WIPO, 2019;

Innovation is costly and therefore highly dependent on (often long-term) investment. However, there is an investment gap between the DF9 and global leaders, even when adjusting for GDP. As a consequence, Europe is lagging behind on the investment-heavy supply side of AI. Stepping up efforts in this area will be critical, not only for Europe to benefit from AI, but also to ensure it has autonomy and control of core technologies.

The public sector has always supported the private sector by providing technology infrastructure, and that continues to be the case as economies digitize. The necessary elements for AI include high-speed 5G networks, supercomputers, and, perhaps in the future, quantum computing. The governments of the DF9 could create momentum in these areas by using their combined spending on technology, innovation, and research to spur development and adoption of AI. Key focus areas may include large-scale, high-risk development projects tied to critical global challenges, such as climate change or health. European cooperation around high-performance computing (HPC) is a good example of how resources have previously been pooled in a targeted way.

The DF9 could additionally focus collective resources on key verticals, ensuring they make the most of their comparative advantages and areas of expertise. In a budget-constrained era, this is likely to be a more fruitful strategy than generic investment across multiple industries. Another likely avenue for collaboration is in fostering currently absent regional AI/tech ecosystems, which are reliable drivers of innovation and growth.

Examples include:

— Create mechanisms to commercialize technology by tying DF9 public procurement contracts to R&D at scale in key verticals.

— Coordinate funding across countries to provide critical infrastructure, including computing power for research and innovation.

— Foster cross-regional AI/tech ecosystems to match global best practices, focusing on key verticals to match global leaders.

— Build collaborative European university AI research centres modeled on institutions such as Mila, the Montreal-based AI research institute, with a focus on commercialization in key verticals.

— Promote private sector investment by, for example, setting up a collaborative AI investment fund as a public-private partnership to support companies in key verticals.

— Open a digital portal for companies seeking funding for AI projects at the national level and support the creation of a unified access point for Europe.

Adopt AI at scale

In addition to fostering AI innovation, the DF9 could benefit from rapidly adopting AI to develop innovative business models. In short, an ability to adopt will become a key differentiator for future productivity and competitiveness.

Of course, it is not easy to create a culture that is open to disruptive change, particularly when that change may cannibalize profit streams and requires significant organizational adaption. Still, the COVID-19 outbreak may establish a good platform for this type of disruption. Already, businesses have been forced to rethink their product and service offerings in light of shifting consumer preferences.[1] Further, the accelerated digitalization resulting from companies and consumers moving online can be expected to provide a stronger foundation for disruptive AI technologies to flourish.

In an (increasingly) AI-driven economy, it will be key for companies to be bold in formulating tightly integrated AI strategies. Indeed, first movers will likely capture the most value. McKinsey & Company research shows that companies with a proactive AI strategy will achieve an operating profit margin of about 7 percentage points above the industry average. Adopters/experimenters and nonadopters, on the other hand, will be around 1.5 percentage points and 2 percentage points, respectively, below industry average profit levels. [2] The lesson is that AI can deliver significant competitive advantage, but only for firms that fully commit.

The importance of a focus on adoption is underscored by the fact that a key trigger for AI investment is competition; rivals' progress increases propensity to invest three times more than the perceived value of AI.

When it comes to redefining business models for AI, the US is ahead, with 8.2 percent of companies embracing radical redesign, compared with 4.6 percent in Europe. In the DF9, there are strong reasons to accelerate adoption efforts.

First, the countries are in the global lead in terms of private sector capabilities (underlying infrastructure and education), probably due to the investment made in the first wave of digitization. Moreover, people are generally positive on new technologies. Looking forward, the DF9 must focus on both AI supply and adoption, but given their smaller scale, adoption is probably simplest and does not require collaboration to the same extent as innovation/supply.

An important element in encouraging adoption will be to ensure the SME segment gets involved. SMEs play a critical role in the DF9 economies but also face the biggest challenges in terms of adoption. They will require significant public sector support and large company leadership to manage the transition.

Finally, the majority of AI investment is in the private sector, suggesting that private sector investment in the DF9 will likely need to rise if the group is going to achieve its AI potential.

Example areas of focus:

— Establish centers of AI excellence at the national level aimed at helping SMEs accrue the benefits of AI adoption (use cases and best practices for areas including implementation and risk management).

— Foster regional and European public sector AI best practices and knowledge sharing.

— Contribute to the development of European open source tools and frameworks for the implementation of AI solutions, as already seen during the COVID-19 pandemic.[3]

1 McKinsey & Company, 2020b
2 "How artificial intelligence will transform Nordic business", McKinsey & Co, 2019. The report notes "it is not straightforward to statistically establish a causal relationship."
3 European Commission, 2020

Offer thought leadership on regulation

Policy makers can have a significant impact on the pace of AI adoption. However, AI presents distinctive regulatory challenges, particularly in relation to cross-border matters. The DF9 could lead the way in Europe on the benefits of proactive and harmonized AI regulation, as well as tech for good, by driving thought leadership on regulation. They are well-positioned due to their small, open economies, history of collaboration, and policy emphasis on safeguards including privacy, fairness, and "explainability."

Focus areas could include:

- Work on best practices for regulatory sandboxes – in line with ethical principles – that lower barriers to the development and testing of AI applications; for example, via favorable taxation of AI investments or fast-track approval processes.
- Contribute to the debate on how to reduce regulatory uncertainty by adapting existing regulation and/or clarifying applicability to AI-enabled products/services, including issues around data privacy, linked to Europe's General Data Protection Regulation.
- Formulate requirements around "explainability" and transparency of methods and models.
- Launch public campaigns and educational efforts to foster a basic understanding of the technology and its opportunities and risks on a national level.
- Support entities tasked with developing guidelines and consulting the public and private sectors on the use of tech for positive purposes.

Promote data access

An important factor in the adoption of AI is whether underlying digital technologies are in place, because this is the technical backbone for its effective rollout. This is especially true of the availability of data, which is the cornerstone of AI.

The DF9 together have significant volumes of data, especially in sectors such as health and education. In addition, Europe boasts a comprehensive data framework that sets out standards for collecting, storing, and accessing data, including the General Data Protection Regulation (GDPR). Yet databases remain fragmented and are governed by a variety of rights of access, which can be an obstacle to innovation.

The DF9 could lead the way in Europe if they:

- Help establish unified and accessible data platforms to facilitate exchange of data in the private sector (focused on key verticals). This may include development of technical infrastructure, aspects of data storage, and the supporting regulatory framework to control elements such as access rights, usage contracts, and data sharing. These schemes could also allow non-governmental and similar organizations more access to data for social purposes.
- Through a public portal, offer open access to relevant government data across multiple countries. This would likely boost consolidation, usability, and compatibility of public data. It could be built leveraging the multinational healthcare database collaborations that have been set up during COVID-19.[1]

1 European Commission, 2020

Ensure the necessary talent is in place

Skill shifts have accompanied the introduction of new technologies in the workplace since at least the Industrial Revolution, but adoption of automation and artificial intelligence (AI) will mark an acceleration over the shifts of even the recent past. The need for some skills, such as technological as well as social and emotional skills, will rise, even as the demand for others, including physical and manual skills, will fall. These changes will require workers everywhere to deepen their existing skill sets or acquire new ones. Companies, too, will need to rethink how work is organized within their organizations.

Our research suggests that the time spent using advanced technological skills will rise by 41 percent in Europe through 2030. We expect the biggest gains will be in demand for advanced IT and programming skills. People with these skills are a minority, even at today's relatively low level of digitization and AI adoption.

While the talent deficit remains a hurdle, it will also be a key progress differentiator. A well-trained workforce equipped with the skills required to adopt AI technologies will ensure that DF9 economies enjoy faster productivity growth and harness talent more effectively. Failure to navigate the shifting skills landscape, meanwhile, could exacerbate social tensions and lead to rising skill and wage bifurcation.

DF9 stakeholders must anticipate AI's potential impact on the workforce, including required scale shifts in the skills base and the impact of AI on job displacement. It will be critical to invest in building the skills that underpin a more knowledge-intensive economy and support the labor force in adapting to new requirements.

The natural starting point is higher education – a DF9 area of strength that is reflected in the high proportion of people with a tertiary education. In the short term, education system redesign is impractical. Companies, therefore, should be proactive in training both new and existing employees. Given the short half-life of technology skills, DF9 stakeholders should also ensure there are opportunities for lifelong learning.

Example focus areas include:

- Aim to promote student uptake of AI-related subjects, such as STEM subjects.
- Create scholarship schemes and facilitate exchange programs between leading universities in the region. Also support a European AI talent program for top students and researchers.
- Attract and retain national and foreign talent, and ease cross-regional mobility; for example, through dedicated visa programs and substantial financial incentives for the top 50 academic researchers.
- Foster partnerships between industry and educational institutions, reducing the number of siloed initiatives.
- Introduce incentives to accelerate workforce reskilling; for example, in the form of subsidies for retraining in STEM subjects.

***

AI is set to become a game changer in the public and private spheres. The technology has the potential both to boost productivity and to help humans work better, faster, and with more knowledge in almost every activity. Around the world, governments and companies are engaged in exploring potential use cases and working out how the technology will impact the workplace and society. Europe is lagging in these efforts, while China and the US are leading.

The DF9 are therefore presented with a historic opportunity. The nine countries together have the technical know-how, investment resources, and digital culture to lead on AI and to put in place the frameworks, structures, and research centers that will drive AI adoption for both corporate profit and social good. Among these are the need for greater collaboration, scaled-up adoption roadmaps, and action on regulation and data. There is also a need to ensure that Europe has the necessary talent in place to fully realize the AI opportunity. Progress on AI is still in a relatively early stage, and as the technology develops, there is a requirement for new ideas, conversations, and partnerships across Europe. It is incumbent now on the DF9 to take the lead and, in the process, ensure Europe reaps the benefits of AI technologies in the years ahead.

.

Appendix

1. Selection of country-level data points

2. Bibliography

APPENDIX 1: Selection of country-level data points (1/2)

Country	Percentage of companies performing big data analysis, 2019	Private sector AI adoption potential by 2030	Percentage of citizens with positive view on AI, 2017	AI start-ups per mn population on Crunchbase 2020	Avg. funding per AI start-up on Crunchbase 2020, EUR mn	STEM graduates per mn pop 2016
Belgium	15%	53%	63%	10	3.3	0.6
Denmark	16%	51%	85%	19	1.3	1.2
Estonia	10%	53%	79%	33	1.1	1.0
Finland	19%	51%	76%	24	1.2	1.2
Ireland	14%	54%	71%	30	1.9	NA
Luxembourg	20%	51%	62%	42	0.6	NA
Netherlands	22%	53%	84%	16	1.2	0.6
Norway	20%	51%	NA	16	1.8	0.7
Sweden	11%	52%	82%	17	2.4	0.6

Source: OECD, 2019; McKinsey Global Institute Analysis; European Commission, 2017; Crunchbase; Stanford University, 2019; UNESCO; Eurostat; World Economic Forum

APPENDIX 1: Selection of country-level data points (2/2)

Country	**People with AI relevant skills** 2019	**People employed within AI** AI hiring index, 2019	**Ratio of female talent in AI** 2019	**AI researchers per 100 researchers,** 2019	**Overall DESI Index Score** 2019	**Open government data score,** 2016
Belgium	1.2	1.6	85%	2.0	59	38
Denmark	1.5	1.9	86%	2.6	69	71
Estonia	1.3	NA	81%	1.8	60	45
Finland	2.2	1.8	75%	2.6	70	60
Ireland	3.5	1.8	82%	3.0	61	51
Luxembourg	1.9	1.8	80%	1.5	62	NA
Netherlands	1.8	2.1	82%	1.9	69	64
Norway	NA	NA	NA	2.2	66	71
Sweden	1.8	1.8	83%	2.9	69	70

Source: LinkedIn, 2019; Stanford University, 2019; LinkedIn Report 2019: AI Talent in the European Labour Market; Center for Data Innovation; Tortoise Media, 2019; European Commission, 2019a; Open Data Barometer;

2. Bibliography

A.

Acemoglu, Daron and Restrepo, Pascual, 2019. Demographics and Automation

Acemoglu, Daron and Restrepo, Pascual, 2019. The Wrong Kind of AI? Artificial Intelligence and the Future of Labor Demand

Adam, Amy, 2019. *Stanford University Launches the Institute for Human-Centered Artificial Intelligence*. Available at https://news.stanford.edu/2019/03/18/stanford_university_launches_human-centered_ai/

AI 4 Belgium, 2019. Think tank that brings together private companies, government agencies, research institutes and start-ups with the aim to gaining insight into the impact of artificial intelligence. Available at https://www.ai4belgium.be/

AI Innovation of Sweden, 2018. *The Data Factory*. Available at https://www.ai.se/sites/default/files/content/resource/files/ai_innovation_of_sweden_-_data_factory_1.pdf

Akamai, 2017. Q1 State of the Internet / Connectivity Report. Available at https://www.akamai.com/us/en/resources/our-thinking/state-of-the-internet-report/global-state-of-the-internet-connectivity-reports.jsp

Angwin, Julia, et al., 2016. *Machine Bias*. Available at https://www.propublica.org/article /machine- bias-risk-assessments-in-criminal-sentencing

Asgard, 2019. *Database for Companies Building AI Solutions*. Available at https://asgard.vc/ global-ai/

Asgard and Roland Berger, 2018. *Artificial Intelligence – A strategy for European Startups. Recommendations for Policymakers.* Available at https://www.rolandberger.com/publications/publication_pdf/roland_berger_ai_strategy_for_european_startups.pdf

Atomico, 2019. The State of European Tech. Available at https://2019.stateofeuropeantech.com/

Autor, David, 2019. Work of the Past, Work of the Future. *American Economic Association: Papers and Proceeding*, May, 109(5), 1–32

Autor, David and Salomons, Anna, 2018. Is Automation Labor-Share Displacing: Productivity Growth, Employment, and the Labor Share. *Brookings Papers on Economic Activity, Spring 2018, 1-63*

Autor, David, et.al., 2017. Concentrating on the Falling Labor Share. *American Economic Review Papers & Proceedings, 107(5): 180–185*

Autor, David, 2015. Why are There Still So Many Jobs? The History and Future of Workplace Automation. *Journal of Economic Perspectives, Summer 2015, 29(3), 3–30*

Autuly, Julie, 2019. *Artificial Intelligence: European R&D Strategies*. Available at blogs.esa.int/philab/2019/01/11/european-artificial-intelligence-rd-strategies/

B.

BARC, nd. *Basic Algorithms Research Copenhagen*. Available at https://barc.ku.dk/

Bertelsmann Stiftung, 2019. Sustainability Governance Indicators – Policy performance. Available at https://www.sgi-network.org/2019/Policy_Performance

Bessen, James E., et al., 2018. The Business of AI Startups. *Boston Univ. School of Law, Law and Economics Research Paper, (18-28)*

Brundage, Miles, et al., 2018. The Malicious Use of Artificial Intelligence: Forecasting, Prevention, and Mitigation. *Electronic Frontier Foundation,* February

Bughin, Jacques & Sir Chis Pissarides, 2018a. The promise and pitfalls of AI, *Project Syndicate*

Bughin, Jacques and Sir Chris Pissarides, 2019. Don't squander the techno revolution, *Project Syndicate*

Bughin, Jacques, 2018. How the future of work may unfold: A corporate demand-side perspective, *VOX EU*

Bughin, Jacques, Laberge, Laura, Mellbye, Anette, 2017. The case for digital reinvention. *McKinsey Quarterly.*

Bughin, Jacques; Lund Susan and Hazan, Eric, 2018b. Automation will make lifelong learning a necessary part of work, *Harvard Business Review*

Business Finland, 2019. AI Business Program. Available at https://www.businessfinland.fi/en/for-finnish-customers/services/programs/ai-business/

2. Bibliography

C.

Cairn, 2018. Leader in e-Government, Laggard in Open Data: Exploring the Case of Estonia.

Cambrian Group and Konrad Adenauer Foundation, 2019. Nation AI Readiness Index. Available at https://www.cambrian.ai/nair-index

Cambridge Network, 2020. COVID-19 breakthrough as Cambridge company identifies top ranked drugs for treatment. April 16. Available at https://www.cambridgenetwork.co.uk/news/covid-19-breakthrough-cambridge-company-identifies-top-ranked-drugs-treatment

Capgemini, 2018. Artificial Intelligence Benchmark. Available at https://www.capgemini.com/wp-content/uploads/2018/07/AI-Readiness-Benchmark-POV.pdf

Capgemini, 2019. Accelerating automotive's AI transformation. Available at https://www.capgemini.com/wp-content/uploads/2019/03/30-min-%E2%80%93-Report-3.pdf

CEFIC, 2020. Facts and Figures of the European chemical industry. Available at https://cefic.org/app/uploads/2019/01/The-European-Chemical-Industry-Facts-And-Figures-2020.pdf

Cellan-Jones, Rory, 2014. Stephen Hawking Warns Artificial Intelligence Could End Mankind. *BBC News*, December 2

Center for Data Innovation, 2019. Think tank for studying the intersection of data, technology, and public policy. Available at https://www.datainnovation.org/about/

Chakravorti, Bhaskar and Caturvedi, Ravi Shankar, Tufts University, 2017. Digital Planet – How competitiveness and trust in digital economies vary across the world.

China Daily, 2019. AI Training Program Enters Chinese Universities. *China Daily*, April 4. Available at http://www.chinadaily.com.cn/edu/ 2018-04/04/content_35977348.htm

China Watch, 2019. AI Industrial Development Plan to Champion Tianjin as Hi-Tech Hub. *The Telegraph,* 17 April. Available at https://www.telegraph.co.uk/china-watch/technology/ai-tianjin-hi-tech-hub/

CIMBI, 2015. *Center for Integrated molecular brain imaging.* Available at https://www.cimbi.dk/

http://csrankings.org/#/ index?all

City of Pittsburgh Proposal, 2016. *Beyond Traffic: The Smart City Challenge.* Available at https://cms.dot.gov/sites/dot.gov/files/docs/78SCCApplicationsOverview.pdf

Climate Action Tracker organization, 2019. Independent scientific analysis that tracks government climate action and measures it against the globally agreed Paris Agreement. Available at https://climateactiontracker.org/about/

CodaLab Worksheets, 2019. Competitions and findings on machine learning. Available at https://worksheets.codalab.org/worksheets/0x818930127c4d47de84c1ceaadf04d014/

Coding Lab, 2019. *About Us*. Available at https://www.codinglab.com.sg/about/

Contreras, Ivan and Vehi, Josep, 2018. Artificial Intelligence for Diabetes Management and Decision Support: Literature Review. *Journal of Medical Internet Research*, Volume 20

Cordoba, Juan Carlos and Ripoll, Maria, 2013. Beyond Expected Utility in the Economics of Health and Longevity. *Iowa State University, Department of Economics working paper number 13008*

Cornell SC, INSEAD, and WIPO, 2019. The Global Innovation Index: Creating Healthy Lives – The Future of Medical Innovation. Available at https://www.globalinnovationindex.org/Home

Corporate Knights, 2020. An index of the global 100 most sustainable corporations in the world. Available at https://www.corporateknights.com/reports/2020-global-100/2020-global-100-ranking-15795648/

Coursera, 2019. Online learning portal. Available at https://www.coursera.org/

Crunchbase, 2019. *Database for Company Data*. Available at https://www.crunchbase.com/

Crunchbase, 2019. *Database for Company Data*. Available at https://www.crunchbase.com/

CSRankings, 2019. *Computer Science Rankings*. Available at http://csrankings.org/#/ index?all

2. Bibliography

D.

Danish Ministry of Finance and Ministry of Industry, Business, and Financial Affairs, 2019. National Strategy for Artificial Intelligence. Available at https://investindk.com/insights/the-danish-government-presents-national-ai-strategy

Danish Technological Institute and the Innovation Fund Denmark, 2018. *Global Hot-spots of Advanced Technology*. Available at https://innovationsfonden.dk/sites/default/files/2018-09/datamining-of-advanced-technologies.pdf

Delft Imaging, 2020. CAD4COVID. Available at https://www.delft.care/cad4covid/

DMEXCO Trend Survey 1-2020, 2020. Survey of more than 800 digital decision-makers. Available at https://dmexco.com/stories/is-the-coronavirus-pandemic-an-engine-for-the-digital-transformation/

Dong Ji, Dawei Zhang, Jing Xu, Zhu Chen, Tieniu Yang, Peng Zhao, George Lau and Enqiang Qin, 2020. Prediction for Progression Risk in Patients with COVID-19 Pneumonia: the CALL Score. *Clinical Infectious Diseases*

E.

ECB, 2018. Economic Bulletin: The recent slowdown in euro area output growth reflects both cyclical and temporary factors. Available at https://www.ecb.europa.eu/pub/economic-bulletin/html/eb201703.en.html#IDofArticle1

EcoSense, 2019. *Description of EcoSense project.* Available at http://cs.au.dk/research/ centers/ecosense/description-of-ecosense project/

EdTech, 2019. *Government Announces Industry-Funded AI Master's Degrees.* Available at https://edtechnology.co.uk/Article/ government-announces-industry-funded-ai-masters-degrees/

Eisingerich, Andreas B., Bell, Simon J. and Tracey, Paul, 2010. How Can Clusters Sustain Performance? The Role of Network Strength, Network Openness, and Environmental Uncertainty. *Research Policy* 39.2: 239-253

Ernst and Young and Microsoft, 2018. *Artificial Intelligence in Europe. Outlook for 2019 and Beyond.*

ESPAS, 2019. Global Trends to 2030. Available at https://espas.secure.europarl.europa.eu/orbis/sites/default/files/generated/document/en/ESPAS_Report2019_V14.pdf

Estonian Ministry of Economic Affairs and Government Office, 2019a. Estonia's national artificial intelligence strategy. Available at https://www.kratid.ee/in-english

Estonian Ministry of Economic Affairs and Government Office, 2019b. Report of Estonia's AI Taskforce. Available at https://www.kratid.ee/in-english

European Commission, 2017. *Special Eurobarometer 460: Attitudes Towards the Impact of Digitisation and Automation on Daily Life.* Available at http://ec.europa.eu/commfront office/publicopinion/index.cfm/ResultDoc/download/DocumentKy/78998

European Commission, 2018a. *Artificial Intelligence: A European Perspective.* Available at https://ec.europa.eu/jrc/en/publication/artificial-intelligence-european-perspective

European Commission, 2018b. *Coordinated Plan on Artificial Intelligence.* Available at https://ec.europa.eu/digital-single-market/en/news/coordinated-plan-artificial-intelligence

European Commission, 2018c. *EU Startup Monitor 2018 Report*. Available at http://startupmonitor.eu/EU-Startup-Monitor-2018-Report-WEB.pdf

European Commission, 2018d. *Ethics Guidelines for Trustworthy AI*. Available at https://ec.europa.eu/digital-single-market/en/news/ethics-guidelines-trustworthy-ai

European Commission, 2018e. *The European AI Landscape*. Available at https://ec.europa.eu/knowledge4policy/publication/european-ai-landscape_en

European Commission, 2019a. The Digital Economy and Society Index. Available at https://ec.europa.eu/digital-single-market/en/desi

European Commission, 2019b. Strengthening Strategic Value Chains for a future-ready EU Industry. Available at https://ec.europa.eu/docsroom/documents/37824

European Commission, 2019c. *Factsheet: Artificial Intelligence for Europe.* Available at https://ec.europa.eu/digital-single-market/ en/news/factsheet-artificial-intelligence-europe

European Commission, 2019d. *A Sustainable Europe by 2030.* Available at https://ec.europa.eu/commission/publications/reflection-paper-towards-sustainable-europe-2030_en

European Commission, 2020. Coronavirus: Commission launches data sharing platform for researchers. April 20. Available at https://ec.europa.eu/commission/presscorner/detail/en/IP_20_680

Eurostat, 2019. Database for various structural business statistics. Available at https://ec.europa.eu/eurostat/home?

Evans, D.S., Hagiu A., Schmalensee R., 2006. Invisible engines: How software platforms drive innovation and transform industries. Cambridge, MA.

2. Bibliography

F.

FAIA, 2019. *What We Do – 3 Main Functions*. Available at https://faia.fi/

FAOSTAT, 2019. Agriculture and food database. Available at http://www.fao.org/faostat/en/

FCA, 2019. *Regulatory Sandbox.* Available at https://www.fca.org.uk/firms/regulatory-sandbox

Federal Ministry of Economic Affairs and Energy, 2018. *AI Made in Germany.* Available at https://www.de.digital/DIGITAL/Redaktion/EN/Standardartikel/artificial-intelligence-strategy.html

FieldSense, 2019. *Crop Monitoring Made Simple*. Available at https://fieldsense.dk/en/

Finnish Center for Artificial Intelligence, 2020. AI can help tackle the COVID-19 outbreak – these FCAI projects focus on the new coronavirus. April 14. Available at https://fcai.fi/news/2020/4/14/ai-can-help-tackle-the-covid-19-outbreak-these-fcai-projects-focus-on-the-new-coronavirus

Finnish Ministry of Economic Affairs and Employment, 2017. Finland's Age of Artificial Intelligence. Available at https://julkaisut.valtioneuvosto.fi/bitstream/handle/10024/160391/TEMrap_47_2017_verkkojulkaisu.pdf

Finnish Ministry of Economic Affairs and Employment, 2019. Leading the way into the age of artificial intelligence. Available at https://julkaisut.valtioneuvosto.fi/handle/10024/161688

Flanders Investment & Trade. Webpage for economic activities in Belgium. Available at https://www.flandersinvestmentandtrade.com/invest/en/sectors/chemicals

Forbes, 2019. Overview of the 2000 largest public companies. Available at https://www.forbes.com/global2000/#7abf216335d8

Fountaine, Tim, McCarthy, Brian, and Saleh, Tamim, 2019. Building the AI-Powered Organization. *Harvard Business Review*

French Government, 2018. *AI for Humanity.* Available at https://www.aiforhumanity.fr/en/

G.

Gartner Research, 2017. Top Strategic Predictions for 2017 and Beyond: Surviving the Storm Winds of Digital Disruption. Available at https://www.gartner.com/en/documents/3471568/top-strategic-predictions-for-2017-and-beyond-surviving-

Gartner Research, 2018. AI survey. Available at https://www.gartner.com/

Global Innovation Index, 2018. *Global Innovation Index 2018*. Available at https://www.globalinnovationindex.org/analysis-indicator

Google, 2019. *Perspectives on Issues in AI Governance.* Available at https://ai.google/perspectives-on-issues-in-AI-governance/

Google, nd. *Om Google Success Online.* Description provided by Google.

Government of the Netherlands, 2019. Strategic Action Plan for Artificial Intelligence. Available at https://www.government.nl/documents/reports/2019/10/09/strategic-action-plan-for-artificial-intelligence

Government of the United States, 2016 and 2019. National Artificial Research and Development Strategic Plan and Maintaining American Leadership in Artificial Intelligence. Available at https://www.whitehouse.gov/presidential-actions/executive-order-maintaining-american-leadership-artificial-intelligence/

Government Offices of Sweden, 2018. National approach to artificial intelligence. Available at https://www.government.se/information-material/2019/02/national-approach-to-artificial-intelligence/

Graetz, Georg, Michaels, Guy, 2015, "Robots at work," CEP Discussion Paper no. 1335, Centre for Economic Performance, Available at cep.lse.ac.uk.

Growth Lab at Harvard University, 2017. Atlas of Economic Complexity. Available at http://growthlab.cid.harvard.edu/

Guide2research, 2019. *Top Computer Science Conferences*. Available at http://www.guide2research.com/topconf/

2. Bibliography

H.

Hamrin, Jane, 2019. *Sweden to Take up Finnish AI Challenge.* Available at https://www.computerweekly.com/news/252461711/Sweden-to-take-up-Finnish-AI-challenge

Harwell, Drew, 2018. Defense Department Pledges Billions Toward Artificial Intelligence Research. *The Washington Post,* September 7. Available at https://www.washingtonpost.com/ technology/2018/09/07/defense-department-pledges-billions-toward-artificial-intelligence-research/?utm_term=.795148e2a94e

Hastie, Trevor et al., 2019. The Elements of Statistical Learning https://web.stanford.edu/~hastie/Papers/ESLII_print5.pdf

Healthcare in Europe, 2020. AI quantifies COVID-19 in chest CT images, April 27. Available at https://healthcare-in-europe.com/en/news/ai-quantifies-covid-19-in-chest-ct-images.html#

Heidegger, Martin, 1954. The Question Concerning Technology. *Technology and Values: Essential Readings* 99: 113

Hijzen, Alexander and Menyhert, Balint, 2016. *Measuring Labor Market Security and Assessing its Implications for Individual Well-being*. OECD Social, Employment and Migration Working Papers number 175

Hyun-jung, Bae, 2018. *Korea to Build Database for Medical Big Data*. The Investor, February 9. Available at http://www.theinvestor.co.kr/view.php?ud=20180209000809

I.

IDA Ireland, 2017. Ireland AI Island. Available at https://www.idaireland.com/newsroom/publications/artificial-intelligence

IDC, 2018. Western Europe Cognitive/AI Survey, 2018: It's the Eleventh Hour for the European Financial Industry. Available at https://www.idc.com/getdoc.jsp?containerId=EMEA44241518

IHS Markit, 2019. Database for gross value added breakdown by NACE industries. For more information see https://ihsmarkit.com/index.html

ImageNet, 2019. Database with +14 million images to use for visual object recognition. Available at http://www.image-net.org/

Innography, 2019. *Patent Database.* Available at https://www.cpaglobal.com/innography-high-quality-data

Innovation Fund Denmark and McKinsey & Company, 2018. *Bridging the Talent Gap in Denmark: Insights from Female Representation in STEM*

Innovation Fund Denmark and McKinsey & Company, 2019. An AI Nation? Harnessing the opportunity of artificial intelligence in Denmark

International Data Comparison, 2018. Revenue of cognitive / AI software platforms. Available at https://www.idc.com/getdoc.jsp?containerId=US45262419

International Labour Organization. Database for labour statistics. Available at https://ilostat.ilo.org/

International Telecommuncation Union, 2019. Statistics regarding ITC. Available at https://www.itu.int/en/ITU-D/Statistics/Pages/stat/default.aspx

Isaksen, Arne, 2016. Cluster Emergence: Combining Pre-existing Conditions and Triggering Factors*. Entrepreneurship & Regional Development* 28.9-10: 704-723

Irish Department of Business, Enterprise, and Innovation, 2019. Future Jobs Ireland. Available at https://dbei.gov.ie/en/Publications/Future-Jobs-Ireland-2019.html

Ezell, Stephen, 2016. “The impact of digitalization and robotization on employment.” Presentation at “The Next Production Revolution,” OECD conference in Stockholm, November 18, 2016, available from Information Technology and Innovation Foundation, itif.org.

2. Bibliography

J.

James, Gareth et al., 2019. An Introduction to Statistical Learning http://faculty.marshall.usc.edu/gareth-james/ISL/

Jennings, Ralph, 2018. Why Google, IBM & Microsoft are All Expanding in Taiwan This Year. *Forbes,* April 4. Available at https://www.forbes.com/sites/ralphjennings/2018/04/04/why-google-ibm-and-microsoft-all-decided-to-expand-in-taiwan-this-year/#14d5fc085c72

Ji-young, Sohn, 2019. Korea Kick-starts Financial Regulatory Sandbox Experiment. *The Korea Harald*, April 1. Available at http://www.koreaherald.com/view.php?ud=20190401000602

Jones, Charles I. and Klenow, Peter E., 2016. Beyond GDP? Welfare Across Countries and Time. *American Economic Review, Volume 106, Number 9*

Jovanovic, Boyan and Rousseau, Peter L., 2005. General Purpose Technologies. *Handbook of Economic Growth*. Vol. 1. Elsevier.

K.

Kahn, Jeremy and Morales, Alex, 2018. U.K. Unveils $1.4 Billion Drive into Artificial Intelligence. *Bloomberg*, April 26. Available at https://www.bloomberg.com/news/articles/2018-04-25/u-k-announces-1-4-billion-drive-into-artificial-intelligence

Kleiner Perkins, 2018. Internet Trends 2018. Available at https://www.kleinerperkins.com/perspectives/internet-trends-report-2018/

Kurzweil, Ray. *The Singularity is Near: When Humans Transcend Biology*. Penguin, 2005

L.

Lambda, nd. *A Revolutionary New School That Invests in You.* Available at https://lambdaschool.com/

Lehmann, Erik E., and Matthias Menter, 2018. Public Cluster Policy and Performance. *The Journal of Technology Transfer* 43.3: 558-592

Lewis, Gregory, 2017. The most in-demand hard and soft skills. LinkedIn, January 22, 2018.

LinkedIn Economic Graph. Digital representation of the global economy based on 610 million LinkedIn members. Available at https://economicgraph.linkedin.com/

LinkedIn Economic Graph, 2019. AI Talent in European Labour Market. Available at https://economicgraph.linkedin.com/research/ai-talent-in-the-eu

LLB, 2017. *Tech boost: Theresa May doubles talent visas, setting out fund for 'world-class' tech sector.* Available at https://londonlovesbusiness.com/tech-boost-theresa-may-doubles-talent-visas-setting-out-fund-for-world-class-tech-sector-2/

Lohr, Steve, 2018. MIT Plans College for Artificial Intelligence, Backed by $1 Billion. *New York Times*, October 15

2. Bibliography

M.

MADALGO, 2017. *About MADALGO.* Available at http://cs.au.dk/research/centers/madalgo/ about-madalgo/

MADE, 2019. *Innovationsnetværket For Fremtidens Produktion*. Available at https://www.made.dk/innovationsnetvaerk/

Matheson, Rob, 2018. Artificial Intelligence Model 'Learns' from Patient Data to Make Cancer Treatment Less Toxic, *MIT News*, August 9

McKinsey Analytics, 2018. *An Executive's Guide to AI*

McKinsey & Company, 2017. *Shaping the future of work in Europe's digital front-runners*

McKinsey & Company, 2018a. *Artificial intelligence: The time to act is now*

McKinsey & Company, 2018b. *AI adoption advances, but foundational barriers remain*

McKinsey & Company, 2019. *How Artificial Intelligence Will Transform Nordic Businesses*

McKinsey & Company, 2020a: *COVID-19: Briefing materials*. Version April 24. Available at https://www.mckinsey.com/~/media/McKinsey/Business%20Functions/Risk/Our%20Insights/COVID%2019%20Implications%20for%20business/COVID%2019%20April%2013/COVID-19-Facts-and-Insights-April-24.ashx

McKinsey & Company, 2020b. *A global view of how consumer behavior is changing amid COVID-19*

McKinsey & Company, 2020b. *A global view of how consumer behavior is changing amid COVID-19*

McKinsey & Company, 2020d. *Survey: Chinese consumer sentiment during the coronavirus crisis*. Survey period April 15-19

McKinsey Global Institute, 2017. *Artificial Intelligence. The Next Digital Frontier?*

McKinsey Global Institute, 2018b. *Notes from the AI Frontier: Applying AI for Social Good*

McKinsey Global Institute, 2018c. *Notes from the AI Frontier: Insights from hundreds of use cases*

McKinsey Global Institute, 2018d. *Notes from the AI Frontier: Modeling the impact of AI on the world economy*

McKinsey Global Institute, 2018e. *Skill Shift. Automation and the Future of the Workforce*

McKinsey Global Institute, 2019a. *Tech for Good: Smoothing Disruption, Improving Well-being*

McKinsey Global Institute, 2019b. *Notes from the AI Frontier: Tackling Europe's Gap in Digital and Artificial Intelligence*

McKinsey Global Institute, 2019c. AI adoption and use survey. Summary available at https://www.mckinsey.com/featured-insights/artificial-intelligence/global-ai-survey-ai-proves-its-worth-but-few-scale-impact

McKinsey Global Institute, 2019d. SME AI adoption and use survey.

MedTech Europe, 2019. The European Medical Technology Industry. Available at https://www.medtecheurope.org/resource-library/the-european-medical-technology-industry-in-figures-2019/

Mento, Maria Di, 2018. Donors Pour $583 Million into Artificial Intelligence Programs and Research, *Chronicle of Philanthropy*, October 15

Microsoft, 2019. Microsoft Academic Graph. Available at https://www.microsoft.com/en-us/research/project/microsoft-academic-graph/

Microsoft. *Microsoft Research Lab – Montreal*. Available at https://www.microsoft. com/en-us/research/lab/microsoft-research-montreal/

MIT and Harvard, 2017. *The Ethics and Governance of Artificial Intelligence Initiative*. Available at https://aiethicsinitiative.org/

MIT Sloan School, 2019. Winning With AI. Available at https://sloanreview.mit.edu/projects/winning-with-ai/

MIT Technology Review, 2018. *MIT has Just Announced a $1 Billion Plan to Create a New College for AI*. Available at https://www.technologyreview.com/f/612293/mit-has-just-announced-a-1-billion-plan-to-create-a-new-college-for-ai/

MIT, 2019.

My Telescope, 2020. The methodolgy. Available at https://mytelescope.io/methodology-corona-detection

2. Bibliography

N.

National Bureau of Statistics China, 2020. *Retail Sales data* extracted from statistical database April 30. Available at http://www.stats.gov.cn/english/

Nordhaus, William D., 2015. Are we Approaching an Economic Singularity? Information Technology and the Future of Economic Growth. No. w21547. *National Bureau of Economic Research*

Norwegian Ministry of Local Government and Modernisation, 2019. National Strategy for Artificial Intelligence. Available at https://www.regjeringen.no/en/dokumenter/nasjonal-strategi-for-kunstig-intelligens/id2685594/?ch=1

Norwegian Open AI Lab, 2019. *About Norwegian AI Lab.* Available at https://www.ntnu.edu/web/ailab/about

Novo Nordisk foundation Center for Protein Research, nd. *Disease Systems Biology.* Available at https://www.cpr.ku.dk/research /disease-systems-biology/

O.

OECD, 2015. *PISA 2015 Results.* Available at https://read.oecd-ilibrary.org/education/pisa-2015-results-volume-i_9789264266490-en#page46

OECD, 2017. Artificial Intelligence in Society. Available at https://www.oecd.org/publications/artificial-intelligence-in-society-eedfee77-en.htm

OECD, 2017. *Better Life index.* Available at http://www.oecdbetterlifeindex.org

OECD, 2019a. *Talent Attractiveness.* Available at https://www.oecd.org/migration/talent-attractiveness/

OECD, 2019b. *Labor productivity and utilisation.* Available at https://data.oecd.org/lprdty/labour-productivity-and-utilisation.htm#indicator-chart

Open Data Barometer. Data capability in government. Available at https://opendatabarometer.org/4thedition/report/

Open Data institute, 2019. *UK's First Data Trusts to Tackle Illegal Wildlife Trade and Food Waste*. Available at https://theodi.org/article/uks-first-data-trusts-to-tackle-illegal-wildlife-trade-and-food-waste/

Open Knowledge Foundation, 2017. Global Open Data Index. Available at https://index.okfn.org/

Oxford Insights, 2019. *Government Artificial Intelligence Readiness Index 2019*. Available at https://www.oxfordinsights.com/ai-readiness2019

P.

Pan, Xiongfeng, et al., 2018. Innovation Network, Technological Learning and Innovation Performance of High-tech Cluster Enterprises. *Journal of Knowledge Management*

Piątyszek-Pych, Alina, 2013. Determinants of the Emergence and the Development of Clusters / Determinanty Powstania i Rozwoju Klastrów. *Management* 17.1: 58-77

PitchBook, 2018. *Venture Capital, Private Equity, and M&A Database*. Available at https://pitchbook.com/

Porter, Michael E., 1990. The Competitive Advantage of Nations. *Harvard Business Review*

Porter, Michael E., 1998. Clusters and the New Economics of Competition. *Harvard Business review,* Vol. 76. No. 6.

PwC and Microsoft, 2019. How AI can enable a Sustainable Future. Available at https://www.pwc.co.uk/sustainability-climate-change/assets/pdf/how-ai-can-enable-a-sustainable-future.pdf

PwC, 2017a. The Economic impact of artificial intelligence on Ireland's economy.

PwC, 2017b. Sizing the prize: What's the real value of AI for your business and how can you capitalise? Available at https://www.pwc.com/gx/en/issues/analytics/assets/pwc-ai-analysis-sizing-the-prize-report.pdf

PwC, 2018. What doctor? Why AI and robotics will define New Health. Available at https://www.pwc.com/gx/en/industries/healthcare/publications/ai-robotics-new-health/ai-robotics-new-health.pdf

2. Bibliography

R.

Raj Dandekar, George Barbastathis, 2020. Quantifying the effect of quarantine control in Covid-19 infectious spread using machine learning. *medRxiv – the preprint server for health sciences*

Reuters, 2018a. *Israel Hopes New Database Will Make it Medical Powerhouse.* Available at https://www.ynetnews.com/articles/0,7340,L-5224075,00.html

Reuters, 2018b. *Beijing to Build $2 Billion AI Research Park: Xinhua*. Available at https://www.reuters.com/article/us-china-artificial-intelligence/beijing-to-build-2-billion-ai-research-park-xinhua-idUSKBN1ES0B8

Rosenbaum, Eric, 2018. Silicon Valley is Stumped: Even A.I. Cannot Always Remove Bias from Hiring, *CNBC*, May 30

S.

Scherer, Matthew and Lotito, Michael, 2018. *Germany: Germany Announces €3 Billion "Artificial Intelligence (AI) Made in Germany" Initiative.* Available at http://www.mondaq.com/germany/x/764158/new+technology/Germany+Announces+3+Billion+Artificial+Intelligence+AI+Made+In+Germany+Initiative

Schultz, Steven, 2018. *Google to Open Artificial Intelligence Lab in Princeton and Collaborate with University Researchers.* Available at https://www.princeton.edu/news/2018/12/18/google-open-artificial-intelligence-lab-princeton-and-collaborate-university

Scimago Journal Ranking, 2017. *Scimago Journal & Country Rank*. Available at https://www.scimagojr.com/

Scott, Stephanie, Hughes, Mathew and Kraus, Sascha, 2019. Developing Relationships Innovation Clusters. *Entrepreneurship & Regional Development* 31.1-2: 22-45

Shahriari, Kyarash and Shahriari, Mana, 2017. IEEE Standard Review—Ethically Aligned Design: A Vision for Prioritizing Human Well-being with Artificial Intelligence and Autonomous Systems, *IEEE Canada International Humanitarian Technology Conference*

Shakera Halim, 2020. COVID-19 research may be on the horizon with the help of Cerebriu. Health Europa, April 7. Available at https://www.healtheuropa.eu/covid-19-research-on-horizon-with-cerebriu/99203/

Shoham, Yoav, et al., 2018. *The AI Index 2018 Annual Report*. Available at http://cdn.aiindex.org/2018/AI%20Index%202018%20Annual%20Report.pdf

Simula, 2020. Simula is working with the Norwegian Institute of Public Health. Available at https://www.simula.no/news/eng-simula-working-norwegian-institute-public-health

Smart Nation Singapore, 2019. *FinTech Sandbox.* Available at https://www.smartnation.sg/what-is-smart-nation/initiatives/Startups-and-Businesses/fintech-sandbox

SODAS, nd. *About Copenhagen Center for Social Data Science.* Available at https://sodas.ku.dk/about/

Stanford Question Answering Dataset (SQuAD), 2019. Database for testing a systems ability to answer / reading comprehension questions. Available at https://rajpurkar.github.io/SQuAD-explorer/

Stanford University, Institute for Human-Centered Artificial Intelligence, 2019. Artificial Intelligence Index Report. Available at https://hai.stanford.edu/sites/g/files/sbiybj10986/f/ai_index_2019_report.pdf

Startup Genome, 2019. Global Startup Ecosystem Report. Available at https://startupgenome.com/gser2019

Strategic Council for AI Technology, 2017. *Artificial Intelligence Technology Strategy.* Available at https://www.nedo.go.jp/content/100865202.pdf

2. Bibliography

T.

Talent Garden, 2020. Robots Combating COVID-19: An Irish Startups AI Solution for Healthcare. Available at https://talentgarden.org/da/ireland/robots-combating-covid-19-an-irish-startups-ai-solution-for-healthcare/

Tech Nation, 2019. *About Us.* Available at https://technation.io/about-us/

Teknologiradet, 2018. Opportunities, Challenges and a Plan for Norway. Available at https://teknologiradet.no/en/publication/ai-and-machine-learning-possibilites-challenges-and-a-plan-for-norway/

TESA, 2019. *TechSkills Accelerator (TeSA).* Available at https://www.imda.gov.sg /imtalent/about-us/frameworks-and-initiatives/techskills-accelerator--tesa

The Government of the Grand Duchy of Luxembourg, 2019. Artificial Intelligence: a strategic vision for Luxembourg. Available at https://digital-luxembourg.public.lu/initiatives/artificial-intelligence-strategic-vision-luxembourg

The Observatory on Borderless Higher Education, 2019. Think tank on disruptive innovations within education. Available at http://www.obhe.ac.uk/

The State Council of China, 2017. New Generation of Artificial Intelligence Development Plan. Available at https://flia.org/wp-content/uploads/2017/07/A-New-Generation-of-Artificial-Intelligence-Development-Plan-1.pdf

Times Higher Education, 2019. *World University Rankings 2019 by Subject: Computer Science.* Available at https://www.timeshighereducation.com/world-university-rankings/2019/subject-ranking/computer-science

Tortoise Media, 2019. The Global AI Index. Available at https://www.tortoisemedia.com/intelligence/ai/

Tufts University, 2017. Digital Evolution index. Available at https://sites.tufts.edu/digitalplanet/dei17/

Tugend, Alina, 2019. Exposing the Bias Embedded in Tech. *New York Times.* Available at https://www.nytimes.com/2019/06/17/ business/artificial-intelligence-bias-tech.html

U.

UAE, 2019. Region's First Artificial Intelligence Summer/Spring Camps. Available at https://www.aicamp.ae/

UK Government, 2019a. Policy Paper AI Sector Deal. Available at https://www.gov.uk/government/publications/artificial-intelligence-sector-deal/ai-sector-deal

UK Government, 2019b. *£18.5 Million to Boost Diversity in AI Tech Roles and Innovation in Online Training for Adults*. Available at https://www.gov.uk/government/news/185-million-to-boost-diversity-in-ai-tech-roles-and-innovation-in-online-training-for-adults

UK Visas, 2019. *Tier 1 Exceptional Talent Visa for Digital Technology*. Available at http://www.ukvisas.com/tier-1-exceptional-talent-visa-digital-technology/

UNESCO, 2019. Japan Pushing Ahead with Society 5.0 to Overcome Chronic Social Challenges. Available at https://en.unesco.org/ news/japan-pushing-ahead-society-50-overcome-chronic-social-challenges

United Nations, 2015. Sustainable development goals (SDGs). Availability at https://www.un.org/development/desa/disabilities/envision2030.html

United Nations, 2018. E-Government Survey. Available at https://www.un.org/development/desa/publications/2018-un-e-government-survey.html

University of Helsinki, 2018. Finland is Challenging the Entire World to Understand AI by Offering a Completely Free Online Course – Initiative got 1% of the Finnish Population to Study the Basics. Available at https://www.helsinki.fi/en/news/data-science-news/finland-is-challenging-the-entire-world-to-understand-ai-by-offering-a-completely-free-online-course-initiative-got-1-of-the-finnish-population-to

University of Luxembourg, 2020. University Receives Funding to Research COVID-19. April 29. Available at https://wwwen.uni.lu/index.php/university/news/latest_news/university_receives_funding_to_research_covid_19

2. Bibliography

V.

Vinnova, 2018. Artificial intelligence in Swedish business and society – summary. Available at https://www.vinnova.se/contentassets/29cd313d690e4be3a8d861ad05a4ee48/vr_18_09.pdf

W.

Walch, Kathleen, 2018. Is South Korea Poised to be a Leader in AI? *Forbes*, Sep. 7. Available at https://www.forbes.com/sites/cognitiveworld /2018/09/07/is-south-korea-poised-to-be-a-leader-in-ai/#5ba9e565fa2f

Wiggers, 2020. How utilities are using AI to adapt to electricity demands. Venture Beat. April 20. Available at https://venturebeat.com/2020/04/20/utilities-energy-usage-COVID-19-ai-machine-learning/

WIPO, 2019. Global AI Policy, Technology Trends 2019: Artificial Intelligence. Available at https://www.wipo.int/edocs/pubdocs/en/wipo_pub_1055_exec_summary.pdf

Won-Chang, Youn, 2018. Korean Gov.t to Invest 2.2 Tril. Won in AI by 2022. *BusinessKorea*, May 16. Available at http://www.businesskorea.co.kr /news/articleView.html?idxno=22291

Wood, Beth, 2019. *Turing AI Fellowships now Open as Part of Wider UK Government AI Skills Package.* Available at https://www.turing.ac.uk /research/research-programmes/artificial-intelligence-ai/programme-articles/turing-ai-fellowships-now-open-part-wider-uk-government-ai-skills-package

Work in Estonia, 2020. Estonia created Suve, a state-approved automated chatbot to provide trustworthy information during the covid-19 situation. March 23. Available at https://www.workinestonia.com/estonia-created-suve-a-state-approved-automated-chatbot-to-provide-trustworthy-information-during-the-covid-19-situation/

World Bank 2015-2019. Database of R&D expenditure, public expenditure as a percentage of GDP. Available at https://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS

World Economic Forum, 2016. Networked Readiness Index. Available at http://reports.weforum.org/network-readiness-index/

World Economic Forum, 2017-2019. The Global Competitiveness Report. Available at http://www3.weforum.org/docs/WEF_TheGlobalCompetitivenessReport2019.pdf

World Economic Forum, 2019. A Framework for Developing National Artificial Intelligence Strategy. Available at https://www.weforum.org/whitepapers/a-framework-for-developing-a-national-artificial-intelligence-strategy

World Economic Forum, 2019. A Framework for Developing National Artificial Intelligence Strategy. Available at https://www.weforum.org/whitepapers/a-framework-for-developing-a-national-artificial-intelligence-strategy

X.

Xi, Chen, 2019. China to Open 400 Big Data, AI Majors in Universities for Global Competition. *Global Times*, February 26. Available at http://www.globaltimes.cn/content/1140260.shtml

Y.

Yale and Columbia University, 2019. Environmental Performance Index. Available at https://epi.envirocenter.yale.edu/

Youtie, Jan, and Shapira, Philip, 2008. Building an Innovation Hub: A Case Study of the Transformation of University Roles in Regional Technological and Economic Development. *Research Policy*: 1188-1204

Z.

Zuboff, Shoshana, 2019. *The Age of Surveillance Capitalism.* Profile Books