The Danish Robotics Cluster in a Global Perspective

December 2019

IRISgroup

Introduction

This publication presents an analysis of the Danish robotics cluster and its economic significance and future potential in a global perspective.

The analysis first offers an overview of the previous development and current size of the Danish robotics cluster.

Next, the analysis covers the future global growth potential in the field of robotics.

Finally, the profile and characteristics of the Danish robotics cluster are compared to some of the leading regions and robotics clusters in other countries.

The analysis is based on register data, existing literature, and interviews with Danish and international experts in the field of robotics. The attached appendix offers a more detailed description of the methods and data sources used.

The analysis and publication were completed by IRIS Group on behalf of the partners of Robotics Alliance and published in December 2019.

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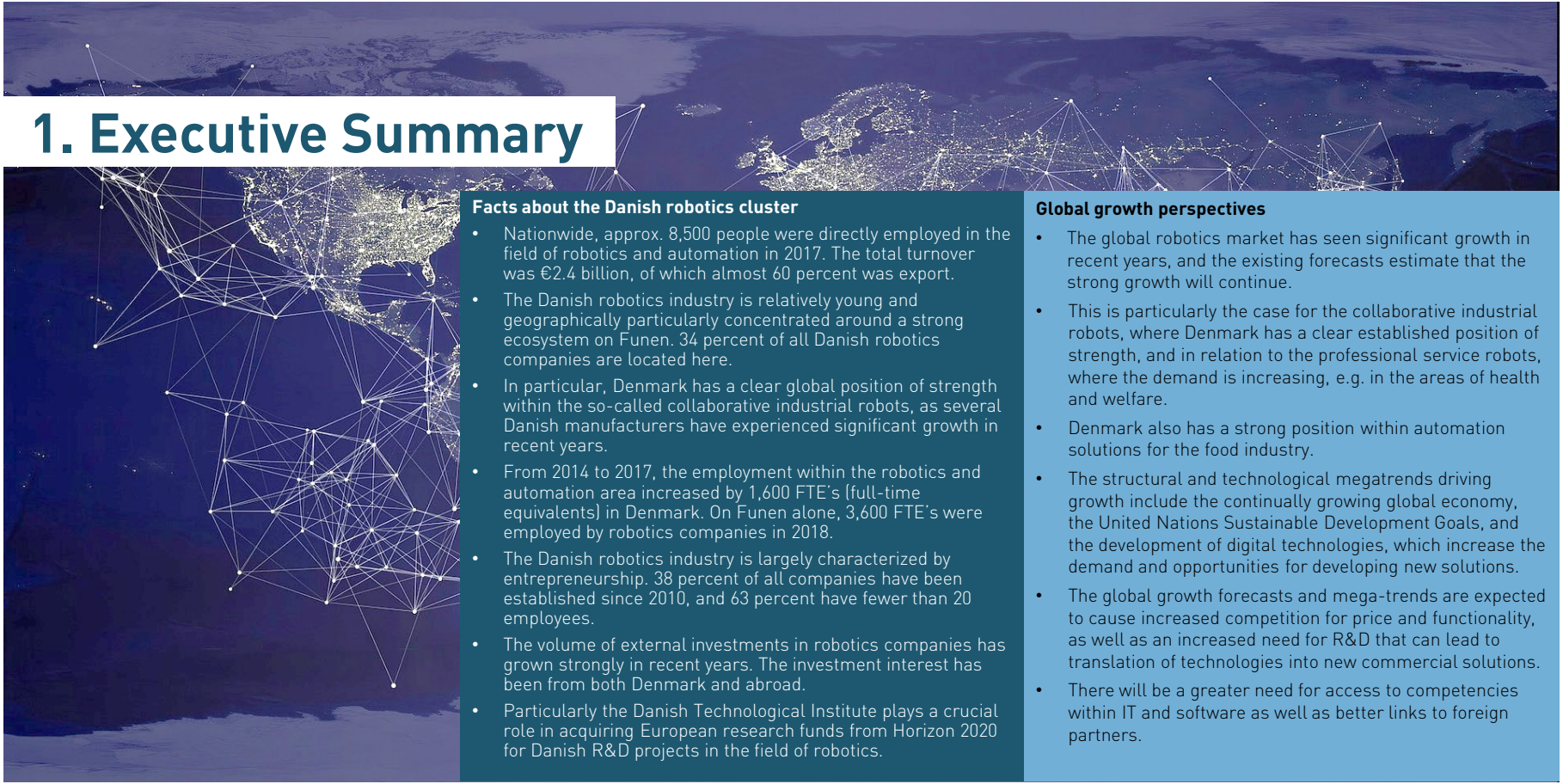


1. Executive Summary

Facts about the Danish robotics cluster

- Nationwide, approx. 8,500 people were directly employed in the field of robotics and automation in 2017. The total turnover was €2.4 billion, of which almost 60 percent was export.
- The Danish robotics industry is relatively young and geographically particularly concentrated around a strong ecosystem on Funen. 34 percent of all Danish robotics companies are located here.
- In particular, Denmark has a clear global position of strength within the so-called collaborative industrial robots, as several Danish manufacturers have experienced significant growth in recent years.
- From 2014 to 2017, the employment within the robotics and automation area increased by 1,600 FTE's (full-time equivalents) in Denmark. On Funen alone, 3,600 FTE's were employed by robotics companies in 2018.
- The Danish robotics industry is largely characterized by entrepreneurship. 38 percent of all companies have been established since 2010, and 63 percent have fewer than 20 employees.
- The volume of external investments in robotics companies has grown strongly in recent years. The investment interest has been from both Denmark and abroad.
- Particularly the Danish Technological Institute plays a crucial role in acquiring European research funds from Horizon 2020 for Danish R&D projects in the field of robotics.

Global growth perspectives

- The global robotics market has seen significant growth in recent years, and the existing forecasts estimate that the strong growth will continue.
- This is particularly the case for the collaborative industrial robots, where Denmark has a clear established position of strength, and in relation to the professional service robots, where the demand is increasing, e.g. in the areas of health and welfare.
- Denmark also has a strong position within automation solutions for the food industry.
- The structural and technological megatrends driving growth include the continually growing global economy, the United Nations Sustainable Development Goals, and the development of digital technologies, which increase the demand and opportunities for developing new solutions.
- The global growth forecasts and mega-trends are expected to cause increased competition for price and functionality, as well as an increased need for R&D that can lead to translation of technologies into new commercial solutions.
- There will be a greater need for access to competencies within IT and software as well as better links to foreign partners.

1. Executive Summary

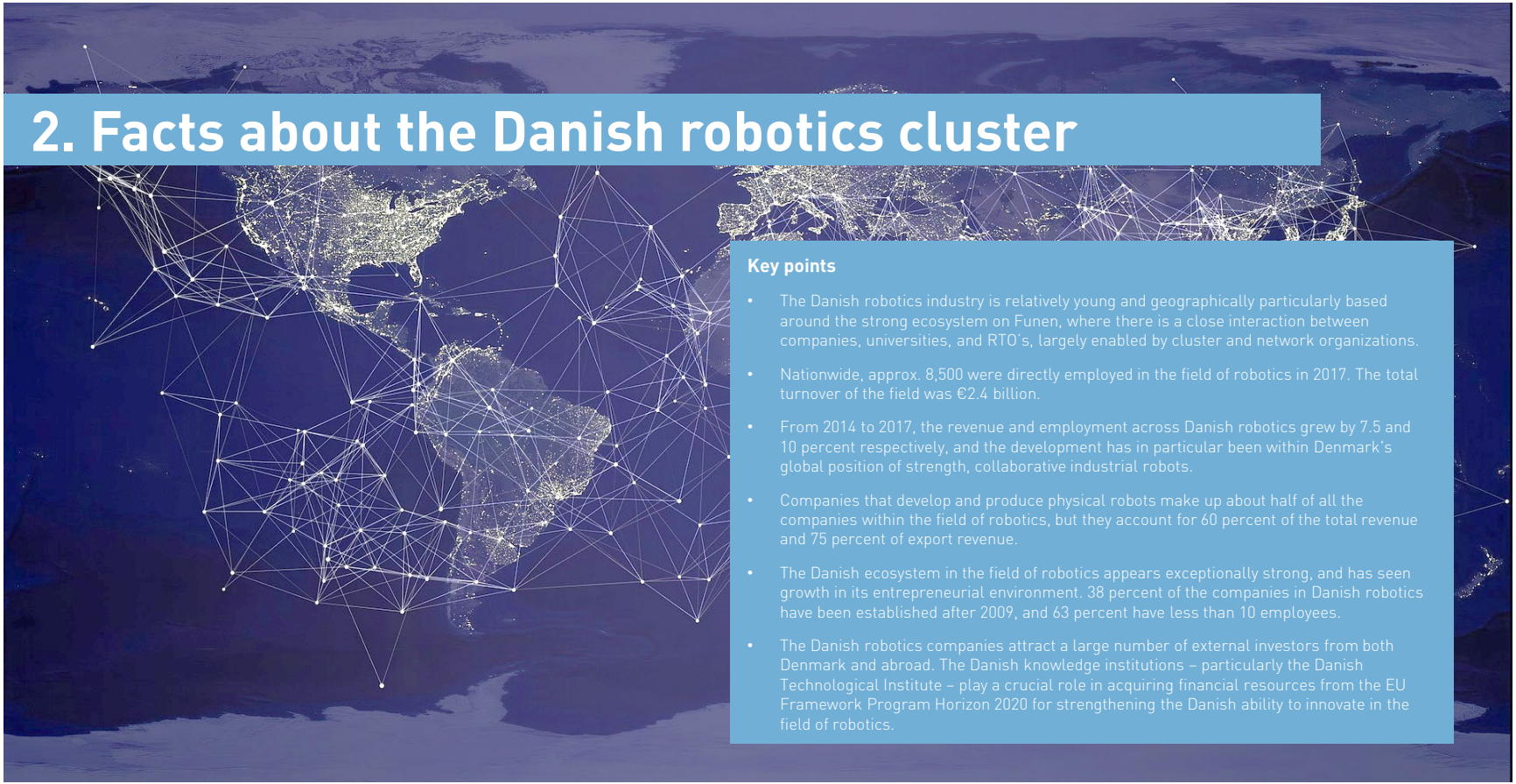
Danish positions of strength

- The Danish positions of strength within the robotics area are relatively new compared to leading foreign regions and companies, many of which have been in the field since the1970s, and have (had) close ties to the automotive industry in particular.
- In contrast to several of the foreign robotics clusters, the Danish cluster and positions of strength are not linked to particular industries, and the collaborative industrial robots have a wide range of functions and large growth potentials.
- When measuring the export of industrial robots, Denmark has seen the largest growth from 2014 to 2018 of all the comparison countries in the benchmark analysis (Sweden, Germany, the Netherlands, France, Italy, the USA, Japan, China, and South Korea).
- The number of Danish research articles within the robot area has also increased significantly in recent years. Thus, the value chain of delivering new research and knowledge - which can be translated into innovative commercial solutions - has been strengthened greatly since 2013.
- In general, the Danish ecosystem and the collaboration between the various actors (companies, universities, RTO's, authorities, cluster organizations, etc.) appear extraordinarily strong in the field of robotics. No other European country has worked as systematically and strategically to make the development and production of robots an independent growth area.

Danish growth potentials

- Overall, the analysis indicates that Denmark can continue to benefit from strong growth potential in the field of robotics in the future.
- That is based on the global growth forecasts, the clear commercial positions of strength, and the strong companies and knowledge environments (and collaboration between them).
- The analysis indicates that the Danish robot industry can better utilize the global growth potentials in various ways.
- Sales of collaborative industrial robots to the global segment of SME's can be further scaled and new application areas and possibilities can increase demand among old and new customer segments in the global market.
- In addition, the Danish robotics industry can gain a greater share of the growth in the emerging and growing markets for professional service robots within, e.g., health and welfare, agriculture, and drones, if the existing strong technical and commercial competencies in Denmark can be exploited and expanded to these areas.

2. Facts about the Danish robotics cluster



Key points

- The Danish robotics industry is relatively young and geographically particularly based around the strong ecosystem on Funen, where there is a close interaction between companies, universities, and RTO's, largely enabled by cluster and network organizations.
- Nationwide, approx. 8,500 were directly employed in the field of robotics in 2017. The total turnover of the field was €2.4 billion.
- From 2014 to 2017, the revenue and employment across Danish robotics grew by 7.5 and 10 percent respectively, and the development has in particular been within Denmark's global position of strength, collaborative industrial robots.
- Companies that develop and produce physical robots make up about half of all the companies within the field of robotics, but they account for 60 percent of the total revenue and 75 percent of export revenue.
- The Danish ecosystem in the field of robotics appears exceptionally strong, and has seen growth in its entrepreneurial environment. 38 percent of the companies in Danish robotics have been established after 2009, and 63 percent have less than 10 employees.
- The Danish robotics companies attract a large number of external investors from both Denmark and abroad. The Danish knowledge institutions – particularly the Danish Technological Institute – play a crucial role in acquiring financial resources from the EU Framework Program Horizon 2020 for strengthening the Danish ability to innovate in the field of robotics.

2. Facts about the Danish robotics cluster – introduction and history

The Danish robotic cluster is highly anchored both historically and geographically on Funen and in Odense. But elsewhere in the country, there are also strong research and commercial players within the field of robotics, and the area can increasingly be described as an established Danish position of strength.

In this chapter, a number of facts detailing the size and importance of the robotics field throughout Denmark are first presented, before more in-depth facts detail the robotics cluster in and around Odense.

We have chosen to distinguish between the following four types of robots :

- **Traditional industrial robots**
  Typically includes larger, fixed robot installations that operate independently of people and surroundings.
- **Collaborative industrial robots (cobots)**
  Typically includes smaller and physically flexible robots that are able to work with people in a common work environment.
- **Professional service robots**
  Includes both robots within e.g. logistics, cleaning, defense, health, cleaning, and surveillance, as well as drones.
- **Personal service robots**
  Includes robots aimed at the private consumer segment within e.g. entertainment, housekeeping, care, and cleaning.

The analysis primarily focuses on the first three categories of robots, as they have the most significant relevance to the Danish robotics industry and the global growth potentials.

The history of the Danish robotics cluster on Funen

The historical development of the Danish robotics cluster has been described and covered by a number of researchers and journalists in recent years. Below is a short summary of the most important milestones in the construction of the Danish robotics cluster.

- **1985**: The Odense Steel Shipyard begins using robot technology.
- **1999**: The AP Møller Foundation donates €10 million to the University of Southern Denmark (SDU) for the construction of a building for Institute of Production Technology.
- **2001**: The research project AMROSE begins (Autonomous Multiple Robot Operation in Structured Environments). The project is funded by the Odense Steel Shipyard, the Danish Academy of Technical Sciences, The University of Southern Denmark, and an information program of the Danish Council for Strategic Research.
- **2002**: The network for competencies and innovation, RoboCluster, is founded.
- **2001-2004**: A team of researchers in Denmark receive a number of grants from e.g. Danish foundations to reinvent the industrial robot.
- **2005**: Universal Robots is founded by researchers, who have developed the idea for UR5, a lightweight, user-friendly, and flexible cobot, which was designed to boost automation in small and midsized industrial companies.
- **2008**: The Growth Fund, SDI and Enrico Krog Iversen invest approx. €1.5 million in Universal Robots. Enrico Krog Iversen enters as the new CEO.
- **2013**: Niels Jul Jacobsen (who was on the board of Universal Robots) founds Mobile Industrial Robots (MIR).
- **2014**: The Municipal cooperation, Udvikling Fyn (Development Funen), establishes Odense Robotics and Odense Robotics Startup Hub, an incubator for new robot companies.
- **2015**: Teradyne acquires Universal Robots for €250 million (+ bonuses of approx. €70 million).
- **2015-2018**: A large number of new robot companies are established, e.g., On Robot, Flow Robotics and Purple Robotics.
- **2018**: Teradyne acquires MiR for €230 million, of which approx. €90 million is in bonuses.

Source: Steno, Carsten, "En klynge der virker" (2016) and the International Federation of Robotics classification of industrial robots and service robots) and Mandag Morgen June 3, 2018: "Robotklynge bugner af kontanter".

2. Facts about the Danish robotics cluster – significance for Denmark

On this page, a summary of the latest available key figures for the Danish field of robotics in terms of size and significance is presented.

The main conclusions are summarized in the text box below, while a more detailed description of the various categories of companies is presented in the dark blue text box on the right of the page.

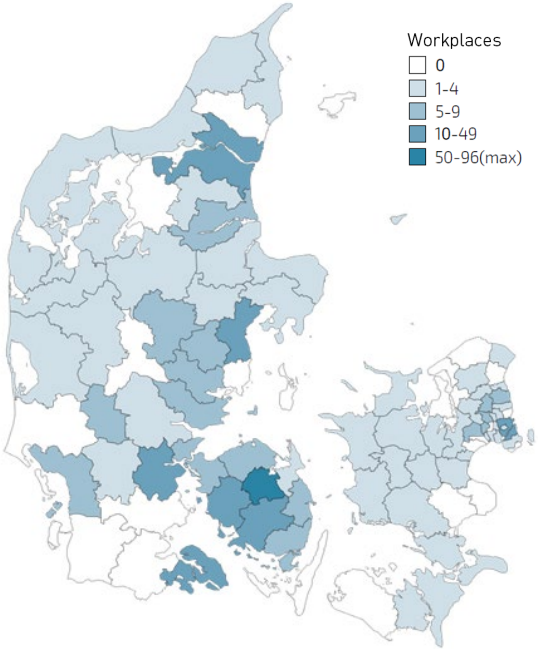
Key figures on the significance of the robotics industry for Denmark

- The companies within the robotics and automation area employed approx. **8,500 FTE's**. In just three years, the number has increased by a total of 1,600, which corresponds to an annual growth of just under 7.5 percent.
- **The robot manufacturers have created the highest amount of new jobs**. The number of FTE's among the manufacturers increased by 1,000 from 2014 to 2017, meaning that they employed about 4,600 in 2017, which corresponds to more than half (55 percent) of all employees in the field of robotics in Denmark.
- The robotics and automation industry had a **turnover of €2.4 billion** in 2017, and revenue is rapidly growing. Since 2014, revenue has grown by more than €600 million. This corresponds to an annual growth of over 10 percent.
- **The robot manufacturers had a turnover of approx. €1.4 billion**, which corresponds to 60 percent of the Danish robotics and automation industry's turnover. Meanwhile, the manufacturers also had the largest revenue growth with an annual increase of 11 percent.
- **The export of the Danish robotics and automation industry amounts to more than €1.3 billion**. In total, exports make up almost 60 percent of the revenue.
- **The robot manufacturers account for approx. 75 percent of exports**, and thus exports more than the integrators, consultants and retailers in the sector. The manufacturers' exports have increased by 14 percent annually from 2014 to 2017, whereas the exports of the integrators, consultants and retailers during the same period have increased by 8-11 percent per year.

Source: Damvad Analytics: "Analyse af den danske robotindustri" (April 2019) and Odense Robotics "Insight Report 2019"

The map shows that the 292 robotics companies in Denmark are distributed throughout the country. The largest concentration is on Funen, and in particular in Odense. 34 percent of the companies are located on Funen, and these are primarily integrators and manufacturers. 10 percent of the workplaces are located in Northern Jutland and 15 percent in the Eastern Jutland, where the companies are distributed more evenly between manufacturers, integrators, consultants, and retailers. Furthermore, there are small groups of companies around Sønderborg and around The Technical University of Denmark (DTU) in Lyngby and Copenhagen.

Distribution of companies in the Danish robotics sector



Categories of robotics companies

Manufacturers: Companies that develop and produce the physical robot units, including drones.

Integrators: Companies that work to develop and design solutions to integrate robots in automation processes.

Retailers: Companies that distribute and/or sell robots and robot-related products.

Advisors: Companies that sell advisory and consulting services in relation to robots and automation.

In addition, a number of *suppliers* exist that supply parts and/or services related to the robots. These are not included in the data for this analysis.

2. Facts about the Danish robotics cluster – development and growth

The three figures on this page outline the development in the number of employees, turnover, and exports in the Danish robotics industry.

Overall, the figures reflect the strong growth and development that the robotics area in Denmark has experienced in recent years.

Revenue and exports

The revenue in the Danish robotics sector has increased by 34 percent from 2014 to 2017, corresponding to €616 million. The annual average growth was 10.5 percent. In 2017 the total revenue was €2.4 billion, of which 60 percent is from exports.

The export has also increased, both in numbers and in share of revenue. The increase was 43 percent from 2014 to 2017, an annual growth of 12.5 percent.

Figure 1. Development in the revenue of the Danish robotics sector (mil. EUR)

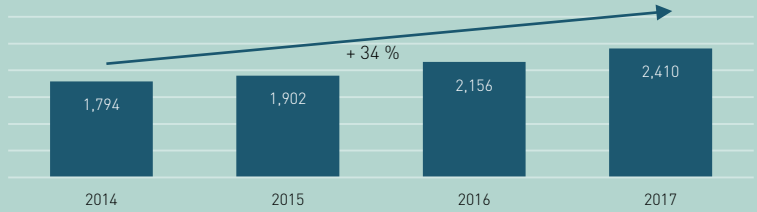
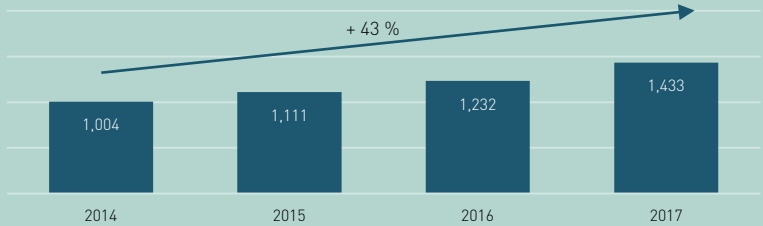


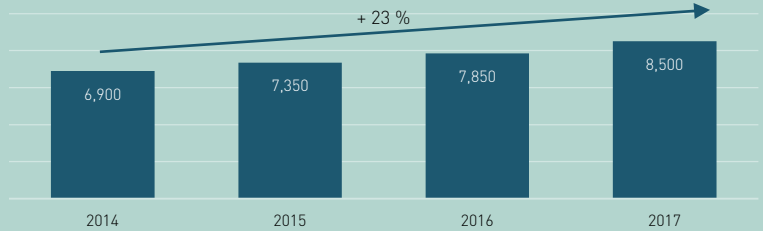
Figure 2. Development in the exports of the Danish robotics sector (mil. EUR)



Employees and companies

The Danish robotics sector employed approx. 8,500 people full-time in 2017, corresponding to an increase of 23 percent since 2014. The annual growth was a little less than 7.5 percent.

Figure 3. Development in the number of full-time employees in the Danish robotics sector



About the growth and the development in the robotics cluster on Funen

The entire Danish robotics sector has experienced significant growth in recent years. However, the growth has been particularly strong in the robotics cluster on Funen, where the growth in employment increased from 2,200 in 2015 to 3,600 in 2018 (64 percent).

In 2017, the turnover in the Funen cluster was approx. €763 million – just under one third of the total revenue for the entire Danish robotics industry. While growth in revenue for the total robotics industry was 10.5 percent annually between 2014 and 2017, it was about 15 percent annually in the robotics cluster on Funen.

The same trend is seen for export statistics. Here, the annual growth for the total Danish robot industry was 12.5 percent from 2014 to 2017, while the annual growth was 21 percent in the Funen robotics cluster.

Source: Damvad Analytics: "Analyse af den danske robotindustri" (April 2019) and Odense Robotics "Insight Report 2019"

2. Facts about the Danish robotics cluster – distribution of companies

The three figures on this page show how the 292 companies in the Danish robotics industry are distributed in relation to size, age, and type. In addition, some examples of some of the leading Danish robotics companies are given.

Company size and age

63 percent of the companies in the Danish robotics sector have fewer than 20 employees, and 12 percent have more than 100 employees. 38 percent of the companies were established after 2009.

Overall, the two figures reflect that the Danish robot cluster is relatively young, and that it is characterized by a few large and many small, newly-established companies.

Interviews also show that the area has been characterized by entrepreneurship and many new companies to a great extent in recent years. Among the leading entrepreneurial companies are, e.g., MiR and OnRobot, which originated from Universal Robots.

Figure 4. Distribution by company size

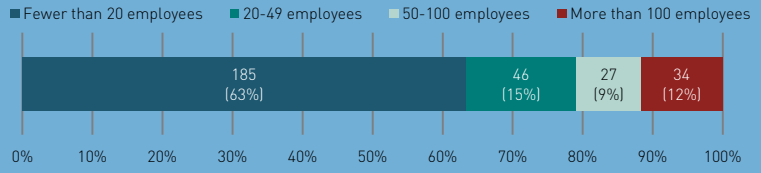


Figure 5. Distribution by year of company establishment

Source: Damvad Analytics: "Analyse af den danske robotindustri" (April 2019) and Odense Robotics "Insight Report 2019"

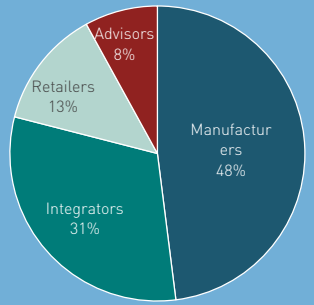
Company type

The figure shows, that almost half of the companies in the Danish robotics sector are manufacturers, who develop and produce the physical robot units.

This category of companies generates the largest growth, employment, turnover and exports, and can be considered the core of the Danish robotics sector.

The second-largest share is made up of integrators (31 percent), while the remaining companies are within advisory and retail (18 & 13 percent, respectively).

Figure 6. Distribution by company type



Examples of leading Danish robotics companies

Among the manufacturers of collaborative service robots, Universal Robots is the beyond doubt the leading company. In 2017, the company had a turnover of €150 million, corresponding to approx. 6 percent of the total revenue in the Danish robotics sector.

Mobile Industrial Robots (MiR), which was sold for €230 million in 2018, is also among the leading manufacturers. Within professional service robots for the health and welfare area, Blue Ocean Robotics is among the leading Danish companies.

Beyond the companies described above, ABB, Cabinplant, Jorgensen Engineering, LT Automation and Gibotech are some of the interesting and leading robotics companies in Denmark.

2. Facts about the Danish robotics cluster – ecosystem

The interviews conducted with Danish and foreign experts indicate that there is an extraordinarily well-functioning ecosystem in Denmark, which significantly contributes to strengthening the growth and development of Danish robotics companies, e.g. by improving their access to business partners, capital, labour, knowledge, etc.

At the same time, it has been pointed out that Odense Robotics has, in recent years, played a major role in uniting the cluster, facilitating effective collaboration between the various robotics companies and stimulating the entrepreneurial environment, e.g. through the Odense Robotics Start Up Hub.

In addition to the private companies, the University of Southern Denmark, the Danish Technological Institute, Odense Robotics, and Odense Municipality are some of the key players of the ecosystem. An appendix is enclosed with a complete record of the actors in the cluster.

The figures in the box on the right show the development and the sources of the external investments in the companies in the Danish robot cluster.

In March 2019, a new national partnership, the Robotics Alliance, was established in Denmark. The mission of the partnership is to expand and strengthen collaboration and coordination across actors throughout the country, cf. the box below.

About the Robotics Alliance

The Robotics Alliance is a national partnership across business organizations, innovation networks, stake-holders, and companies, which seeks to strengthen the framework conditions and the ecosystem of the Danish robotics and automation industry

ROBOTICS alliance

Specifically, the partnership will work to:

- Strengthen research and innovation in robot and automation technology, including drones
- Strengthen export opportunities
- Ensure competencies and attract talent
- Gather and strengthen professional activities in local networks
- Promote robotics and automation, including the drone area in Denmark and internationally

So far, the participants of the partnership are RoboCluster, the nationwide innovation network, Odense Robotics, Sønderborg Growth Council and UAS Denmark, but the partnership plans to expand and include companies from various areas of Denmark.

External investments in the robotics cluster

The figure below shows that the external investments in companies in the Funen robotics cluster has increased significantly in recent years. Since 2015, more than €750 million has been invested in the Danish companies, with the major part originating from private investors from Denmark and abroad.

The interviews indicate that the access for capital has been no hinderance for growth and development of the Danish robotics companies, and that Invest in Odense has allowed for an efficient and systematic ecosystem at this point.

Figure 7. Total external investments in the companies of the cluster (mil. EUR)

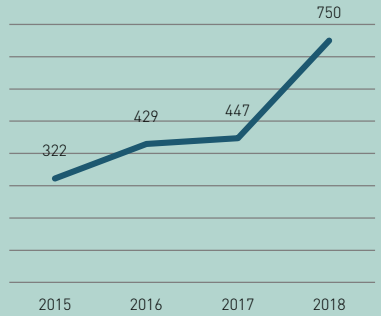
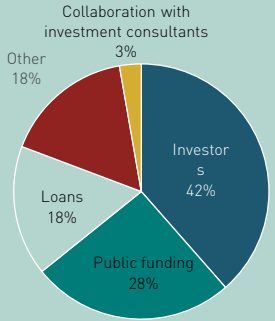


Figure 8. Sources of the external investments



Source: Odense Robotics "Insight Report 2019" and www.robotics-alliance.dk

"The ecosystem of the Danish robot cluster is very strong and unique. No one in Europe is close to Denmark when it comes to building a growth strategy on robot technology. There is a strong supply chain and "multiplier effect" in Denmark where the many start-ups deliver innovation and new ideas to the established robot companies who has access to the global markets"

- Ali Muhammad, Senior Scientist
VTT Finland

"Odense Robotics plays a crucial role in bringing together companies and making the Danish positions of strength visible abroad. In addition, the municipality also does a unique job in terms of improving the access to capital and qualified labour for the companies through Invest in Odense and International Community Odense, respectively. At the moment, there is generally good access to external capital – while the companies of the cluster are mainly challenged by recruitment and retention of qualified labour"

- Claus Risager, PhD & CEO
Blue Ocean Robotics

2. Facts about the Danish robotics cluster – Horizon 2020 funding

Horizon 2020 is the EU's research and innovation program for the period 2014-2020 and is generally regarded as the largest and most important international program for Denmark. Horizon 2020 supports projects at all stages from basic, strategic and applied research to innovation projects and companies' product development.

Overall, more than 40 billion euros has been distributed for almost 22,000 projects. The program is so large, that analyses of activity levels (funds received) can provide an insight into the research and innovation activity of organizations, by region or sector in different countries.

Thus, on this page, an analysis is presented of how many funds the various Danish actors have received in within the sector of drones, robotics, and automation.

A total of 90 different relevant Danish players have been identified, which combined have participated in 103 different Horizon projects within the sector. The 103 projects received a total of €648 million. Of these, approx. 10 percent – equivalent to €66 million – went to the 90 Danish actors/partners in the sector. Of this, the players from the cluster in Odense received €20.7 million., which corresponds to 31 percent of the total funds allocated to Danish partners in the sector.

The two tables to the right show the three largest players/categories and the total return of Horizon funds in the robotics sector for the robotics cluster in Odense and for the whole country. The two figures show how funding is distributed among different categories of actors.

As can be seen from the tables, the Danish Technological Institute plays a very large role in relation to receiving funds for Denmark from Horizon 2020 in the robotics area. The Danish Technological Institute has taken out almost a quarter of all the funds for Danish robotics and accounts for a total of 76 percent of the funding in the cluster in Odense. The spread in the rest of the country is significantly larger.

Among the international experts interviewed, it is pointed out that, due to the close collaboration between the private companies, RTO's and universities, Denmark is in a strong position in terms of receiving project funding in the coming program period (Horizon Europe), where a lot of funds are expected to be spent on projects dealing with the development and application of artificial intelligence in automation processes.

Table 1. Recipients of Horizon-funds in total and for the top-3 of the Funen robotics cluster (from 2014 to March 2019)

Name	EU funding ('000 EUR)	Share
Danish Technological Institute (TI)	15,759	76%
Private companies	2,439	12%
University of Southern Denmark (SDU)	1,997	10%
Others	473	2%
Total	**20,668**	100%

Table 2. Recipients of Horizon-funds in total and for the top-3 of the Danish robotics sector (from 2014 to March 2019)

Name	EU funding ('000 EUR)	Share
Danish Technological Institute (TI)	15,759	24%
The Technical University of Denmark (DTU)	5,747	9%
Aalborg University (AAU)	4,454	7%
Others	40,275	61%
Total	**66,235**	**100%**

Figure 9. Horizon-funds distributed by actor categories for the Funen robotics cluster

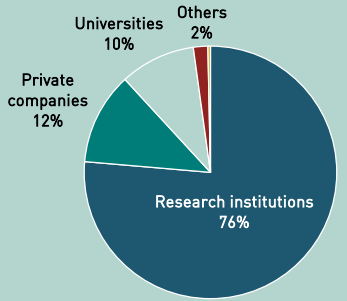
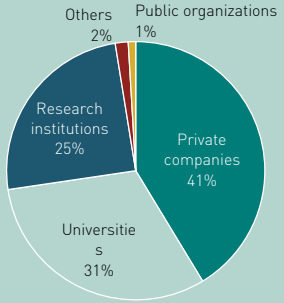


Figure 10. Horizon-funds distributed by actor categories for the Danish robotics sector



Source: The EU Cordis database

3. Global growth potentials in the field of robotics

Key points

- Overall, the analysis concludes that the future will continue to hold high global growth potential for Danish companies in the field of robotics and automation.
- The existing growth forecasts indicate that, in the future, growth is expected to be particularly strong for collaborative industrial robots, where Denmark has a strong position, which can still be scaled and spread further to new markets and application areas.
- The field of robotics has experienced significant global growth in recent years, and the total number of sold industrial robots increased from 60,000 in 2009 to 381,000 in 2017. At the same time, the field is characterized by a strong development of new knowledge and new technological solutions.
- The growth within robotics is largely driven by a number of overall structural and technological megatrends. These megatrends include a growing global economy and the development of digital technologies, which cause increased demand and opportunities for developing products and solutions within the field of robotics.
- In addition, the Danish robotics cluster has potential for spreading within the field of professional service robots, e.g. in the health and welfare areas.

3. Global growth potentials in the field of robotics – historical growth and development

The strong growth in the Danish robotics cluster over the last few years (cf. section 2) is largely related to the global development in the general field of robotics. The three figures on this page provide a comprehensive insight into how the robot area has developed globally the past few years.

Figure 12 shows the development of global sales of industrial robots from 2009 to 2017. Figure 13 shows the development of patent applications in robot technology from 2010 to 2018. Figure 11 shows the top 10 of countries with the most industrial robots in relation to the number of employees in the manufacturing sector and visualizes how the global distribution of industrial robots is geographically distributed.

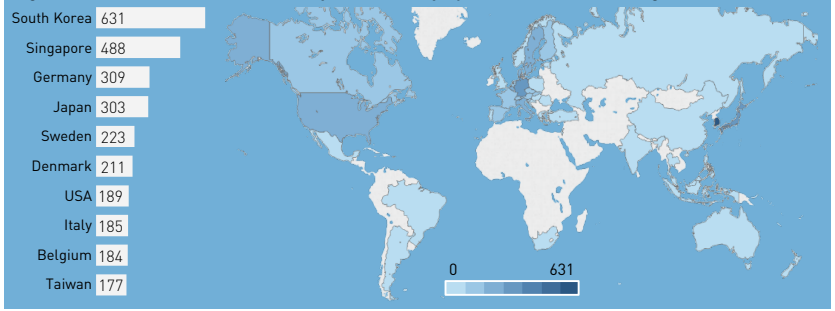
The global spread of industrial robots

The number of industrial robots in the manufacturing sector is rising rapidly worldwide. From 2015 to 2016, the global average number of industrial robots per 10,000 employees in the manufacturing sector rose from 66 to 74.

The figure shows the level of automation in the manufacturing sector. The most robot-intensive countries in the world today are South Korea, Singapore, Germany, Japan, Sweden and Denmark. Singapore and Denmark on this list are the only countries that do not have an extensive automotive production, which is otherwise one of the sectors that cause the most use of robotics.

The number of operational industrial robots in Denmark increased from 1,400 in 2000 to 4,250 in 2010 and 5,900 in 2016, and is expected to continue growing in years to come.

Figure 11. Number of industrial robots per 10,000 employees in the manufacturing sector, 2016

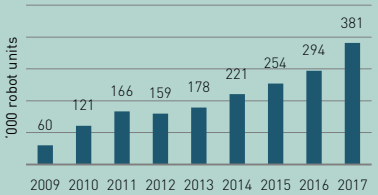


Global sales of industrial robots

The total global sales of industrial robots have strongly grown since 2009. According to the International Federation of Robotics, the number of sold robot units increased from 60,000 in 2009 to 381,000 in 2017. From 2016 to 2017 alone, sales increased by 30 percent.

Historically, it has been the automotive industry and the electronics industry, which, overall, have purchased the majority of the industrial robots.

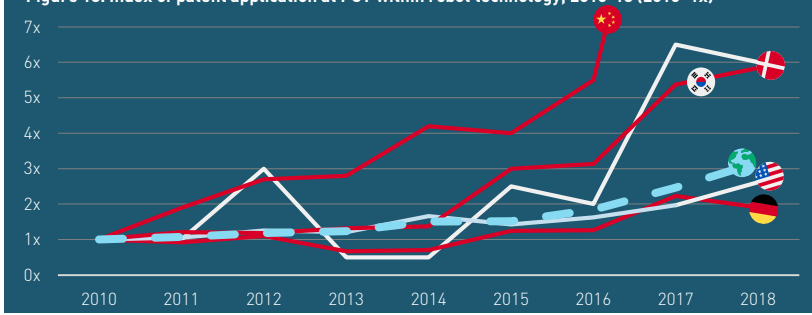
Figure 12. Development in global sales of industrial robots



The robotics patent application globally

The number of patents in the field of robotics has been accelerating since the 1980s, but has particularly grown over the past decade. In 2018, three times as many patents were applied for globally in the field of robotics as in 2010. The increase has been particularly strong in China, which had almost 30 times as many patent applications in 2018 as in 2010. Denmark is among the 'best of the rest', with six times as many patent applications in 2018 as in 2010 – a development that exceeds all the other countries in the study, except China*.

Figure 13. Index of patent application at PCT within robot technology, 2010-18 (2010=1x)



Note: Measured against Sweden, Norway, Germany, USA, South Korea, Japan, the Netherlands, United Kingdom, France, and Australia – that is, neighbouring countries and key countries within robot technology.
Source: Dansk Metal; International Federation of Robots; analysis of patent data from the World Intellectual Property Organization patent database.

3. Global growth potentials in the field of robotics – vital megatrends

Global growth in the field of robotics is driven by a variety of technological and structural megatrends. This page summarizes a number of global megatrends, that are considered to be crucial for the supply and demand of the robotics area.

Structural megatrends of vital importance to the field of robotics

Increasing focus on local and sustainable production

The demand for cost reduction, the acquisition of knowledge and innovation, shorter time-to-market and a better opportunity for flexible adaptation to local requests all create an increased need for producing locally and in smaller and more flexible series. In addition, the focus on climate impact and resource consumption can lead to interest in local production (to minimize transport), while there is a growing focus on sustainable/responsible production (cf. the SDG's).

Stronger financial incentive

Increasing labour costs and falling robot prices have created stronger economic incentives to introduce automation into production processes in order to increase productivity. In other words, the economic business case in relation to introducing robots has become more attractive to private companies.

Increasing global prosperity, longevity and consumption

The global economy and middle class are progressing rapidly. This increase the demand for a wider variety of goods and services that can be produced and delivered using robotics technology. The global economic and demographic development will thus increase the demand for both physical products and consumer goods within, e.g., the automotive and electronics industries. Meanwhile, the increasing life expectancy can boost the need for health robots.

Technological megatrends of vital importance to the field of robotics

Developments in available hardware

Digital hardware is continually improving in a wide range of areas, making robots cheaper and better. This applies both to performance measures, such as RAM, storage, memory, etc., but sensors, cameras, batteries, etc. have also significantly progressed in quality, while the price of these units have decreased. This has played and will play a major role in the distribution and availability of robotics.

Developments in computer technology and software

Recent software technologies such as machine learning, visual processing, artificial intelligence, voice recognition, etc., enable robots to act at a more independent and informed level. Meanwhile, the expectations of continued development of software, that may enable autonomous and creative robots in the future, also increase the interest in robots.

Developments in connection

On several parameters, the world becomes more connected, which makes the usability of robots even greater, as it enables communication between more devices. The number of Internet-of-Things units is expected to double between 2015 and 2020, but cloud robotics and the upcoming 5G network are also expected to make possible even more application areas for robots.

Source: Dansk Metal; International Federation of Robots; analysis of patent data from the World Intellectual Property Organization patent database.

3. Global growth potentials in the field of robotics – general growth forecasts

This page shows various forecasts for the expected continued growth of robotics in the future. The forecasts have been made by international research institutes on the basis of historical growth and expected future trends.

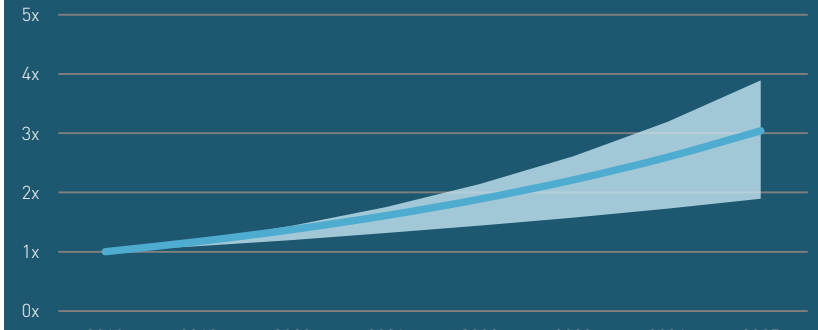
Figure 14 shows the expected total revenue growth for the entire sector from 2018 to 2025. This growth is further divided in figures 15 and 16, which illustrates the expected growth within the two main groups of robot technology.

The figures' blue line indicates the median value for growth in turnover among the selected forecasts, while the light blue shadow indicates the minimum and maximum values. The light blue shadow thus shows the spread in the existing quantitative growth forecasts, which gives an indication of the uncertainty associated with the growth forecasts.

Overall global growth forecast in the field of robotics

As seen in figure 14, there is an expectation of significant growth in robotics technology sales up to at least 2025. The most optimistic expectations are around 4 times the 2018-level, while more conservative bids are 2 times. The median value corresponds to an annual growth of 17 percent. By comparison, the expected annual growth in the period is approx. 5 percent for green energy and approx. 5.5 percent for the pharma sector[1].

Figure 14. Expected growth of robotics, 2018-2025[2]



Global growth forecasts for industrial and service robots

Figures 15 and 16 show that the expected growth is greater within the service robot sector. Here, the forecasts are more than quadrupling towards 2025. For industrial robots, the growth forecasts are slightly lower, as it is estimated to double between 2018 and 2025.

Among the industrial robots, the median forecast value for the annual expected growth is 11 percent per year. According to IFR, this growth is particularly due to growth in the electronics and metal industries, as they are increasingly catching up to the automotive industry, which remains the world's most robot-intensive sector.

Among the service robots, the median value for the annual expected growth is as high as 22.5 percent, where the low part of the spread is, however, 17 percent. IFR expects the growth to be particularly sustained by robots in agriculture and in the health sector, but the large areas of logistics and PR are also expected to grow significantly. In Denmark, automation is particularly being adopted within the industries of food, plastic, metal and pharmaceuticals. Hence, there are clear expectations for growth in the home market for the Danish robot manufacturers. However, the global growth is expected across many different sub-areas of production, indicating a general maturation of the market.

The two figures also indicate a higher level of uncertainty among the existing growth forecasts on the development of service robots than for industrial robots.

Figure 15. Expected growth of industrial robots

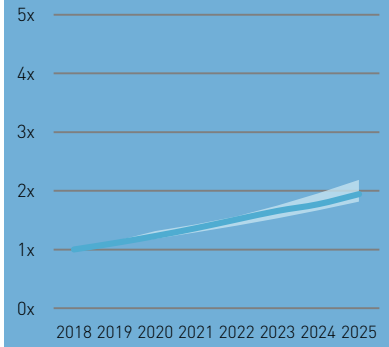
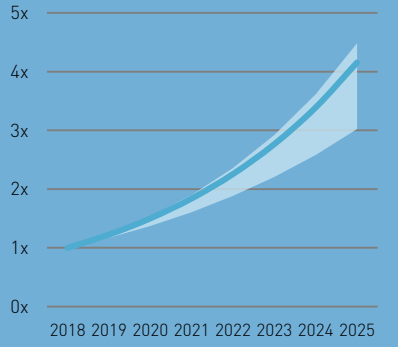


Figure 16. Expected growth of service robots



1) Allied Market Research (2018); QunitilesIMS (2017).
2) In the overall growth forecast, three data sources are used: International Data Corporation (2018), Transparency Market Research (2018) & Siemens (2017). In the industrial robots growth forecast, five data sources are used: Energias Market Research (2018), IFR (2018), ResearchAndMarkets (2018), Global Market Insights (2018) & ABI Research (2016). In the service robots growth forecast, three data sources are used: ResearchAndMarkets (2018), Mordor Intelligence (2018) & Allied Market Research (2016).

3. Global growth potentials in the field of robotics – growth forecast for cobots

As shown on the previous page, the overall forecasts indicate that continued high growth is expected both within industrial and service robots in the coming years. However, there is a significant difference in the level of growth expected within the different types of industrial robots.

The figures on this page show a couple of more specific growth forecast solely for the collaborative industrial robots (cobots), which is the key strength position of the Danish robotics cluster (cf. chapter 2). This robotics area is expected to have particularly high global growth in the coming years.

Figure 17 shows an index of the expected development in the average sales price of a collaborative robot, while figure 18 shows the expected global development in the number of cobots sold. The text box summarizes some of the key issues that, according to existing literature and leading experts, are the basis for the vigorous global growth of collaborative robots.

Background for the global growth of cobots

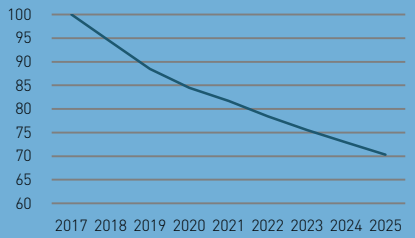
- The cobots are small, flexible and user-friendly and are relatively easily programmed
- They can safely work alongside people in common work environments
- They are economically and resource-wise more affordable than traditional industrial robots, which often require relatively large investments and reconstruction of production facilities. Cobots are thus available to large segment of SME's
- They can enable increased quality and precision in the production processes
- They can reduce production costs and increase productivity

Expected development in sales prices

While a large increase in global revenue and demand for cobots is expected, figure 17 shows that the average sales price per cobot is expected to decline in the years to come.

This happens as technology and collaborative robots become more developed and widely used.

Figure 17. Index of expected development in average sales price per cobot (2017=100)



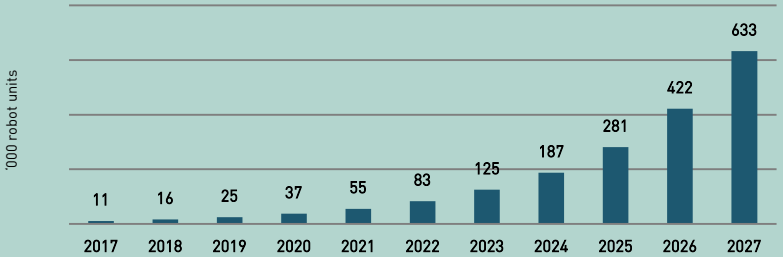
Global growth forecast for cobots

According to the global forecasts, an annual growth of around 50 percent is expected within the field of collaborative industrial robots. This means that the expected number of collaborative robot units sold worldwide will have increase to around 633,000 by 2027.

Considering that the global sales of industrial robots, according to the International Federation of Robotics, was 381,000 in 2017 (see figure 12), it must be concluded that an extremely high global demand for collaborative robots is expected in the coming years.

In monetary terms, it is expected that the global market for collaborative industrial robots will grow to as much as €10.5 billion in 2027.

Figure 18. Expected development in the number of sold collaborative robot units globally



Earlier forecasts[1] predicted that the number of collaborative robots sold would have already exceeded 30,000 by 2017 and that a level of over 600,000 robot units would have been reached by 2024. However, according to the latest available forecast shown in figure 18, this level will not be reached before 2027. Hence, it must be emphasized that the existing growth forecasts are associated with some uncertainty.

However, the uncertainty is primarily related to *when* the significantly increased demand in the world market is expected to occur. In other words, there is widespread agreement that there is very high potential for growth, but the uncertainty is related to how quickly new sectors and industries, e.g. within the health sector, will be able to adapt and use the technology.

1) Earlier forecasts from e.g. "Asian Robotics Review" for HMC Investment Securities
Source: Figure 18 is based on data from ABI Research in "Robotter og automatisering" by Region Southern Denmark (August 2018), while figure 17 is based on "Barclays Equity Research"

"The Danish robotics cluster is not closely linked to any particular industry – unlike most of the foreign robot regions – and the collaboration between the manufacturers and the integrators is good. This means that the Danish robotics companies are strongly positioned to deliver flexible holistic solutions to manufacture companies across countries and industries. And the global market for collaborative industrial robots is far from having reached saturation point"

- Mads Bruun Ingstrup, Associate Professor
University of Southern Denmark

3. Global growth potentials in the field of robotics – industrial robot sales

The table and figures on this page offer a closer look at which industries and parts of the world are driving growth and demand for industrial robots.

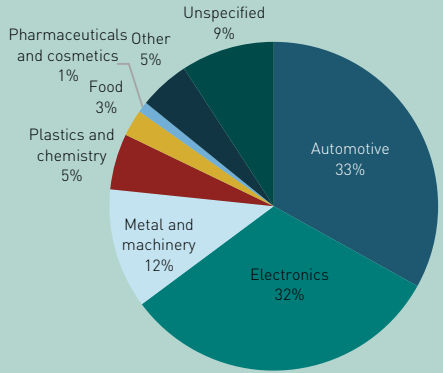
Global sales of industrial robots by sector

The figure below shows how the total of about 381,000 sales of industrial robots in 2017 was distributed among different industry areas.

In 2017, the automotive and electronics industries acquired around one third of all industrial robots worldwide each, and they are thus the two industries that purchase the vast majority of all industrial robots. In recent years, there has been significant growth in demand in the electronics industry in particular – in the period of 2012 to 2017 the average annual growth in the number of robots sold to the electronics industry was 30 percent.

The figure also shows that, for example, the food and medicine area still acquire a relatively modest share of the industrial robots. However, existing forecasts indicate that the demand for industrial robots in these areas will also grow in line with increased quality assurance and the need for reduction in cost and production time.

Figure 19. Global sales of industrial robots by sector (2017)



Global sales of industrial robots by country and continent

The table below shows that nearly three-quarters of the 381,000 industrial robots in 2017 were sold to China, Japan, Korea, the United States, and Germany and that these five countries are still expected to be the dominant part of the world market in the years to come.

The numbers reflect that it is in particular the large, car-manufacturing countries that have driven the growth and demand for industrial robots so far, and that the electronics industry will also lead to growth in the future.

The table also shows that the total number of sold industrial robots in 2021 is expected to grow to 630,000 and that global growth in the coming years will continue to be driven mainly by China and the Asian markets.

However, it should be noted that increased sales of industrial robots are expected in all countries and continents.

Table 3. Sales of industrial robots by country (2017 and estimated 2021)

Country	2017		2021 (estimate)	
	Number	Share	Number	Share
China	137,920	36%	290,000	46%
Japan	45,566	12%	64,000	10%
South Korea	39,732	10%	46,000	7%
USA	33,192	9%	46,000	7%
Germany	21,404	6%	26,000	4%
Rest of Europe	44,855	12%	62,600	10%
Rest of Asia (incl. Australia)	38,608	10%	67,600	11%
Rest of the Americas	12,926	3%	17,500	3%
Africa	451	0%	800	0%
Not specified	6,681	2%	9,500	2%
Total	**381,335**	**100%**	**630,000**	**100%**

Source: Table 3 is based on "World Robotics 2018 Industrial Robots", International Federation af Robotics (2018).

3. Global growth potentials in the field of robotics – service robots

This page further explores the global growth forecasts for service robots, which can be subdivided into professional and personal sub-categories.

Figure 20 summarizes some of the various underlying categories of service robots, and figure 21 shows the geographical distribution of the approx. 700 service robot manufacturers that existed in 2017, according to the International Federation of Robotics. The box on the right shows two specific growth forecasts for professional service robots. The column chart shows the overall forecast for growth in the number of professional service robots sold from 2018 to 2021, while table 4 shows the expected distribution by the main application areas, measured by sales value.

Among the experts interviewed, it has been pointed out that the market for professional service robots is in a powerful maturation process, where robots increasingly move from being "gimmicks" to being systematically designed to fit the needs of the users. In this process, the market value and commercial potential of the robots is significantly increased.

Figure 20. The various categories of service robots

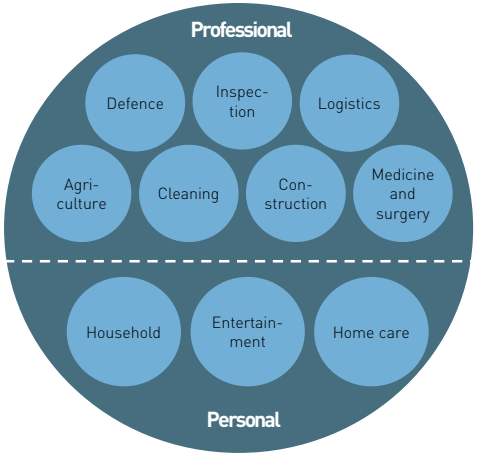
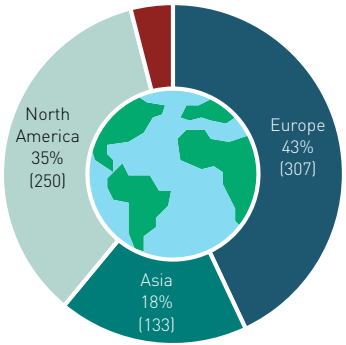


Figure 21. Distribution of manufacturers by continent (2017)



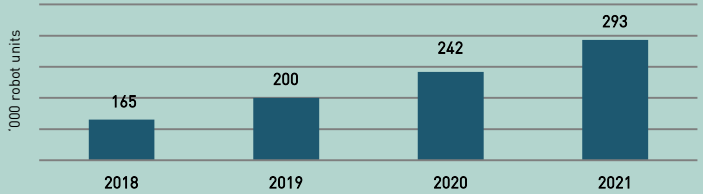
Source: International Federation of Robotics "World Robotics 2018 Service Robots" (2018)

Global growth forecasts for professional service robots

According to the International Federation of Robotics, the total global sales of professional service robots were around €7.1 billion in 2018. On average, it is expected to grow by 19 percent annually until 2021, where the value of total global sales will have increased to approx. €11.9 bn.

The number of units sold was 165,300 in 2018, and this number is expected to grow by 21 percent annually to approx. 293,000 units in 2021, as shown in the figure below.

Figure 22. Expected development in the number of professional service robot units sold globally



Both in terms of number and economic volume, it is particularly the logistics area which account for a lot of the professional service robots.

The health and surgery sector is also a relatively large application area. This area is characterized by high regulation and high unit prices, and leasing models are therefore particularly widespread.

The application area of agriculture mainly concerns robots for harvesting and milking.

Table 4. Expected global sales of professional service robots by application area

Application area	2018	2019	2020	2021	Share (2021)
Logistics	€3.1 bn.	€3.7 bn.	€4.5 bn.	€5.3 bn.	44 %
Health and surgery	€1.9 bn.	€2.2 bn.	€2.7 bn.	€3.2 bn.	26 %
Agriculture	€0.9 bn.	€1.0 bn.	€1.2 bn.	€1.5 bn.	12 %
Defence	€0.8 bn.	€0.9 bn.	€1.1 bn.	€1.3 bn.	11 %
Other	€0.4 bn.	€0.5 bn.	€0.6 bn.	€0.7 bn.	6 %
Total	**€7.1 bn.**	**€8.4 bn.**	**€10.0 bn.**	**€11.9 bn.**	**100 %**

"As the sector of service robotics has matured, our products are increasingly based on use cases and the wishes of customers rather than standard products. More business and software people have come into the field to assist in meeting customers' needs and complement the engineers, which makes for more customized and useful end products"

- Jade Le Maitre, Directrice Associée, Partner HEASE Robotics

3. Global growth potentials in the field of robotics – global growth drivers and demands

In general, there is some uncertainty about how fast the growth of robotics will develop. But the global forecasts give a clear picture of the fact that the field of robotics has a great potential for growth in the coming years. This applies in particular to the collaborative industrial robots and to professional service robots, e.g. in the areas of health and welfare.

On this page, some of the most important assumptions regarding the technological and commercial developments that support the growth forecasts are summarized, as well as what new requirements and challenges that may be in store for the Danish robot cluster.

Generally, the market and demand-driven growth drivers are closely linked to the global megatrends outlined on page 15, and the growth forecasts are largely based on robotics continuing to undergo strong technological development and innovation in the coming years.

In other words, the increasing global demand and growth requires that robots continue to be improved upon and further developed and that it will succeed in making visible and disseminating the knowledge of the (new) possibilities and potentials of robot technology both among existing users and new user segments throughout the world.

Growth drivers within market and demand

- Focus on energy efficiency and the use of new materials requires continuous conversion of production processes
- Spread of production to more countries and geographical locations to meet local needs, shorten time-to-market and reduce political and logistical risks
- Increased need for fast and flexible conversion of production processes
- Continued pressure to reduce production costs
- Conversion to the production of electric cars in the automotive industry
- A growing global economy and consump-tion of electronics, materials, food, etc.
- Increasing life expectancy and health expenses

Essential future demands to the Danish robotics cluster

The global growth and development will most likely affect the Danish robotics cluster in the following ways:

- The growth potential of the robotics area is well-known, and although the demand will increase, it is expected that **increased global competition** can be expected both in terms of price and functionality.
- The need for research, development and **innovation that can be translated into new commercial solutions for the needs of users and industries** will increase with the growth in global competition and technological development. This applies to both developing new application areas for the collaborative industrial robots, as global price competition on the hardware will increase, and within the emerging growth areas such as the professional health and welfare robots.
- There will be a (still) greater need for **access to skills within IT and digitalisation** and a (continued) close interaction between manufacturers and integrators in relation to **delivering holistic solutions** and not just hardware.
- The need for **access to business partners** in other countries and in other sectors will grow both in order to develop new and innovative solutions, to gain better market access and to understand local needs and regulatory and commercial market conditions.
- Growing demands for solutions **that support the UN's Sustainable Development Goals** and data ethical guidelines.

Growth drivers within science and technology

- Increased functionality and more applications. This includes the development of new application areas
- Increased ease-of-use and easier programming and integration of flexible robots to work within existing processes and workflows (plug-and-play)
- Greater operational safety and quality assurance
- Decreasing costs per robot unit
- More digital and intelligent robots that can learn and implement optimizations based on AI and data sharing via cloud solutions and machine learning between robots performing the same types of tasks. So-called "Cloud Robotics".

3. Global growth potentials in the field of robotics – potentials for the Danish cluster

The global megatrends and growth forecasts for the robot area provide a clear indication that, in the future, there are still major growth potentials for the Danish robotics cluster, both within the existing positions of strength and possible emerging growth areas.

On this page, a number of different strategic ways have been summarized on how the Danish robotics cluster can exploit the global growth potentials in the best possible way. In addition to existing studies and analyses in the field, the findings are based on interviews with a number of leading Danish and international experts (cf. the appendix).

Scaling of existing strength positions in collaborative industrial robots

An obvious potential for the Danish robot cluster is to continue the development and sales scaling of collaborative industrial robots to the global segment of small and medium-sized enterprises. This market is expected to keep growing significantly, and it is estimated that the existing global market among SME's is far from saturated.

In light of these global growth forecasts, it is clear that the future potential can be realized through technological development and scaling of sales to SME's. Gaining access to these relevant target groups, and business segments will typically require collaboration with local partners and distributors.

Development of new application areas for collaborative industrial robots

The growth potential of the collaborative industrial robots is very much linked to the development of new applications that enable robots to handle increasingly complex, agile and demanding processes. In metal and mechanical engineering, for example, the tasks relate to welding and assembling components rather than simply handling and moving physical elements.

The development of new application areas will thus greatly contribute to increasing the demand and growth of the collaborative industrial robots, both among new and existing global customer segments.

Development of industrial robots targeted clinical processes

Growth forecasts indicate that there may be an untapped growth potential within, for example, the food and pharmaceutical industries, where major clinical and regulatory requirements for production processes in terms of tests, documentation, and certification exist.

Besides, Denmark has historically had a strong position in automation solutions for the food industry.

This means that there is a potential for the Danish robotics cluster to develop new and innovative automation solutions, e.g. in collaboration with some of the major international suppliers of production plants in the life science and food sector.

Development of emerging growth areas within the field of professional service robots

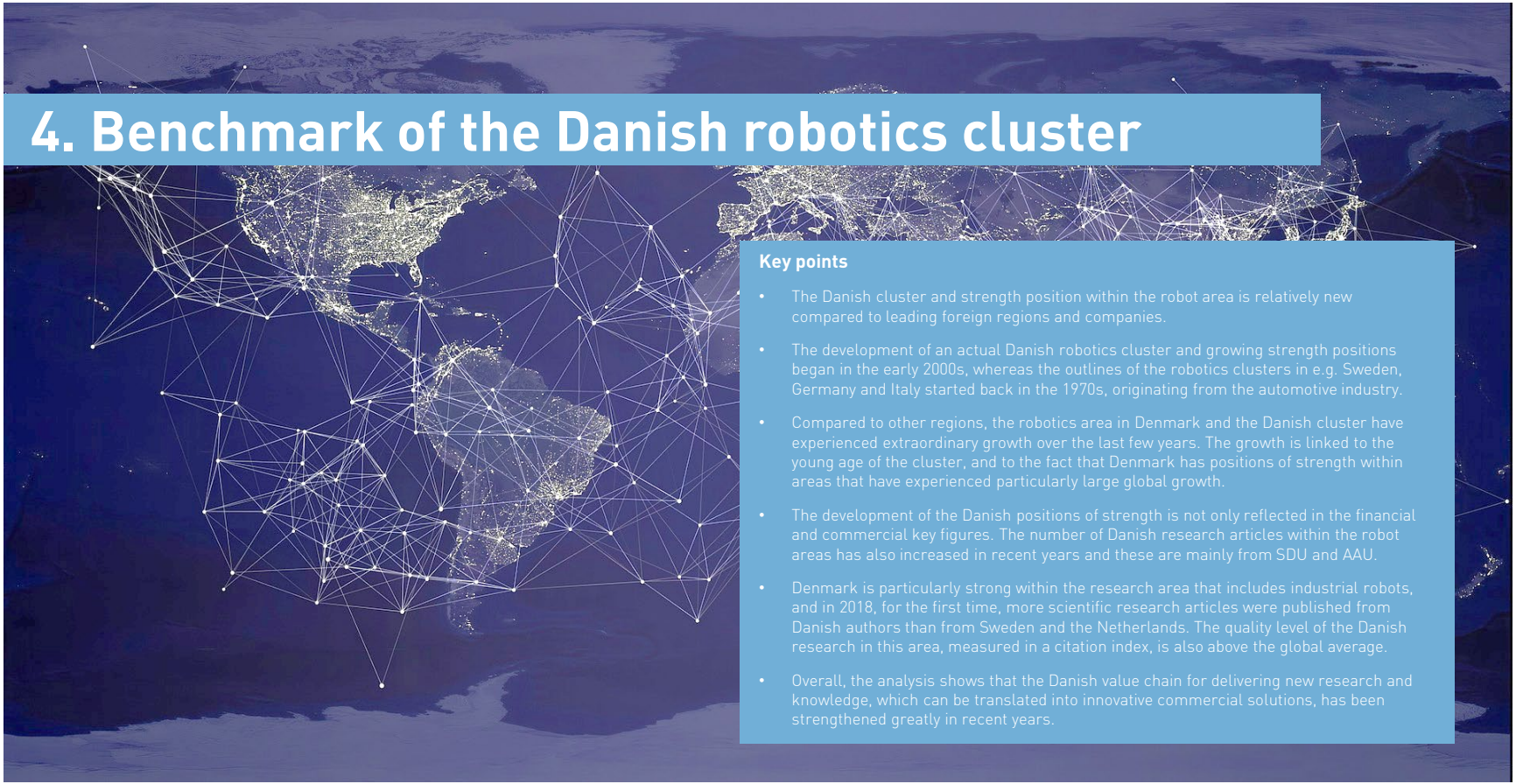
As shown on the previous pages, huge growth is expected within the field of professional service robots (including drones), and in particular in the health and welfare area, where robot technology and growth potential is still on the rise.

In general, there is a need for further innovation as well as technological and commercial development within the area, but the Danish robotics cluster is considered to be in a good position for utilizing future potentials and opportunities within the emerging growth area.

The good position is due to the fact that, among other things, an increasing share of entrepreneurs and newly established professional service robot companies have come into the Danish robot cluster in recent years. At the same time, there are already leading manufacturers (e.g. Blue Ocean Robotics) of professional service robots for the health and welfare sector.

Going forward, the Danish robotics cluster will most likely be able to stand strong, as long as the existing technical and commercial competencies can be utilized and spread to an increasing number of new companies working with professional service robots in the cluster. These include, for example, agriculture, logistics, and drones for inspection, surveillance, and transport.

4. Benchmark of the Danish robotics cluster



Key points

- The Danish cluster and strength position within the robot area is relatively new compared to leading foreign regions and companies.
- The development of an actual Danish robotics cluster and growing strength positions began in the early 2000s, whereas the outlines of the robotics clusters in e.g. Sweden, Germany and Italy started back in the 1970s, originating from the automotive industry.
- Compared to other regions, the robotics area in Denmark and the Danish cluster have experienced extraordinary growth over the last few years. The growth is linked to the young age of the cluster, and to the fact that Denmark has positions of strength within areas that have experienced particularly large global growth.
- The development of the Danish positions of strength is not only reflected in the financial and commercial key figures. The number of Danish research articles within the robot areas has also increased in recent years and these are mainly from SDU and AAU.
- Denmark is particularly strong within the research area that includes industrial robots, and in 2018, for the first time, more scientific research articles were published from Danish authors than from Sweden and the Netherlands. The quality level of the Danish research in this area, measured in a citation index, is also above the global average.
- Overall, the analysis shows that the Danish value chain for delivering new research and knowledge, which can be translated into innovative commercial solutions, has been strengthened greatly in recent years.

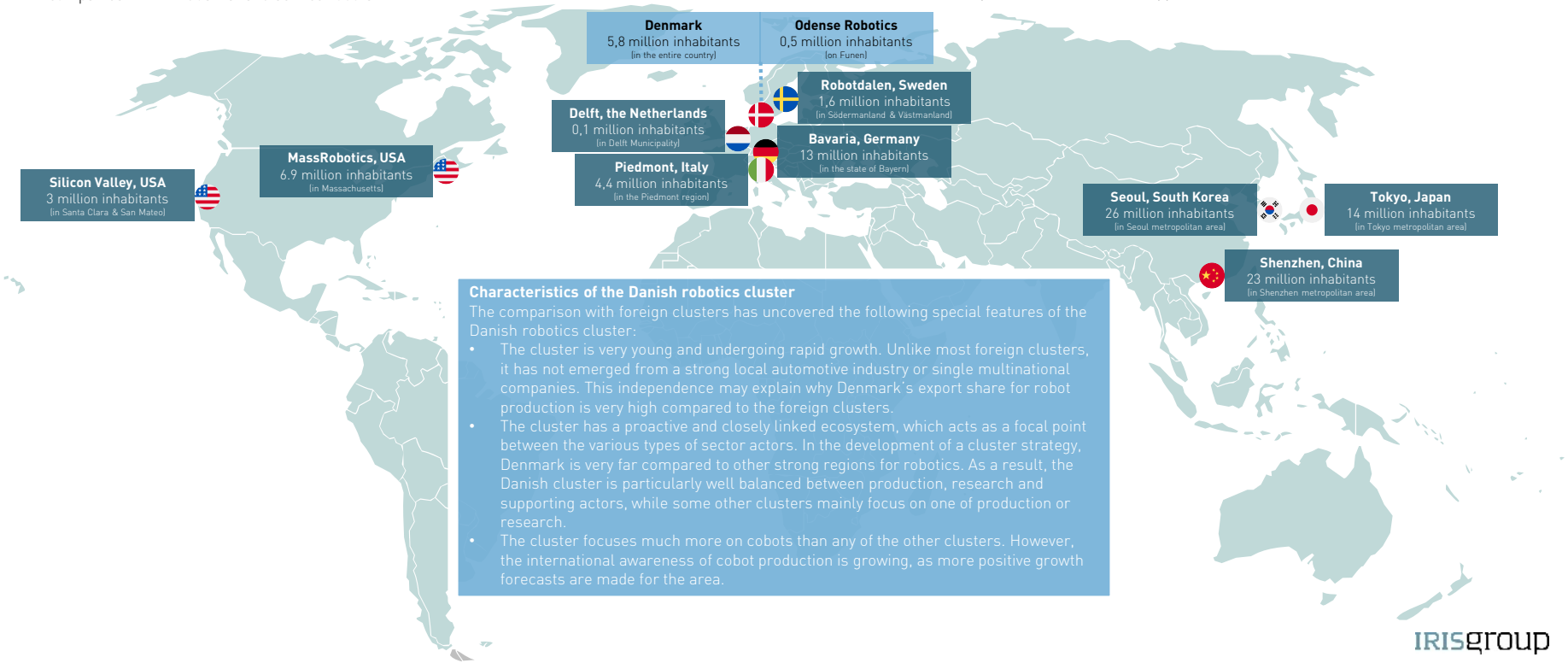
4. Benchmark of the Danish robotics cluster – introduction to the comparison clusters

In this chapter, the Danish robotics cluster is compared to some of the largest and most prominent robotics regions in the world.

The foreign robotics clusters and regions have been selected based on two criteria: there must be some comparability in their profile in relation to the Danish robotics cluster, and they must include companies within industrial and service robots.

The map below shows the nine selected clusters/regions as well as the geographical delimitation and the number of inhabitants in each of the areas.

On the next page, a brief description of the individual clusters' profile and history will be given before they are compared to the Danish robot cluster. A detailed overview of the data sources behind the individual cluster descriptions is attached as an appendix.



Characteristics of the Danish robotics cluster

The comparison with foreign clusters has uncovered the following special features of the Danish robotics cluster:

- The cluster is very young and undergoing rapid growth. Unlike most foreign clusters, it has not emerged from a strong local automotive industry or single multinational companies. This independence may explain why Denmark´s export share for robot production is very high compared to the foreign clusters.
- The cluster has a proactive and closely linked ecosystem, which acts as a focal point between the various types of sector actors. In the development of a cluster strategy, Denmark is very far compared to other strong regions for robotics. As a result, the Danish cluster is particularly well balanced between production, research and supporting actors, while some other clusters mainly focus on one of production or research.
- The cluster focuses much more on cobots than any of the other clusters. However, the international awareness of cobot production is growing, as more positive growth forecasts are made for the area.

4. Benchmark of the Danish robotics cluster – introduction to the comparison clusters

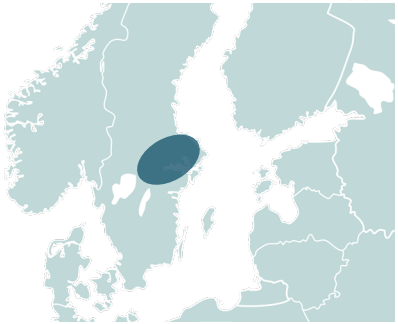
Robotdalen, Sweden

Essential companies

ABB Robotics (industrial/cobots)
Atlas Copco (industrial)
ESAB (industrial)
Giraff (health)

Essential knowledge institutions

Örebro Universitet
Mälardalen Högskola
ABB Corporate Research



History and strengths

Sweden's history of robotics dates back to 1974, when ASEA (today ABB) created one of the world's first commercial industrial robots. In 2003, Robotdalen was founded in an association of universities (Mälardalen Högskola and Örebro Universitet), a large number of companies (including Volvo and ABB), as well as a number of municipalities, regions and hospitals. The area's robotics sector is characterized by proximity to the automotive industry and Volvo, which forms the foundation of the area's robotics industry together with large companies such as ABB, Atlas Copco and ESAB.

Robotdalen has particular core competencies within four areas:

- Industrial robots, especially in the automotive industry
- Logistics robots, e.g. for moving hospital beds
- Field robots, e.g. for mining
- Health robots, e.g. for elderly care

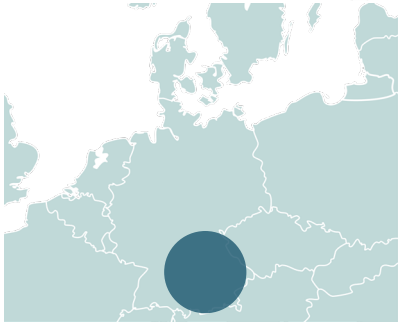
Bavaria, Germany

Essential companies

KUKA (industrial/health/cobots)
TGW Logistics (logistics/industrial)
SCHUNCK (industrial/cobots)

Essential knowledge institutions

Technische Universität München
Deutsches Zentrum für Luft- und Raumfahrt
Technische Universität Darmstadt (Hesse)
Karlsruher Institut für Techn. (Baden-Württ.)



History and strengths

Germany is Europe's largest robotics nation, and it is especially Bavaria that leads in research and production of robots. The region's history of robotics can be traced back to the 1970s, where KUKA, formerly a manufacturer of machinery and public transport, started producing industrial robots. Since both BMW, Audi, MAN and Mercedes-Benz have factories in the area, it has historically been the automotive industry that has caused the growth in robot demand, but the region also produces many other types of industrial robots.

Bavaria's strength in robotics is mainly derived from the region's tradition of strong mechanics and a highly concentrated software industry. In Bavaria, there are a number of highly ranked robotics institutes, including the Technische Universität München, which is leading in Europe. The region has special competencies within:

- Industrial robots, including for the automotive industry, and in recent years within cobots
- Professional robots, especially within health and logistics

In Germany as a whole, about 66,000 people were employed in the robotics area in 2017, up from about 43,000 in 2011. That makes the country one of the largest producers in Europe.

4. Benchmark of the Danish robotics cluster – introduction to the comparison clusters

Delft/RoboValley, the Netherlands

Essential companies

Penta Robotics (industrial)
ExRobotics (inspection)
Mythronics (inspection)
Delft Dynamics (drones)

Essential knowledge institutions

TU Delft
Universiteit Twente (Twente)
TU Eindhoven (Eindhoven)

History and strengths

RoboValley was founded in 2015 by the largest technology university in the Netherlands, TU Delft, with the purpose of strengthening the connection between the university and the business community within robotics technology. The cluster is relatively research-intensive, with more than 170 robot researchers affiliated with the university robotics department, which was established in 2012 by computer scientists and mechanical engineers.

The cluster today houses approx. 30 start-up companies within robotics, as well as a handful of large robot companies. The area's robotics research and business sector has three main focus areas, which may be considered positions of strength:

- Industrial robots, including cobots
- Swarm robotics, i.e. groups of coordinating robots or drones
- Service work robots, e.g. for agriculture, inspection and professional cleaning

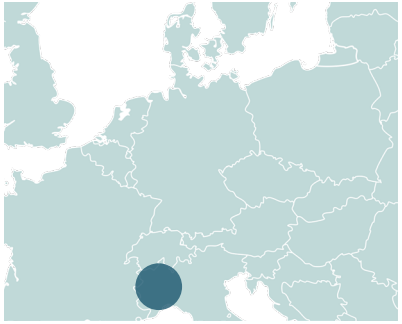
Piedmont, Italy

Essential companies

Comau (integrator)
FIAT-Chrysler (automotive)
TAU Industrial Robotics (industrial)

Essential knowledge institutions

Politecnico di Torino
Università di Torino
Istituto Italiano di Tecnologia (Genoa)
Università di Genova (Genoa)



History and strengths

Turin is the capital of the Italian region of Piedmont, where about ¾ of Italy's robotics industry is located, measured by turnover and the number of employees. Piedmont is leading in Italy in terms of general research funding and university-business-collaboration, and the community includes the Università di Torino and Politecnico di Torino, which form an important part of the robotics area. In addition, there are many manufacturing companies in northern Italy, which in recent years have proven more than ready to implement robotics in many different sectors.

Piedmont houses, among other things, one of the world's largest robot integrators, Comau, which since it was founded as part of FIAT in 1973, has spread to many parts of the world. Otherwise, most robotics companies in the region are relatively small, which is also typical of the general population of manufacturing companies in the area.

The region's strengths are within traditional industrial robots, and particularly in plastic, laser cutting and welding. There is little to no focus on collaborative robots, which makes up a very small part of the robot production in the area.

4. Benchmark of the Danish robotics cluster – introduction to the comparison clusters

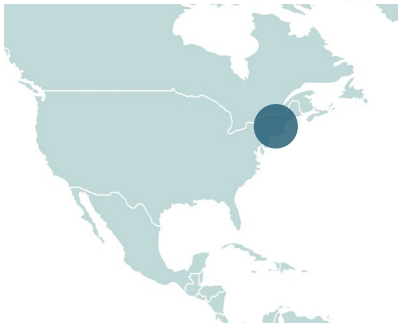
MassRobotics, MA

Essential companies

Brooks Automation (industrial)
iRobot (household cleaning)
QinetiQ (defence)
Boston Dynamics (humanoid/defence/rescue)

Essential knowledge institutions

Massachusetts Institute of Technology
Harvard University
University of Massachusetts



History and strengths

The MassRobotics cluster covers the state of Massachusetts, which is the centre of the US robotics sector on the east coast. The state's history of robotics can be traced back to the 1960s, where one of the world's leading technical universities, MIT, created a department for artificial intelligence. In the 1990s, the university produced, among other things, two central robot companies in Boston Dynamics and iRobot. Today, the cluster also houses Teradyne, which in Denmark is best known as the acquirer of the two largest robot successes in Denmark so far: Universal Robots in 2015, and Mobile Industrial Robots in 2018. Overall, there are about 120 robot companies in the area.

Massachusetts' robotics research and business is spread across a wide range of areas, but some of the most significant strengths are the following:

- Industrial, collaborative robots. In addition to Teradyne, Rethink Robotics, a major manufacturer of leading collaborative robots, is also located in Boston.
- Health robots, e.g. for transporting food, medicine and medical equipment in hospitals
- Logistics robots, including Amazon's storage robots
- Defence robots, e.g. tactical field robots and drones

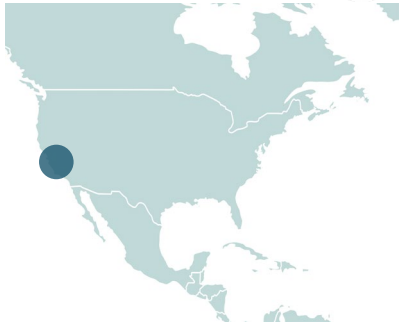
Silicon Valley Robotics, CA

Essential companies

Adept (industrial)
Bosch (service, logistics)
Google (humanoid/industrial/rescue)
X Development (misc.)

Essential knowledge institutions

University of California at Berkeley
Stanford University
University of Southern California



History and strengths

The first multifunctional robot in the world was invented at the Stanford Research Institute (SRI) in the 1960s, which, together with moon landing vehicles and the world's first SCARA robot, initiated the production of robots in Silicon Valley, California. To ensure coherence between the state's educational and research institutions and companies, the cluster organization Silicon Valley Robotics was set up in 2010 by 30 companies. Today, it considers itself the largest robotics cluster in the world, with 325 start-ups and 660 investors.

Distinctive companies in the area include Bosch, Adept, SRI International and Google Robotics/Alphabet. The latter has in recent years carried out a large number of acquisitions. Silicon Valley's robot area consists mainly of service robots, and in particular within:

- Home Robots
- Logistics Robots
- Health robots, e.g. for surgery

Due to the limited focus on industrial robots in the area, collaborative robots has not been a priority for the sector.

4. Benchmark of the Danish robotics cluster – introduction to the comparison clusters

Seoul, South Korea

Essential companies

Samsung (industrial)
LG (industrial)
Hyundai Robotics (industrial/cleaning)
Rainbow Robotics (health/cobots)

Essential knowledge institutions

Seoul National University
Advanced Institute of Science and Technology
Hanyang University

History and strengths

South Korea has the most industrial robots in the world per employee in the manufacturing sector, but the country is also well-advanced in the production of robots. Shortly after the turn of the century, robot production was designated as a national main area for the future, and since then the country's production of robots has increased more than tenfold. The area has fitted well with the country's strengths within ICT, electronics and cars, where especially LG, Samsung, Hyundai and KIA are major players in the country. All of these are headquartered in Seoul, which is also the centre of the robotics sector in South Korea.

Seoul's robotics strengths mainly include:

- Automotive robots, typically where the car companies do not develop the robots themselves
- Manufacturing robots for the ICT and electronics industry
- Cleaning robots, both for professional and personal use
- Inspection robots, e.g. for monitoring road maintenance

In addition, the production of cobots is growing and is clearly prioritized for the years to come.

Tokyo, Japan

Essential companies

FANUC (industrial)
Toyota (automotive)
Honda Robotics
SoftBank Robotics

Essential knowledge institutions

University of Tokyo
Tokyo Institute of Technology
Waseda University

History and strengths

The robotics sector in Japan has historically been the world-leading. The country's patent applications and number of companies in the sector peaked in the 1990s, but over the last 10-15 years, the rest of the world has increasingly caught up to Japan. However, Japan still accounts for much of the world's production of industrial robots. This is not least due to a domestic market that has historically been at the forefront of robot innovation. For instance, the extensive automotive industry, where Toyota, Nissan and Honda have and have had a large need for robots.

Tokyo accounts for a particularly large part of Japan's robotics sector. Tokyo produces nearly every type of robots. However, there is a particular focus on:

- Automotive robots, which the car companies have historically developed on their own to a great extent
- Manufacturing robots, including some cobots
- Health, e.g. for patient service and relocation
- Inspection and rescue robots for monitoring and rescue for natural disasters etc.

4. Benchmark of the Danish robotics cluster – introduction to the comparison clusters

Shenzhen, China

Essential companies

DJI (drones)
Han's Robot (industrial/cobots)
Jasic (industrial)
Adtech (industrial)
TC Robotics (industrial/cobots)

Essential knowledge institutions

South China University of Technology
Chinese University of Hong Kong (Hong Kong)

History and strengths

Shenzhen has grown from a population of 30,000 in the 1970s to 12.5 million in 2019. The area's production has traditionally consisted of electronics - 90 percent of the world's electronics, such as smartphones and televisions, is produced in and around Shenzhen.

The robotics sector has also grown significantly. Today it consists of approx. 600 companies, up from fewer than 60 before 2010. The reason for increase in the industry is first and foremost the Chinese government's focus on making the region central to robot production in China. This began with China's medium and long-term plan for, among other things, AI and robotics in 2006, but this has since been built upon with additional action plans.

Today, the area has a particularly high amount of industrial robot manufacturers, constituting approx. 75 percent of the companies. However, service robot production has been increasing in recent years. The area houses the world's largest drone producer, DJI, which has a market share of 74 percent worldwide in the drone market. In the past 2-3 years, there has been a growing focus on cobots, e.g. by the companies Han's Robot and TC Robotics which have begun producing for the Chinese market in particular. These robots are largely inspired by the Universal Robots models.

"A lot of applications demand robots that have a better understanding of humans. I have been surprised to see how many sectors cobots can grow bigger in. All types of factories and fields have had an increased awareness of and wish for these types of robots."

- Andrea Maria Zanchettin, Assistant Professor
Politecnico di Milano

"Denmark excels in computer science, which plays very well with the megatrends. Robotics focus is evolving rapidly from its origin as a mechanical-centered business, with functionality and added-value quickly migrating from hardware to software. Odense is small but still big enough to impose its' own platform and ecosystem"

- Mirko Bordignon, PhD
Fraunhofer IPA

4. Benchmark of the Danish robotics cluster – export

Export of industrial robots, as share and index 2014-18

Description of the data

The figures to the right compare available and internationally comparable figures for the export of industrial robots in Denmark and the eight countries that house the comparison clusters of this analysis, measured by amount of money.

Figure 23 shows the share of exports, where the nine countries together sum to 100 percent, in 2014 and 2018, respectively. Figure 24 shows an index for the export, where 2014 is set to 1.

Figure 23 shows that in 2014, Denmark accounted for two percent of the total export of industrial robots from the nine countries.

As can be seen in both figures, there has been significant growth in Danish exports since 2014. In 2018, Denmark's export of industrial robots was almost seven times greater than in 2014. None of the comparison country has had a growth similar to that level. The countries that came the closest were the Netherlands, who had three times as much export in 2018 as in 2014, and China, who had twice as much.

Due to the growth in 2018, Denmark's export of industrial robots was larger than exports from Sweden and the Netherlands, individually.

The increase corresponds to the growth of large robot companies in Denmark during this period, as well as Denmark being a small country. Many of the larger nations, such as the USA, China, and South Korea, have huge home markets that consume almost the entire domestic productions of robots. At the same time, Denmark has in recent years produced a number of distinctive industrial robots, which were, at least initially, very distinct from the robots offered in the domestic markets of the importing countries.

Figure 23. Distribution of the total export of industrial robots from the nine comparison countries, 2014 & 2018

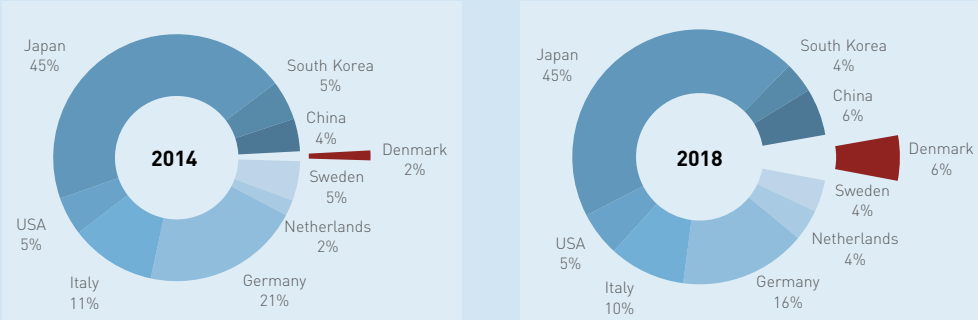
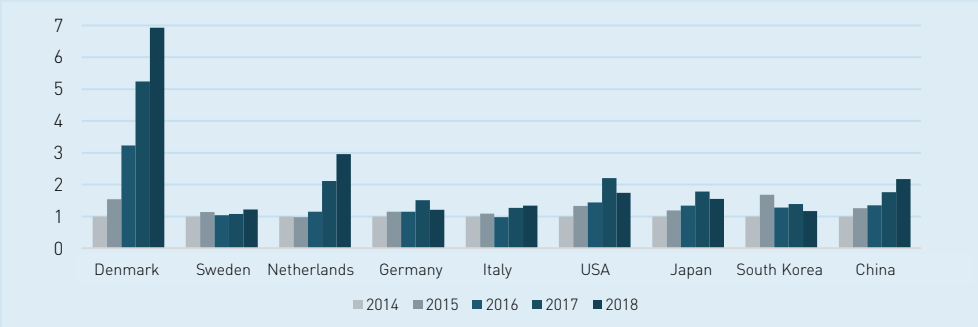


Figure 24. Index of the total export of industrial robots from the nine comparison countries, 2014 & 2018



Source: International Trade Center, 2019: Trade Map.

4. Benchmark of the Danish robotics cluster – research

In the following, a bibliometric benchmark analysis of Denmark's robotics research measured against the comparison countries is presented. The benchmark analysis shows the development in the extent and quality level of the Danish research in robot technology.

The data for the analysis is from the international research database Scopus, which categorizes and presents research publications from around the world. The database uses so-called "subject clusters" which group publications with topics that are often found in the same publications. These can be considered *research areas*, and particularly two of these are essential for robotics. The two areas are presented below. The areas are not overlapping – each has unique subcategories. The analysis of each area is based on two indicators. One is about volume, while the other is about quality. They are described in more detail in the light blue text boxes on the right.

Both indicators are widely recognized, and together they assess the strength of research measured qualitatively and quantitatively. While the volume is assessed in terms of the development of national research output from 2013 to 2018, the quality assessment is an average score for the entire period.

Please note that the research areas do not match the larger area, "Computer science and robots"[1], which covers much more broadly, and which is a manifested position of strength for Denmark.

Quantity – Volume

Measures the number of articles produced in the research area at various research and knowledge institutions in the country.

The development is shown from 2013 to 2018, in order to show the increase or decrease in the volume of the countries.

Quality – Citation index

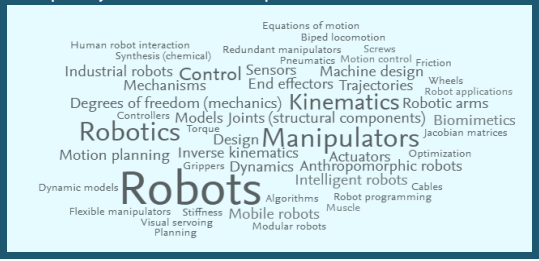
Measures the quality of the articles

The citation index is a figure for how often the articles have been quoted compared to the world average of the field. For example, an index of 2 equals twice as many citations as the average worldwide.

Research area 1: Robots, Robotics, Manipulators

This research area concerns the fields of computer technology, engineering, and physics, as well as how robots can "manipulate" elements in the physical world. The research is mostly concerned with the physical things a robot can do, and therefore mainly relates to industrial robots - both traditional and collaborative. The research publications are often about mechanical functions, sensors, control, and movement.

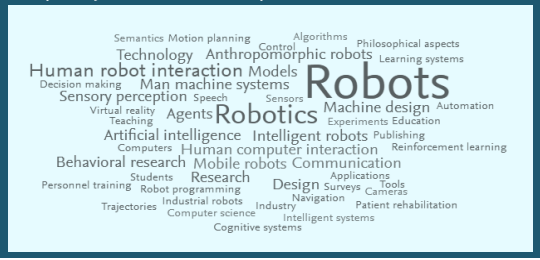
Most frequently used words in the publications from research area 1



Research area 2: Robots, Robotics, Human robot interaction

This research area concerns computer technology, software, and interaction with people. There is a particular focus on how robots communicate and learn in relation to changing surroundings. The area therefore mainly relates to service robots – both within logistics, but within types that are more suited to work directly with people.

Most frequently used words in the publications from research area 2



1) This area is used in e.g. IRIS Group (2019): "Danske styrker inden for forskning, teknologi og uddannelse"

4. Benchmark of the Danish robotics cluster – research area 1

This page shows the number of research publications within the first research area presented on the previous page. Table 5 shows the number of research publications per year for Denmark and the comparison countries from 2013 to 2018. Below, the same distribution is shown but calculated per 1 million inhabitants in figure 25 and as an index in figure 26, where 2013 is set as the reference year.

Overall, Denmark had relatively few publications within the research area in 2013 compared to the other countries, but in recent years, Denmark has experienced a significant increase in the number. This is evident of the robotics sector being a young but rapidly growing research area in Denmark. The small number of publications compared to the larger countries is partly explained by time required to build up international research networks, etc.

The increase means that Denmark went from being one of the countries with the fewest publications per inhabitant in 2013, to have significantly more than all the comparison countries in 2018. The increase in figure 26 shows a quadruple in the number of research publications from Denmark, while the other countries did not experience noteworthy increases. Table 5 shows that Denmark, in terms of absolute numbers, was ahead of both Sweden and the Netherlands for the first time in 2018.

The citation index shows that Denmark, despite of few articles in general, is on a par with the comparison countries average in terms of quality – except for Italy, which is higher, and the Asian countries, which are lower.

Table 5. Number of research publications, 2013-18

	2013	2014	2015	2016	2017	2018
Denmark	14	36	48	31	51	55
Sweden	60	67	64	51	60	52
Netherl.	48	53	68	53	57	54
Germany	468	452	558	445	447	403
Italy	356	339	359	341	362	313
USA	847	900	946	844	926	833
Japan	697	608	580	575	581	538
S. Korea	336	278	238	260	302	280
China	1,662	1,703	1,558	1,719	1,860	2,323

Table 6. Citation index, 2013-18

	Citation index
Denmark	1.45
Sweden	1.55
Netherl.	1.38
Germany	1.49
Italy	1.94
USA	1.59
Japan	0.76
S. Korea	0.70
China	0.62

Figure 25. Number of research publications in the research area per 1 million inhabitants,

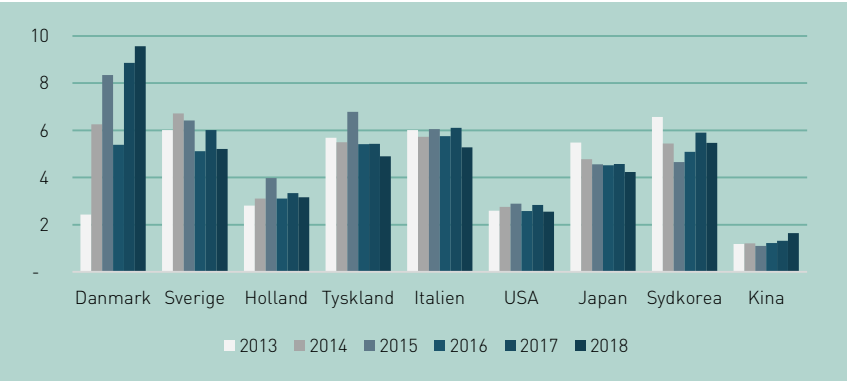
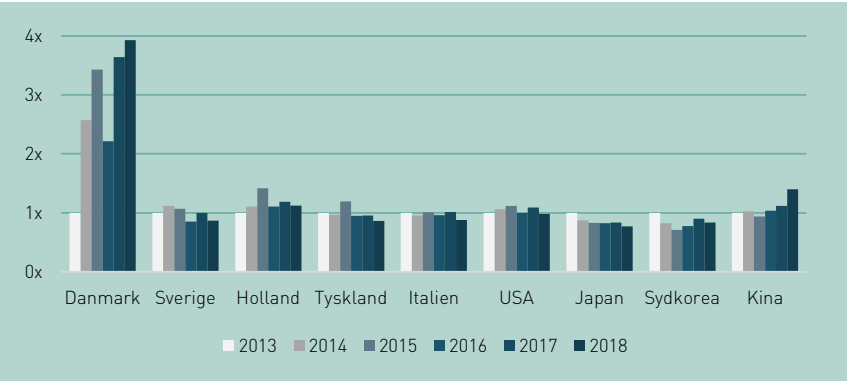


Figure 26. Index of the number of research publications in the research area, 2013-18



4. Benchmark of the Danish robotics cluster – research area 2

This page shows the number of research publications within the second research area. Table 7 shows the number of research publications per year for Denmark and the comparison countries from 2013 to 2018. Below, the same distribution is shown but calculated per 1 million inhabitants in figure 27 and as an index in figure 28, where 2013 is set as the reference year.

Table 7 shows that Denmark has also experienced a relatively large increase in the number of publications in this area. However, the increase has not been as significant as in research area 1, and Denmark has fewer publications than all the other countries, measured in absolute numbers.

However, figure 28 shows that Denmark has a high proportion of publications measured per 1 million inhabitants. Here, Denmark is among the top-three, though with some distance up to Sweden. Figure 28 shows that Denmark has also been among the highest growing countries, although there was a significant decrease from 2017 to 2018.

The citation index shows that Denmark's level corresponds to the world average, but is below the United States and the other European countries included in the comparison, when it comes to quality. This is a difference from the previous area, where Denmark was well in line with some comparison countries (the USA and in Europe). Denmark is still ahead of the Asian countries, that score quite low.

Table 7. Number of research publications, 2013-18

	2013	2014	2015	2016	2017	2018
Denmark	18	34	33	36	35	26
Sweden	46	45	37	53	52	62
Netherl.	85	75	63	72	89	77
Germany	191	181	210	243	236	199
Italy	99	95	111	135	140	154
USA	336	412	424	488	483	511
Japan	445	382	324	358	332	303
S. Korea	92	72	91	57	79	77
China	182	174	132	153	177	201

Table 8. Citation index, 2013-18

	Citation index
Denmark	1.01
Sweden	1.41
Netherl.	1.49
Germany	1.42
Italy	1.46
USA	1.74
Japan	0.70
S. Korea	0.63
China	0.66

Figure 27. Number of research publications in the research area per 1 million inhabitants, 2013-18

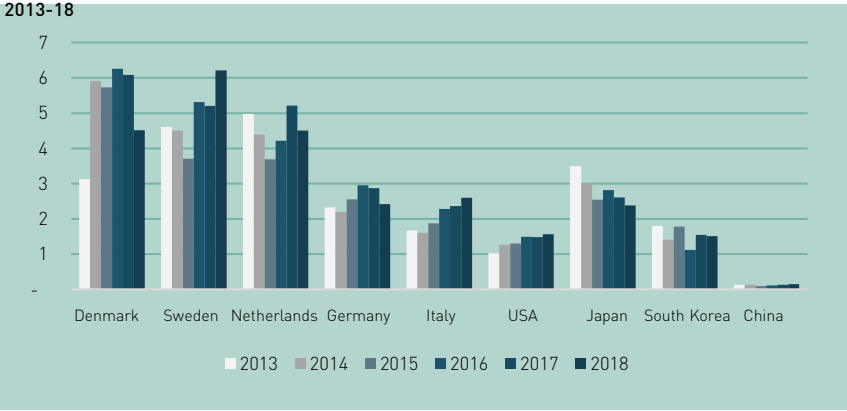
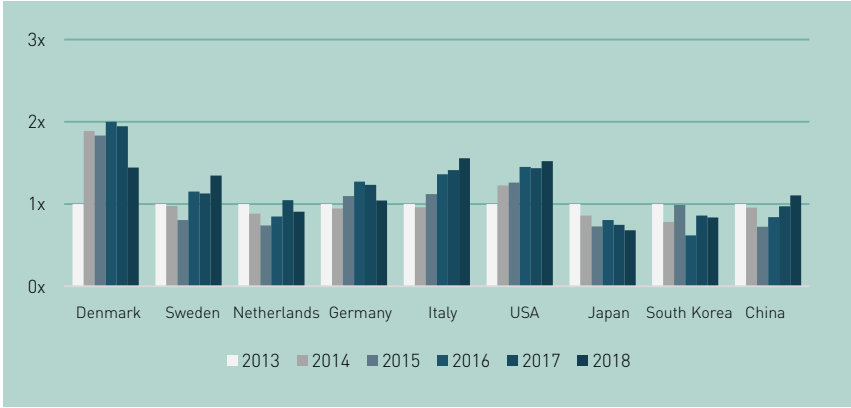


Figure 28. Index of the number of research publications in the research area, 2013-18



4. Benchmark of the Danish robotics cluster – distribution on knowledge institutions

Below is shown the distribution of research publications within the two research areas for the three best-represented knowledge institutions for each country, both as a total and for each of the two research areas. It is also shown whether the institution is considered to be geographically close to the cluster - relatively speaking. The analysis shows, among other things, that Denmark's robot research is very centred on 2-3 knowledge institutions – just 20 percent of the publications are from institutions outside the country's top-three.

Geographical proximity to the selected clusters

	Area 1	Area 2	Total
University of Southern Denm.	96 (41%)	49 (27%)	145 (35%)
Aalborg University	86 (37%)	50 (27%)	136 (33%)
DTU	30 (13%)	22 (12%)	52 (12%)
Others	23 (10%)	61 (34%)	84 (20%)

	Area 1	Area 2	Total
KTH Royal Inst. of Technology	121 (34%)	51 (17%)	172 (27%)
Chalmers Univ. of Technology	46 (13%)	37 (13%)	83 (13%)
Lund University	62 (18%)	20 (7%)	82 (13%)
Others	125 (35%)	187 (63%)	312 (48%)

	Area 1	Area 2	Total
TU Delft	133 (40%)	94 (20%)	227 (29%)
Twente University	92 (28%)	96 (21%)	188 (24%)
TU Eindhoven	41 (12%)	85 (18%)	126 (16%)
Others	67 (20%)	186 (40%)	253 (32%)

	Area 1	Area 2	Total
TU Munich	359 (13%)	86 (7%)	445 (11%)
RWTH Aachen	103 (4%)	166 (13%)	269 (7%)
DLR	226 (8%)	24 (2%)	250 (6%)
Others	2,085 (75%)	984 (78%)	3,069 (76%)

	Area 1	Area 2	Total
Italian Institute of Technology	555 (27%)	65 (9%)	620 (22%)
Milan Polytech-nic University	142 (7%)	71 (10%)	213 (8%)
University of Genoa	148 (7%)	54 (7%)	202 (7%)
Others	1,225 (59%)	544 (74%)	1,769 (63%)

	Area 1	Area 2	Total
Carnegie Mellon University	308 (6%)	120 (5%)	428 (5%)
MIT	230 (4%)	126 (5%)	356 (4%)
Georgia Institute of Technology	179 (3%)	114 (4%)	293 (4%)
Others	4,579 (86%)	2,294 (86%)	6,873 (86%)

	Area 1	Area 2	Total
University of Tokyo	326 (9%)	105 (5%)	431 (8%)
Osaka University	194 (5%)	186 (9%)	380 (7%)
Waseda University	192 (5%)	100 (5%)	292 (5%)
Others	2,867 (80%)	1,753 (82%)	4,620 (81%)

	Area 1	Area 2	Total
Advanced Inst. of Science and Tech	209 (12%)	75 (16%)	284 (13%)
Seoul National University	215 (13%)	30 (6%)	245 (11%)
Hanyang University	144 (9%)	15 (3%)	159 (7%)
Others	1,126 (66%)	348 (74%)	1,474 (68%)

	Area 1	Area 2	Total
Chinese Academy of Sciences	721 (7%)	53 (5%)	774 (7%)
Ministry of Education China	657 (6%)	43 (4%)	700 (6%)
Tsinghua University	565 (5%)	29 (3%)	594 (5%)
Others	8,882 (82%)	894 (88%)	9,776 (83%)

Appendix: Methods and data

Literature

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List of interviewees

- Andra Keay, Silicon Valley Robotics
- Andrea Maria Zanchettin, Politecnico di Milano
- Christian Hannibal, Dansk Industri
- Claus Risager, Blue Ocean Robotics
- Jade Le Maitre, HEASE Robotics
- Klaus Funk, ZD-B
- Mads Ingstrup, SDU
- Mikkel Christoffersen, Odense Robotics
- Mirko Bordignon, Fraunhofer IPA
- Muhammad Ali, VTT
- Ran Zhao, Innovation Center Denmark Shanghai
- Roi Rodríguez de Bernardo, FundingBox
- Tom Ryden, MassRobotics

Approach for the Horizon 2020 analysis

The projects have been identified by keywords (robot/robotics, drone/drones and automation/automate) in the EU's Cordis database. The search, completed April 4 2019, identified 227 projects with Danish participation. A review of the summaries, ensuring that the projects were actually within the subject areas, left 103 relevant projects.

These projects are then linked to the EU Commission database for individual organizations' funding from Horizon 2020 per April 4 2019. This means that organizations that appear from the identified lists of robotics companies for the whole country and for the region of Odense Robotic who have not participated in the identified project will not be included in this analysis. The analysis only includes projects financed through Horizon 2020 – that means national programs (e.g. the Innovation Fund) and other international programs (e.g. EuroStars) are not included.

Appendix: Methods and data

Robotdalen/Sweden

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- Robotdalen, 2019: Verksamhetsberättelse 2018
- VINNOVA, 2010: From Robotdalen to Robot Valley - International evaluation of Robotdalen
- Västerås Stad, 2013: Beslut - Medfinansiering av projektet Robotdalen

RoboValley/Netherlands

- Holland Robotics, 2018: Kansen voor de Nederlandse robotica
- SHADANA, 2016: Robotics in the Netherlands
- TU Delft Robotics Institute, 2017: Creating the Next-Generation Robots
- TU Delft Valorisation Centre, 2016: Smart robots from Delft conquer the world

Bavaria/Germany

- Dauth et. al., 2017: German Robots - The Impact of Industrial Robots on Workers
- Germany Trade & Invest, 2018: The Robotics & Automation Industry in Germany
- The Danish Trade Council, (web): Robotics in Southern Germany
- ZD.B., 2018: Künstliche Intelligenz und Robotik: Motor für Innovation

Piedmont/Italy

- Compagnia di San Paolo, 2017: Digital Disruption and the Transformation of Italian Manufacturing
- European Commission, 2018: Regional Profiles Italy
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Appendix: Methods and data

MassRobotics/USA

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- Biz Journals, 2018: The Largest Robotics Companies in Massachusetts
- Massachusetts Technology Leadership Council, 2009: Achieving Global Leadership - A Roadmap for Robotics in Massachusetts

Silicon Valley Robotics/USA

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- Executive Office of the President, 2016: Artificial Intelligence - Automation, and the Economy
- Silicon Valley Robotics, 2019: Robotics in Silicon Valley 2020

Seoul/South Korea

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- IROBOT News, 2019: Robot Industry Survey in 2017 - Revenue and import/export trends
- KIRIA, 2019: Introduction on KIRIA & Korean Robot Industry

Tokyo/Japan

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- The Headquarters for Japan's Economic Revitalization, 2015: New Robot Strategy

Shenzhen/China

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- Chinese Ministry of Industry and Information Technology, 2016: China Intelligent Manufacturing Industry Depth Research and Investment Forecast...
- Chinese Ministry of Industry and Information Technology, 2016: China Human-Computer Interaction Market Investment Analysis and Forecast...
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