AN AI NATION?

Harnessing the opportunity of artificial intelligence in Denmark

McKinsey & Company

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1. EXECUTIVE SUMMARY

Artificial intelligence (AI) already influences our lives and economy in a multitude of ways, whether filtering unwanted e-mails, automatically recognizing photos of friends on social media, determining malignant cancer cells, controlling air traffic, or determining credit worthiness. Yet we are still only in the beginning of the AI (r)evolution, and AI is set to reshape Danish industries, jobs, and lives over the coming years and decades. Not only does it have the potential to boost GDP growth through increased productivity and innovation, helping both the public and private sectors deliver new products and come up with entirely new solutions to unsolved problems. It also offers an opportunity to fundamentally improve human well-being, including making lives healthier, longer, and filled with more leisure.

Still, the impact of technology is not always positive. History is littered with examples of much more nuanced effects. Electricity brought substantial productivity gains, but also a long transition to an industrial economy, which was accompanied at times by stagnating real wages. Once-thriving manufacturing towns have been depleted by the shift to a technology- and services-based economy. The effects of AI will have a similar duality: It could displace some jobs, but also improve work conditions. It may increase stress by boosting work intensity but could also improve health and longevity if used to drive breakthroughs in personalized medicine and better disease prevention. Its deployment will require new skills, but could also help make education more accessible. It will consume large quantities of energy, but may also help make homes, offices, and vehicles more energy efficient.

In Denmark, AI can become a clear force for good, if properly managed. Possibilities for positive societal impact range from increased environmental sustainability to more meaningful jobs focused on creativity and social skills. However, some of its effects can have both positive and negative implications. For instance, some 40 percent of Danish working hours are estimated to be automatable using current technology, implying a likelihood of both productivity gains and job losses.[1] Our analyses suggest that AI's potential to be a force for good is contingent on it being used to pursue innovation-led growth rather than just cost savings, on employers ensuring that AI diffusion is actively accompanied by transition management that equips employees with new skills, and on the public and private sectors making it a strategic priority to stay ahead of the curve, investing in AI research, data availability, safeguarding of ethical and data privacy concerns, and cross-sectoral collaboration. If policy makers, corporate leaders, educationalists, and other stakeholders can manage the negative effects and proactively capture the upside, the net impact is expected to be positive.

In this report, we aim to:

- Provide a fact base on AI in Denmark, including insights on AI-related innovation, research, and adoption across the public and private sectors
- Stimulate discussion around opportunities and challenges, and hopefully prompt new research that will refine our methodology and insights
- Present a framework of prioritized opportunity areas to inspire policy makers and other stakeholders to grasp the full potential and establish Denmark at the forefront of the AI transformation

[1] McKinsey & Company, 2017

Key insights

- **AI is a general-purpose technology that will impact *all* Danish sectors and industries.** AI will change the rules of the game for Danish companies. While requiring changes to companies' culture and organizational structures, it is also capable of radically increasing productivity and unlocking an array of new products and business models. We estimate that it offers Danish companies DKK 100 to 160 billion of value potential (not adjusted for implementation costs). This may emanate from applications such as predictive maintenance, next-product-to-buy recommendations, and AI-driven hiring and retention. Moreover, AI might create new winners and losers, with companies adopting a proactive AI strategy achieving an operating profit margin about seven percentage points above the industry average. AI's range of applications are far-reaching – from battling cancer to achieving carbon neutrality, it offers opportunities to solve some of the greatest business-related and societal challenges we know of, and even change our everyday lives.

- **AI can be a clear force for good: Denmark has the potential to gain 1.6 percentage points in incremental annual GDP growth by 2030 from AI technologies (equivalent to around DKK 35 billion annually), alongside net welfare benefits that go beyond productivity growth.** AI will help us work smarter and more efficiently. It will facilitate Danish businesses and government actors in delivering new and innovative solutions, and it may give companies access to whole new markets. Although AI will also be costly to implement and may increase unemployment for certain groups, its net effect on the Danish economy is expected to be positive. Its potential to boost Danish GDP is even bigger than that of the first-wave web technologies and early robotics – by a factor of two to three. But AI does not just bring economic benefits; it also has the potential to significantly improve the welfare of Danish citizens by up to 0.4 percent annually in GDP equivalents (corresponding to around DKK 9 billion annually in economic value). Why? Because it will enable innovations that will help Danes live healthier and longer lives filled with more leisure time. Importantly, however, to reap the biggest welfare benefits, Denmark must distribute the gains in a way that limits increases in inequality brought by AI technologies.

- **AI will reshape the Danish labor market and lead to a talent gap of 20,000 to 80,000 people with deep analytical skills by 2030.** AI will require workers to adopt a new set of skills. By 2030, demand for technological skills is expected to increase by more than 50 percent, along with increased demand for social and emotional competencies, while the need for physical and manual competencies will drastically decrease. A key change will be the need for people with deep analytical and AI-specific knowledge. Through analysis of around two million LinkedIn profiles, we identified around 10,000 people with AI-specific skills in Denmark, with the most prominent skills being natural language processing, signal processing, and machine learning. Nevertheless, supply of talent is unlikely to keep pace with demand. Already Danish startups and established enterprises report a significant lack of people with AI-related skills. Demand for AI-specific skills has grown by more than 20 percent annually over the past decade, and as Denmark is neither producing enough graduates with AI-related skills nor re-skilling people fast enough, this is expected to accumulate to a significant skill gap by 2030.

- **Denmark is digitally advanced and has unique strengths that it can leverage to build a competitive advantage within AI**. Denmark is confidently riding the first wave of digitalization, and has one of the most digitally advanced public sectors and a world-class pool of public data. Among Europeans, Danes have the most positive view of robotics and AI, and they rank second in Europe when it comes to mastering the skills that will be needed in the future workforce, such as social cooperation, creativity, and digital skills. Moreover, Denmark is at the forefront of research in several AI sub-disciplines, with particularly strong environments in algorithmics, machine learning for audio, robotics and computer vision, and natural language processing.

- **Nevertheless, Denmark currently trails its peers on readiness for AI adoption and on public and private investments in AI.** Denmark is not yet ready to reap the full benefits of AI; it ranks eight in Europe on readiness for AI, versus first or second on many parameters related to digital adoption. Danish SMEs are far behind on AI adoption, and only 20 percent of large Danish enterprises have included AI as a core part of their corporate strategy. Denmark lags particularly behind on investments. In terms of public investments in AI, Sweden plans to invest the same amount every year that the Danish government in its 2019 strategy for AI has planned for the next eight years. In PE, VC, and M&A investments, when adjusting for GDP, Denmark ranks 25th globally – behind all its Nordic peers. Moreover, Denmark has no cities in the top 50 leading AI eco-systems, and Copenhagen ranks behind peers such as Stockholm, Amsterdam, and Helsinki. This is particularly due to having too few superstar AI researchers and to a lack of leading tech companies that can push the AI frontier. Making the necessary – public and private – investments and building technology clusters that can drive innovation on a local level are some of the key areas critical to building up Denmark's absorption and adoption capacity for AI.

- **The global AI frontrunners, including the U.S., China, Singapore, the UK, and Israel, are implementing ambitious strategies and investing heavily in AI.** There is an immense momentum for AI across continents, led in particular by the U.S. and China, which boast 11 of the top 15 universities in AI and account for more than half of all AI startups in the world. No single European country is a close contender, and Europe has an emerging gap in development and adoption of AI technologies versus the world leaders. By way of illustration, the European Commission's investment in R&D in AI and robotics of around DKK 20 billion through the Horizon 2020 program is only somewhat larger than the amount that China is spending (around DKK 15 billion) on a single AI technology park in a suburb of Beijing. Denmark likely will need to step up its collaboration on AI to become a leading AI adopter.

AI IN DENMARK

Some key points

THE IMPACT POTENTIAL

AI may bring with it up to

DKK ~35

billion annually in additional GDP by 2030

and it has the potential to **improve welfare of Danish citizens** by up to

0.4%

annually by 2030

SKILLS AND TALENT

The **demand for AI-specific skills** in Denmark has grown by more than

20%

annually over the past decade

Today

51%

of **Danish enterprises** say that **lack of talent** is a key barrier to implementing AI

and

35%

of **Danish AI startups** agree that talent is the biggest barrier to working with AI

Towards 2030, demand for **technological competencies** is expected to increase by

55%

By 2030, Denmark will face a **talent gap** of

20,000 to 80,000 people

ADOPTION AND INVESTMENTS

Only

20%

of **large Danish enterprises** have included AI as a core part of their **corporate strategy**

and just

5%

of **Danish SMEs** currently **work with AI**

Denmark ranks

25th

globally on **PE, VC, and M&A investments in AI** when adjusting for GDP

and Copenhagen ranks

65th

as an AI eco-system globally, behind Stockholm, Helsinki, and Amsterdam

RESEARCH

Multiple Danish universities **rank in top 15 in Europe** within AI sub-disciplines

Danish universities plan to **expand the number of AI-related programs** by

23%

per year from 2018 to 2020

Six opportunity areas for Denmark

Harnessing the full potential of AI requires Denmark to be ambitious while also mitigating some of the downside effects, e.g., by up-skilling the workforce.

In this report, we aim to identify opportunity areas for Denmark to position itself as a leading AI adopter and innovator. These are not exhaustive, and should be subject to further analysis and qualification, but can nevertheless serve as a starting point for discussion. More specifically, our core focus has been to identify actions that Denmark can take to promote research, investment, and collaboration that provide fruitful conditions for AI to be turned into innovative solutions that benefit the Danish society. For Denmark to be a leading AI adopter and innovator, a concerted effort across the public and private sectors is necessary. Our analyses indicate that there are six areas in particular that merit attention:

1. **Talent and skills:** Denmark has a well-educated workforce, yet will still face a shortage of 20,000 to 80,000 people with deep analytical skills by 2030. To address this, Denmark should consider working to increase the proportion of graduates in AI-related fields as well as attract international talent. Moreover, Denmark must prepare its younger generation and existing workforce for a world with AI, for instance by equipping children with AI-relevant skills (such as coding) and re-skilling the existing workforce.

2. **Data access:** Denmark has a world-class, though fragmented, pool of public data and a culture of inter-company collaboration that could be leveraged for data sharing. Denmark should consider promoting initiatives to consolidate and increase the compatibility of its public sector data, particularly focusing on modernizing its data regulation and facilitating inter-company collaboration on data sharing.

3. **Research and application:** Denmark has an excellent AI research community and strong institutions for turning research into business applications. Still, there is scope for Denmark to increasingly link cutting-edge AI research with commercial success. Moreover, there is scope for Denmark to further strengthen its research community by attracting a few superstar AI researchers who can act as magnets for other experts and researchers.

4. **SME AI adoption:** Denmark has an industry structure dominated by SMEs, who generally have a technology backlog and lag particularly behind on AI adoption. To address this, Denmark could seek ways to enable easier access to AI talent for SMEs in the shorter term (e.g., through “AI trainers”) and leverage the Danish technology ecosystem further to support SME adoption.

5. **AI clusters and investments:** Denmark has a tradition of collaboration between public and private actors, but no leading AI eco-systems and limited public and private investments in AI. Denmark should consider promoting collaboration among eco-system actors to build one or two AI-related clusters around the biggest Danish cities, leveraging local strengths.

6. **International collaboration:** Denmark has a tradition of international collaboration from being a small, open economy, yet could do more to drive the international AI agenda. Denmark should consider promoting standardization and common legislative frameworks, as well as driving international investments and partnerships, to achieve sufficient scale and enable Denmark to focus on its comparative strengths.

Scope

The scope of this report is to develop a broad view of developments and opportunities in AI, with a deep dive on the current state on innovation and research, both in Denmark and abroad. Other (equally important) topics, pertaining to, for instance, the ethical or legal challenges of AI are not analyzed in depth here.

AI is here defined as the ability by systems or machines to acquire and apply knowledge and data in simulating intelligent behavior. When discussing AI, we mainly refer to AI-related *analysis* and *usage* of data (using techniques such as machine learning, deep learning, natural language processing, and computer vision) rather than *collection* of data, which would otherwise include more adjacent topics such as internet of things and big data. We recognize that AI is a moving target that continue to develop within a wide range of disciplines such as computer science, biomedicine, cognitive science and engineering. What was commonly defined as AI 10 years ago, such as navigation systems, is today a widely applied normality and few consider their navigation system "intelligent" in the same way. So, it is virtually impossible to provide a fixed definition and complete overview across all disciplines and time. Therefore, when assessing its value opportunity, we consider the incremental value of current, known *AI technologies*, recognizing that there will be future waves of development.

The report comprises the following sections:

- A collection of current knowledge on AI technologies and their potential impact
- A view on the global current state on AI, including an analysis of trends among actors in the global AI ecosystem – from universities to startups
- A detailed mapping of the current state of AI in Denmark, laying out the landscape in terms of investments, eco-systems, university activities, adoption in the public and private sectors, and skill levels in the workforce
- An assessment of the economic, welfare, and workforce implications of AI in Denmark
- A catalogue of opportunities and potential priority areas, which may allow Denmark to be a frontrunner on AI adoption and innovation as it has largely done in the first wave of the digital transformation

Methodology

Our results build on extensive McKinsey experience and research, such as an analysis of more than 600 use cases on how AI can contribute to societal well-being, as well as novel models and simulations developed by McKinsey Global Institute (MGI), including a macro-economic model to estimate the impact potential of AI and a model that estimates the broader impact of AI on society in quantitative terms. To understand the demand and supply of deep analytical skills in Denmark, we have analyzed more than three million online job postings, close to two million Danish LinkedIn profiles, and official data from Statistics Denmark. Moreover, to learn from leading AI nations and Denmark's peers, we have conducted extensive research of more than 15 countries' approaches to AI through their official strategies, white papers, communications, and reports, in combination with interviews with local McKinsey experts.

For the purpose of this report, we have interviewed more than 50 people, including university professors within AI, founders of innovative AI startups, public sector officials, and Danish CEOs – some presiding over organizations that are far along the AI journey and some running companies that are just about to embark on it. Moreover, the analyses and the conclusions of the report have been discussed with an advisory board of around 20 experts and stakeholders.

We have conducted three exclusive surveys for this report. First, we have surveyed more than 60 senior executives of the largest Danish enterprises, understanding their current levels of AI adoption, their AI-related ambitions, and the barriers they are facing to achieve those ambitions. Second, we have surveyed almost 60 Danish AI startups that specialize in delivering innovative AI solutions, understanding who they are, what their customer base looks like, and the barriers they face in delivering their AI solutions. Finally, we have surveyed more than 100 bachelor and master students who study AI-related subjects at the Technical University of Denmark, gaining insights into what barriers exist for Denmark to retain and attract students into AI. In addition to the three surveys, we have collaborated with all eight Danish universities to collect data on their current and planned AI activities; they have each provided detailed data on their AI-related courses, programs, researchers, research projects, planned activities, and strategies, to help us create the most wide-range mapping of AI-activities at Danish universities.

All this in combination with insights from an extensive academic literature within the field gives us a comprehensive foundation to provide a perspective on Denmark's current position within AI, the opportunities and barriers it faces, and the potential actions it can take to capture the opportunities of AI technologies.

Contributors

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2. AI'S POTENTIAL

AI is a general-purpose technology that promises to change all industries in the coming years and transform our everyday lives, while providing opportunities to solve some of society's biggest challenges. Though the concept of AI is half a century old, interest in the technology has grown rapidly over the past decade. This has particularly been driven by increased data availability, a lower cost of data processing, and new advanced mathematics, allowing for significantly lower costs of predictions and analytical capacity. Possible applications are far-reaching – from reducing CO2 emissions to battling cancer.

2.1 AI is capable of radically increasing productivity across industries and enabling entirely new solutions to unsolved problems; in some ways it can be compared to the next wave of electricity

AI is a branch of analytics, albeit to the extreme end in terms of sophistication. It can perform tasks that are characteristic of human intelligence (such as planning, recognizing language, learning and responding through a self-selected "decision"). Commercially, AI is the latest step in the digital lifecycle (beyond core and advanced digital technologies) and can be a key driver of competitive advantage, as shown by large tech companies (such as Facebook, Netflix, and Amazon) that have put AI at the center of their business models. We are seeing particularly fast growth in three areas of AI:

- **Text:** Today, a wealth of information can be found in text format (books, articles, social media posts, chat conversations, etc.). AI subfields such as natural language processing can be used to extract meaning and insights from such text, which can be used to make lives easier, help businesses make smarter decisions, or help governments deliver better services.
- **Speech:** AI can also be used for speech recognition, which translates spoken words into text. Some of the world's top tech companies are already offering this feature on various devices through services like Google Home, Amazon Echo, and Siri.
- **Image:** One of the most common uses of AI is image recognition. Present-day internet users, equipped with high-quality mobile cameras, produce and consume huge quantities of image and video content every day. AI can be used to categorize, edit, and parse this image data; Facebook, for examples, uses it for facial recognition when tagging people on users' photos.

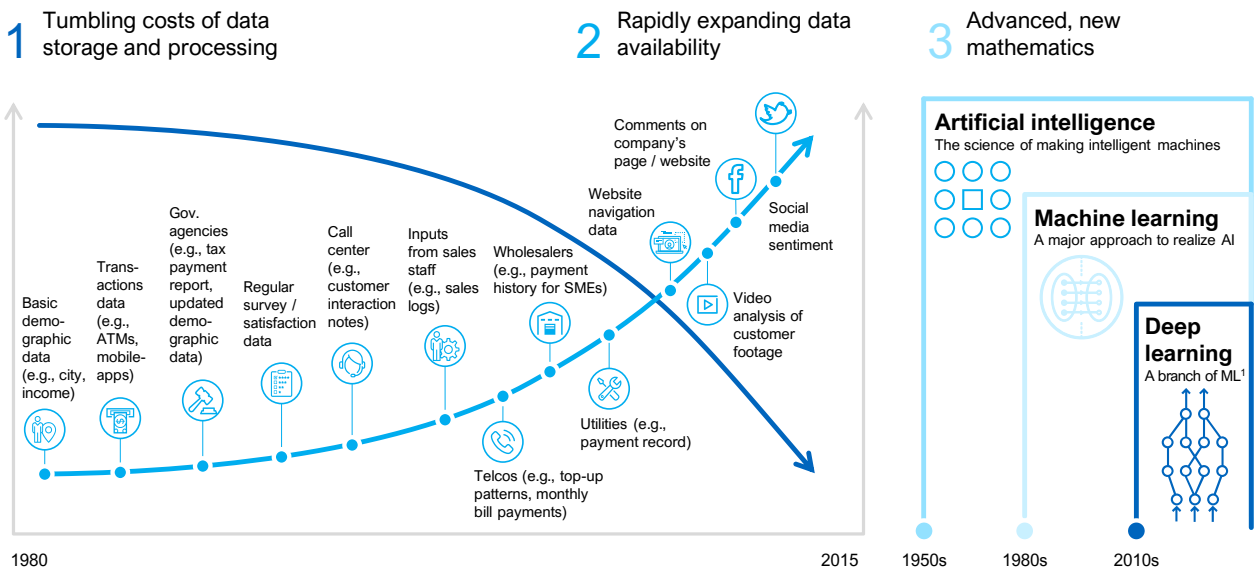
The idea of AI is more than 50 years old; the first self-learning algorithm was developed by American computer scientist Frank Rosenblatt in 1958. So, what is different now? Over the past decade, interest in and uses for AI have exploded. This renaissance can be explained by algorithm advances, increased computing power and storage, and improved data availability.[2] AI now outperforms humans on speech recognition (error rates of about 27 percent by leading models in 1997 versus less than 5 percent error today, surpassing human performance).[3] For instance, the algorithm "Corti" helps the Danish emergency service, 112, identify callers with heart failure by listening to the person's breathing, voice, and words. Though employees at the emergency phone are experts at spotting heart failure (they identify it correctly 75 percent of the time), Corti is even better – it recognizes heart failure correctly 92 percent of the time.[4]

[2] McKinsey Analytics, 2018
[3] An example is Microsoft's speech recognition technology which achieved an error rate of 5.1 percent in 2017
[4] Sundhedspolitisk Tidsskrift, 2018

AI is an industry- and sector-agnostic, general-purpose technology with the potential to impact society on a scale akin to the impact of other general-purpose technologies, such as the 19th century advances in electricity or the development of the internet. General-purpose technologies have three fundamental features: (1) they are *pervasive* and spread to most sectors, (2) they *get better over time,* and hence keep lowering their usage costs, and (3) they *spawn innovation,* making it easier to invent new products, services, or processes.[5] They cause disruption not only through their direct contributions, but also by creating spill-over effects, enabling a wide range of complementary innovations. For instance, the internal combustion engine, another general-purpose technology, gave rise to the car, the airplane, and the modern transportation and logistics network. AI will impact our societies and economies on a similar scale; it will not just shock a single sector or product, it will make analytical capacity affordable and available everywhere, and has the potential to gradually spread to all corners of society.

EXHIBIT 1

THREE TRENDS HAVE PUT AI WITHIN EVERYONE'S REACH



1. Machine learning
SOURCE: McKinsey Global Institute analysis

2.2 AI offers opportunities to solve some of the biggest challenges and will likely impact *all* industries and types of work

AI will help address some of the biggest challenges we face in Denmark (and beyond), from the growing proportion of elderly people and a growing number of lifestyle diseases putting pressure on the health care sector to climate changes from current energy sources and a modern way of life. In this report, we try to estimate the impact beyond GDP from some of these effects (more on this in Chapter 5).

Technology has for centuries both excited the human imagination and prompted fears about its effects. Philosophers and economists from Plato to Karl Marx and Martin Heidegger have given technology a central role in world views that veer between optimism and despondent pessimism.

[5] Jovanovic and Rousseau, 2003

Today's technology cycle is no different, provoking a broad spectrum of hopes and fears. At one end are the "techno-optimists" who emphasize the benefits to the economy and society, and at times promote theories of technology's "singularity," under which rapid growth in computing power and AI accelerates and brings a cascading series of improvements through the economy.[6] At the other end are "techno-pessimists", who worry about the potentially damaging consequences for society, particularly of AI, sometimes in apocalyptic terms.[7] Surveys suggest that most people have a nuanced view of technology but still worry about the risks. While generally positive about longer-term benefits, especially for health, a non-trivial proportion (between 15 and 25 percent) is also concerned about the immediate impact on their lives, in particular in the areas of job security, living standards, safety, equal opportunities, and trust.[8]

Intrinsically, technology is neither good nor bad – it is the use to which it is put that makes the difference. Malicious uses include mass disinformation campaigns, cyberattacks that seek to jeopardize national security, and cyber fraud targeting consumers.[9] Positive uses include applications for early detection and better treatment of diseases such as cancer and diabetes.[10] Most technology applications can generate both good and bad outcomes – sometimes for the same person. While automation and other technologies may threaten some jobs and the living standards of displaced workers, the same technologies can also be a source of new jobs and help people retrain and acquire new skills. They can also reduce the cost of basic goods and services for the same people as consumers.[11]

McKinsey Global Institute has identified ten domains in which AI can create social impact by improving existing solutions. These include healthcare, energy efficiency and sustainability, and (fake) news monitoring for improved information verification and validation. The same research shows that existing AI capabilities can tackle issues across all 17 of the United Nation's Sustainable Development Goals, potentially helping hundreds of millions of people in both advanced and emerging economies.[12]

A few examples illustrate the vast potential of AI for social good in Denmark:

- **AI to reduce deaths and complications after surgery:** The Danish research project WARD monitors high-risk patients to support hospital personnel in reducing deaths and complications post-surgery. Around 30 percent of the 150,000 operations conducted yearly in Denmark lead to serious complications. However, by using sensors to monitor more than 10 different values per patient in real time (e.g., blood pressure, oxygen levels, and heart rate) anomalies can be detected with a bio-medical AI algorithm that can immediately alert the hospital personnel to avoid serious complications.[13]

[6] The notion of singularity is often attributed to mathematician John von Neumann and was popularized in the 1950s and '60s, including by Herbert Simon (1965), and featured more recently in futuristic studies including Kurzweil (2005). For a detailed critique, see Nordhaus (2015)
[7] For example, Stephen Hawking warned that "primitive forms of artificial intelligence we already have proved very useful. But I think the development of full artificial intelligence could spell the end of the human race" (Cellan-Jones, 2014)
[8] European Commission, 2017
[9] Brundage et al., 2018
[10] See, for example, Matheson, 2018; Contreras and Vehi, 2018
[11] McKinsey Global Institute, 2019a
[12] McKinsey Global Institute, 2018a
[13] Innovation Fund Denmark, 2018

- **AI to optimize agricultural output:** The Danish startup Ceptu has created FieldSense, which combines AI with analysis of satellite and weather data to help farmers detect problems before they are visible to humans. Fields are automatically monitored, and farmers receive alarms when specific threats occur, enabling them to take precise and immediate action. The solution can detect diseases up to 14 days in advance of conventional methods.[14]

- **AI to prevent drowning:** The project "Tryghavn" monitors Aalborg harbor with thermic cameras, and uses AI to analyze the data. The technology can alert the authorities when someone enters the water and track the person's position. The technology has already saved several lives.[15]

EXHIBIT 2

AI HAS THE POTENTIAL TO SOLVE A WIDE RANGE OF SOCIETAL CHALLENGES

SOURCE: McKinsey Global Institute analysis

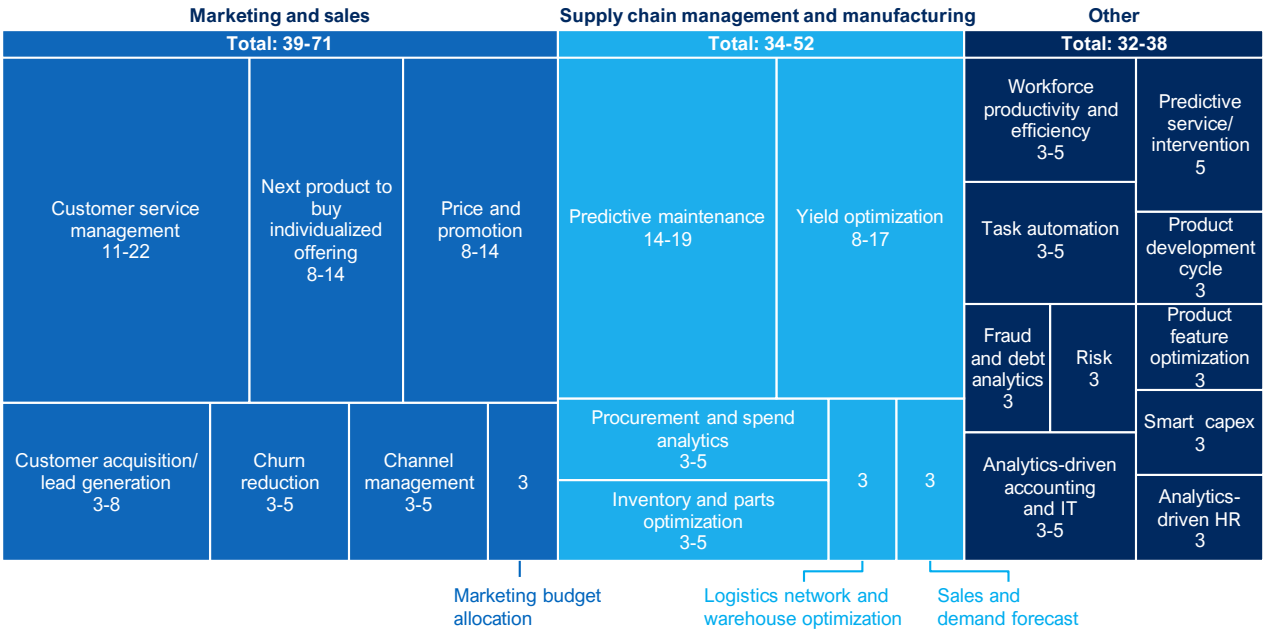
[14] FieldSense, 2019; Landsbrugsavisen, 2018
[15] Tryghavn, 2018; Videbæk and Kosar, 2018

AI is set to radically reshape the way companies do business. From retail to finance, machines are likely to play a growing role in making companies more efficient, responsive, and relevant to customers' lives. AI is not only an automation play. It is also an augmentation and enhancement play. It can provide predictions at a scale and depth of detail impossible for individuals and has the power to transform human behaviors – the prospect of self-driving cars and computer-based healthcare is not far on the horizon. In the future, we are likely to see significantly more organizations shaping their activities and business models around AI and data, which will in many cases become a key strategic asset. As a result, the onus will be on companies to ramp up their systems and capabilities.

AI offers opportunities across all industries and functional domains. Our research suggests that applying AI-techniques we know today can unlock DKK 100 to 160 billion in value in the Danish private sector, equivalent to approximately 2 to 3 percentage points in profit margin uplift.[16] These numbers are based on an analysis of 400 use cases across 19 industries, yet only constitute the direct impact from currently proven AI techniques and applications.[17] But AI should not only be assessed on the basis of its current potential; it also represents a still emerging trajectory that will create winners and losers. For instance, a recent McKinsey study shows that frontrunners could achieve double the cash flow of non-adopters by 2030. This is due to the fact that establishing endowments of data and the right organizational capabilities will be required to harvest AI's full potential, and establishing such assets and capabilities take time, creating clear first-mover advantages.

EXHIBIT 3

DANISH AI IMPACT BY CAPABILITY TYPE, DKK BILLION



Numbers may not sum up due to rounding. Not to scale
SOURCE: McKinsey Global Institute analysis

[16] McKinsey & Company, 2019
[17] For this analysis, we explicitly considered techniques related to "deep learning", "reinforcement learning", and "transfer learning"

Ethics and frontier technologies: A burgeoning field of research and debate

The rapid recent progress in AI and other frontier technologies means that cars that drive themselves, AI-powered mass surveillance systems, autonomous weapons, and other smart applications that can affect human life – potentially catastrophically – are no longer science fiction. At the same time, we are increasingly using algorithms as tools to make decisions in highly sensitive areas, including hiring, criminal justice, and healthcare, sometimes without fully understanding how the algorithms reach their conclusions.

These developments have sparked a growing debate about the ethics of this new technological era: Can we teach machines to "behave" according to accepted human ethical norms – and if so, what are those norms? How do we counteract bias in algorithms trained on data sets that largely reflect our own human bias? And what should businesses and governments do to draw the line between right and wrong in a machine learning world?

Academic researchers, business leaders, policy makers, and technical professional bodies are looking carefully at the social uses and potential abuses of AI. In recent months, donors including technology company executives have stepped up funding for major programs. Massachusetts Institute of Technology's (MIT's) Media Lab, Harvard's Berkman Klein Center for Internet and Society, Stanford University, and the University of Toronto are among institutions studying the implications of AI, including how it will affect people's lives and serve humanity.[18] International organizations such as the European Commission and the United Nation's International Telecommunication Union have created working groups and frameworks for "trustworthy" AI and its ethical use.[19] Individual governments are increasingly publishing white papers and guidelines, even as they outline national AI research and development programs.[20]

Identifying problems and flashpoints is an essential first step – and the exercise can at times hold up a mirror to human failings. The issue of bias and fairness is one example. Algorithms can embed human and societal biases and deploy them at scale. For example, an analysis by ProPublica of scores used to predict future criminal activity in Broward County, Florida, showed that algorithms were nearly twice as likely to incorrectly label African-American defendants as higher risk as to incorrectly label white defendants.[21] Researchers at MIT have found that error rates in facial analysis technologies differed by race and gender – with a much higher error rate for black women than for white men.[22][25] These failings, however, largely reflect biases in society and in the historical data used to train the algorithms. It may be argued that AI can actually reduce subjective interpretation of data, as machine learning algorithms learn to consider only the variables that improve their predictive accuracy. To quote Andrew McAfee of MIT, "If you want the bias out, get the algorithms in."[23]

Beyond the theoretical discussion is the more difficult practical application of ethical decisions. How do we ensure that AI outputs are fair; that new levels of personalization do not translate into discrimination; that data acquisition and use do not sacrifice individuals' privacy; and that organizations balance transparency about how decisions are made with the performance benefits of AI? It is likely that regulation will be required to ensure democratic and ethical development. Denmark has widespread trust in the public sector and democratic values anchored deeply in society – perhaps Denmark could invest in an ethics-focused "AI for the people" as a specific skill center for the country?

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[18] Lohr, 2018; Mento, 2018; MIT and Harvard, 2017
[19] See European Commission, 2018b; World Economic Forum, 2018b; Shahriari and Shahriari, 2017
[20] For a list of European AI initiatives, see Autuly, 2019
[21] Angwin et al., 2016
[22] Buolamwini and Gebru, 2018
[23] Rosenbaum, 2018

3. THE AI FRONTIER – GLOBAL TRENDS

There is an immense momentum for AI right now across all continents, though particularly in China and the U.S. Countries across the globe are designing their nation-wide approaches; merely since the beginning of 2018, more than 15 countries have launched national strategies for AI. From analyzing countries' approaches to AI, we find that there is no one-size-fits-all approach. Each country must take an approach to AI that fits with the size and structure of its economy. The most important thing is that countries take a proactive and ambitious approach – at least, all the global leaders on AI do. Indeed, AI leaders, whether governments, universities, enterprises, or startups are investing immense sums in AI. Danish policy makers and business leaders should therefore keep in mind that a concerted effort across the economy may be required to stay ahead of the curve on AI adoption and innovation.

3.1 The global dynamics – China and the U.S. are leading, while countries in Europe are falling behind

The U.S. and China are leading the race on AI, while Europe lags on adoption and diffusion. For instance, looking at digital information and communication technology (ICT) as a percentage of GDP in 2017, Europe was at less than half of that of the U.S. (1.66 percent vs. 3.33 percent).[24] Not one of the ten biggest internet companies is European. Now, since digital tools are arguably the most important precondition for diffusion of AI, Europe's digital gap is affecting its ability to fully leverage the promise of AI, and so Europe's digital gap versus the world's leaders is now being compounded by an emerging gap in adoption of AI technologies.

Of course, Europe is not standing still on digital and AI. Some metrics suggest considerable momentum. For example, European countries are now investing four times more capital in tech than five years ago, and the UK announced an investment of DKK 8 billion from the private and public sectors in April 2018, with initiatives such as 200 doctoral studentships in AI, a national AI retraining scheme and an increased number of visas for specialized talent.[25]

Nevertheless, the U.S. has a well-established top position. Leading companies in AI (e.g., Facebook, Google, Amazon, Apple, Microsoft, Netflix) have headquarters in the U.S., which is partly a result of a large military spend and the presence of a majority of the top universities within AI. Between 2012 and 2018, the U.S. invested more than 20 times as much in AI and big data companies than Europe – DKK 1,500 billion versus DKK 70 billion.[26] The American digital ecosystem, largely based in hubs such as Silicon Valley, Seattle, and Boston, is large, innovative, and diverse, encompassing private companies, world-leading research institutions, universities, and governmental institutions, including the military. In 2015, the top ten Silicon Valley startups achieved a turnover in ICT of approximately DKK 4,000 billion.[27]

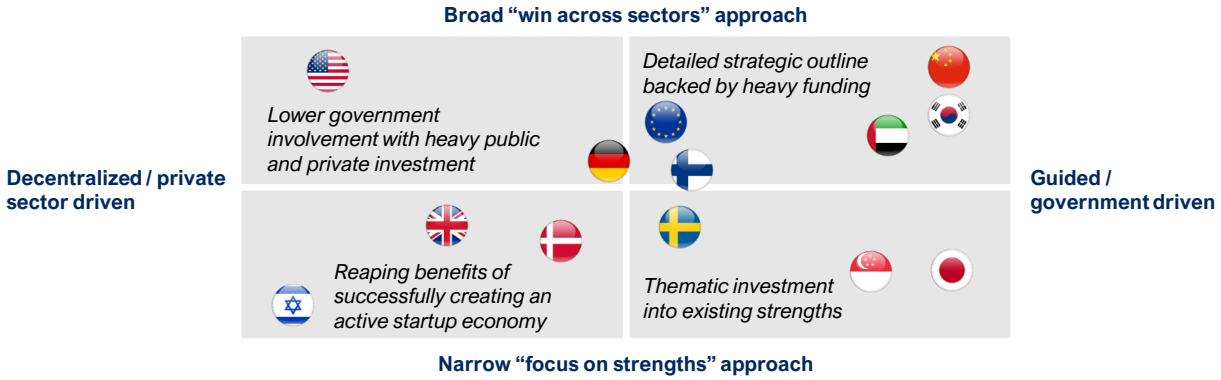
Still, while the majority of investments in the last ten years have come from the U.S., Chinese investments have grown more rapidly, amid aggressive government financial support and military spend, flexible legalization, and massive amounts of data. On the talent side, the Chinese government has said it will establish 400 majors in big data, AI, and robotics during 2019, help train 10,000 science teachers through an online portal, and cultivate AI talent through five-year talent programs with a goal to educate 5,000 AI

[24] McKinsey Global Institute, 2019b
[25] Kahn and Morales, 2018; UK government, 2019a
[26] McKinsey analysis based on Pitchbook VC, PE and M&A investments in AI and big data companies
[27] McKinsey Global Institute, 2019b

students.[28] Also on the research side, China is leading the way; it has more than four times the cumulative number of patent applications than Europe, and though Europe in 2017 had more AI publications than China (approximately 17,000 in Europe versus approximately 15,000 in China), China is likely to overtake Europe as it experienced annual growth of 17 percent from 1998 to 2017 versus Europe's nine percent growth rate over the same period.[29]

EXHIBIT 4

CATEGORIZATION OF COUNTRY AI STRATEGIES



SOURCE: Country strategies; McKinsey analysis

3.2 China and the U.S. take broad "win across sectors" approaches, while non-European frontrunners and Denmark's peers often take a narrower "focus on strengths" approach

In general, large economies such as China and the U.S. take a broad "win across sectors" approach to AI (see exhibit 4). However, they differ in terms of government involvement – the Chinese government is more directly involved in driving the agenda than the U.S. government. Some smaller economies take a similar approach. For instance, South Korea is positioning itself as a frontrunner with a similar "win across sectors" approach, setting highly ambitious targets for the development of AI talent, backed by significant public investments.[30]

Other countries, such as Japan, Singapore, and Israel are successfully taking a narrower "focus on strengths" approach. In this case, the AI agenda is being driven in industries within which the countries already have a strong starting position. Japan, for example, focuses on healthcare, agriculture, infrastructure, and smart cities as part of the development towards *Society 5.0*, in which AI is perceived as essential in realizing an inclusive, human-centered, and sustainable society.[31]

There is no "one size fits all" approach and it is uncertain whether either of the strategies outlined above would suit Europe. However, Europe is falling behind in terms of investments and clarity of direction. Despite policy makers' calls to prioritize AI, there appears to be limited appetite for unlocking synergies across the European area. As a result, AI initiatives remain fragmented and investment is low. Consider, for instance, that the European Commission's DKK 20 billion investment in R&D in AI and robotics through the Horizon 2020 program is only slightly more than the amount that China is spending (around DKK 15 billion) on a single AI technology park in a suburb of Beijing.[32]

[28] Xi, 2019; China daily, 2018
[29] Danish Technological Institute and The Innovation Fund Denmark, 2018; Shoham et al., 2018
[30] Walch, 2018
[31] Strategic Council for AI Technology, 2017; UNESCO, 2019
[32] European Commission, 2019; Reuters, 2018b.

From our analyses, we see that four main categories of actors are key ingredients of any AI ecosystem:

1. **Governments,** which provide a governing structure and financial support
2. **Universities,** which develop pioneering solutions and educate the next generation of talent
3. **Enterprises,** which supply business problems and data to developers and financial support
4. **Startups,** which pioneer new AI applications while attracting talent and capital

Major advancements in AI are happening now and this means that the AI landscape is changing fast. Across the four types of actors, several trends are emerging.

3.3 Governments: The leading governments within AI are investing heavily, pushing strategies for talent development and research, and setting up governing bodies to capture AI's full potential

Across the world, AI is high on government agendas, and it has the potential to permeate all corners of the public sector – whether citizen services, military activities, or legislative processes. Among recent initiatives, the U.S. Department of Defense has said it will invest more than DKK 13 billion in new AI programs, Japan is to increase its science and innovation budget by DKK 55 billion by 2020, and Tianjin, a single city in China, plans to support AI industrial development with an investment of DKK 10 billion.[33]

AI frontrunners are implementing strategies for developing talent and for pushing the AI research frontier. For instance, Finland has developed a free online AI course, "Elements of AI", with the goal of teaching one percent of the population the basic concepts behind AI, while the United Arab Emirates has launched six AI summer camps in collaboration with Microsoft, SAP, Careem, IBM, Oracle, and Autodesk.[34] On the research side, many governments are taking an active role in pushing AI research and innovation, from establishing open AI labs for basic and applied interdisciplinary AI research (Norway) to helping global companies such as Google and Microsoft recruit local talent to increase the attractiveness of establishing a headquarter in the country (Taiwan).[35]

Some of the most ambitious governments are starting to think about setting up distinct government institutions to drive their AI efforts as well as seizing the opportunity to think strategically about the societal impact they want AI to have. For instance, the UK has assigned responsibility to three individual agencies for strategic leadership, implementation, and ethical innovation of AI, while the French government is thinking about both the positive and negative impact of AI on environmental sustainability.[36] AI offers incredible opportunities to transform the public sector and the lives of its citizens, and the most ambitious governments are setting up the frameworks, targets, and governing bodies to seize those opportunities.

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[33] Harwell, 2018; Fuyuno, 2017; China Watch, 2019
[34] University of Helsinki, 2018; UAE, 2019
[35] Norwegian Open AI lab, 2019; Jennings, 2018
[36] UK government, 2019a; French government, 2018

3.4 Universities: AI research and teaching are rapidly growing fields, in which the U.S. and China are taking the lead

For AI to continue its progress, both in terms of developing and diffusing the technology, it requires research and talent – requirements for which universities play a central role.

On this point, the trends look positive. The amount of research and the number of AI graduates being educated have seen rapid growth in recent years. The number of AI papers published annually grew more than eightfold from 1996 to 2017, which is one third more than the growth in computer science papers during the same time period. Similarly, the number of AI patents rose more than tenfold from 2007 to 2017. The U.S. and China are taking the lead on AI research, with approximately three quarters of all AI patents being held by the two countries. Furthermore, ranking universities on three key parameters (including size of AI faculty, researchers' computer science citations, and publications at top AI conferences), we find that 11 of the top 15 universities are situated in the U.S. and that China is the only other country to have two universities in the top 15 – see exhibit 5. Those leading institutions are investing heavily in the field. For instance, MIT has committed DKK 7 billion in long-term funding for AI, and Stanford University has launched a new research center, the Stanford Institute for Human-Centered Artificial Intelligence, that combines over 200 faculty from seven schools at the university in researching AI technologies and applications.[37]

Correspondingly, on the teaching side, there has been rapid growth; for instance, leading universities within AI saw a four to five time increase in AI course enrollment from 2012 to 2017. Online courses have also become increasingly popular – the most popular AI course on Coursera has more than two million people enrolled and the machine learning courses on the platform saw more than a 55 percent increase in enrollment from 2016 to 2018.[38]

[37] MIT Technology Review, 2018; Adam, 2019
[38] Data provided by Coursera

EXHIBIT 5

TOP 15 GLOBAL UNIVERSITIES FOR AI-RELATED RESEARCH AND EDUCATION WITHIN COMPUTER SCIENCE

Rank	Universities	Computer Science[1] (CS) Citations Index (weight = 50%)	AI Conference Index (weight = 30%)	AI Faculty Size Index (weight = 20%)	Overall Index
1	Stanford University	100.0	88.8	87.2	94.1
2	Carnegie Mellon University	94.5	90.8	95.5	93.6
3	University of Texas at Austin	95.9	89.4	80.4	90.8
4	Cornell University	89.7	84.7	87.6	87.8
5	University of California - Berkeley	94.8	75.1	88.0	87.5
6	Massachusetts Institute of Technology	95.3	71.7	89.8	87.1
7	University of California, Los Angeles	87.3	90.0	79.7	86.6
8	University of Washington	93.1	77.2	82.7	86.2
9	Georgia Institute of Technology	89.2	81.4	86.1	86.2
10	Tsinghua University	82.5	81.7	100.0	85.8
11	ETH Zurich	92.8	77.9	79.7	85.7
12	The Hong Kong University of Sci. & Tech.	87.9	84.0	80.4	85.2
13	University of Illinois at Urbana-Champaign	90.4	75.3	85.0	84.8
14	University of California, San Diego	90.7	77.9	80.4	84.8
15	University of Toronto	90.0	74.8	84.6	84.4

CS Citations Index

Measures both quality and quantity of AI research, as it measures the associated researchers' citation amount

Combines 3 citation indices:
- QS H-index (2018)
- QS citations (2018)
- THE citations (2019)

AI Conference Index

Measures the quality of AI research, as it expresses the number of publications at top AI conferences[2] controlling for AI researchers affiliated with the university in the period from 2014 to 2018

AI Faculty Size Index

Expresses the number of top researchers working within AI

Measures the number of researchers publishing at top AI conferences in the period from 2014 to 2018

Note

All indices are relative (e.g., faculty size index does not directly show number of researchers)

See deep dives on individual indices in the appendix for more details

1. Only based on computer science departments – a drawback is that it does not capture relevant research done in other disciplines, e.g., engineering
2. As defined by CSRankings

SOURCE: McKinsey analysis based on Times Higher Education, QS Top Universities, and CS Rankings

3.5 Enterprises: Enterprises are leading the way on AI innovation and research, aiming to capture the immense value potential of AI for businesses, estimated to a potential of DKK 23 to 38 trillion in annual value across sectors

It is not just universities that invest in AI research; some of the institutions at the absolute forefront of AI research are enterprises such as Google, Amazon, Samsung, and Netflix.[39] Seven of the 20 most represented organizations at the top ten AI conferences in 2014 to 2018 were industry players, and 26 of the top 30 AI patent holders are companies. The leading players try to solidify their position by intensifying the battle for top AI talent (e.g., offering researchers 10 times their academic salaries), building new research labs, and ramping up AI startup acquisitions. For instance, IBM has in collaboration with MIT invested approximately DKK 1.5 billion in establishing the IBM-Watson AI Lab and Samsung has established a total of seven global AI centers in five countries across the world.

Companies are investing because they believe that AI represents an extraordinary business opportunity – and the data supports that. However, data also supports that AI is not only

[39] In addition to commercial research, several of the leading tech companies are also launching white papers on the governance and ethical issues regarding AI – see for example Google (2019) "Perspectives on Issues in AI Governance"

relevant to big tech. In fact, it has the potential to impact almost all industries and functions, whether it be to optimize price, enhance yields in manufacturing, recommend next product to buy, predict maintenance, inform hiring and retention, optimize inventory and parts, or boost customer service management. According to McKinsey research, AI has the potential to create DKK 23 to 38 trillion globally and (as previously mentioned) DKK 100 to 160 billion in Denmark in annual value across industries, with the value potential as a percentage of industry revenues ranging from 1.4 percent in the public and social sector to 10.2 percent in high tech and 11.6 percent in the travel industry.[40]

In 2018, 19 to 30 percent of companies across continents had embedded AI capabilities in at least one business unit, and just as many were piloting AI in one or more business units.[41] Competitive pressure is the main driver for AI adoption, as companies fear they may be at a competitive disadvantage if they do not match rivals' investments. Research by the McKinsey Global Institute indicates that perceived competition increases the probability of AI adoption by about 51 percent.[42] This focus by companies on competitive pressures may, however, miss the fact that being proactive can unlock significant additional value; companies with a proactive AI strategy achieve an operating profit margin about seven percentage points above the industry average, McKinsey research shows.[43]

AI will determine the winners and losers of tomorrow. Taking a proactive approach will help enterprises beat the odds and gain a competitive advantage in a fast-moving marketplace.

3.6 Startups: Startups are at the forefront of AI innovation, and some of the most valuable companies of today and tomorrow are AI startups.

Several of the most valuable companies today did not exist a few years ago (e.g., Google, Facebook, Alibaba, and Amazon are all less than 25 years old). Similarly, some of the most valuable companies 20 years from now are likely not founded yet – and AI startups will likely be among those. In fact, some of the most valuable recently-launched companies were AI startups. In early 2019, there were 32 AI unicorns globally, with the most highly valued being the Chinese ByteDance (valued at approximately DKK 500 billion), which operates several machine learning enabled platforms, including its flagship product Jinri Toutiao ("Today's Headlines"), a news aggregation service that uses AI to track reader habits and push stories from various sources.[44]

Today, the global AI startup landscape is dominated by the U.S. – 77 of the top 100 AI startups are located there.[45] In the U.S., the number of active AI startups rose 113 percent from 2015 to 2018, compared with a 28 percent rise in the overall number of active startups in the U.S.[46] The U.S. leads the global AI ecosystem with 40 percent of all startups, while some of the contenders include China (11 percent) and Israel (ten percent), with Israel greatly outperforming its size. If we take Europe as a whole, it pushes China out of second place, with 22 percent of the global total; however, the European ecosystem is fragmented, and no individual European country achieves critical mass – the UK ranks fourth (seven percent), France seventh (three percent), and Germany eighth (three percent) globally.[47]

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[40] McKinsey Global Institute analysis
[41] McKinsey & Company's Global AI Survey of February 2018 with 2,135 participants
[42] McKinsey Global Institute analysis
[43] McKinsey & Company, 2019
[44] Singularity hub, 2019.
[45] Bessen et al., 2018
[46] Shoham et al., 2018
[47] Asgard and Roland Berger, 2018

4. AI IN DENMARK – THE CURRENT STATE

Denmark is at a good starting point for AI adoption, yet still has some way to go to become a leading nation within AI adoption. Our analyses in this chapter shed light on some of the challenges that Denmark must overcome to establish itself at the forefront of the AI frontier, including low levels of public and private investment, a lack of leading AI eco-systems, a fragmented data infrastructure, and a growing shortage of people with relevant analytical skills. However, we also point out some of the unique strengths that Denmark can leverage on that journey. For instance, Denmark has one of the most digitized public sectors, its enterprises are in general ahead on the adoption of first wave digital technologies, it has a well-educated workforce and a strong research community in certain AI disciplines. Those strengths and weaknesses are summarized below:

KEY OPPORTUNITIES	KEY CHALLENGES
+ A high level of readiness on digital adoption when it comes to first wave digital technologies	÷ Low levels of private sector investments in AI compared with global leaders; also when adjusting for GDP
+ A world-class pool of public data	÷ No leading city-level AI eco-systems in Denmark
+ A well-educated workforce	÷ Low levels of AI adoption among SMEs
+ A strong AI research community within sub-disciplines of AI	÷ A large, and growing, shortage of people with deep analytical skills relevant to AI deployment
+ Agile and non-hierarchical organizations	

4.1 Denmark's readiness for AI adoption: Denmark has come far on the digital journey but still has a long way to go regarding AI

Denmark is confidently riding the first wave of digitalization, with one of the most digitized public sectors, tech-savvy employees, and a population that holds a positive view of AI. Danes have the most positive view of robotics and AI in Europe and three quarters of Danish employees have a positive view of the effects of automation on their professional lives.[48] Danes rank second in Europe when it comes to mastering the skills that will be needed in the future workforce, such as social cooperation, creativity, and digital skills.[49] Danish companies have adopted the first wave of digital technology – a critical precondition for implementing and leveraging AI technologies – and the Danish public sector has a strong data infrastructure. Denmark ranks fourth in Europe in terms of digital ICT as a share of GDP, with relative levels comparable to those of China.[50]

[48] European Commission, 2017; Fagbevægelsens Hovedorganisation, 2019

[49] According to McKinsey's Future Skill Index. The index is based on more than 50 variables assessing countries' strengths within four core skill categories needed for the future of work – digital skills, problem solving and creativity, basic cognitive skills, and social and cooperation

[50] European Commission, 2018a; McKinsey Global Institute analysis

A recent McKinsey analysis assessing countries in terms of their technological readiness supports this conclusion. The analysis looks at a wide range of indicators for adoption readiness, including education and digital skills, share of people employed in knowledge-intensive services, unemployment benefits, technology venture capital spend per capita, and R&D expenditure in ICT. According to this, Denmark ranks third in Europe in terms of its ability to adopt digital technologies. However, Denmark has not adopted AI to the extent that would be expected given its strong starting point. According to the OECD, Denmark ranks eighth in Europe on diffusion of big data and AI technology, while an analysis by McKinsey Global Institute also ranks Denmark eighth in Europe on its readiness for AI adoption, and an analysis by Oxford Insights focusing particularly on government AI readiness ranks Denmark ninth among OECD countries.[51] In all analyses, Denmark ranks below peers such as Finland and the UK, with a low score on adoption of AI in the economy as well as AI investment and R&D expenditure.

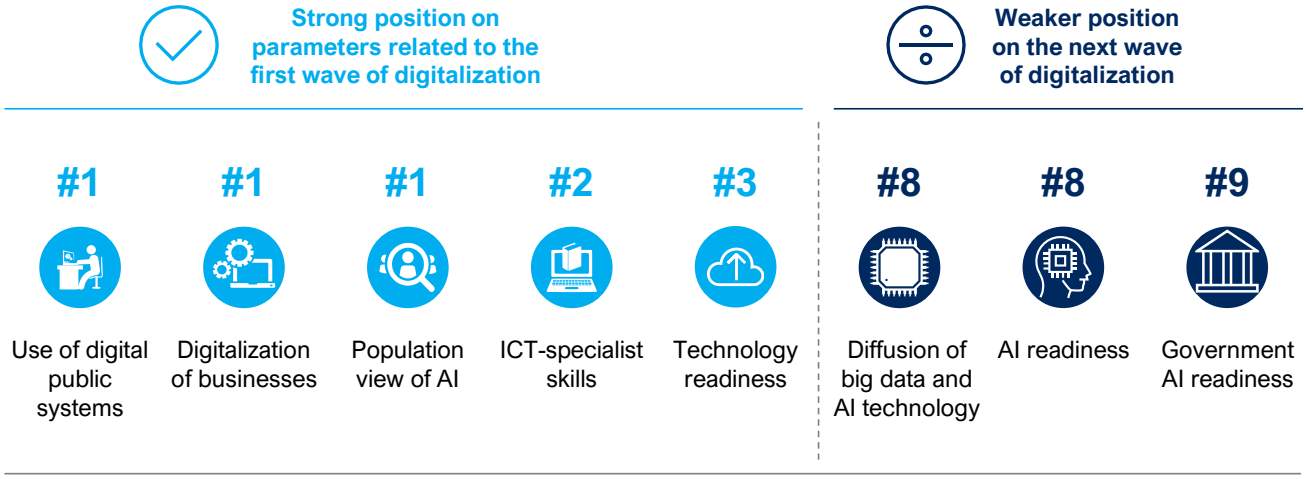
Denmark is not ready to reap the full benefits of AI yet. However, it is at a strong starting point, and it is well within reach for to become a frontrunner on AI adoption and innovation.

In the following sections, we present the key findings of our analyses of the Danish AI eco-system, which are based on a wide range of both primary and secondary sources, including exclusive surveys and interviews. The analyses reinforce the notion that there is indeed huge potential – but also still work to be done.

EXHIBIT 6

DENMARK'S POSITION ON DIGITAL AND AI ADOPTION

Denmark's ranking among OECD / European countries



SOURCE: The European Commission; OECD; Oxford Insights; McKinsey analysis

[51] Oxford Insights, 2019

4.2 The level of investment: Denmark is trailing both European and global leaders on AI investments

To assess Denmark's level of investments in AI compared with those of other countries, we have developed an index that references a diverse set of dimensions, including the level of capital investment, the presence of AI companies, the number of AI patents, and the cognitive / AI software market size (see detailed description below and in appendix 2). Ranking countries on their absolute levels of AI investment, the U.S. and China, unsurprisingly, rank first and second. The remainder of top five are Israel (third), United Kingdom (fourth), and Canada (fifth). In this ranking, Denmark is not able to keep up, which, of course, is also due to the size of the Danish economy.

Adjusting for population size and GDP to provide a relative and fairer picture of Denmark's performance versus peer countries, Denmark is among the group of most well-placed countries, securing a tenth place globally. However, it is worth to note that Denmark is behind peers such as Finland and Sweden. In particular, Denmark does not have a mature capital market to the same extent as, for instance, Sweden; Denmark ranks 25th in the world on private equity (PE), venture capital (VC), and mergers and acquisitions (M&A) investments in AI. To some extent, this might be due to a lack of AI startups to invest in, but it is also a general reflection of Denmark having a limited capital market for Danish startups and enterprises to tap into. Looking ahead, there is reason to worry since Denmark lags behind on making the massive public and private investments necessary to maintain a leading position on AI adoption.

EXHIBIT 7

GLOBAL RANKING ON AI INVESTMENT, 2008-18

Top 10 countries in absolute terms

Country
#1 United States
#2 China
#3 United Kingdom
#4 Canada
#4 Japan
#6 India
#7 France
#8 Israel
#9 Germany
#10 Australia

Top 15 countries when adjusting for population/GDP

Country	1 PE, VC and M&A investment	2 Number of AI companies	3 AI patents and publications	4 AI market size	5 Diffusion of AI and big data
#1 Israel	1	1	25	N/A	N/A
#2 Singapore	5	2	2	N/A	N/A
#3 United States	2	4	15	1	N/A
#3 Finland	15	3	17	4	4
#5 United Kingdom	6	5	13	5	3
#6 Canada	7	5	6	6	N/A
#7 Switzerland	20	9	5	2	N/A
#8 Estonia	9	10	41	N/A	6
#9 Ireland	23	5	6	18	N/A
#10 Sweden	18	5	10	8	12
#10 Denmark	25	11	10	3	8
#12 France	12	13	34	12	10
#13 Netherlands	38	13	19	9	1
#13 Hong Kong	3	21	16	N/A	N/A
#15 Norway	8	13	22	10	N/A

Malta, Luxembourg, Iceland, Macau and Guam have been excluded from the rankings due to small population. Rank based on equal weighted median of each metric.
SOURCE: McKinsey analysis based on Pitchbook, Asgaard, SJR, Innography, IDC, OECD

4.3 Danish cities' performance as AI eco-systems: The development and commercialization of AI is centered in relatively few geographical eco-systems and none of the leading eco-systems are located in Denmark

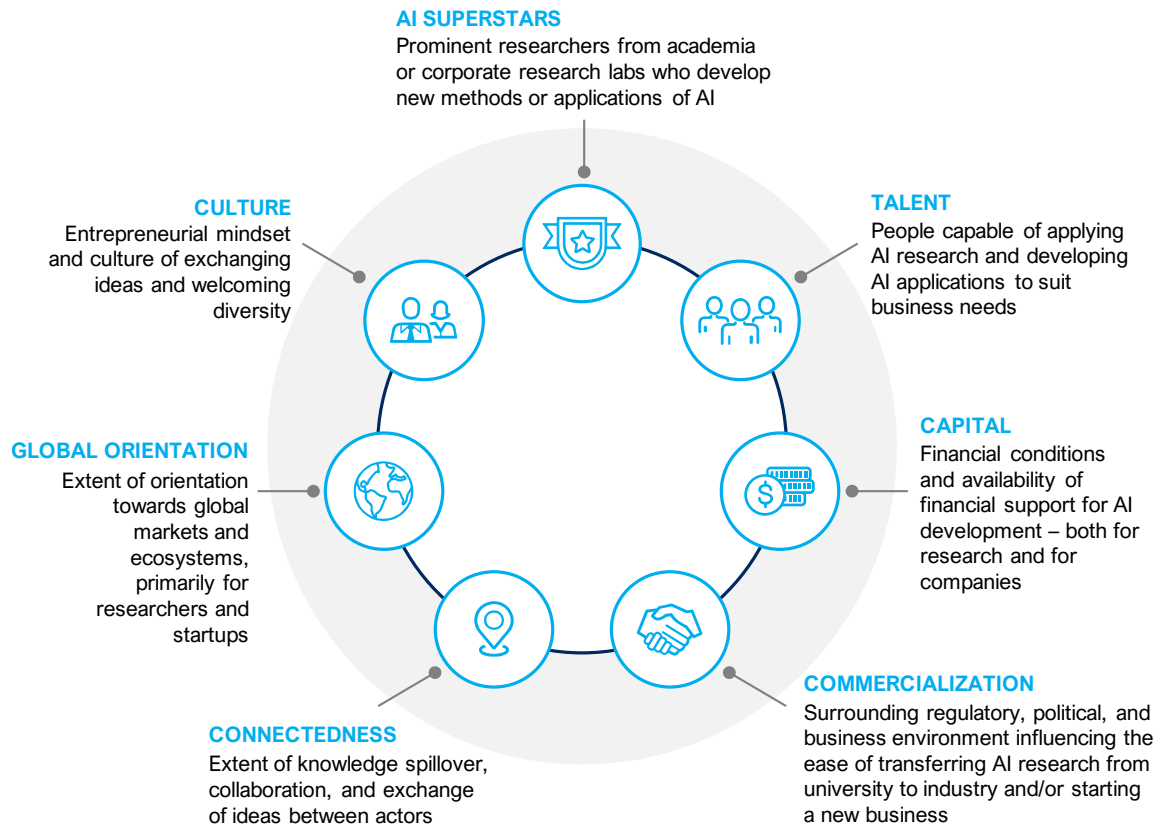
The majority of AI activity is centered in relatively few geographic eco-systems: 40 percent of AI startups and 60 percent of venture funding for AI companies are centered in Silicon Valley, Beijing, London, New York City, and Tel Aviv. Most of these eco-systems are situated outside of Europe, and none of them are located in Denmark. What defines those geographic areas and why is Denmark not in the global top?

To understand what drives the growth and success of AI eco-systems, we conducted a literature review on national advantages, network theory, and cluster development, interviewed AI and eco-system experts, conducted case studies and tested our findings for statistical robustness. We find that the success of AI eco-systems depends on performance along seven dimensions, outlined in exhibit 8 below. These dimensions are products of interactions between a wide range of both public and private actors.

To assess Danish cities' performance as AI eco-systems, we have developed an index measuring these drivers based on 20 variables (see appendix 3), e.g., number of AI startups and AI patents. These variables are proxies for the seven dimensions and are not perfect measures for AI activities. But they reflect activities strongly related to the development and commercialization of AI.

EXHIBIT 8

DRIVERS OF AI ECO-SYSTEMS



SOURCE: Porter, 1990; 1998; Youtie & Shapira, 2008; Piatyszek-Pych, 2013; Pan et.al, 2018; Eisingerich et.al, 2009; Isaksen, 2016; Lehmann & Menter, 2018; Scott et.al, 2018

EXHIBIT 9

RANKING OF AI ECO-SYSTEMS GLOBALLY

SOURCE: McKinsey analysis based on Times Higher Education; QS World Universities; Global Innovation Index; WEF; OECD; Pitchbook; Asgard; Crunchbase; Innography; McKinsey Global Institute

When ranking 294 cities worldwide, U.S. cities perform particularly well, while only four European cities rank in the top 25. Denmark's cities are behind their peers.[52] Copenhagen ranks 65th, after cities such as Helsinki, Stockholm, and Paris. Copenhagen lags particularly behind on parameters pertaining to *connectedness*, in terms of turning AI research into commercial applications; *capital*, as also reflected in the investment analysis; and *AI superstars,* where Denmark, despite having some well-known researchers, still trails leading global eco-systems. Moreover, those superstar researchers are difficult to attract, given that none of the leading tech players have headquarters or large-scale research labs in Denmark.[53]

[52] Some of the factors that the leading eco-system excel at are a good investment environment, research and industry collaboration, a vibrant startup scene, and ambitious public commitments to AI. For instance, London wins by having a high supply of capital for AI startups as well as extensive efforts to develop close ties between leading researchers and industry, e.g., with industry-supported PhDs. The Singaporean government performs well, for instance, by supporting its eco-system through huge investments in talent development and in the "Smart Nation" initiative that aims to drive economic growth and better living through investments in digital technologies. Tel Aviv offers one of the most vibrant startup eco-systems in the world, supported by the Israeli government, where, for example, the Ministry of Defense has been an alternative startup factory and source of talent; e.g., its intelligence "unit 8200" that is focused on gathering signal intelligence and code decryption has trained some of the brightest math and computer science talents (estimated around 5,000 people), and several of Israel's top tech entrepreneurs stem from this specific unit. Source: Tech Nation, 2019; UK government, 2019a; Reed, 2015.

[53] Based on expert interviews, we have chosen cities as the unit of analysis as those are often the epicenters for AI activities. We recognize that there is a big difference between Copenhagen and some of the largest cities in the world like New York or Beijing. Cities have limitations to the number of startups, the size of the capital market, the number of AI researchers, while land prices, congestion or increasing wages all can influence the size of the cities, why Danish cities such as Copenhagen and Aarhus inherently are different from cities such as San Francisco. Nevertheless, even when comparing Copenhagen to other European cities, such as Amsterdam and Stockholm, Copenhagen still lags behind.

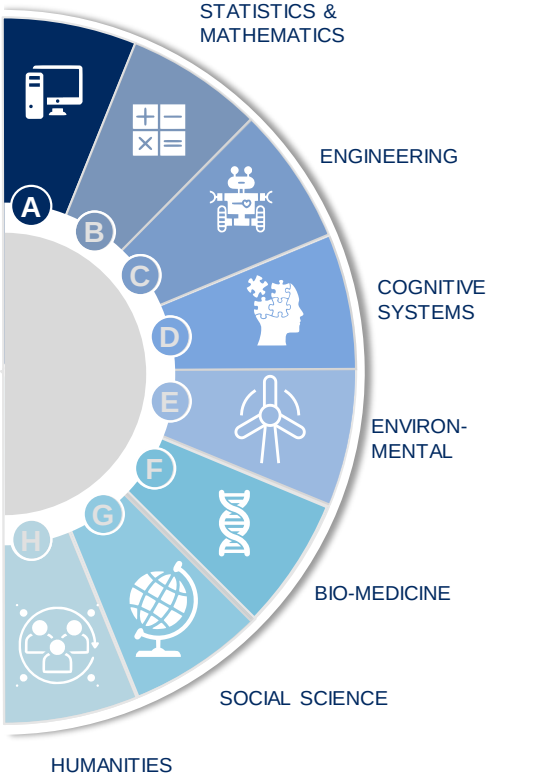
4.4 AI activities at Danish universities: Danish universities are leading in Europe in specific AI sub-disciplines and are ramping up their AI teaching activities

Denmark is a small country, and when comparing to the leading global universities within AI, it is difficult to keep up with their massive investments. MIT, for instance, received almost DKK 4 billion in external funding (in addition to its own long-term commitment to AI of DKK 7 billion) to establish the Stephen A. Schwarzman College of Computing, which gives the institute a shared structure for collaborative education, research, and innovation in AI. Nevertheless, Denmark has several AI strongholds within certain disciplines, which might be built upon.

Focusing on computer science, several Danish universities are among leading universities within AI sub-disciplines. Looking af CS' ranking of universities within AI sub-disciplines, there were two Danish universities in the top 15 European universities within Natural Language Processing and Algorithms and Complexity. [54]

EXHIBIT 10

RESEARCH IN DENMARK IN SELECTED COMPUTER SCIENCE DISCIPLINES



Top 15 European universities within computer science for selected sub-disciplines according to CS Rankings[1], shown by host country 2014-18

	Machine learning & data mining	Natural language processing	Algorithms & complexity
1	Israel	United Kingdom	Israel
2	Switzerland	United Kingdom	Switzerland
3	Switzerland	Israel	Denmark
4	United Kingdom	Germany	Poland
5	France	Denmark	Israel
6	Germany	Netherlands	Switzerland
7	Israel	Israel	Sweden
8	United Kingdom	Israel	Israel
9	Israel	Italy	United Kingdom
10	United Kingdom	Denmark	Denmark
11	Israel	United Kingdom	Netherlands
12	United Kingdom	Germany	France
13	Austria	Israel	Poland
14	Denmark	Germany	Israel
15	United Kingdom	Germany	Austria

1 In the graph we have included the two disciplines that CSRankings itself classifies as core AI related, as well as the discipline of "Algorithms & Complexity" as it is a foundational discipline for AI. It should be noted that this is not a comprehensive list of all AI-related fields.
SOURCE: CSRankings

[54] Some drawbacks to using CSRankings should be mentioned: (a) It looks at number of publications and hence does not adjust for quality (e.g., in terms of the number of citations), (b) it primarily includes computer science researchers, and not researchers from other disciplines that also conduct pioneering AI research, and (c) it only includes a subset of conferences. Despite these drawbacks, we have chosen to use it, since it is the most granular ranking, enabling us to highlight some of Denmark's strengths at a sub-discipline level. Furthermore, we do not use the ranking to benchmark Danish universities, nor derive recommendations from it.

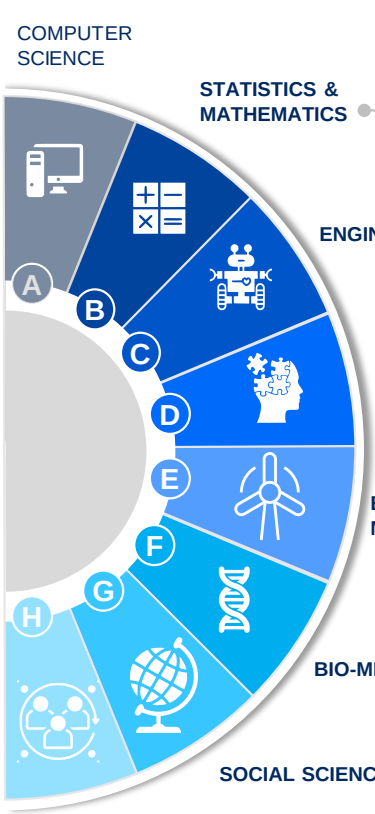
Some of the other Danish AI strongholds include several top research groups and programs within disciplines such as engineering, cognitive systems and bio-medicine, as shown in exhibit 11. For instance, the section for Cognitive Systems at DTU Compute's research in machine learning has been used by the Danish hearing aid manufacturer Widex for its product "EVOKE", which is the world's first hearing aid with real-time machine learning, able to learn from users' input and adapt in real-time to specific listening situations.

Looking at AI-related research projects at Danish universities, almost 90 percent are related to application of AI rather than developing the underlying technology. The most popular applications are in health and biotech (~25 percent), energy and environment (~10 percent) and agriculture (~5 percent).

In addition to research being undertaken at the individual universities, there are a range of collaborative research projects within AI. One of the most notable AI-related research initiatives is the "Danish Center for Big Data Analytics driven Innovation" (DABAI), which has a total budget of around DKK 115 million. DABAI is a partnership between computer science researchers at three Danish universities, Danish IT companies with big data competences, and a number of government institutions. The center aims to develop techniques for big data analysis to be applied, focused on practical cases with a large business and societal potential. Initial cases will be focused on societal data, educational data, and food supply chain data.

EXHIBIT 11

RESEARCH IN DENMARK IN SELECTED DISCIPLINES



Selected examples of completed and ongoing research projects and centers at Danish universities

B
- Basic Algorithms Research Copenhagen at UCPH works with fundamental algorithmic research
- Center for Massive Data Algorithmics (MADALGO) at AU conducted research focused on advancing fundamental algorithmic knowledge

C
- SDU Robotics has unique expertise within several sub-areas such as welfare robotics, industry application and surgical robotics
- The research project "ASIR" develops monitoring systems to make maintenance of sewers more effective

D
- The section for Cognitive Systems at DTU Compute and the research group Hearing Systems at DTU Health Tech have pioneered research within audio and machine learning, and developed the first real-time hearing aid system

E
- The research project "EcoSense" has developed sensing and visualization methods to reduce environmental footprints
- The Center for IT-Intelligent Energy Systems in Cities researches in cities by using AI to forecast, control and optimize energy consumption

F
- The Disease Systems Biology Program at UCPH combines analysis of big biomedical data with molecular biology, and has contributed with unique insights within genetics and bio-informatics
- Two Lundbeck centers (CIMBI and CINS II) have pioneered neuroimaging with, among other things, a smartphone brain scanner

G
- Copenhagen Center for Social Data Science at UCPH brings economists, political scientists, sociologists, anthropologists and psychologists together to explore new possibilities with new forms of data, such as social data

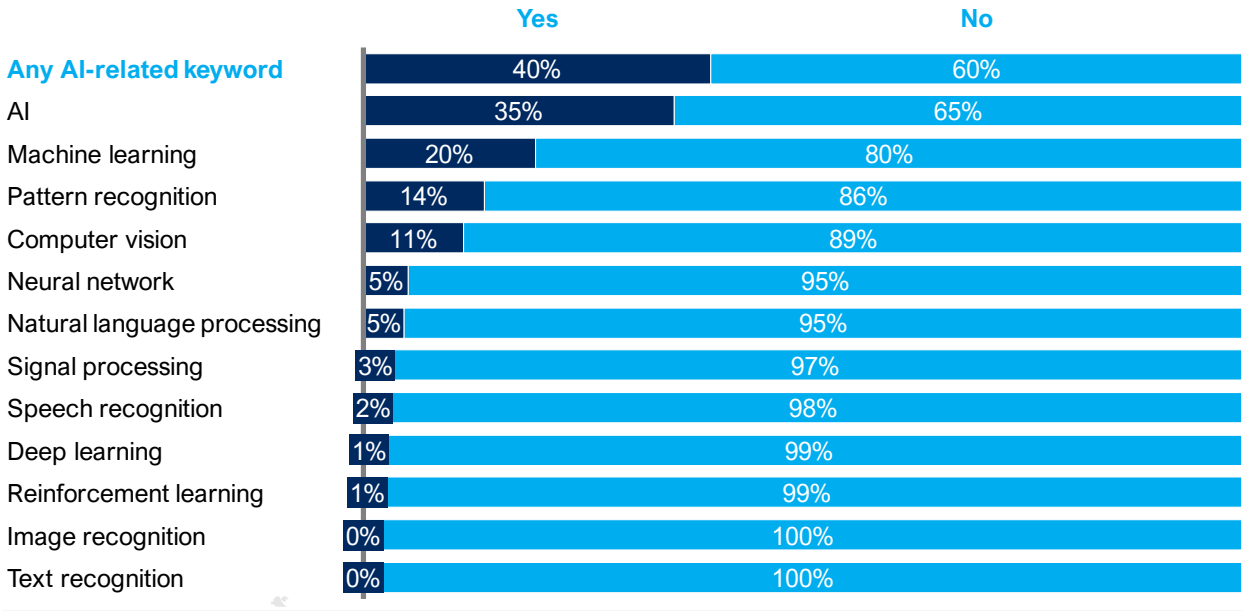
H
- The research project "As if it was a person – social robotics and human self-understanding" has developed a new research area, *robophilosophy*, that explores the interaction between humans, robotics and society

SOURCE: Expert insights; MADALGO, 2017; BARC, nd.; SDU Robotics, nd.; Innovation Fund Denmark, 2018b; DTU Compute, nd.; DTU Health Tech, nd.; Realdania, nd, Ecosense, 2019; Novo Nordisk foundation Center for Protein Research, nd.; Region Hovedstaden, nd; CIMBI, 2015; SODAS, nd; Seibt, nd.

EXHIBIT 12

RESEARCH FOCUS OF DANISH AI RESEARCHERS

Research focus, percent of total with specific AI keyword as a top 20 keyword on Microsoft Academics



1. n = 427; among 443 AI researchers in Denmark (excluding PhDs), 427 had published enough to be identifiable by Microsoft Academic
SOURCE: Microsoft Academics

For this report, we have collaborated with all eight Danish universities, which have provided detailed data on their AI-related courses, programs, researchers, research projects, and planned activities, to help us create the most comprehensive mapping of AI-activities at Danish universities to date.[55]

According to the data reported, 443 researchers in Denmark (excluding PhD students) are doing research in AI or are using AI methods. However, based on an analysis we performed using Microsoft Academics (which employs machine learning to assign keywords to researchers), only approximately 40 percent of these are "core" AI researchers, who research directly in at least one AI-related field – see exhibit 12.

The majority of the top researchers in this group are currently teaching at Danish universities; considering the top three core AI researchers at each university, defined by their total number of citations, only five in total were not teaching during the 2018/19 academic year.

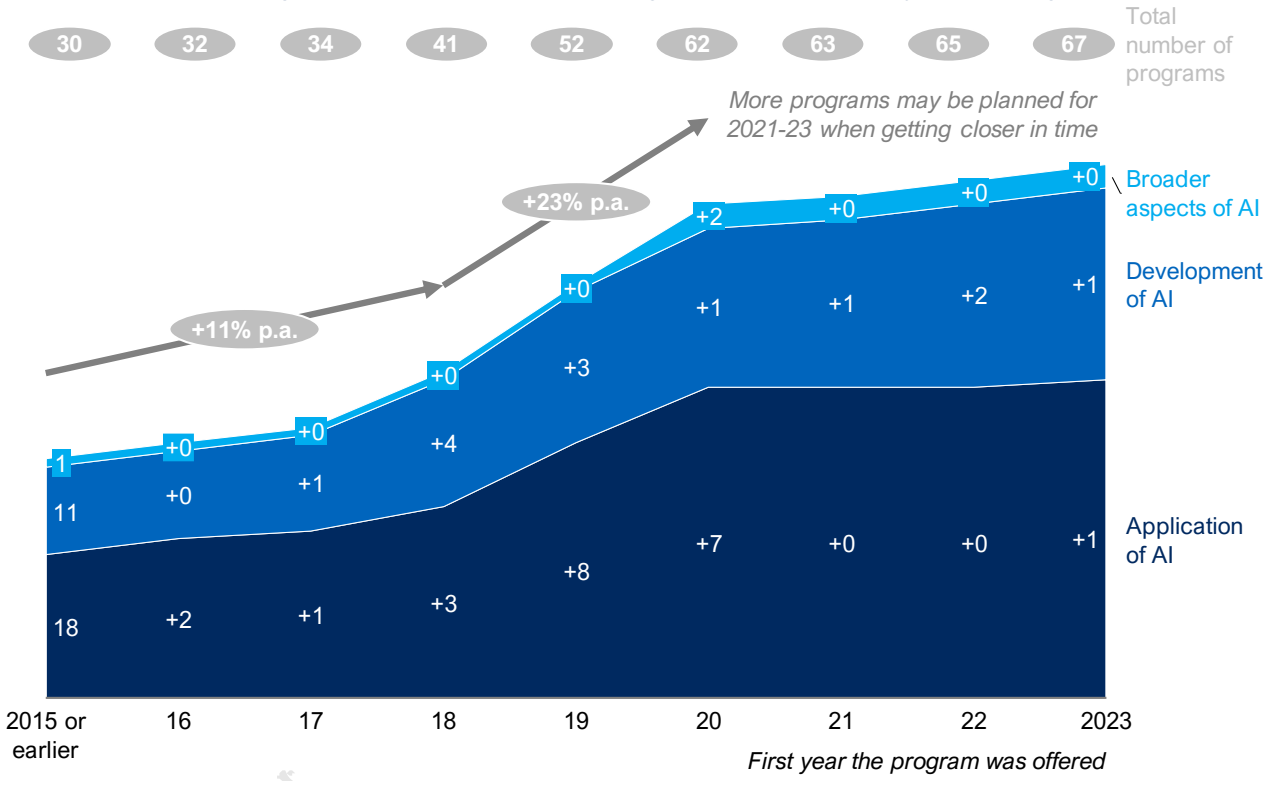
Some 31 percent of core AI researchers have published in top 20 non-conference AI journals. Of those, more than four out of five have published less than five papers in the journals, and close to half only published once, while a small number of superstar researchers, such as Anders Søgaard from UCPH, has published more than ten times.[56]

[55] It includes data not only from computer science departments, but from all departments that the universities themselves deemed relevant
[56] According to Scimago Journal Ranking, 2017. Please note that this excludes conference journals, which means that it is not a fully representative picture, as a lot of pioneering research is published at some of the top conferences

EXHIBIT 13

NUMBER OF AI-RELATED PROGRAMS AT DANISH UNIVERSITIES

Number of AI-related programs in 2015, and additional programs opened up each year following 2015[1]



1. Includes not only programs focused at development of AI (e.g., data science) but also programs in which there is a high degree of application of AI (e.g., bioinformatics or business analytics)
SOURCE: Mapping of AI activities based on input from Danish universities; McKinsey analysis; interviews with universities; university websites

According to our collected data, Danish universities are ramping up their investment in AI-related teaching. The number of AI-related degree-granting programs at Danish universities is expected to increase by 23 percent per year from 2018/19 to 2020/21 (see exhibit 13). By 2023, about three quarters of these are expected to be master's programs, the majority (88 percent) being in engineering and science, with the remaining split evenly between business / social science and humanities / law. Examples of AI-related degrees outside the fields of engineering and science are "IT and Cognition" at the University of Copenhagen and "Cognitive Science" at Aarhus University.

The growth in programs is expected to boost the number of graduates with an AI degree in Denmark; with recent and expected growth in AI programs comes an increase in the number of AI graduates from Danish universities of 11 percent annually from 2015 to 2025. Some 41 percent of them will hold bachelor's degrees and 59 percent of them will have master's degrees.

Danish universities currently offer more than 300 courses related to AI. Around 40 percent of these courses train students to develop the underlying algorithms and software (e.g., "Introduction to Machine Learning and Data Mining" at DTU and "Advanced Topics in Machine Learning" at University of Copenhagen). Almost half of the courses (47 percent) relate to the application of AI (e.g., "Machine Learning for Media Technology" at Aalborg University and "Big Data Analytics" at Copenhagen Business School). The remaining courses relate to the broader aspects of AI, such as "AI and Ethics" at University of Southern Denmark or "Introduction to Robophilosophy" at Aarhus University.

4.5 AI adoption at Danish companies: Large Danish enterprises are piloting AI but are still not implementing at scale. Smaller companies lag behind on AI adoption

Denmark has a solid starting point on ensuring adoption of AI among Danish enterprises. Danish employees are tech-savvy and ready for further digital transformation. Moreover, Denmark has a small, open economy, and many Danish companies compete in export markets, which means they need to stay ahead on the digitalization curve.

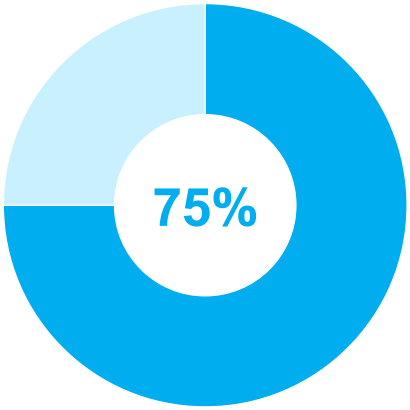
There is reason for Danish companies to take a proactive stance on AI: As mentioned in chapter 2, the technology has the potential to unlock DKK 100 to 160 billion in value for Danish businesses, equivalent to a two to three percentage point profit margin uplift on average across industries. First movers will capture a larger share of this value. As previously mentioned, McKinsey research shows that companies with a proactive AI strategy achieve an operating profit margin about seven percentage points above the industry average.[57] The average margins of experimenters / non-adopters are about 1.5 percentage points and 2 percentage points below the industry average, respectively.

So, are Danish companies reaping those benefits? Already today, the majority of large Danish companies are experimenting with AI; according to our survey of 63 Danish executives, more than three quarters of businesses are piloting or embedding AI into at least one function / business unit. However, AI is not yet a top priority on the Danish C-suite agenda. It is generally not being implemented at scale and few Danish companies are investing heavily in it. Danish companies

EXHIBIT 14

AI ADOPTION AMONG LARGE DANISH ENTERPRISES

Many Danish companies are experimenting with AI



are piloting or embedding AI into at least one function / business unit

However, AI is still not a top priority among Danish executives and is not adopted at scale

Only **2/3** of those experimenting with AI have adopted AI at scale (embedded at least one technology across their business)

Only **20%** of large Danish enterprises have included AI in a core part of initiatives across their corporate strategy

Only **1/4** discusses AI to more than a "medium" extent in their board meetings

2/3 of Danish businesses dedicate less than 3% of total investments to AI

SOURCE: McKinsey Nordic CXOs AI Survey, n=63

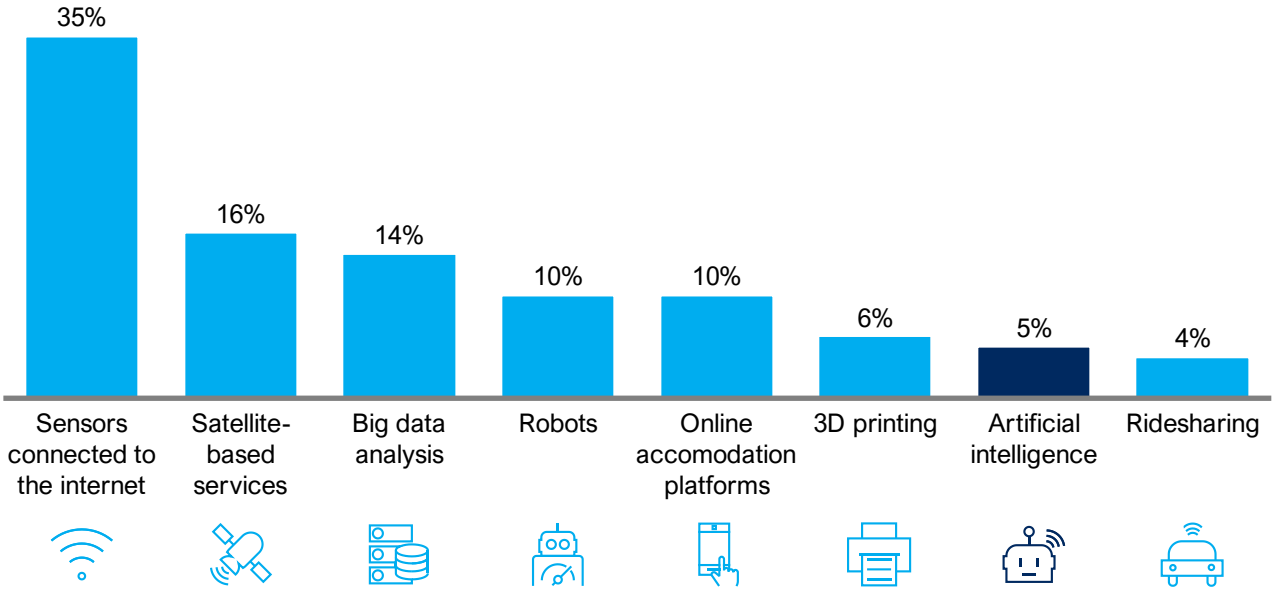
[57] It should be noted that it is, however, not straightforward to statistically establish a causal relationship.

While there is some way to go for large companies, the adoption challenge is, however, much bigger when it comes to small and medium-sized enterprises (SMEs). Denmark's industry structure is centered around SMEs – there are currently more than 300,000 SMEs in Denmark, corresponding to more than 99 percent of Danish companies.[58] When looking at this broader enterprise landscape, the AI adoption rates are markedly different: only 5 percent of Danish companies use AI (see exhibit 15) and, according to experts, there is a technology backlog among Danish SMEs. For example, many SMEs are still struggling with data collection for simple analytical techniques. This backlog must be addressed, as it inhibits Danish SMEs from unleashing the full potential of AI.

EXHIBIT 15

DANISH COMPANIES' USE OF ADVANCED TECHNOLOGIES

% of firms, 2018



Based on published results from Statistics Denmark's yearly survey on IT usage in Danish companies. Total number of respondents was 3,954.
SOURCE: Statistics Denmark

4.6 The Danish AI startup landscape: Denmark ranks high on the number of AI startups in the Nordics. Danish AI startups primarily serve international customers, are founded by industry professionals, and collaborate with universities or other startups

Denmark is far behind global leaders, such as the U.S., China, UK, and Israel, on number of AI startups and funding for those firms. Less than 0.4 percent of AI startups globally are located in Denmark, and they receive just 0.1 percent of total funding. When adjusting for GDP, Denmark ranks 25th globally on funding for AI startups.[59] However, in Europe and the Nordics, Denmark is better positioned, with five of the last 41 European unicorns being Danish (though not all of these are AI related). For instance, the Danish-founded unicorn Tradeshift, which is among the world's largest business commerce platforms, is using AI as an integral part of the business. In 2016, it launched a virtual assistant for payments, and in 2017 it launched "Ada", which learns about users' buying preferences to give them insights into their spend and help them automate their procurement tasks.

[58] Danmarks Statistik, 2019
[59] McKinsey analysis based on Asgard, 2019; Crunchbase, 2019; Pitchbook, 201.

We have performed a thorough assessment of the Nordic AI startup landscape and created a comprehensive sample of 490 Nordic AI startups by leveraging more than ten different sources.[60] Of those 490 startups, a quarter are located in Denmark. Though Sweden has a larger number of startups than Denmark based on our sample (174 vs. 127), the Danish AI landscape has seen the largest growth; two thirds of the AI startups identified in Denmark were founded in the past four years, versus less than half of the identified Swedish and Finnish AI startups being founded in that time period. Compared to the other Nordic ecosystems, the Danish AI ecosystem is very much centered around the capital, with almost three quarters of Danish AI startups being located in Copenhagen. This is perhaps not surprising considering the concentration of universities with significant AI activities (University of Copenhagen, DTU, and IT University of Copenhagen) and the concentration of investors (four of the top 20 Nordic investors in AI startups are Danish, and they are all located in the Copenhagen area).[61]

In addition to the above, we have undertaken an exclusive survey of close to 60 Danish AI startups.[62] According to this, most Danish AI startups do not find their success in the domestic market; more than half of Danish AI startups primarily sell their services and products outside of Denmark (see exhibit 16). They tend to focus on small businesses (50 employees or less), and on developing AI-based solutions for specific industries. Of those industries, the most dominant are IT, financial services, and healthcare and pharmaceuticals. For instance, the Copenhagen-based startup Hedia has developed a personal "diabetes assistant" based on AI. The company's goal is to make life with diabetes easier, and its assistant works by picking up patterns and habits of the individual diabetic, which it uses for insulin recommendations to give the person with diabetes a better insulin-treatment.

Who is founding those startups? Our survey indicates that it might be difficult to launch a startup right out of school. According to the survey, 86 percent of Danish AI startups has at least one founder with recent industry experience and 37 percent has an academic professional as part of the founding team, while only 32 percent has one or more founders who were recent students or graduates when they founded the business. However, a large group of startups bring the best of both worlds; half of the surveyed Danish AI startups both have founders with industry experience and with academic experience (academics or recent students / graduates).

Danish AI startups highly value collaboration and partnership, though there is scope for improving cooperation with larger companies. More than four out of five startups in our survey engage with at least one type of network, with the most popular ones being communities with other startups (68 percent), universities (60 percent), and larger companies (42 percent). However, at the European level almost two thirds of startups cooperate with larger companies, which indicates that there is room to improve cooperation between startups and established enterprises in Denmark.[63] There are, however, great examples of collaboration between startups and large enterprises in Denmark. For example, the Danish startup Optimum Voyage is collaborating with the Danish ship operator Hafnia on a larger study;[64] the startup has developed an algorithm for automated route optimization, replacing meteorologists' manual planning with automated optimization, testing up to 1 million route variations every day during a voyage. Hafnia has supplied vessel and voyage data, providing Optimum Voyage with a testing ground for its algorithm, and the study has uncovered a double-digit savings potential based on fuel savings.

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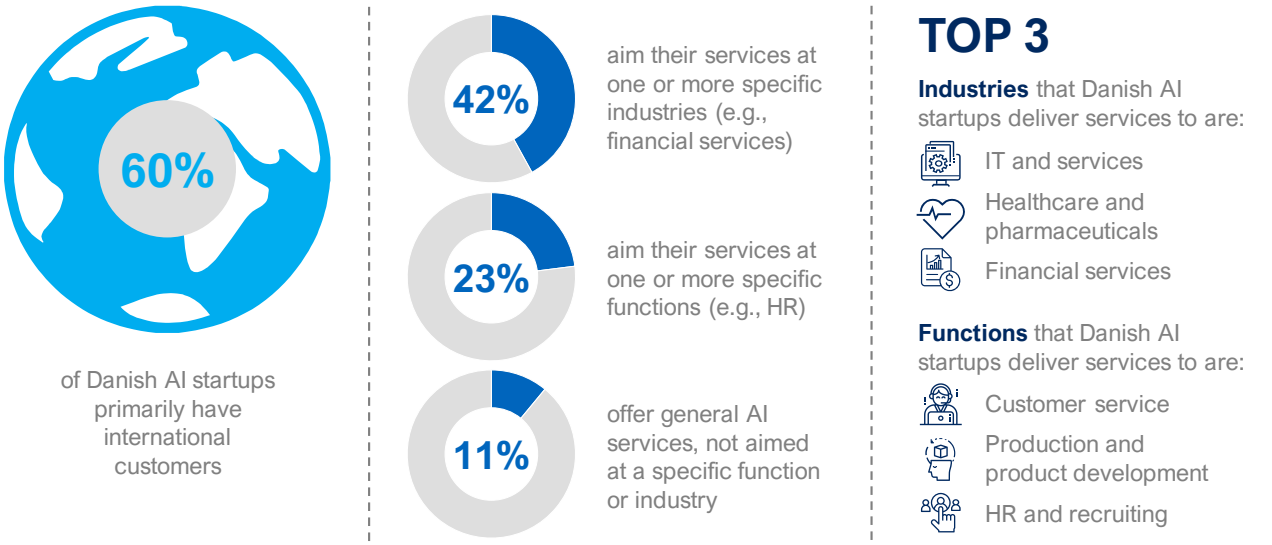
[60] Key sources include Crunchbase, Asgard, LinkedIn, and Nordic.ai
[61] McKinsey analysis
[62] The survey was sent out to 582 Innobooster applicants and grant recipients. We received 101 responses. Of those, 57 have been founded in the past five years and are currently selling products / services based on AI technologies.
[63] European Commission, 2018a – results are based on a survey of European startups (not AI-specific)
[64] The study is happening through the organization Green Ship of the Future

EXHIBIT 16

THE CUSTOMERS OF DANISH AI STARTUPS



SOURCE: Survey of Danish AI startups, 2019, n=57; McKinsey analysis

4.7 AI in the Danish public sector: The Danish public sector is among the most digitized in the world when it comes to first-wave technologies, but is trailing on commitment to AI adoption

With initiatives such as NemKonto, NemID, and mandatory "Digital Post" for businesses and citizens, Denmark has worked for the past 15 years to place itself among the most advanced public sectors in the world when it comes to first wave digital technologies. For instance, Denmark takes a global first place in the UN's 2018 E-Government Development Index, which measures countries' use of IT and digital technologies to deliver public services. Denmark also has a solid starting point on data, as it generally has large amounts of high-quality and structured data. For instance, in the health area, Denmark has a long tradition of collecting data about births, deaths, diseases, and so on. Yet, these data are currently fragmented as they are stored in several hundred registers and databases.

In March 2019, Denmark published its first nation-wide strategy for AI, focused on building a common Danish language resource, implementing a number of signature AI projects in the public sector, and establishing an investment pool for Danish AI companies. Four sectors have been prioritized as strategically important – health, transportation, energy, and agriculture. Denmark is now piloting AI in these and other sectors: Better diagnosis and treatment of patients with life-threatening diseases such as cancer. A more focused and risk-based monitoring of corporate tax fraud. Faster identification of citizens with heart failures. Lower energy usage in supply of drinking water. Those are examples of some of the pilots in the Danish public sector that leverage AI, and they provide just a small glimpse into the versatility and potential reach of the technology:

- **Early cancer diagnosis:** The Region of Southern Denmark is applying AI to diagnose cancer earlier by analyzing pictures of cancer cells. Early diagnosis enables doctors to initiate treatment faster and improve patients' chances of survival.

- **Optimization of the drinking water system:** The project "CHAIN" is using AI to optimize the drinking water system in Aarhus municipality. AI will be used to analyze big amounts of data, e.g., from sensors, about water consumption, in order to optimize energy consumption, thus cutting costs and improving environmental sustainability.
- **Reduction of tax fraud:** The Danish Business Authority is using machine learning to reduce corporate tax fraud. It aims to leverage machine learning to perform a risk-assessment of new businesses, thus implementing a more focused and risk-based control for tax fraud.

With the AI strategy, the Danish government plans to invest DKK 60 million in AI activities in total from 2019 to 2027. However, this strategy does not cover all public Danish AI initiatives; examples of other notable initiatives include DABAI, with investments of DKK 45 million from the Innovation Fund Denmark from 2016 to 2020, the "National Center for research in digital technologies", with a public grant of DKK 100 million, establishment of a Data Ethical Council in May 2019 to foster public debate around data usage and privacy, and the initiative "Datafordeleren" that was initiated in 2012 and merges several public data sets into one platform (e.g., house valuations, geographical data, and data for enterprises).[65] Nevertheless, Danish public investments do not match some of the large-scale commitments of Denmark's peers. The Finnish government, for example, is investing more than DKK 750 million in an investment program for private sector AI projects from 2018 to 2022 – on top of other big AI-related investments, such as building a new data governance structure, re-skilling the population, and accelerating AI startups and SMEs.[66] Continuing this pace of investment may put Denmark at risk of falling behind on the new wave of digital adoption and preventing it from capturing the full potential of AI technologies.

Ambitious investment in AI is key to keeping up with the global frontrunners.[67] Yet, Denmark also has other mechanisms that it should leverage to drive AI innovation and adoption. One group of public sector actors that can help Denmark drive AI adoption, at least among enterprises, is the GTS institutes ("Godkendte Teknologiske Serviceinstitutter"), which provide a link between technology and business, bridging the gap between pioneering research and industry applications. The GTS institutes have a key role to play in diffusing AI technologies to Danish SMEs. Three of the seven institutes in particular have relevant competencies for driving AI adoption: the Alexandra Institute, the Danish Technological Institute, and FORCE Technology. The Alexandra Institute, for example, collaborated with the Aarhus-based company FieldSense to use deep learning to analyze satellite data. Complementing a range of data, including weather data, the algorithm analyzes satellite data to identify divisions between fields, helping farmers make smarter decisions and optimize their fields with much more precision.[68]

[65] Regeringen, 2018; Digitaliseringsstyrelsen, 2018; Datafordeler, nd.
[66] Business Finland 2019
[67] As mentioned previously, McKinsey research shows that in the private sector, first movers will capture a larger share of the potential of AI. Evidence of such a first-mover advantage does not exist for the public sector. Yet, AI is here to stay, and with a proportionally large public sector, Denmark has unique opportunities for driving innovative solutions through the public sector, helping Denmark stay ahead on technology adoption.
[68] GTS-net.dk, 2019

4.8 The AI-related skill level in the Danish workforce: Demand for AI skills is outpacing supply

Across universities, enterprises, startups, and the public sector, Denmark faces several barriers to AI adoption, including a lack of explicit strategies for scaling AI and the lack of a strong AI ecosystem to drive innovation and adoption. However, for all actors in the Danish ecosystem, the biggest challenge seems to be a lack of talent with the right analytical and AI skills. The only common top three barrier to adopting and working with AI among both Danish enterprises and Danish AI startups is a lack of talent (see exhibit 17), and all data and all experts point to the same conclusion: that the Danish workforce right now is in dire need of more AI talent.

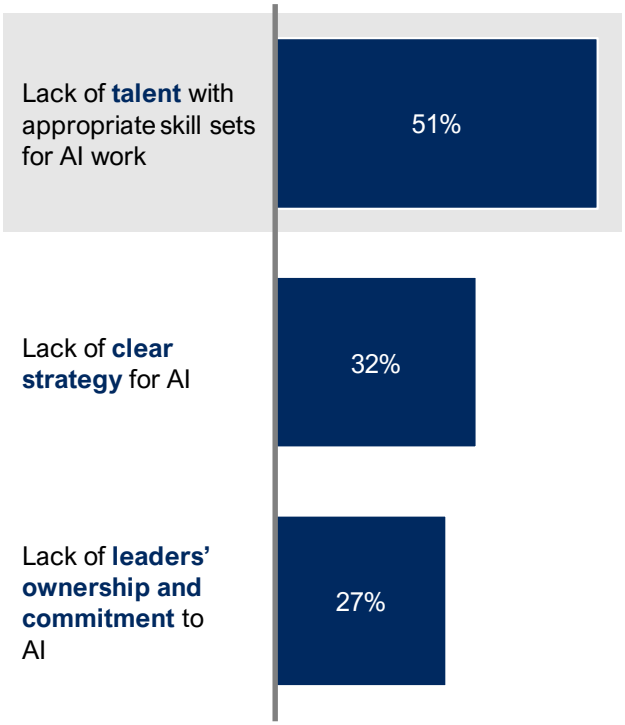
To explore this issue further, we have assessed demand for deep analytical and AI skills, how it has grown, and how it is distributed across the Danish regional and industrial landscape. Moreover, we have mapped the supply of skills within the Danish workforce to identify people with AI skills and to understand their competencies and the barriers to educating more of them.

EXHIBIT 17

BARRIERS TO AI ADOPTION

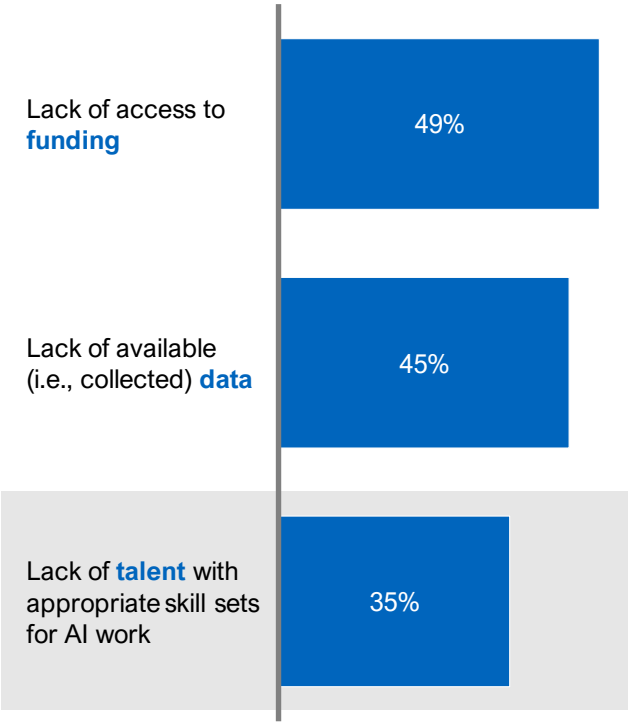
ENTERPRISES

Top 3 barriers to adopting AI in large Danish enterprises, % who selected option as a key barrier



STARTUPS

Top 3 barriers for Danish startups in working with AI, % who selected option as a key barrier



SOURCE: 2019 survey of Danish CXOs (n=63), 2019 survey of Danish startups who were either Innobooster applicants or grant recipients (n=57)

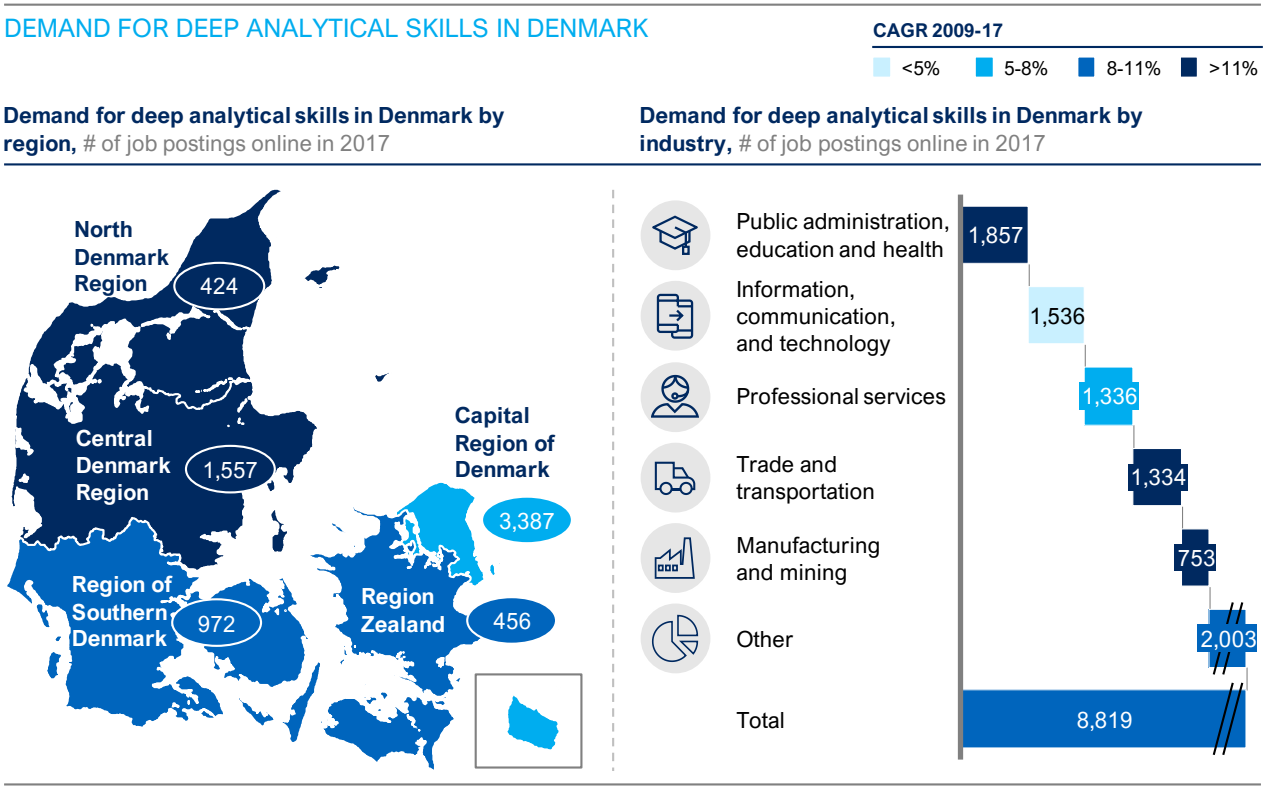
Demand for AI skills in Denmark

Demand for AI talent has been growing rapidly and at a much faster rate than demand for other kinds of analytical talent. To assess the demand for AI-skills, we have analyzed more than three million online job postings. Through this analysis, we identified approximately 90,000 job postings from 2009 to 2017 that look for employees with deep analytical skills, which means that they seek people with the fundamental mathematical and statistical comprehension to work with complex analytical tasks (which includes, as a subset, the ability to work with AI technologies).[69] Additionally, we identified a subgroup of postings that requested AI-specific skills. This analysis shows that from 2009 to 2017, demand for AI-specific skills grew more than twice as fast as the general demand for deep analytical skills; 23 percent versus nine percent.[70]

This growth is not confined to one region or sector: the demand for AI and deep analytical skills is rapidly increasing across all geographical regions and all sectors of the Danish economy. This shows that the need for AI and analytical skills is not confined to tech companies or to companies near Copenhagen. A wide range of Danish enterprises – from manufacturing to transportation companies – need people with deep analytical skills, e.g., people who can code, structure and clean data, and apply advanced analytics techniques, including AI.

EXHIBIT 18

DEMAND FOR DEEP ANALYTICAL SKILLS IN DENMARK



SOURCE: McKinsey analysis based on Højbjerre Brauer Schultz data collection

[69] The full list of deep analytical skills for postings can be found in Appendix 4. The list includes more than 160 skills, including 64 AI specific skills, 37 programming skills, 25 mathematical skills, 12 system architecture skills, 15 supporting skills (such as data mining), and eight visualization skills. Data has been collected and categorized into regions and industries by Højbjerre Brauer Schultz, 2019.

[70] It should be noted that we do not believe that those numbers reflect the total demand in the Danish economy for deep analytical and AI skills; however, we do believe that some of the trends we see in this data to some extent reflect the overall trends in Denmark.

The supply of deep analytical and AI talent

To assess the supply of AI skills in the workforce, we have analyzed close to two million Danish LinkedIn profiles.[71] We find that approximately 100,000 people on LinkedIn in Denmark have deep analytical skills, yet only a small subset of 10 percent currently has AI-specific skills. This illustrates why it is so challenging for enterprises and startups to find and attract AI talent.[72]

Mapping of AI skills in the Danish workforce

What characterizes the Danes with AI-specific skills, and what are the challenges and opportunities based on their skill composition?

First of all, people with AI skills are defined by having an intimate knowledge of one or more AI technologies. This could be, for instance, deep learning, neural networks, or natural language processing. Beyond this, however, our analysis also suggests that working with AI demands a wide combination of skills. For instance, people with AI-specific skills typically have multiple mathematical and programming skills – a quarter of the AI profiles we analyzed know three or more programming languages – and AI profiles typically complement their AI knowledge with supporting skills. Data mining, big data, and data science are the most common supporting skills for AI profiles. What does this imply for the

EXHIBIT 19

DEEP ANALYTICAL AND AI SPECIFIC SKILLS IN DENMARK

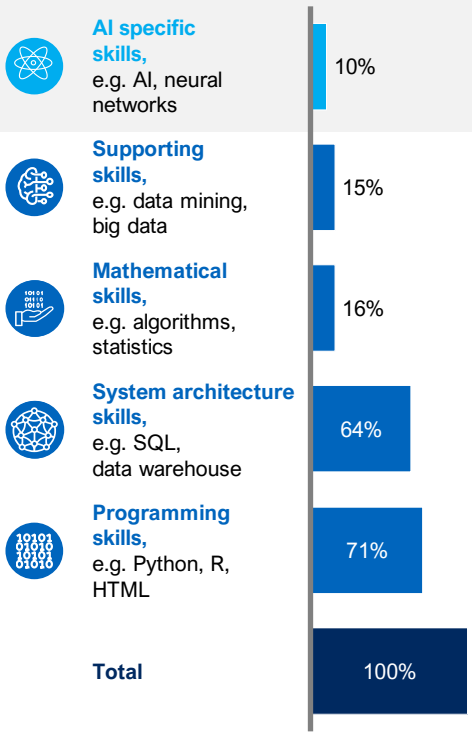
We have analyzed
~1.9M
LinkedIn profiles in Denmark

Of those,
5%
were people with deep analytical skills

Analyzing their skills in more depth, we see that of people with deep analytical skills,
10%
have AI specific skills

On the right, we show a breakdown of people with deep analytical and AI skills

Breakdown of people with deep analytical skills on LinkedIn, % of people with deep analytical skills



Top 20 skills among AI profiles (people with AI-specific skills)

Rank		% of AI profiles w. given skill	AI specific
1.	Matlab	30%	
2.	NLP	28%	✓
3.	Signal processing	25%	✓
4.	Machine learning	23%	✓
5.	Java	19%	
6.	C	19%	
7.	Python	18%	✓
8.	Algorithms	17%	
9.	Robotics	14%	✓
10.	SQL	13%	
11.	Statistics	13%	
12.	Simulations	13%	
13.	Linux	12%	
14.	Javascript	10%	
15.	R	8%	
16.	HTML	7%	
17.	Computer vision	7%	✓
18.	Data mining	6%	
19.	XML	5%	
20.	Pattern recognition	5%	✓

1 See full list of skills by category in the appendix 2 Numbers do not add up to 100% as one person can have several skills
SOURCE: McKinsey analysis based on LinkedIn data

[71] Profiles were collected based on a list of 160 skills that can be found in appendix 4.
[72] The sample pool of around 100,000 people is based on self-reported skills, which is why there will be biases in who is represented in the sample. However, the data provides indications of the specific skills for the Danish workforce, and LinkedIn data is one of the only sources to understand the specific skill structure in the Danish labor market.

Danish workforce? It implies an opportunity: Today, there is a significant group of people with relevant programming and mathematical skills similar to those of AI profiles, but without AI-specific skills. For instance, of the people with deep analytical skills that do not have AI-specific skills, one third of them know at least two or more programming languages. With most of the basic skills in place, this group is well-positioned to become re-skilled with AI-specific skills.

Second, there is a distinction between the ability to *apply* versus *develop* AI technologies. We see that the majority of Danish AI-profiles have the skills to apply AI technologies (e.g., to use and understand a specific AI application for a real-life business problem), while only a quarter has the necessary deep mathematical skills to develop the underlying algorithms. This presents a challenge; for instance, our survey of Danish AI startups shows that people with the skills to develop the underlying algorithms and software are the scarcest talent resource (45 percent report that this is the type of talent they lack the most, versus 23 percent reporting that they primarily lack people with the skills to apply AI / design advanced use cases).

The barriers to developing more AI talent

Many companies, both in Denmark and abroad, are willing to pay high salaries to attract the right AI talent. So why are more people not choosing to study AI-related fields and build the relevant skills? We conducted a survey of 105 bachelor's and master's students who have taken AI courses at DTU Compute.[73] According to this survey, the biggest barriers to attracting more students to the field are (1) that people do not understand what AI is, and (2) that the field seems to technical. AI is still a black box to many; it seems technical and complex, indicating a need to increase awareness and basic knowledge. Another finding indicating a need for wider awareness relates to the importance of attracting a more heterogenous group to the field; a quarter of the DTU Compute students pointed out that too few women in the field is one of the biggest barriers for students to choose AI-related topics. The diversity challenge also relates to the ethical challenges highlighted in chapter 2. Not having diverse teams may result in algorithms and AI solutions that are biased. This bias is seen in the results that the solutions produce. For example, voice recognition tools that rely on AI often do not recognize higher-pitched voices, and facial recognition is far more accurate for lighter-skinned men than for women or darker-skinned people.[74]

Still, there is reason for optimism. From world-leading foundational research, to tech-savvy employees, a digitized public sector, and a highly-educated population, Denmark has many strengths that it can leverage in extracting the potential of AI. A proactive and ambitious strategy and continuous commitment among all actors could help Denmark position itself to capture the impact potential of AI technologies.

[73] It should be noted that the survey's results are not necessarily representative of the students in Denmark in general. This group of students represents a subsample of students with technical expertise and an interest in AI
[74] Tugend, 2019

5. IMPLICATIONS OF AI FOR DENMARK

AI presents clear economic and welfare opportunities for Denmark. It will help Danes work smarter and more efficiently, and it will allow Danish businesses and public entities to deliver innovative solutions that can transform the Danish society. However, AI will also fundamentally change the skill structure and needs of the Danish economy. Jobs will be lost and new jobs will be created, on the one hand, demanding more people with technical skills who can develop and use AI, and, on the other, freeing up more capacity for people to unfold their creativity and their social and decision-making skills. AI will also require us to work in new ways; a job market transformed by AI will require continued re-skilling and more dynamic organizations, with employees rapidly transitioning from one job to another. We summarize this in four implications for Denmark:

Implication #1: AI has a substantial potential for delivering increased wealth in Denmark – by 2030, it has the potential to boost Danish GDP growth by 1.6 percentage points annually

McKinsey Global Institute estimates that by 2030 the potential impact of AI could be up to around DKK 35 billion annually (1.6 percentage points in additional annual GDP growth) if Denmark adopts AI at scale. This economic boost will be delivered through a combination of increased workforce productivity and higher economic demand, surpassing the costs associated with AI.

AI-related technologies may increase productivity along several channels. Machines and algorithms may substitute humans in certain tasks, especially in manufacturing, which involves many routine tasks. However, machines and humans may also work side by side, as AI augments labor in more abstract tasks, helping people become more efficient in their jobs. AI may catalyze new products, services and business models, which in turn can increase productivity. It may also generate increased demand for products and services. As an open and digitally advanced economy, Denmark is expected to benefit from increased data flows and reinvestment of income generated by AI.

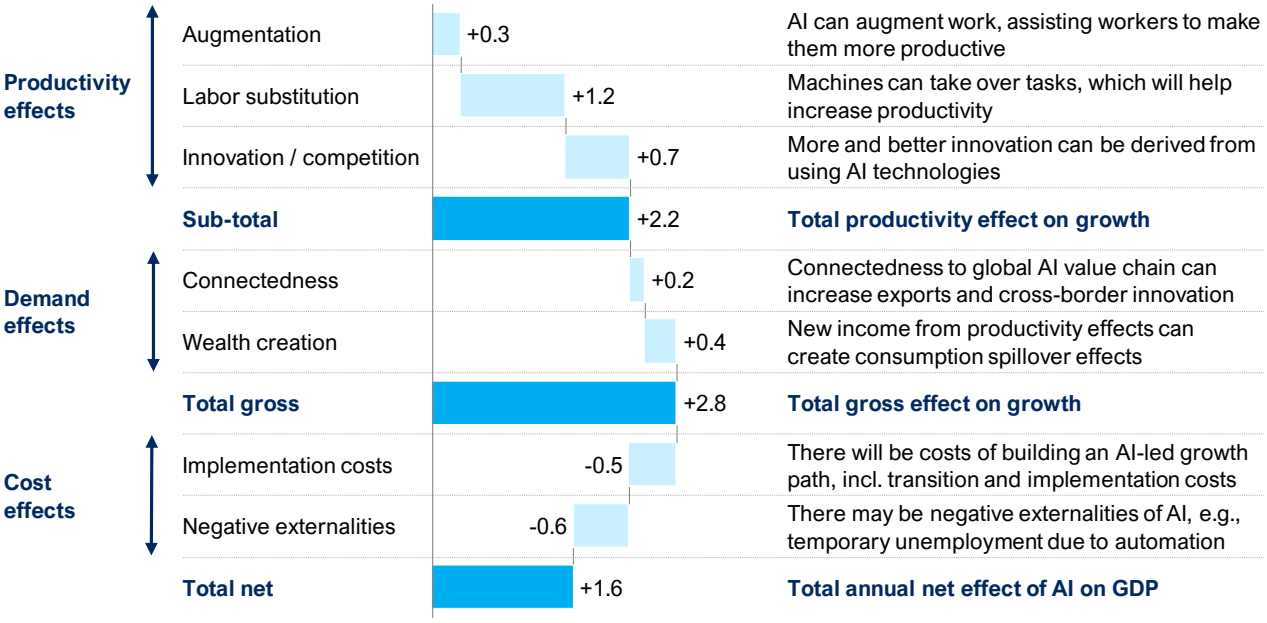
However, AI adoption also has its costs. As the Danish economy transitions to AI-supported production methods, both companies and employees may incur significant losses. Firms need to invest in building the necessary capabilities to operate new AI tools – including hiring the right employees, ensuring proper data management, and introducing new technological infrastructures. During this transition, people may need to undergo re-skilling, which can entail temporary unemployment.

In exhibit 20, we have summarized the expected macroeconomic effects based on our model framework that estimates the impact of AI on the Danish economy.

EXHIBIT 20

ESTIMATED EFFECT OF AI ON THE DANISH ECONOMY

Additional annual GDP uplift achieved by 2030, difference in percentage points



Midpoint scenario, numbers may not sum up due to rounding.
SOURCE: McKinsey Global Institute analysis

Implication #2: AI can bring significant welfare benefits beyond GDP growth

AI has the potential to fundamentally disrupt many aspects of society, and so GDP as a measure in itself does not necessarily capture the full range of societal implications of AI. In a recent analysis, McKinsey Global Institute explored factors that can help society achieve welfare benefits and it made a pioneering attempt to calculate the impact of technology adoption on welfare.

A whole branch of economics is concerned with quantifying utility – or welfare – across populations. Such utility is usually measured in monetary or "GDP equivalent" terms. In quantifying the welfare implications of AI, McKinsey Global Institute drew extensively on a welfare methodology proposed by two economists at Stanford University.[75] The modeling incorporated factors that (1) have been found to be among the biggest drivers of welfare and (2) that can be modeled robustly. These factors include job security, consumption inequality, health and leisure.[76]

Preliminary results indicate that a digitally advanced economy like Denmark may leverage AI to raise welfare significantly. This can be achieved through a combination of innovation-led growth and proactive policies. Measuring this additional welfare gain in GDP-equivalents, McKinsey Global Institute estimates that the well-being of citizens could rise by an economic value of around DKK 9 billion annually by 2030

[75] Jones and Klenow, 2016
[76] However, it is important to note that we do not claim that the model is exhaustive. The welfare quantification excludes a number of components that are important for well-being but are difficult to quantify, such as the implications of AI on social connectedness or environmental sustainability. Also, while taking into account the potential for governments and companies in promoting advances in AI-related technologies, McKinsey Global Institute has only considered a limited set of choices at governments' and businesses' disposal in order to focus on market dynamics rather than nonmarket interventions. Hence, there is some uncertainty to the predictions that we present, and they may largely depend on how the public and private sector respond to advances in AI.

(equivalent to 0.4 percent of GDP), amid both health- and work-related effects.

Though rigorous, the McKinsey Global Institute estimates of welfare potential are based on simulations. But the results indicate that for countries, such as Denmark, which are seeing rising healthcare costs, advances in health technologies have significant societal value. AI-related technologies, for example, may ease access to low-cost healthcare through telemedicine solutions; as AI-technologies become more sophisticated, remote healthcare services such as virtual consultations may become a realistic alternative to physical consultations. McKinsey Global Institute estimates the economic potential of improved health and increased longevity of life to amount to one percent of GDP annually. However, AI-induced stress among workers brings down the net potential to 0.8 percent of GDP per year.

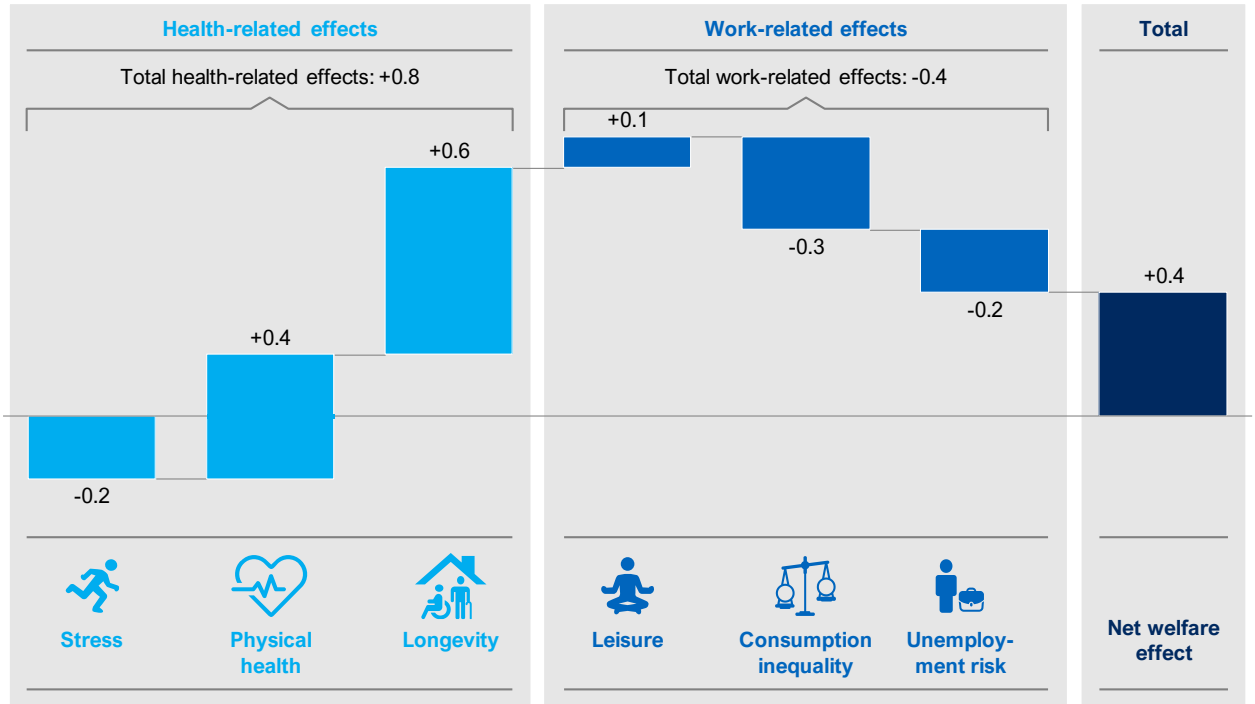
As AI-adoption in Danish companies takes off, employees performing manual tasks, such as assemblers, building workers, and clerks, may need to acquire new skills, as their jobs are automated or augmented by AI. This means that they may be subject to periods of temporary unemployment. Not only may such periods of unemployment reduce overall welfare; also, the mere risk of unemployment in itself may result in lower well-being. In addition, gains from transitioning to AI-supported production methods may not be distributed equally across the population, leading to higher economic inequality. The effect of temporarily higher inequality and job risk, balanced by an increased quantity and quality of leisure time (e.g., due to automation), may amount to a net economic effect of -0.4 percent of GDP annually until 2030, according to McKinsey Global Institute. It should, however, be noted that unlocking leisure benefits will, to some extent, be influenced by continued tripartite collaboration, as working hours in Denmark are regulated through collective agreements.

The health, work, and total effects are summarized in exhibit 21. See further description of the methodology and its limitations in appendix 6.

EXHIBIT 21

POTENTIAL EFFECT OF AI ON WELFARE IN GDP EQUIVALENTS

Additional non-GDP welfare growth in GDP equivalents, estimates of incremental compound annual growth rate, 2018–30, %



Estimates are based on simulations and represent early indications of non-GDP welfare effects. See more description of methodology and limitations in appendix 6.
SOURCE: McKinsey Global Institute analysis

Implication #3: AI will bring about structural changes to the Danish labor market, changing the skills needed in the future workforce

When machines gradually take over certain tasks in the economy, jobs will be lost. According to recent McKinsey analyses, approximately 40 percent of Danish working hours can be automated with existing technologies.[77] However, this will also free up capacity to focus on new tasks. As companies build AI-capabilities and employees undergo re-skilling, new jobs will be created.

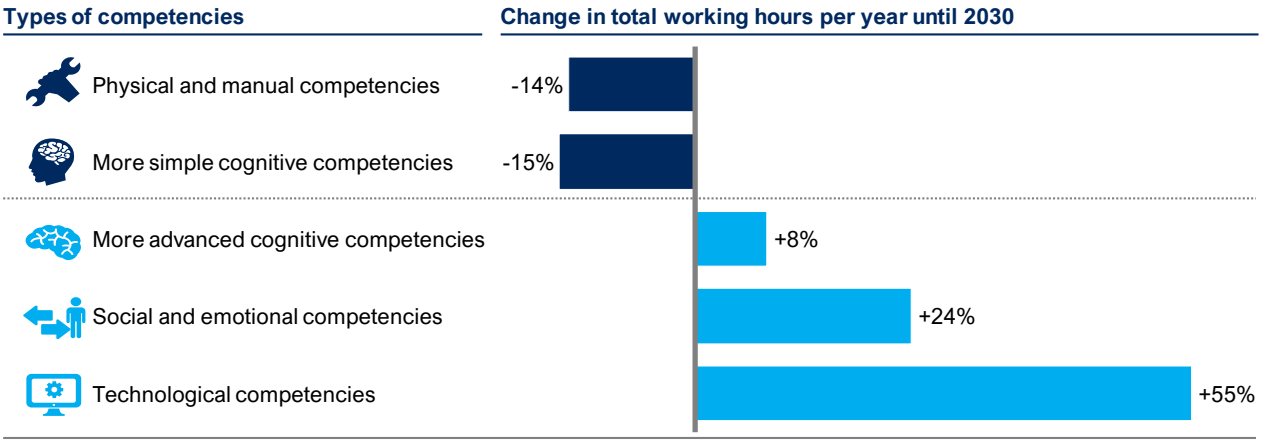
Such changes will disrupt how the current labor market functions, and it will fundamentally alter the needed skill composition in the economy. A McKinsey Global Institute analysis shows that the need for physical and manual competencies will fall, while demand for technological skills, such as advanced IT, programming, and mathematical skills, will (not surprisingly) increase – see exhibit 22. Moreover, it shows that demand for complementary skills like advanced cognitive competencies (e.g., critical thinking and creativity) and social and emotional skills (e.g., coaching and leadership) is expected to rise too.

AI will impact sectors at different magnitudes, reflecting its disruptive nature. Also, new jobs may not open up in the same sectors as those in which they disappear, implying that the sector distribution of jobs may change over time. The type of employment may also change. With the new digital platform economy, more firms (such as Wolt or Upwork) offer flexible and convenient alternatives to payroll jobs. This implies that more workers will effectively be self-employed and undergo quicker transitions between tasks / jobs (e.g., freelance work).

The future labor market and future skill requirements mean that organizations will need to have more dynamic organizational structures in which employees can shift quickly between tasks. The agile way of working is especially suited to this type of work. Here, the typical matrix structure is broken down and employees instead work in teams on a specific task for a limited and intense period of time. This is ideal for a more fluid labor structure, and especially with more and more experts whose experience will be needed for projects across the organization. Agile ways of working have been shown to increase productivity by up to 30 percent and to improve employee motivation. Leading AI companies tend to be digitally advanced and agile, with limited hierarchy and a flexible labor force. Danish enterprises should be well suited to follow in the footsteps of these global leaders.

EXHIBIT 22

CHANGE IN RELATIVE DEMAND FOR SKILLS TOWARDS 2030



Source: McKinsey Global Institute workforce skills model. McKinsey Global institute analysis

[77] McKinsey & Company, 2017

Implication #4: Beyond re-skilling the overall workforce, Denmark will need to educate and attract more people with deep analytical and AI expertise to close an expected talent gap of 20,000 to 80,000 people by 2030

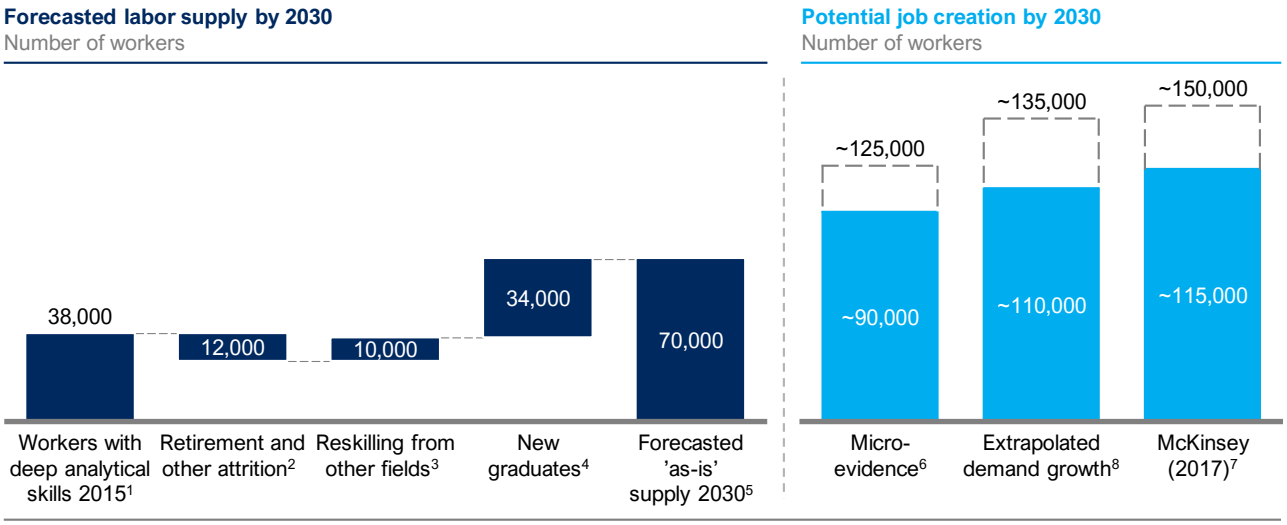
Beyond skilling the wider population and workforce, Denmark also needs to educate and attract more experts who have the deep analytical and AI expertise to drive the development and application of AI. As described in chapter 4, Denmark already seems to have a shortage of people with AI skills. This shortage is only expected to grow in magnitude. One of the biggest drivers of change in the composition of the Danish workforce and skill structure will be a growing need for people with the deep analytical skills necessary to work with AI; across all sectors, actors, and industries, one barrier stands out as the most pervasive and most critical – and that is the lack of talent with the right skills to develop and apply AI solutions.

Looking towards 2030, a McKinsey analysis shows that Denmark will face a significant scarcity of people with deep analytical skills; given current education rates, there is expected to be a supply of people with deep analytical skills of 70,000, while the potential demand for people with such skills will be between 90,000 to 150,000.[78] This implies a talent gap of 20,000 to 80,000 people by 2030.

Market forces may come into play to balance out this gap; for instance, wages may increase to attract more people to the field, companies may outsource some AI-related work to other countries with more analytical talent, or they might even move their business out of Denmark.[79] Denmark cannot and should not only

EXHIBIT 23

THE TALENT GAP FOR PEOPLE WITH DEEP ANALYTICAL SKILLS



1 Includes workers with educations which entail advanced training in mathematics, statistics and/or machine learning, based on 41 selected educations in the 8-digit HFSSP hierarchy from Statistics Denmark out of a total of ~3,000 education codes 2 Assumes workers older than 51 years old in 2016 will generally have left the workforce by 2030 3 Based on share of current data scientists in Danish companies that have background outside educations included in (1), based on analysis of LinkedIn profiles 4 Assumes growth trend from 2007-2015 (3%) will continue towards 2030, net of retirement and attrition 5 Assumes that all with analytical background supply their skills 6 Based on micro-level firm evidence of ratio between data scientists and FTE workhours automated in major European financial institutions (robotics process automation) 7 Imputed employment given forecasted capital-labor ratio and increases in capital investments to facilitate automation 8 Extrapolation of high-skill IT-related jobs based on number of job postings in 2016 and growth rate from 2012-2016 (~23-25% CAGR)

SOURCE: Statistics Denmark; Danish Ministry of Employment, Danish Agency for Labour Market and Recruitment, LinkedIn, McKinsey OrgSolutions Analytics

[78] McKinsey & Company, 2017

[79] It should be noted that an existing analysis performed by the Ministry of Employment found no confirmation of the view that there is a shortage of people with IT profiles, when looking at indicators such as wage increases versus peers, higher job turnover, faster promotions, etc. However, the analysis looks at IT-profiles very broadly, whereas we are here analyzing a more specialized field. Moreover, the analysis looks at graduates in the period of 2010 to 2012, whereas our analysis is forward-looking, assessing trends over the coming 10-15 years. Source: Beskæftigelsesministeriet, 2018

use AI technologies developed in Denmark or hire Danish AI talent; there is ample scope to outsource AI-related tasks, and many Danish companies will absorb and adopt AI technologies and solutions developed abroad. Nevertheless, to maintain its position as a knowledge-based society, it is strategically important for Denmark to continue to accumulate knowledge internally, which requires a sufficient talent pool. Given this, a talent gap of 20,000 to 80,000 people by 2030 is indeed a significant challenge that Denmark will need to address.

The growing gap may be exacerbated by the fact that Denmark is becoming less attractive to international talent. Though Denmark is considered to be among the most livable countries in the world, it is not among the most attractive countries for international talent.[80] According to the OECD "Indicators of Talent Attractiveness", Denmark ranks 13th among OECD countries both on its attractiveness to university students and to highly educated workers (those with master's and doctoral degrees), behind its Nordic peers.[81] Moreover, recent reforms, for instance, reforms to reduce the number of courses taught in English, decrease the attractiveness of Denmark to international talent. This makes it more difficult for international talent to come to Denmark to study, while also making it less attractive for international AI professors to come to Denmark, as they struggle to fulfill their teaching requirements.

Denmark also faces barriers to retaining the talent it already has. Experts we have spoken to note that the country is losing talent to other countries, and that to retain the best talent in the AI field, it is essential to create a world-class AI ecosystem, including having leading tech players in Denmark to provide attractive employment opportunities. This is supported by our survey findings. AI students say that finding opportunities for personal development and relevant employment within their field are the two most important factors in choosing their jobs.[82] Being able to offer exciting and challenging jobs within AI-specific fields is thus essential for Denmark to retain its top AI talent. Moreover, experts say that retaining top researchers requires strong local research hubs and communities for them to tap into and become a part of, reinforcing the notion that creating an AI ecosystem of both top research and commercial applications is critical to retaining AI talent in Denmark.

The issue of AI talent is complex and permeates all aspects of the Danish AI ecosystem. To solve it, Denmark could work to create more and higher-quality opportunities for both Danish and international AI talent, including creating a world-class AI innovation ecosystem that spans industries and regions.

[80] According to the OECD (2017), "Better Life Index" that measures "livability" of a country, Denmark ranked 3rd among OECD countries in 2017
[81] OECD, 2019
[82] According to our survey among DTU Compute students, n=105

6. SIX OPPORTUNITIES FOR DENMARK

To ensure that Denmark does not fall behind global AI frontrunners and that the technology is leveraged to create societal wealth and welfare, Denmark must think boldly about how different players can ease the transition and push Denmark to the forefront of AI adoption and innovation. Based on the analyses outlined in previous chapters, we have identified six opportunities with associated priority areas, which Denmark can consider addressing to establish itself as a leading AI adopter and innovator:

	TOPIC	DESCRIPTION	PRIORITY AREAS
1	**AI talent & skills** 	Develop and attract a leading pool of AI talent to address the growing talent gap, and upskill the wider population to prepare them for a world with AI	▪ 1.1. Increase share of graduates in AI fields ▪ 1.2. Increase female representation ▪ 1.3. Equip the younger generation with AI skills ▪ 1.4. Reskill existing workforce ▪ 1.5. Attract international talent
2	**Data access** 	Consolidate private and world-class public sector data and encourage inter-company collaboration to create a competitive advantage on data for Denmark	▪ 2.1. Increase consolidation and compatibility of public data ▪ 2.2. Facilitate inter-company collaboration on data
3	**Research & application** 	Further strengthen Denmark's research community, and link cutting-edge research with commercial success	▪ 3.1. Attract superstar AI researchers in selected areas ▪ 3.2. Foster collaboration to drive applied research
4	**SME AI adoption** 	Strengthen ecosystem support for SMEs and give them easier access to relevant AI talent to accelerate their adoption of AI	▪ 4.1. Leverage the Danish technology ecosystem to support SME adoption ▪ 4.2. Enable easier access to AI talent for SMEs
5	**AI clusters & investments** 	Build one to two AI clusters around the biggest Danish cities and push to catch up with peers on investments in AI	▪ 5.1. Bring actors together to build one to two AI clusters around the biggest Danish cities ▪ 5.2. Encourage public and private investments in AI
6	**International collaboration** 	Promote further international collaboration to achieve sufficient scale and enable Denmark to focus on its comparative strengths	▪ 6.1. Promote standardization and common legislative frameworks ▪ 6.2. Drive international investments and partnerships

These six opportunities and their priority areas have been identified through our research and interviews with a wide range of experts and stakeholders. We believe that they are the key points for Denmark to consider in order to establish itself at the forefront of AI adoption and innovation.

It is not within the scope of this report to define a detailed roadmap for implementation. Below, however, we describe the potential priority areas, and point to examples of how other countries have addressed them. We do not claim that those priority areas are exhaustive nor that they are definite answers. For instance, they do not cover the regulatory issues pertaining to ethical and data privacy concerns, as this has not been a key focus for this report. Nevertheless, we hope that the priority areas can serve as ideas that can spark a debate on how Denmark can take the lead on AI adoption and innovation.

Opportunity #1: Develop a leading AI talent and skill pool

Denmark has one of world's most well-educated workforces, but still faces a significant shortage of people with deep analytical skills – and this shortage is only expected to grow. As described in chapter 4 and 5, lack of talent is one of the biggest barriers that Denmark will need to tackle to become a leading AI nation; 51 percent of Danish enterprises point to the lack of people with the right skills as one of the most critical barriers to adoption. By 2030, we estimate that Denmark will face a gap of 20,000 to 80,000 people with deep analytical skills. To tackle the talent challenge, Denmark needs to develop and attract a much larger supply of people with AI-relevant skills. Moreover, to prepare the population for the skills that AI will require, there is a need to up-skill the wider population.

Priority area 1.1: Increase share of graduates in AI-related fields

Denmark should strive to produce more STEM (Science, Technology, Engineering, and Mathematics) and AI talent; that is, both in general educate more people with deep analytical skills and specifically educate more people with the ability to develop and apply AI technologies. In several countries, governments are taking steps to drastically increase the number of people with AI-related skills. For instance, China's Minister of Education announced in February 2019 that the government aims to offer 400 new majors in big data, AI and robotics at Chinese universities. Similarly, South Korea recently announced that the country will spend approximately DKK 13 billion on educating 5,000 AI specialists before 2022, while the UK plans to offer 200 new master's programs through a combination of industry funding and public investments amounting to around DKK 900 million. In Scandinavia, Finland in particular is innovating to educate more AI graduates. In a recent initiative, Aalto University, University of Helsinki, and VTT Technical Research Center of Finland launched a nation-wide competence center that coordinates AI-related course offerings and programs at universities and links students to industry partners.

Moreover, educating more AI talent requires an increase in the number of people able to teach AI-related fields. This could, for example, be achieved by increasing the number of AI-related professorships or by sharing professors or courses across universities.

Priority area 1.2: Increase female representation among STEM and AI graduates

As it aims to support STEM and AI, Denmark could consider initiatives that specifically target women. With only 33% of STEM bachelor entrants in Denmark being female, women are significantly underrepresented in the STEM field, so attracting more women to STEM and AI could help bridge the talent gap.[83] Additionally, increasing female representation may foster AI algorithms that are less shaped by current and historical biases. Increasing representation could be done, for instance, by implicitly and explicitly using communication targeted to female audiences. In one example, DTU has tried to attract more female students by highlighting descriptors of their programs and program titles that better express purposes that women typically seek to accomplish through education; words such as "bio", "life science", "environment", and "design" have been proven to have a positive effect on attracting young women to STEM fields.[84]

Priority area 1.3: Equip the next generation with AI skills

Educating the next generation of AI talent also requires initiatives targeted at the youngest part of the population, equipping school children with the necessary mathematical competencies. Even though not all children will become AI experts (or programmers for that sake), Denmark will need to prepare the younger generation for the changes that AI will bring. In the future, all Danes will need to have a fundamental understanding of what advanced

[83] Innovation Fund Denmark and McKinsey & Company, 2018
[84] Innovation Fund Denmark and McKinsey & Company, 2018

technologies are and what they can be used for. This does not mean that all Danes need to be coding experts or that learning AI skills will solve all the challenges of a changing labor market. However, part of the general education should be to build foundational skills in programming and mathematics. Initiatives in other countries can serve as inspiration: For instance, Singapore is opening several AI-related learning environments for children and teenagers. Founded by an MIT alumnus, Coding Lab is an example of that. It is a learning system for children between the ages of four and 18, in which students develop computational thinking and problem-solving skills for AI-related purposes. The program has proven highly successful and is currently also being rolled out in Japan and Australia.[85] Another program in Singapore, AI for Kids (AI4K), is designed to develop interest in and understanding of AI-related concepts among primary school children with the ultimate aim of teaching them to develop their own AI-based solutions.[86] Also targeting the younger generation, the United Arab Emirates is rolling out a series of free AI camps with the purpose of giving the younger generation an opportunity to learn AI-specific skills and collaborate with some of the leading companies in AI, e.g., Microsoft.[87]

Increasing awareness of AI among students in primary school and high school will also have spillover effects on priority area 1.1. According to our survey of Danish AI students, the two main barriers to getting more students to study AI are (1) that people do not understand what AI is, and (2) that the field seems too technical. Initiatives increasing awareness and making AI more accessible could therefore encourage more students to choose AI-related degrees. Moreover, a study by Google shows that encouragement and exposure are some of the most important controllable factors influencing girls' decision to choose a computer science education. Thus, equipping the younger generation with AI skills could have the positive effect of attracting more women to the field in the long run.[88]

Priority area 1.4: Re-skill the existing workforce

A key priority for Denmark is also to re-skill and up-skill the existing workforce. First of all, this means equipping the population with a fundamental AI understanding. Here, inspiration could be drawn from Finland, which has developed an online and easily-accessible AI-course in Finnish and English, which consists of an introductory component and a component concerned with developing AI-related solutions.[89] More than one percent of the Finnish population has completed the course, and more than 142,000 people (with an almost equal split between men and women) from 110 countries have signed up for it.

Secondly, re-skilling means retraining the workers whose jobs will be lost to automation and those who will have to learn to work side by side with machines. Among private sector initiatives, for example, the Lambda School offers a nine-month, immersive program that transforms relatively unskilled workers into developers.[90] However, importantly, re-skilling employees is not just about teaching a small sub-group deep technical skills. It is also about providing application-oriented training to a larger group of people, thus building a sizable pool of employees able to use AI technologies for hands-on and value-creating applications. Inspiration might be drawn from the public-private partnership "Success Online", which has

[85] Coding Lab, 2019
[86] AI Singapore, 2019
[87] UAE, 2019
[88] Google, 2014
[89] Hamrin, 2019
[90] Lambda, nd.

equipped around 60,000 Danes with business-related digital skills.[91]

Finally, re-skilling requires training existing deep analytical talents with AI-specific skills to increase the Danish pool of AI experts. An example from abroad on this is the UK government, which has invested DKK 155 million in retraining 2,500 people to become experts in computer science and AI through master's conversion courses.[92] As another example, Singapore has established the "TechSkills Accelerator", which offers various technology re-skilling programs. These programs offer certificates through physical and online courses and help enterprises develop career maps for employees in addition to providing coordinated career services with job matching, group mentoring, and leadership programs.[93]

All of the above areas likely require both public and private sector commitment. It will be difficult for employees to re-skill in their spare time, as this will require a significant time commitment, and so employer support is likely required. Introducing planning for re-skilling in a similar way to vacation planning in companies could support the re-skilling effort. Employee-led re-skilling might include both on-the-job training and off-site learning opportunities.

The Danish flexicurity model already today plays a key role in ensuring a flexible workforce. Denmark might consider strengthening this model further in light of the pressures that AI puts on the Danish workforce (e.g., unemployment policies targeted at impacted groups), ensuring that the negative implications of AI are proactively managed and that employees continue to be as supportive of AI as they are today (with three quarters believing that AI will positively impact their professional lives).

Priority area 1.5: Attract international AI talent

A final way to address the issue is to attract international talent. With a talent gap of 20,000 to 80,000 people by 2030, it will be challenging for Denmark to solve the issue purely within its own borders. The solution requires Denmark to think openly and ambitiously about how it can attract students, professionals, and professors to Denmark. Other countries are reaching the same conclusion. For instance, the UK is expanding its efforts to attract global AI talent. One initiative involves increasing the number of "Exceptional Talent" visas, aimed in particular at attracting workers in the tech sector.[94] These visas provide tech professionals and researchers with better opportunities to apply for settlement in the UK after three years of work or study.[95] To attract foreign professionals and experts, Denmark could consider expanding on existing initiatives, e.g., the Fast-track scheme. Moreover, to make it easier for students and researchers to come to Denmark, it could consider expanding the offering of AI-related programs and courses taught in English.

[91] Google, nd.
[92] UK government, 2019b
[93] TESA, 2019
[94] UK visas, 2019
[95] LLB, 2017

Opportunity #2: Use a strong data foundation to create a competitive advantage

Access to structured data is a challenge for Danish companies to realize the full potential of AI. According to our survey of Danish AI startups, half of them see availability of data and usefulness of existing data as significant barriers to working with AI.[96] However, Denmark has several strengths to leverage in creating a world-class data pool, including a strong (though fragmented) public data pool and a tradition of inter-company collaboration.

Priority area 2.1: Increase consolidation and compatibility of public data

Denmark is at a great starting point with a generally high quality of public data; yet these data are inaccessible and fragmented, being stored in several hundred databases. Such data fragmentation and lack of openness are inhibiting, not only in relation to helping universities and companies gain access to public data, but also simply in terms of increasing access across public institutions. Countries such as Israel, South Korea, and Finland face similar challenges, but are already starting to take action. Israel, for example, has invested approximately DKK 1.8 billion in establishing one database that pools healthcare data, which enterprises and organizations can access.[97] Similarly, South Korea has started an initiative that consolidates genetic and biometric data for 10 million people in one database to support research into health initiatives.[98] Finland has taken even more wide-ranging measures with its "*MyData*" initiative. The initiative aims to centralize all citizen data under one data management structure, giving citizens transparency and control over how companies use their data and enabling organizations to combine data and incorporate citizens' data into their business models (as long as the individuals have consented).[99] In Denmark, Digital Hub Denmark has launched a project around open APIs and public data; the project is still at an early stage but aims to support companies and startups that wish to get access to public data.[100]

Danish AI and data experts note that the most critical barrier to increased data access in Denmark is not the technical infrastructure but rather regulation around data sharing. Part of the technical infrastructure is already in place with the project "Datafordeleren", which centralizes data from multiple public institutions (though there is still scope to further expand this initiative).[101] However, the Danish "register"-related legislation and regulation are mostly suited for analyses based on clear linear thinking (testing whether x leads to y), whereas AI researchers often approach a problem in a less structured manner, given AI's ability to analyze huge amounts of data. Such regulation likely needs to be reassessed in a world in which more and more analyses will leverage AI tools.

In reassessing regulation, Denmark could also consider allowing for flexibility, under controlled circumstances, to enable companies to experiment with new innovations. Countries such as the UK, Singapore, and South Korea have been successful with "sandboxes", which are fast-track legal approaches to working with AI to test technical and commercial viability of innovations.[102] For instance, the UK has established a fintech sandbox for companies to test AI solutions in an environment with limited duration and number of customers. It has supported more than 500 enterprises since its establishment in 2014.[103]

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[96] Survey among Danish AI startups, n=57
[97] Reuters, 2018a
[98] Hyun-Jung, 2018
[99] Ministry of Transport and Communication, 2018
[100] Digital Hub Denmark, nd.
[101] SDFE, nd.
[102] Smart Nation Singapore, 2019; Ji-young, 2019; FCA, 2019
[103] FCA, 2019

It should be noted that a critical concern when expanding access to public data should be to retain citizens' trust in the public sector's handling of their data. When increasing access to data, it is critical to ensure that it happens under controlled circumstances and with consideration to citizens' data privacy. Denmark is to a large extent a society built on trust, and such trust can be considered a pre-condition for collecting the world-class data that Denmark has today.

Priority area 2.2: Facilitate inter-company collaboration on data

Denmark has another strength in its long tradition of collaboration in the private sector, for instance, with unique Danish concepts such as "andelsforeninger" (company cooperatives). This collaborative tradition provides a good foundation for sharing data between companies to realize the necessary scale to produce meaningful insights. Several of Denmark's peers already work specifically with providing the right conditions for data sharing across organizations. Sweden, for example, has established a national center for AI-related research, in which a *"Data Factory"* is established as a platform for organizations to share data. Organizations can upload their data on the platform, and researchers and developers from different organizations can then use them, while the platform ensures that the data are used according to agreed principles and constraints.[104] In the UK, the Governmental Office for AI has collaborated with the private sector to initiate two pilot projects that establish data trusts to solve societal challenges, e.g., to reduce food waste. In the pilot projects, data from NGOs are collected and made accessible to researchers and developers to develop and test solutions.[105] Such data aggregation and establishment of large-scale data pools may be driven by either public actors or commercial providers.

[104] AI Innovation of Sweden, 2018
[105] Open Data institute, 2019

Opportunity #3: Link cutting-edge research with commercial success

Denmark has a strong AI research community and institutions for turning research into commercial applications. It ranks in the global top in AI subfields such as natural language processing and algorithmics. However, it still has some way to go on some of the disciplines most critical to the application of AI, notably deep learning. More than half of Danish AI startups use deep learning techniques, but only two percent of Danish AI researchers actively research in deep learning.[106] Moreover, though Denmark has strong partnerships for turning research into business applications (e.g., MADE), it is still relatively immature when it comes to converting AI technologies into viable business applications, particularly for SMEs.

Priority area 3.1: Attract superstar AI researchers in selected areas

There is an opportunity for Denmark to further strengthen its AI research community, particularly by attracting a few superstar AI professors in select research topics (notably deep learning). Having world-leading AI professors disproportionately affects the quality of the ecosystem, e.g., by attracting other international talents and some of the bigger tech companies. One way to attract such researchers is by establishing a few attractive research positions with globally competitive salaries and dedicated research teams of PhDs / postdocs with autonomy for the universities to hire talent in a fast and flexible way. Attracting a few world-leading AI professors may catalyze a snowball effect, helping create and attract the next generation of AI talent. This means that reaping the full benefits of attracting those superstar AI professors also requires the funding to hire the additional researchers attracted to Denmark by the AI superstars. "Superstar programs" abroad include one in the UK, in which the government has provided around DKK 70 million of funding for five top AI research fellowships through the Alan Turing Institute.[107] An initiative in Germany seeks to strengthen the AI research community via an investment in 100 new professor positions, aiming to avoid an AI brain drain to global hubs such as China and the U.S.[108]

Priority area 3.2: Foster collaboration to drive applied research initiatives

Bringing together actors across industries, universities, and the public sector is important to ensure that pioneering AI technologies do not only stay at the universities but are also transformed into viable commercial applications. Denmark has strong collaboration on other innovation topics; for instance, inspiration might be drawn from the "Manufacturing Academy of Denmark" (MADE), which facilitates collaboration between enterprises, GTS institutes, and universities, with the goal of providing a platform for applied research and innovation relevant to Danish manufacturers. Enterprises are often brought into the program through innovation networks that support companies in their digital transition through conferences, innovation labs, workshops, and pilot projects to test the commercial viability of technologies and innovations.[109] There might also be even more scope for Danish universities to collaborate with enterprises on research, following examples from abroad such as Google that has opened an AI research lab in collaboration with researchers from Princeton University, or the Danish-founded Unity Technologies, which collaborates closely with some of the leading American universities within AI as well as other industry players, e.g., DeepMind, on AI research topics.[110]

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[106] Survey among Danish AI startups, 2019, n=57; mapping of Danish universities' AI activities, 2019
[107] Wood, 2019
[108] Scherer and Lotito, 2018
[109] MADE, 2019
[110] Schultz, 2018

Opportunity #4: Support SMEs in digital and AI transformation

Some 99 percent of Danish companies are SMEs, and today they lag behind on adoption of advanced technologies; therefore, continued AI and digital transformation of Danish SMEs is critical to harness the opportunities of AI. Such a transformation can be supported by multiple means:

Priority area 4.1: Leverage the Danish technology ecosystem to support SME adoption

Denmark already has an ecosystem for supporting SMEs on technological and digital transformation, including Digital Hub Denmark, the GTS institutes (such as the Alexandra Institute and the Technological Institute), and InfinIT. Such organizations help bridge the gap between pioneering research and the everyday-reality in SMEs, and they help showcase examples of how advanced technologies can create business value for smaller enterprises. This ecosystem can be leveraged not only to drive digital transformation, but also to drive AI adoption, though this requires investment in AI-specific capabilities and programs. Today, Denmark has several initiatives in place that help drive digital adoption, though these are not AI-specific; for example, SMV:Digital, which enables SMEs to apply for grants of DKK 100,000 for advisory help on digital transformation.[111] Other countries have developed AI-specific accelerator programs to drive SME transformation. For instance, Finland has AI programs that support SMEs and startups in three ways: (1) a six-month accelerator program that brings together organizations working with similar challenges; (2) a playbook built from lessons from accelerator programs to guide new enterprises; and (3) a publicly available overview of AI companies in Finland to help build connections among companies.[112]

Priority area 4.2: Enable easier access to AI talent for SMEs

In the long term, successful transformation of Danish SMEs requires increased access to talent, fostered by the priority areas in opportunity #1. Nevertheless, there may be short-term ways to support such increased access to talent for SMEs. For instance, Digital Hub Denmark in 2019 launched "Deep learning as a service", which helps Danish companies get access to some of the few Danish deep learning scientists.[113] Denmark could consider expanding upon such initiatives to further increase access to talent. An example from abroad is the German "Mittelstand 4.0 Center of Excellence" that offers specialized AI trainers to support SMEs in the use of AI with the goal of helping at least 1,000 companies a year.[114] More initiatives like this, with talent at multiple skill levels (from deep learning experts to people able to apply AI to specific use cases), could in the short term support the AI transformation of SMEs.[115]

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[111] Erhvervsstyrelsen, 2019
[112] FAIA, 2019
[113] Digital Hub Denmark, 2019.
[114] Federal ministry of Economic Affairs and Energy, 2018
[115] It should be noted that another solution is for Danish SMEs to outsource their AI activities, thereby leveraging external talent.

Opportunity #5: Build one or two leading AI clusters and push for catching up with peers on investments in AI

Our research indicates that it is a virtuous circle to have a leading AI eco-system with a strong presence of innovative startups, companies willing to invest in AI, private and public research centers supplying world-leading research, universities educating the best talent, and a strong public sector that is committed both to large-scale investments in AI and to create favorable conditions for companies investing in AI. Lessons from experts involved in Odense's successful robotics cluster highlight that it is critical that all actors come together and collaborate for such a cluster to come into place. In Odense, a unique combination of companies with innovative technologies, a university willing to invest in building niche expertise, and a risk-taking local municipality helped create what today is one of the world's leading clusters in robotics. Denmark has a wealth of organizations that aim to facilitate collaboration in the Danish AI eco-system, e.g., Digital Hub Denmark, the GTS institutes, and InfinIT. Leveraging these organizations and networks even further to promote investment and collaboration is a key tool for Denmark to unlock valuable synergies and build one or more leading AI clusters.

Priority area 5.1: Bring actors together to build one to two AI clusters around the biggest Danish cities

For Denmark to succeed in the AI race, it could consider bringing together actors to collaborate on building a few AI-related clusters in areas in which Denmark already has a comparative advantage; whether that is within specific areas in AI, such as algorithmics or natural language processing, or within certain applications, such as public administration or renewable energy. This requires close collaboration between all actors; startups, established companies, municipalities, government departments, and relevant interest groups. Examples include cluster-building initiatives in Canada, where the government has invested in transforming Montreal and Toronto into deep learning clusters, with the establishment of three national AI centers and a talent program for top AI researchers. The Canadian clusters are further strengthened by the presence of AI research labs of leading tech players, including Microsoft and Google.[116] Denmark can also consider encouraging global tech players to invest in research labs in Denmark, which would strengthen the research community and help Denmark retain AI talent. Other countries are actively encouraging investment by these tech players. The Taiwanese government, for instance, has helped Microsoft and Google recruit and train talent to enable the companies to expand their AI-related business in Taiwan.[117]

Priority area 5.2: Encourage public and private investments in AI

Our analysis shows that Denmark lags behind the global leaders in both public and private investments in AI. When considering the size of its population / economy, Denmark ranks among the top ten countries globally on a broader AI investment index (which includes variables related, e.g., to private investments, total market size for AI technologies, and number of patents). This, however, does not tell the whole story; specifically, when looking at PE, VC, and M&A investments in AI, Denmark ranks 25th globally. This is a function of Denmark in general having a limited capital market for Danish AI startups and enterprises to tap into. For Denmark to establish a leading AI ecosystem, it should work to promote and attract private sector investments.

The public sector too has a key role to play. Currently, Denmark is behind some of its peers on public investment and there is scope to assign more investments to AI initiatives (i.e., not merely to digital initiatives but to AI-specific initiatives).

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[116] Metz, 2016; Microsoft, nd
[117] Jennings, 2018

For instance, while Denmark with its national strategy has committed DKK 60 million to AI activities from 2019 to 2027, Finland has established an investment program for AI projects, running from 2018 to 2022, with a budget of more than DKK 1.5 billion, of which the government will provide half.[118] The UK – with its "AI Sector Deal" – will invest more than DKK 8 billion of public funds in AI through increased R&D budgets, talent development, and digital infrastructure in both the public and private sectors.

Opportunity #6: Collaborate internationally to achieve scale and leverage comparative strengths

Denmark cannot crack the issue of AI adoption alone. Technology knows no borders, and this can be leveraged as an advantage if countries come together to collaborate on promoting the AI agenda.

Priority area 6.1: Promote standardization and common legislative frameworks

As a small, open economy, Denmark can benefit from driving the international AI agenda, ensuring standardization of regulation across markets. Examples of issues that could be addressed internationally include requirements for data quality, for "explainability" and transparency of methods or models, and for liability concerns. Moreover, some areas might be addressable in more detail on a European level, e.g., through EU-wide regulation and standardization. For instance, issues around data privacy, linked to GDPR and beyond, are relatively similar across European nations.

Priority area 6.2: Drive international investments and partnerships

Denmark could consider identifying sub-areas in which it can leverage existing international research partnerships within AI. Coordination through partnerships would enable each country to focus on its individual comparative advantages while also supporting partners in leveraging their strengths. For instance, Denmark could focus on leveraging its strengths, e.g., in machine learning for audio, robotics, algorithms, or natural language processing, becoming a hub for such research and offering its expertise to the rest of Europe. Moreover, looking at the investment volumes in leading nations such as the U.S. and China, no single European country will be able to keep up. To illustrate: in 2018, VC, PE, and M&A investments in AI and big data companies were more than DKK 260 billion in the U.S., more than DKK 60 billion in China, and just below DKK 10 billion in the UK, which was the EU country with the highest level of investment.[119] Initiatives such as Horizon 2020 and Horizon Europe to some extent address this issue. However, Europe could be even more ambitious in terms of pooling investments, knowledge, and data to be able to play in the same league as the world's leading AI countries.

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Our research has shown us that there is reason for optimism. With a highly digitized public and private sector and tech savvy employees, Denmark's digital foundation is in place. It is fully within reach for Denmark to establish itself as a leading nation within AI adoption and innovation. But doing so will require a concerted, ambitious, and collaborative effort on behalf of policy makers, universities, companies, startups, and interest groups. Setting off from a unique starting point, now is the time for those actors to work together on shaping a better future for Denmark by harnessing the promise of AI.

[118] Business Finland, 2019
[119] McKinsey analysis based on Pitchbook database

7. APPENDIX

Appendix 1: Description of university index

The following describes the underlying methodology for constructing the index for the global university analysis in chapter 3.

The index scales and aggregates information from three different sub-indices to measure the quality of AI research at universities on a global level. Based on data from Times Higher Education and QS Top Universities, the computer science citations index expresses both the frequency of publications from computer science departments at different universities as well as the number of citations of such publications. Using data from CSRankings, we also include information on research activities that are directly related to AI at different universities: The conference index expresses the frequency at which researchers from each university publish at global top AI conferences[120], while the faculty size index expresses the size of the pool of people who publish at such conferences at each university. See exhibit 24.

EXHIBIT 24

OVERVIEW OF VARIABLES FOR GLOBAL UNIVERSITY ANALYSIS

Topic	Variables	Source
Computer science citations index	Citations index, 2019	Times Higher Education
	Citations index, 2018	Top Universities (QS)
	H-index, 2018	Top Universities (QS)
AI Conference Index	Mean count of papers published at top conferences across all subareas of AI in the period from 2014-2018[1] controlling for AI Faculty	CSRankings
AI Faculty Size Index	Number of faculty members who have published at top conferences in any subareas of AI in the period from 2014-2018[2]	CSRankings

1 The variable "count" within "Artificial intelligence", "computer vision", "machine learning & data mining" natural language processing" and "the web & information retrieval", 2014-2018 2 The variable "faculty" within "Artificial intelligence", "computer vision", "machine learning & data mining" natural language processing" and "the web & information retrieval", 2014-2018
Source: Times Higher Education, Top Universities (QS), CSRankings

Appendix 2: Description of investment index

The following describes the underlying methodology for constructing the investment index for the investment analysis in chapter 4.

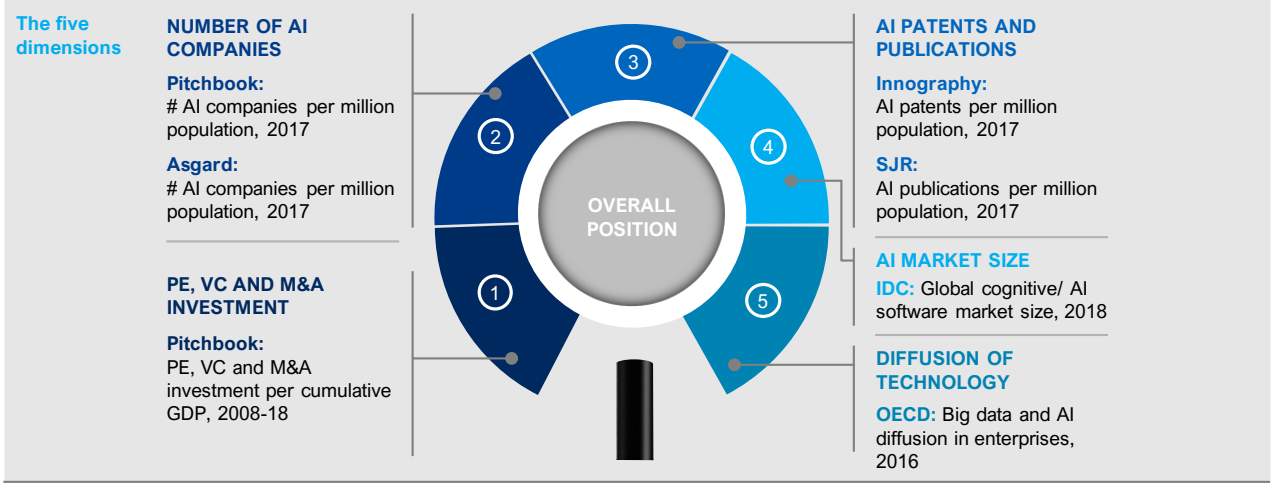
Currently, there is no perfect data for sizing AI investments globally or at the country level for a number of reasons: AI as a term includes tools, approaches, and applications of technology that are evolving; startups and established firms in all industries are adopting AI, but not labelled as AI companies; and most AI investments are made internally in large corporations with limited public reporting. In order to overcome these challenges and obtain the most accurate directional answer, a triangulation approach has been taken in which we account for different country size.

To assess the overall ranking of countries on their AI investments, we have constructed five indices to rank countries with more than one million inhabitants. We have found one or several variables measuring each dimension, and by computing the median across all seven variables, one overall rank for each country was constructed. See exhibit 25.

[120] Considering only universities with at least five AI-researchers

EXHIBIT 25

OVERVIEW OF METHODOLOGY FOR INVESTMENT ANALYSIS



Malta, Luxembourg, Iceland, Macau and Guam have been excluded from the rankings due to small population. Rank based on equal weighted median of each metric.
SOURCE: McKinsey analysis based on Pitchbook, Asgaard, SJR, Innography, IDC, OECD

Appendix 3: Description of eco-system index

The following describes the underlying methodology for constructing the index for the eco-system analysis in chapter 4.

The success of AI eco-systems depends on the performance along at least seven drivers. For these drivers, we collected data for more than 30 variables, but to avoid too strong correlation between variables (and hereby double-counting variables), we ended up using the 20 measures listed below – see exhibit 26. To combine the measures into a composite measure, we normalized the variables using z-scores.

The seven drivers were each allocated a weight according to the identified importance of the driver. Superstars, talent, and capital were recognized as the most necessary drivers for AI eco-system emergence, thus allocated twice the weight of the less important drivers. The division of the necessity of the drivers were supported by statistical regression and cluster analysis, e.g., strong performance on superstars, talent, and capital is positively correlated with number of AI startups, number of AI companies that has received funding, and AI investor presence. Within each driver, equal weights were used.

The 20 variables are proxies for the seven dimensions, as some of the variables reflect wider computer science activities, while several of the variables were only available on country-level. However, as supported by our regression analysis, these variables are closely related to AI activities such as AI startups.

We sampled data on more than 400 cities. However, we wanted to make sure we only included relevant cities, i.e., cities with actual AI activity. Hence, we decided only to include a city in the ranking if it satisfied one of the following criteria

1. It appeared in at least two of the seven AI-specific city-level sources and had a population of more than 200,000
2. It appeared in at least five of the seven AI-specific city-level sources

This resulted in a sample of 294 cities worldwide. However, not all cities were represented in all measures, which resulted in missing data. On city-level AI-specific measures, missing data was treated as a zero-observation. On other measures, cities with missing values were assigned the mean score of all other cities.

EXHIBIT 26

OVERVIEW OF VARIABLES FOR ECO-SYSTEM INDEX

Weight of driver[1]	Driver	Weight within driver[1]	Measure	Level of analysis	Source
20%	Superstars	33%	Citations per paper for Computer Science departments		QS rating
		33%	University Ranking and reputation within Computer Science of best university, 2018		Times Higher Education
		33%	H-index of Computer Science departments		QS rating
20%	Talent	25%	# of startups building AI solutions, 2018		Asgard
		25%	Number of top 200 universities within computer science, 2018		Times Higher Education, QS
		25%	PISA Scales in math and science, 2015		OECD PISA
		25%	Researchers, FTE/mn pop, 2018		Global Innovation Index
20%	Capital	33%	AI companies: Valuation and funding received[2]		Crunchbase, McKinsey & Company
		33%	Access to funding for AI companies[3]		Crunchbase, Pitchbook
		33%	Basic investor conditions, 2018		Global Innovation Index
10%	Commerciali-zation	50%	Political, regulatory and business environment, 2018		Global Innovation Index
		50%	AI patents, 2010-2018		Innography
10%	Connected-ness	33%	Density of AI startups, 2018		Asgard
		33%	University/industry research collaboration and state of cluster development, 2018		Global Innovation Index
		33%	JV-strategic alliance deals/bn PPP$ GDP, 2018		Global Innovation Index
10%	Global orientation	33%	Global R&D firms, avg. exp. Top 3, mn $US, 2018		Global Innovation Index
		33%	Patent families filed in 2+ offices/bn PPP$ GDP, 2018		Global Innovation Index
		33%	MGI connectedness index, 2018		McKinsey & Company
10%	Culture	50%	Appeal to foreign talent, 2018 index		World Economic Forum
		50%	Rating of quality of life in country, 2017 index		OECD index

1. Numbers may not sum to 100% due to rounding 2. Combined measure of number of unicorns (2018) and total received equity funding for AI companies (2014-primo 2019) 3 Combined measure of: (1) # seed/venture investments in AI companies (2014-primo 2019), (2) # AI exits (2014-2018), (3) # AI companies received funding (2014-primo 2019) and (4) # funding rounds for AI companies (2014-primo 2019)
Source: Times Higher Education, QS World Universities, Crunchbase, Pitchbook, Global Innovation Index, Innography, Asgard, World Economic Forum, OECD, McKinsey & Company

Appendix 4: Overview of deep analytical skills

See exhibit 27 for a list of the list skills used for the skill and competence analysis in chapter 4.

EXHIBIT 27

DEEP ANALYTICAL SKILLS

Skill category	List of skills
AI specific	artificial intelligence, machine learning, deep learning, neural networks, natural language processing, nlp, speech processing, speech recognition, voice recognition, image recognition, signal processing, pattern recognition, reinforcement learning, proprietary algorithms, advanced machine learning, ai technology, speech analysis, speech analytics, predictive analytics, text analysis, text analytics, language processing, object recognition, virtual assistant, automated planning, automated optimization, robotics, computer vision, biometrics, edtech, computational semantics, kunstig intelligens, maskinlæring, automatisk læring, neurale netværk, sprogteknologi, talegenkendelse, stemmegenkendelse, billedegenkendelse, mønstergenkendelse, objektgenkendelse, virtuel assistent, biometri, naturlig sprogforståelse, algorithm design, apache pig, artificial neural networks, computational linguistics, computational neuroscience, decision tree, gradient boosting, machine vision, topic modeling, topic models, parallel computing, parallel programming, statistical signal processing, supervised learning, support vector machine, support vector machines, svd, svm, unsupervised learning, superviseret læring, usuperviseret læring, support vektor maskine
Mathematical	Algebra, statistical modelling, algorithms, optimering, statistisk modellering, bayesian networks, bayesian statistics, cluster analysis, cluster detection, clustering, data clustering, markov chain, naive bayes, nearest neighbor, outlier detection, pca, predictive modeling, principal component analysis, sentiment analysis, simulations, singular value decomposition, stochastic modeling, text mining
Programming	Programming, sas, matlab, keras, scikit-learn, theano, randomforest, xgboost, pytorch, voice, c, c++, c#, cuda, api, .net, c/c++ stl, git, java enterprise edition, linux, perl, ruby, scheme, servlets, unix, xml, bash, html, html5, javascript, jquery, json, Rstudio, python, scala, tensorflow, java, data mining
System architecture	Data varehus, server arkitektur, SQL, Oracle, API, data warehouse, solution architecture, MongoDB, OLAP, Relational database, SQL server, server architecture
Visualization	Matplotlib, Seaborn, ggplot2, shiny, Plotly, Bokeah, D3
Supporting	Data mining, data science, data scientist, Hadoop, Java, ApacheSpark, Apache, Cloudservices, Microsoft Azure, Google Cloud, Amazon Web Services(AWS), Datamining, Big Data, Data analytics, API

SOURCE: Experts, McKinsey Digital, McKinsey Analytics

Appendix 5: Modeling the impact of AI on the Danish economy

The following describes the underlying methodology for the macroeconomic analysis outlined in chapter 5. To gauge the macroeconomic consequences of AI adoption until 2030, McKinsey Global Institute has built a detailed micro-founded model that forecasts the effect of AI on economy-wide value creation and labor demand based on microeconomic firm data as well as country-specific macroeconomic variables. By simulating AI adoption in the private sector using detailed firm-data from multiple surveys and use-cases, McKinsey Global Institute builds a strong foundation for estimating the intensity and pace at which AI affects macroeconomic outcomes.

Steps to estimate the effect

The simulation of the impact of AI on macroeconomic outcomes in Denmark is based on seven steps that cover the procedures of estimating the microeconomic foundation for AI in firms, constructing a foundational macroeconomic model and adjusting this model to simulate the specific impact of AI in Denmark

Step 1 – Integrate data sources: The research combines several data sources, including:

- Two large, independent corporate surveys to gauge private investment behavior and activities

- A database of 400 existing AI use cases across industries and functions to confirm the impact of AI on profits, costs, and revenue
- A database on 2,000 activities and their required types of capabilities in 800 types of occupations to understand the impact of AI on labor demand

Step 2 – Simulate AI adoption: The data is used in an econometric model that endogenizes corporate adoption based on competitive and strategic value of AI. Based on this model, the simulated rate of AI adoption is faster than average technology diffusion, suggesting that AI is strongly disruptive.

Step 3 – Simulate "gross" GDP impact: Based on the microeconomic foundation, McKinsey Global Institute builds a foundational model that gauges the macroeconomic factors expected to be influenced by AI. These macroeconomic factors are namely labor augmentation, labor substitution, product and service innovation, the impact on the global value chain, and the feedback loop in the macroeconomy. Simulating the impact of AI on the global value chain, the MGI research accounts for flows of data and adjustments on foreign direct investments and trade caused by AI adoption.

Step 4 – Simulate "net" GDP impact: The McKinsey Global Institute research also models the net economic impact of AI. This is done by taking into account the costs related to implementation of AI, including investments in the deployment of systems and transition costs associated with labor (for instance, the cost of labor displacement, retraining, and rehiring). The research also assesses negative externalities such as loss of consumption during unemployment as well as social costs incurred by paying benefits to unemployed during transition.

Step 5 – Simulate the impact on labor markets: Based on the micro- and macroeconomic simulations, the MGI research links the economic impact with the effect on labor markets, taking into account different skill and wage levels as well as the degree of digital content in tasks carried out.

Step 6 – Model the most likely scenario for Denmark: Finally, the foundational framework can be used to model the impact on the Danish economy specifically. The research identifies enablers in the Danish economy that correlate strongly to factors driving adoption of AI, such as innovation capacity, human capital, and connectedness. The model also considers factors specific to Denmark such as the digital infrastructure, automation potential, and unemployment benefits.

Step 7 – Analyze Danish sensitivity to selected variables: In order to gauge the sensitivity to different assumptions in the model, McKinsey Global Institute has investigated the impact of changing key variables (e.g., the pace of AI adoption in the private sector).

The effects of AI on the Danish economy

In estimating the effects of AI on GDP, the research considers three main effects; productivity effects, demand effects, and cost effects. While the productivity effect and the demand effect are predicted to cause significantly positive effects of AI on macroeconomic outcomes in the long run, the cost effects associated with implementation costs and re-skilling of workers may dampen some of the positive effects of AI – in particular in the short run. The three effects can be decomposed into seven subcomponents – see exhibit 28

EXHIBIT 28

EFFECTS OF AI ON THE DANISH ECONOMY

	Effect	Description
Productivity effects	Labor augmentation	AI-related technologies may make workers more productive in carrying out certain tasks – hence, AI may augment labor in production activities.
	Labor substitution	AI-related technologies may be used to undertake certain tasks at a lower cost than using human labor, giving employers incentive to replace workers by machines or algorithms.
	Innovation / competition	Adoption of AI in the private sector may help firms expand their portfolios of products and services, develop new business models, or some combination of the two. Thereby, firms may expand their production possibility frontier, allowing for more production at given levels of inputs
Demand effects	Connectedness	AI can contribute to increased connectedness of economies either by facilitating more efficient cross-border commerce or by improving supply chain efficiency and reducing complexities associated with global contracts, classification, and trade compliance. These factors will enable companies to sell their products and services on new markets
	Wealth creation	When AI increases productivity of companies, some of the resulting increases in profits and wages are reinvested in economy, thereby contributing to increased economic activities through a positive feedback loop
Cost effects	Implementation costs	As companies adopt AI-augmented production methods, they may incur significant costs. These costs may, for instance, arise when firms restructure their organization to accommodate new business models, when they pay out severance to displaced workers, and when they build up new capabilities to operate AI-related tools
	Negative externalities	AI adoption may also lead to negative externalities; for instance, when firms adopt AI-related technologies in production, some workers will undergo temporary periods of unemployment where they need to upgrade and adapt their skills to new production technologies

SOURCE: McKinsey Global Institute

Appendix 6: Welfare implications of AI

The following describes the underlying methodology for assessing the welfare implications of AI in chapter 5. In the McKinsey Global Institute analysis that estimates the welfare implications of AI, the concept of economic welfare is applied to compare factors associated with well-being with those associated with GDP. In order to quantify the impact of advanced technologies on well-being, welfare in this analysis is measured in monetary or "GDP-equivalent" terms. This follows the methodology in the standard welfare literature in economics, including the seminal contribution by Charles I. Jones and Peter E. Klenow of Stanford University.[121]

The analysis aims at measuring the impact of AI on parameters that affect citizen well-being, but are not captured in standard GDP measurements. Hence, to the degree that goods associated with education, health, housing, safety, and environmental protection are enhanced by automation and innovation inside the production boundary, such changes are implicitly captured in GDP and not considered in this analysis. Acknowledging that AI and other advanced technologies may affect the well-being of citizens through a tremendous number of channels, this analysis only takes into account those channels that are considered of major importance while also being possible to measure with a sufficient degree of accuracy. These include the following:

Consumption – Income only contributes to citizen well-being to the extent that it is consumed. The McKinsey Global Institute analysis adjusts utility estimates for changes in the ratio of consumption to GDP, primarily driven

[121] Charles I. Jones and Peter E. Klenow, "Beyond GDP? Welfare across countries and time," *American Economic Review*, September 2016, Volume 106, Number 9

by changes in unemployment which, in turn, relates to job security.

Consumption inequality – To the extent that society has an aversion towards inequality, higher inequality at a given level of income may reduce overall welfare in society. In line with the Arrow-Pratt approach to risk, this component is measured as the variance of the distribution curve for consumption. Increases in this variance is mainly driven by effects associated with unemployment and higher dispersion in wages. These factors are, in turn, driven by asymmetries in the effects of adoption of AI and advanced technologies on occupations, sectors, and workers with different skills.

Risk of unemployment – Even among those who are employed, simply the mere risk that they could lose their job can lead to a reduction in well-being. Using the Arrow-Pratt variance method, disutility associated with higher unemployment risks has been included in the analysis.

Leisure – AI and other advanced technologies may both increase quality and quantity of leisure time through automation and other productivity-enhancing technology. This analysis takes into account that utility from hours of "forced leisure" due to unemployment is considered significantly lower than utility arising from "voluntary leisure".

Health and longevity – AI and other advanced technologies may both increase how long people live as well as the quality of each year that individuals live. If people live longer, they can enjoy the utility derived from the components above for a longer period of time. Also, a healthier life year is generally considered more valuable to individuals. Therefore, any likely improvements in life expectancy and health arising from improvements in technology have been incorporated in the welfare quantification.

Limitations

Though rigorous, the McKinsey Global Institute estimates of welfare implications is based on simulations, and the estimates is therefore indicative of the full potential. In particular, we may emphasize a set of limitations that have potential to alter the estimations if included in the analysis:

- The quantification of the impact of AI on welfare on top of GDP excludes a number of components that are important for well-being but difficult to quantify, e.g., the impact of AI on social connectedness and environmental sustainability, while building on
- The scope of technologies considered is important for the quantification of welfare effects. In the analysis, large branches of technologies such as automation, AI, ledger technologies, and all previous digital technologies such as big data, the cloud, mobile internet, and IoT have been included. Expanding or reducing the set of considered technologies may significantly alter the predictions of the analysis.
- The welfare loss associated with risks of unemployment and income inequality are based on a commonly used variance approach (the Arrow-Pratt variance method[122]), but this computation of risks may be overly restrictive.[123]
- A very limited set of choices at governments' and businesses' disposal has been assumed. This is mainly because the analysis primarily focuses on market dynamics rather than nonmarket interventions. If, for instance, governments initiate large-scale reforms in order to accommodate the AI-transition, the impact of advanced technologies on citizen well-being may be either larger or smaller.

[122] Hijzen and Balint, 2016
[123] Cordoba and Ripoll, 2013

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