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Advanced Technologies for Industry – Sectoral Watch

Technological trends in the electronics industry

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Introduction

This sectoral report has been prepared in the framework of the '*Advanced Technologies for Industry*' (ATI) project, initiated by the European Commission, Directorate General for Internal Market, Industry, Entrepreneurship and SMEs and the Executive Agency for Small and Medium-sized Enterprises.

It analyses trends in the generation and uptake of advanced technologies, as well as related entrepreneurial activities and skills needs in the value chain of electronic components and systems. It covers in particular industry domains, but also with an emphasis on trends and challenges in the area of micro- and nanoelectronics (MNE). It interprets data from a list of data sources, compiled to monitor advanced technologies and their applications in industry across Europe and key competitor economies.

The starting point of this analysis has been 16 advanced technologies that are a priority for European industrial policy, which enable process, product and service innovation throughout the economy and hence foster industrial modernisation. 'Advanced technologies' are defined as recent or future technologies that are expected to substantially alter the business and social environment, and include advanced materials, advanced manufacturing, artificial intelligence, augmented and virtual reality, big data, blockchain, cloud technologies, connectivity, industrial biotechnology, Internet of Things, micro- and nanoelectronics, mobility, nanotechnology, photonics, robotics, and security.

The relevance of these specific technologies in the electronics industry has been explored through patent analysis and data on private equity investments, skills and technology uptake. The full methodology behind the data calculations is available here: https://ati.ec.europa.eu .

This report is structured as follows:

- The first section sets the industrial and market context.
- The second section analyses technological trends in advanced technologies applied in the electronics industry, based especially on patents and text-mining of company websites.
- The third section presents findings about private equity investment and startup/spinoff activity.
- The fourth section explores the supply and demand of skills related to advanced technologies in the electronics industry.
- The fifth chapter concludes with a short future outlook.

Section 1

1. Setting the scene: industrial context

Key messages

While the electronics sector was traditionally driven by the consumer electronics market, this has recently been overtaken by markets more closely related to **embedded electronics**.

Semiconductors have a pervasive use throughout numerous application sectors. While semiconductor content in equipment has experienced a rapid growth, **markets around AI and IoT** related semiconductors are also seeing significant growth forecasts.

Europe is especially well positioned in electronics segments covering the **automotive industry, industrial, aeronautics, defence, security and healthcare electronics**, but weaker in the stand-alone and consumer electronics segments. While EU27 electronics employment is concentrated in a handful of countries, Central Eastern European countries, in particular, have experienced **employment growth**.

1.1 Electronics value chain: market size and value evolution

The global electronics market – both in industrial and consumer domains – faces a rapid technology evolution affecting its dynamics and growth rates. Traditionally, the electronics sector has been driven by the consumer electronics markets (€992 bn), covering PCs, telecoms, audio and video among others, but the embedded electronics market (€1026 bn) has gradually overtaken these markets. New markets more closely related to embedded electronics, such as automotive, industrial, aerospace, defence, security and medical, have a high predicted growth whereas growth is predicted to be lower for consumer electronics markets.[1]

The value chain of electronic components and systems, covering micro- and nanoelectronics, semiconductors, IoT, software, photonics and artificial intelligence (AI) among others, has a significant impact on the economy. Europe has a significant global share of production in materials and tools (17%) for the production of electronic components, and in professional and embedded electronics segments (22%), which further diffuses through to end-user equipment (20%) in these sectors. However, its global position is weaker in semiconductors (9%), electronic equipment (7%) and electronic boards (10%), as well as in stand-alone electronics (6%).[2]

The pervasive use of semiconductors in a multitude of application sectors make them a main driver of market growth. The global semiconductor industry had a turnover of €389 bn in 2017. Europe's semiconductor activities[3] benefitted from a compound annual growth rate of 3.8% from 2010 to 2017. However, its share of world global semiconductor output declined from 13% in 2010 to 9% in 2017.[4]

The market for AI related semiconductors is projected to grow from approx. €5.5 bn in 2018 to around €27 bn by 2022.[5] Further to this, the forecasted IoT semiconductor spending is valued at more than €30 bn in 2020.[6] It was estimated that the semiconductor content in equipment – coupled to the increase of intelligence embedded in modern devices and appliances – increased from around 20% in 2013 to approx. 25% in 2017. While well positioned in established technologies, Europe lacks capacity to produce advanced semiconductor technologies (i.e. below 22 nanometre) which impacts its opportunities for exploiting this growth economically.

1.2 Growth trends in application areas

Turning to key application areas, Europe has a considerable share of global production in the automotive, industrial, aeronautics, defence,

[1] European Commission. (2020). *Study on emerging technologies in electronic components and systems (ECS) – opportunities ahead*. SMART 2018/0005.
[2] Electronics Leaders Group. (2019). *Boosting Electronics Value Chains: An industrial strategy for Europe – Implementation plan* & European Commission. (2019). European Commission. (2020). *Study on emerging technologies in electronic components and systems (ECS) – opportunities ahead*. SMART 2018/0005.
[3] Covering for instance design, production, packaging and commercialisation of semiconductor devices.
[4] European Commission. (2019). *Study on the Electronics Ecosystem – Overview, Developments and Europe's Position in the World. Final Report*. SMART 2016/0007.
[5] PWC. (2019). *Opportunities for the global semiconductor market. Growing market share by embracing AI*.
[6] Deloitte. (2018). *IoT opportunity in the world of semiconductor companies*.

security and healthcare electronics markets; these end-user electronic segments all show high growth potential over the next years.[7]

Europe has a strong position in industrial electronics, ranked second (with 20%) after China but ahead of the US. In comparison to a growth rate of 7.8% per year for the global industrial electronics market from 2010 to 2016, Europe's growth was 3.7%. The market for industrial control and factory automation is predicted to grow to almost €140 bn by 2022.[8]

Important Projects of Common European Interest (IPCEI) on microelectronics

Through the IPCEI framework's support for microelectronics, €1.75 bn is provided by France, Germany, Italy and the UK, aiming to mobilise an additional €6 bn of private investments to enable research and develop innovative technologies and components in microelectronics.

The IPCEI focusses on downstream applications, research and innovations, complementary to upstream R&I activities, and is anticipated to have an impact on respectively consumer devices (e.g. home appliances and connected cars) and commercial and industrial devices (management systems for batteries used for electric mobility and energy storage).

In terms of impact, it is expected to promote the delivery of energy efficient chips, power semiconductors, smart sensors, advanced optical equipment and compound materials.

In the automotive sector innovations originate to a large extent from electronics.[9] Europe remains a leader in automotive electronics production, pushed forward mainly by Germany, but also France; Europe has 27% of production in global automotive electronics. Automotive electronics grew by 370% overall between 2000 and 2017.[10]

There is equally a strong performance in aeronautics, defence and security electronics for Europe (22%) relative to China (24%) and North America (19%). A yearly growth of 5.5% is projected at global level from 2017 to 2022. Beyond growth in commercial and military aircraft and Unmanned Aerial Vehicle markets, the air traffic management market is expected to grow from around €45 bn in 2016 to more than €85 bn in 2022.[11]

While the US (with 40%) is leading in health and wellbeing electronics equipment, the EU is still accounting for 19% of global health and care electronics. The healthcare IT market is expected to grow from approx. €120 bn in 2016 to more than €250 bn in 2021; the global medical device connectivity market is foreseen to reach approx. €1.2 bn by 2021.

The US and China are leading in consumer and stand-alone electronics. In particular Asia has gained a significant share of mass market segments (PCs, audio-visual and phones).

1.3 Electronics employment – a driver of growth

The broader EU27 electronics industry currently employs roughly 2.2 million workers. Around 70% of EU27 electronics employment is concentrated in a handful of countries: Germany has the largest share with approx. 813,000 employees, followed by France, Italy, Poland and Czech Republic.[12] Out of these, there are around 200,000 high-skilled jobs in the microelectronics sector in Europe.[13]

The sector is dominated by SMEs. 98% of enterprises in the electronics industry employ less than 250 persons in the EU27 (Eurostat, 2017). According to the figures of the Structural Business Statistics, there were 76,000 firms active in Manufacture of computer, electronic and optical products and Manufacture of electrical equipment in 2017, out of which 1,540 were large firms[14].

Although still below pre-2008 recession levels, employment in the electronics industry has regained growth – in particular, in recent years (2017-2018) – with around half of EU27 countries experiencing an increase in employment from 2011 to 2018. The growth was concentrated especially in CEE countries, with a yearly employment increase of 2.1%, but also Austria, Germany, Portugal and Spain have benefitted from the growth trajectory.

Comparing to the electronics sector in the US, it similarly faced a decline in jobs from 2008 onwards, however, the US employs a higher share of workers (above 11% versus approx. 8% in Europe) relative to the total manufacturing employment. It is forecasted that the electronics sector's employment will grow with around 0,2% per year between 2018 to 2023.

[7] European Commission. (2020). *Study on emerging technologies in electronic components and systems (ECS) – opportunities ahead*. SMART 2018/0005.

[8] Thompson, H., Reimann, M. Et al. (2018). *Platforms4CPS. Key Outcomes and Recommendations*.

[9] European Commission. (2019). *The Economic and Social Impact of Software & Services on Competitiveness and Innovation*. Smart 2015/0015. Final Report.

[10] ZVEI. (2019). *Mikroelektronik – Trendanalyse bis 2023. Vorstellung langfristiger Trends 2013 – 2018 – 2023*.

[11] Thompson, H., Reimann, M. Et al. (2018). *Platforms4CPS. Key Outcomes and Recommendations*.

[12] Oxford Economics. (2019). *Evolving employment trends in the European electronics sector and potential implications for skills needs – preliminary findings*.

[13] METIS. (2020). *The Challenge*. Retrieved April 2020, from metis4skills.eu: http://www.metis4skills.eu/the-challenge

[14] https://ec.europa.eu/eurostat/web/structural-business-statistics

Section 2

2. Technological trends

Key messages

The trends in Micro- and nanoelectronics patent applications over the period 2010-2017 points to a **declining share for the EU27, Japan and the USA,** while China's patenting activity has soared from around 10% to almost 20% over a four-year period. Within the EU, especially **Germany and France** have contributed to MNE patenting development. Relative to their total domestic patent applications Belgium and Austria had the highest share in MNE in 2015-2017.

With regard to new technology development, the areas where electronics firms tend to patent most dynamically include **Security, AI, Big Data and Robotics**. Some of these trends are also reflected in the actual use of technologies by the industry. **Cybersecurity** is a major consideration as products and services become increasingly interconnected. Activity in this area is partly related to the emergence of GDPR and also from high visibility attacks that have occurred.

In terms of the use of advanced technologies, **Photonics and IoT** are applied the most. As a new trend, electronics firms are developing relevant new **IoT driven services** based on data and connectivity.

2.1 Technology shifts and advances – emergence of advanced technologies, computing and software technologies

The electronics value chain is exposed to a variety of technology trends including the emergence of the data economy. Table 1 offers a high-level snapshot of technological opportunities at the different levels of the electronics value chain.

Table 1: Overview of application, enabling and materials-related technologies

Application related technologies	**Advanced technologies:** - IoT, photonics, robotics, etc. **Emerging computing technologies:** - AI and computing paradigms (edge/neuromorphic/quantum computing)	
Underlying enabling technologies	**Software technologies:** - Embedded, intelligent and platform related software	**'More than Moore' technologies**
Materials related technologies	**Advanced materials** (incl. Fully Depleted Silicon on Insulator)	

Source: draws on European Commission. (2019). *Study on the Electronics Ecosystem – Overview, Developments and Europe's Position in the World. Final Report*. SMART 2016/0007 & Electronics Leaders Group. (2019). *Boosting Electronics Value Chains. An Industrial Strategy for Europe. Implementation Plan*. June 2019 & Maloney. C. (2019). *Key Digital Technologies. 2020 and beyond*. Presentation, EFECS, 21 November 2019.

The emergence of new computing paradigms (neuromorphic and quantum computing accelerators and complex integration) are also being pushed forward as a consequence of the need for new generation distributed and edge computing serving AI.[15] Connected sensors and IoT devices, smart cities, smart grids, software-defined networks, data-driven cognitive networking and cyber security utilise edge computing networks, and thereby facilitate data transmission over large distances on the basis of distributed and connected communication devices.

Complex electronic value chains require more and more pairing of microelectronics with software. Hardware and software parts are becoming increasingly hard to dissociate, and different software layers, beyond embedded software, are gaining relevance among electronics industries. Software is co-integrated with chips to create complex systems and open up new applications. In addition, at the level of semiconductor companies there is a shift in value creation focus from the hardware to software value chain.[16]

While the More Moore approach concerns the need to double the speed and transistor density every 2 years, the focus of More than Moore is on the diversification of applications. In this context, the share of wafer fab capacity for the manufacturing of integrated circuits is decreasing for Europe – Europe is expected to have around 5,3% share of

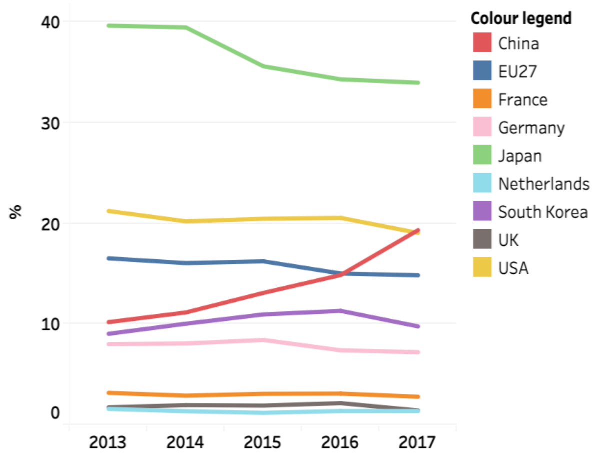
[15] Electronics Leaders Group. (2019). *Boosting Electronics Value Chains: An industrial strategy for Europe – Implementation plan*.
[16] McKinsey & Company. (2019). McKinsey on Semiconductors – Creating value, pursuing innovation, and optimizing operations. Retrieved December 2019, from mckinsey.com: https://www.mckinsey.com/~/media/McKinsey/Industries/Semiconductors/Our%20Insights/McKinsey%20on%20Semiconductors%20Issue%207/McK_Semiconductors_Oct2019-Full%20Book-V12-RGB.ashx.

world manufacturing capacity forecast by 2022, decreasing from 8,1% in 2010. The main share of European capacity corresponds to 200mm, while Europe has almost no manufacturing below 22 nanometre.[17]

2.2 Trends in patenting of MNE technologies: stable EU27 share while China is on the rise

The technological trends and development have been captured through patent analysis[18] and the evolution of patents has been analysed specifically for Micro- and nanoelectronics (MNE) technologies. Starting with the progress in global patent applications, Figure 1 sketches out the share of global MNE patent applications for the EU27 relative to major competitors.

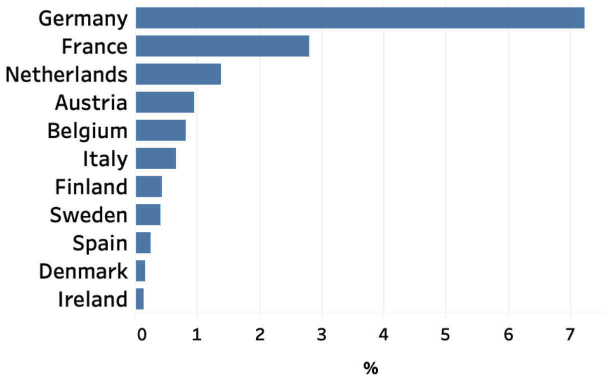
Figure 1: Share of global patent applications (2013-2017)[19]



Source: ATI, 2019 Fraunhofer calculations

The leading country with the highest share of total patent applications in MNE is Japan with an average of approx. 39% for the 2013-2017 period; it is followed by the US (21% on average) and the EU27 (16% on average). The trends in MNE patenting over time however point to a declining share for Japan, the US and EU27, while China's patenting activity has soared from around 10% to almost 20% over a five-year period. Within the EU, Germany and France, in particular, contribute to MNE patenting development, although the Netherlands, Austria and Belgium have a high relative share of MNE patents as well. Figure 2 presents the EU Member States with the highest share of global patent applications.

Figure 2: EU Member States' share of global patents in MNE (2017)

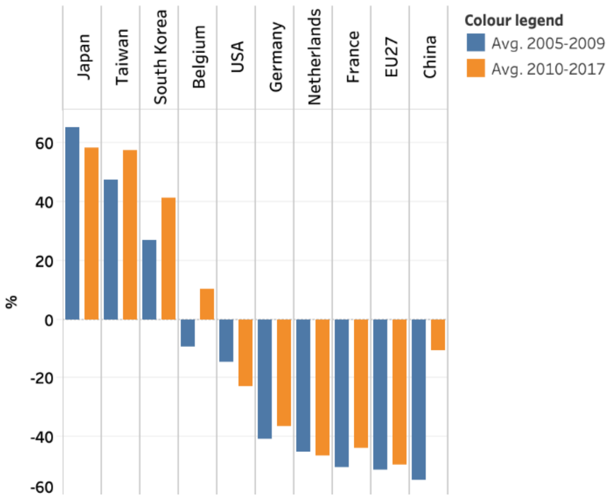


Source: ATI, 2019 Fraunhofer calculations

Germany, in particular, is a key contributor to patent applications in the field of MNE within the EU27 with approx. 7,2% of global patent applications. France (2,8%), Netherlands (1,4%), Austria (1%), Belgium (0,8%) and Italy (0,7%) follow. A handful of countries (Finland, Sweden, Spain, Denmark, Ireland, Poland and the Czech Republic) have around 0,05% to 0,4% of global MNE patent applications.

A revealed patent advantage index (RPA[20]) – see Figure 3 – displays the extent to which countries have specialised in MNE.

Figure 3: Change in Revealed Patent Advantage (RPA) Index in MNE (2005-2009; 2010-2017)



Source: ATI, 2019 Fraunhofer calculations

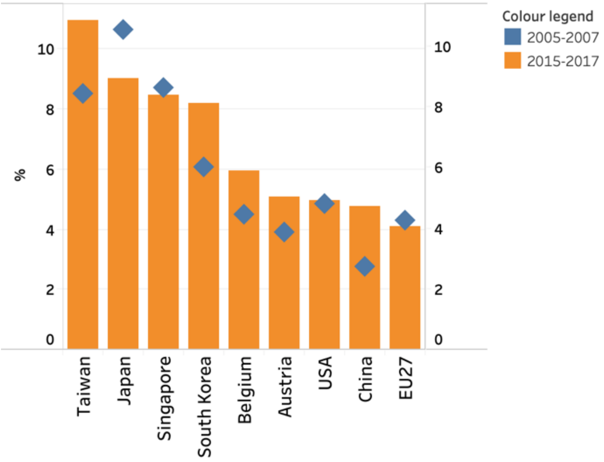
Among the most specialised countries at the global level are Japan, Taiwan and South Korea. Belgium,

[17] European Commission. (2019). *Study on the Electronics Ecosystem – Overview, Developments and Europe's Position in the World.* Final Report. SMART 2016/0007.
[18] The patent analysis reflects the owner (applicant) of the technology, since patents have been localised based on the location of their legal owner.
[19] All diagrams in this report have been created with the help of tableau software.

[20] The RPA index measures the share of an economy's patents in a specific technology relative to the share of total patents owned. The RPA indices between -100 and -60 indicate an absence of specialisation, whereas values between -60 and -20 points to a weak specialisation, between -20 and +20 to an average specialisation, between +20 and +60 to an above average specialisation and between +60 and +100 to a strong specialisation.

Germany, the Netherlands and France have the highest level of specialisation in the EU27, though to a lesser extent compared to the global level, with the exception of Belgium which has an average specialisation. Based on the RPA analysis, most European countries are generally relatively unspecialised or have a rather weak specialisation in the field of MNE. Although diversification and advancing scientific knowledge in potentially related technologies to MNE can be a strength, it is important to avoid too much fragmentation. Figure 4 portrays MNE patenting's relative weight of total patenting at country-level.

Figure 4: Share of MNE patent applications over total patent applications at country-level (comparison of 2005 - 2007 and 2015 - 2017)



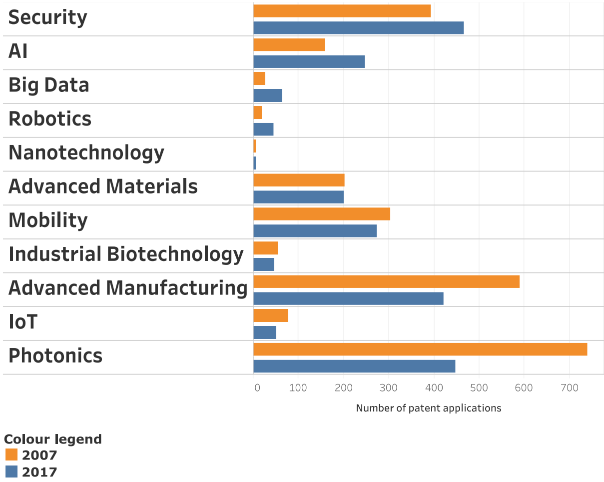
Source: ATI, 2019 Fraunhofer calculations

The highest share of MNE patent applications relative to total domestic patent applications in the period from 2015 to 2017 was recorded by Taiwan (10,9%), Japan (9%), Singapore (8,5%) and South Korea (8,2%). Europe's share of patent applications in MNE within the total domestic patents has slightly decreased from roughly 4,2% in 2005-2007 to 4,08% in 2015-2017. Within the EU27, Belgium (5,96%) and Austria (5,1%) had the highest share of MNE patent applications in 2015-2017 relative to total domestic patent applications.

2.3 Technological patenting of electronics firms – security, artificial intelligence, big data and robotics

With regard to technology development, the areas where electronics firms increased their patenting activity the most over the period from 2007-2017 include **Security, AI, Big Data and Robotics**. Measured on the basis of total patent applications, Security, Photonics and Advanced Manufacturing Technologies are the most relevant. The analysis also shows that the number of patents has dropped significantly in Photonics and Advanced Manufacturing even if these two technologies are still key to the electronics industry (see Figure 5).

Figure 5: Number of patent applications by electronics firms in advanced technologies – ranked by highest absolute growth, EU27 (2007 – 2017)



Source: ATI, 2019 Fraunhofer calculations

Cybersecurity is a major consideration as products and services become increasingly interconnected. Activity in this area is partly related to the development of GDPR and also to highly visible attacks that have occurred. There is thus now a greater awareness of the potential threats and of the need to protect our key infrastructure as well as private data. In the area of AI, a joint JRC and OECD study found a high concentration of **AI related patents** in a few sectors, with close to 50% of AI related patents filed by companies in the field of computers and electronics.[21]

Comparable trends can also be witnessed in China and the US, although patents in Security have grown more in the EU vis-à-vis other regions in recent years (see Figure 77).

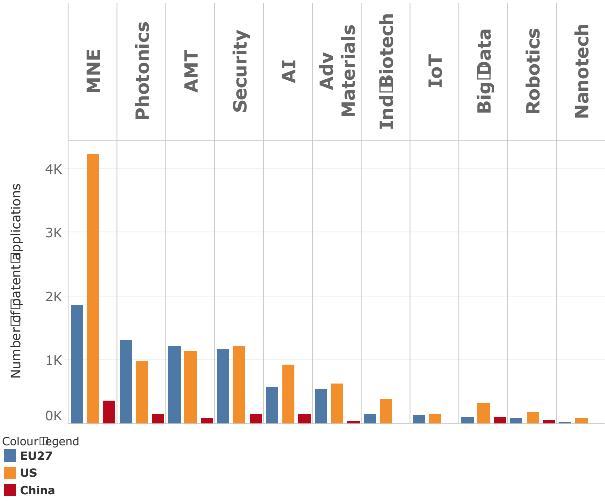
The international comparison shows that European firms in the electronics industry filed more patent applications than their US and Chinese counterparts in the area of Photonics and Advanced Manufacturing Technologies over the period 2015-2017. The US is ahead of the EU27 in several advanced technologies especially in AI, Big Data, Industrial Biotechnology, Advanced Materials and Robotics.

Filing patents in the area of Micro- and nanoelectronics is self-evident for electronics firms. The gap between the US and EU27 is in line with the results of the MNE world patent analysis

[21] Dernis H., Gkotsis P., Grassano N., Nakazato S., Squicciarini M., van Beuzekom B., Vezzani A. (2019). *World Corporate Top R&D investors: Shaping the Future of Technologies and of AI. A joint JRC and OECD report*. Retrieved December 2019, from ec.europa.eu: https://ec.europa.eu/jrc/en/publication/world-corporate-top-rd-investors-shaping-future-technologies-and-ai.

as in the previous section. However, Chinese firms patented much less than in the EU27 or the US[22].

Figure 6: Technology patent applications filed by electronics firms – international comparison (2015-2017)



Source: ATI, 2019 Fraunhofer calculations

2.4 Technology adoption for enhanced products and services

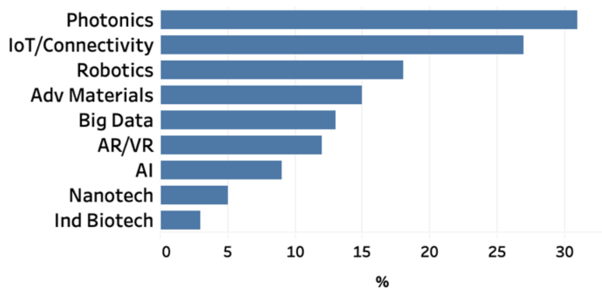
Advanced technologies create opportunities for innovation and disruption in the electronics industry. Not only can firms take advantage of technological transformation to improve their production processes and productivity, but electronics technology, coupled with expertise in ICT, delivers solutions for smart cities, energy management, mobility and personalised healthcare. On one hand, manufacturers use IoT, AI or AR/VR to add new services to their products, and create connected devices, AI-enhanced or immersive experiences. On the other hand, semiconductors serve as an important input to build robots, AI and components that enable IoT systems.

A large-scale text-mining[23] of company websites belonging to the electronics industry shed some light on how advanced technologies are changing the rules of the game in this sector. This analysis has been conducted in the framework of the 'Advanced Technologies for Industry' project based on a search algorithm and keywords. From the analysis (see Figure 7), the advanced technologies appearing most frequently in online content are photonics and IoT. A considerable share is also referencing Advanced Materials, Big Data, AR/VR and AI technologies.

Photonics technology is widespread in electronics that makes use of laser-cutting technologies or LED lights. In addition, photonic computing is also extremely important for ecological reasons. As a new trend the interfaces of electronics and Photonics, and their integration on a single silicon chip, is expected to add new functions to computers where a key advantage is more energy efficiency and speed of communications that will be important for future data centres. Photonics chips use light instead of electricity and consume relatively little power in the process. They can process massive neural networks millions of times more efficiently than before.

Electronics firms do not only provide products but develop relevant services for **new IoT/IIoT (Industrial Internet of Things) models** based on data and connectivity. Technological trends in electronics and semiconductors are driven by changing demand patterns in segments and industrial applications. Many of the text-mined electronics companies are developing sensors, cellular gateways, and components for connectivity, such as the connected house, smart cities and smart factories.

Figure 7: Share of electronics company websites referencing advanced technologies (2019)



Source: Technopolis Group analysis

Note: based on ca 6000 websites from Belgium, France, Germany, Italy, Netherlands, Poland and Spain

Firms offer services and entire solutions supporting the shift to IoT-driven production models. Through the integration of complex systems, they can enable the management of connected devices; for instance, EcoStruxure is Schneider Electric's IoT enabled architecture used in homes and buildings. Another example, the VUSION IoT platform, combines advanced

[22] Due to restrictions in the available dataset, it is possible that the latest years for Asian countries are not accurate in absolute terms.

[23] Based on a search algorithm, company websites were analysed for links to each specific technology. The analysis included 6,112 websites of electronics firms across seven European countries, including Belgium, France, Germany, Italy, Netherlands, Poland and Spain. This analysis can reflect about the use of technologies embedded in new products and services and about technological advantages that companies communicate about. It cannot be used, however, to conclude about the adoption of advanced technologies in terms of the hidden production processes that are being less revealed in these types of online content.

electronic shelf labelling technology, IoT ultra-low power communication infrastructure, high-resolution colour displays and sensors. Smart connectors are also increasingly being used in the field of predictive maintenance.

Leveraging AI in electronic devices takes many forms, even if there are only few AI enhanced examples of electronics devices. Dedicated microelectronics that integrate AI or support AI processes at the hardware level are gaining increased importance: it is currently growing with significant growth rates (above 40% per year) due to a surge in demand from different applications. This market segment is largely dominated by US companies. However, China is progressively expanding its technological knowhow in this high growth and future-oriented field of technology.[24] More specific sub-technologies include the use of interactive voice response, machine vision, and machine and deep learning. A study by McKinsey[25] analysed the opportunities (within computing, memory, storage and networking) offered by AI technology for semiconductor companies, for example by increasing computational efficiency or facilitating the transfer of large data sets.

Semiconductors are the natural medium for AI, but AI enables electronics manufacturers to become more productive. In workshop-based production systems, production scheduling optimisation systems can be based on AI and optimise production schedules. AI is also instrumental in improving electronic design automation. Another trend of AI chips brought to life a new generation of microprocessors which are specifically designed to process AI tasks faster and using less power. The industry is also using AI to reshape product development cycles, improve product design processes, reduce defects and deliver products faster to the market.

Sensor-generated big data from electronic devices are used in a variety of ways. Battery-operated sensors process data sources such as temperature and humidity, images, sounds and vibrations. Big data also enables the survival analysis of electronics products and failure rate analysis. Moreover, processing at the edge is becoming increasingly relevant since data captured from sensors and multi-sensing platforms need local advanced processing, which also is linked to AI chips.

Advanced materials and components are used in electrical and electronics engineering, especially in new electronic devices, integrated circuits and digital systems.

AR/VR technology supports electronic design. Vuforia AR solutions enable domain experts to create scalable augmented reality content to empower maintenance technicians with contextual knowledge in real-world environments. High-tech manufacturing and service organisations leverage innovative AR technology to optimise change-over, reduce downtime and decrease scrap. Firms are developing advanced applications in 3D vision systems and reverse engineering. In turn, MEMS technology is also used to develop sensors that ensure vertigo is never an issue in AR technologies.

Robotics technology brings advancements to electronics components and assembly manufacturers, in particular through factories of the future. Advanced electronics firms use automated vehicles for material delivery and robots for palletising. The result of the text-mining analysis in this case is lower than Eurostat data suggest. According to Eurostat figures, the share of firms using industrial robots in the manufacture of computer, electronic and optical products sector was 17% and in the manufacture of electrical equipment, machinery and equipment sector it was 22% in 2018.

The multiple interconnections between the supply chain and advanced technologies are mapped in Table 2.

Table 2: Interconnections between technologies and the supply chain

Technologies / Supply chain	IoT	Robotics	AI	AR/VR	Big data	Photonics	Advanced manufacturing
Electronics design				x	x		
Materials / components		x				x	x
Chip production			x				
Assembly electronics	x	x			x		
System integration	x	x	x				
Electronics equipment / end-product	x		x	x		x	

Source: Technopolis Group

[24] Allied Market Research. (2019). *Global Artificial Intelligence Chop Market Expected to Reach $91,185 Million by 2025. Retrieved January 2019*, from alliedmarketresearch.com: https://www.alliedmarketresearch.com/press-release/artificial-intelligence-chip-market.html.

[25] McKinsey & Company. (2019). *McKinsey on Semiconductors – Creating value, pursuing innovation, and optimizing operations*. Retrieved December 2019, from mckinsey.com: https://www.mckinsey.com/~/media/McKinsey/Industries/Semiconductors/Our%20Insights/McKinsey%20on%20Semiconductors%20Issue%207/McK_Semiconductors_Oct2019-Full%20Book-V12-RGB.ashx.

3. Private equity investment and startup creation

Key messages

Private equity and venture capital investment in Micro- and nanoelectronics has been higher in China and the US compared to EU27 in 2000-2019 and also in the most recent years. **China has witnessed huge investment** in electronics in the last decade. In Europe, MNE investment in absolute terms is led by Germany, France, the Netherlands, Sweden and Spain.

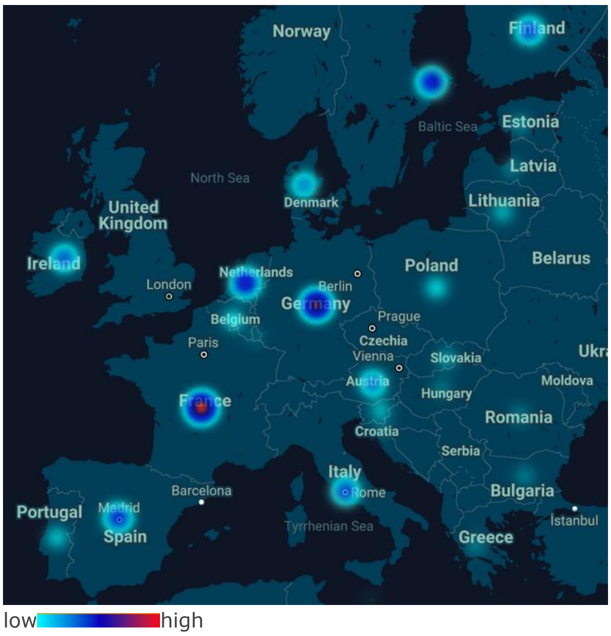
From an entrepreneurship perspective, the major European startup hubs in the field of electronics are located in France (Paris), Germany (Munich), the Netherlands (Eindhoven, Delft), Spain (Barcelona, Madrid) and Italy (Milano). A significant share of startups in the electronics industry are specialised in **consumer electronics, IT, semiconductors, hardware, software and IoT.**

Startups in the EU that received the highest funding in the past three years are active in the area of **photonics and sensors, batteries, automotive/mobility, healthcare and AI**. Startup creation in the field of hardware and semiconductors for AI has been as dynamic in the EU27 as in the US. These startups are concentrated in Germany, France, Netherlands and Italy within the EU27.

3.1 Private equity and venture capital investment in the electronics industry

Within Europe, the average private investment deal size has been highest in Germany and France, followed by the Netherlands, Sweden and Spain in the period 2000-2019. Figure 8 displays the concentration of private investments among EU27 countries in the MNE field.

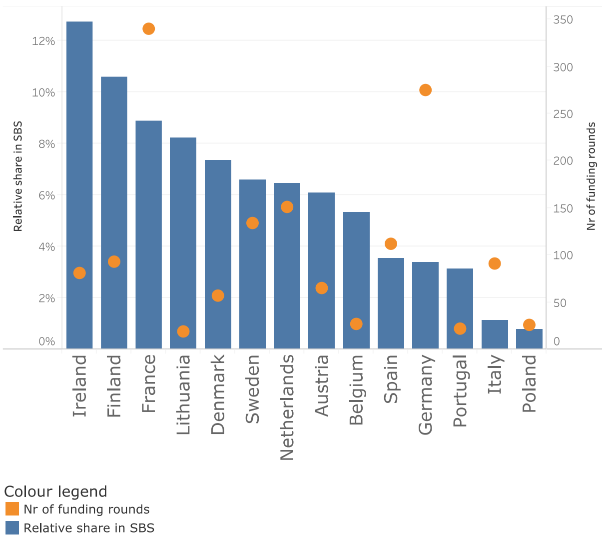
Figure 8: Concentration of MNE investments (2019)



Source: Technopolis Group based on Crunchbase and Dealroom data using geolytics map

If one takes the share of the number of investment transactions compared to the number of firms in the electronics industry, it can be observed that the relative number of investment-backed firms was actually highest in Ireland, Finland, France, Lithuania and Denmark (Figure 9). Lithuania has for example been focusing on complex automotive electronics components in its investment strategy for a while.

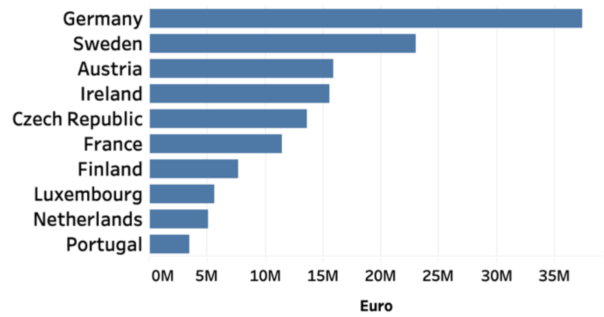
Figure 9: Number of funding rounds and share relative to the number of electronics companies in Structural Business Statistics (C26-27) (2019)



Source: Technopolis Group based on Crunchbase and Dealroom data

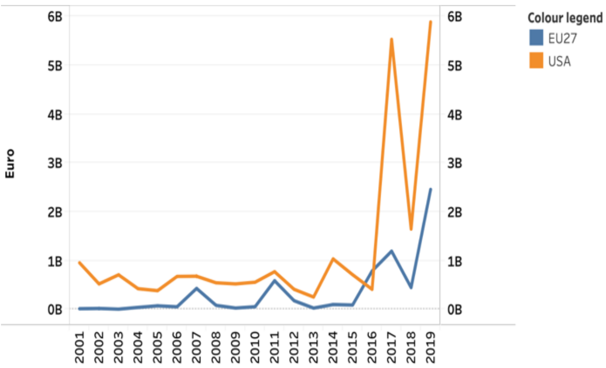
To provide further insights, the average private equity and venture capital investment – as outlined in Figure 10 – was highest in Germany, Sweden and Austria during the timeframe of 2000-2019.

Figure 10: Average private equity investment in Micro- and nanoelectronics (2000 – 2019)



Investment deals in Micro- and nanoelectronics by private investors, such as venture capital funds or corporate investors, have gradually been increasing since 2001. Nevertheless, the US has comparably been exposed to much higher funding values relative to EU27 (see Figure 11).

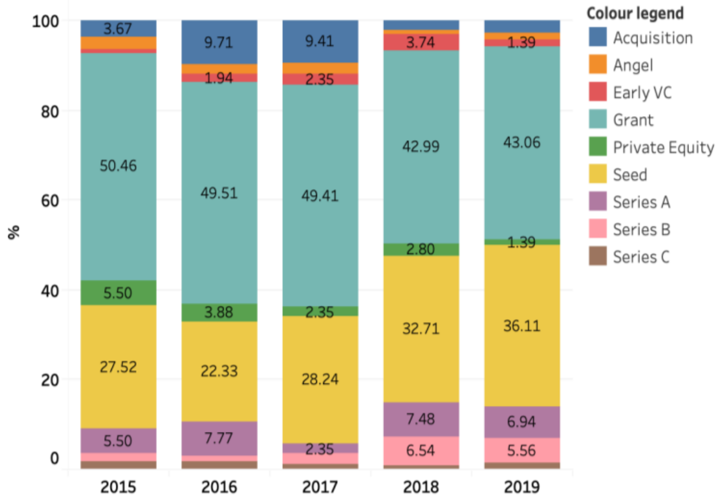
Figure 11: Last funding amount in international comparison (2001 – 2019)



Source: Technopolis Group based on Crunchbase and Dealroom data

Figure 12 shows the prominence of funding types in Micro- and nanoelectronics during the last decade. Funding included various types and series and witnessed an increase in seed financing (from 2015 onwards) in particular. There is, however, a lack of growth funding which is a clear issue for Europe and results in foreign firms buying up innovative European businesses.

Figure 12: Type of funding in MNE in EU27 (2015 – 2019)



Source: Technopolis Group based on Crunchbase and Dealroom data

The European electronics sector[26] also has a substantial presence of non-European investors: 54% of all assets of the sector are owned by non-EU investors. The share of foreign assets has increased in the electronics sector from 2007 to 2016, driven by strong growth rates in the manufacture of electrical equipment, which grew from 39% to nearly 63%, and in the manufacture of computer, electronic and optical products, which increased from 52% to 62% during the same timeframe. While the US in particular has made acquisitions regularly since 2007, China has increasingly emerged since 2015.[27]

The international comparison of funding trends (Figure 13) shows that US and Chinese electronics firms received more venture capital investment than the EU27. In terms of average amount of funding deals, the EU27 has smaller deals than the US, China and Japan.

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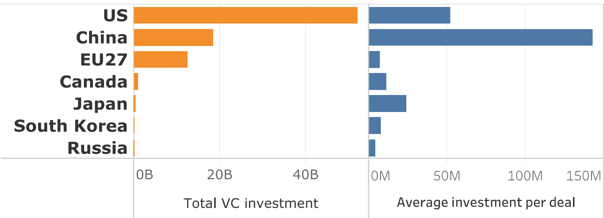
[26] The analysis is based on NACE codes: NACE 26 - Manufacture of computer, electronic and optical products and NACE 27 - Manufacture of electrical equipment.

[27] European Commission. (2019). *Commission Staff Working Document on Foreign Direct Investment in the EU*. Following up on the Commission Communication "Welcoming Foreign Direct Investment while Protecting Essential Interest" of September 2017. SWD(2019) 108 final. Retrieved December 2019, from trade.ec.europa.eu: https://trade.ec.europa.eu/doclib/docs/2019/march/tradoc_157724.pdf.

Figure 13: International comparison of total and average investments in electronics/MNE (2000 – 2019)

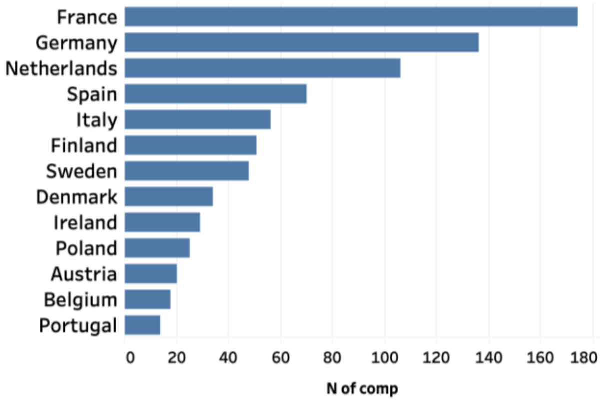


Source: Technopolis Group based on Crunchbase and Dealroom data

3.2 Startup/spinoff[28] creation: regional startup hubs and specialisations

From an entrepreneurship perspective, the major European startup hubs in the field of electronics are located in France (Paris), Germany (Munich), the Netherlands (Eindhoven, Delft), Spain (Barcelona, Madrid) and Italy (Milano) (Figure 14), which have the highest number of startups and spinoffs launched over the last decade in EU27.

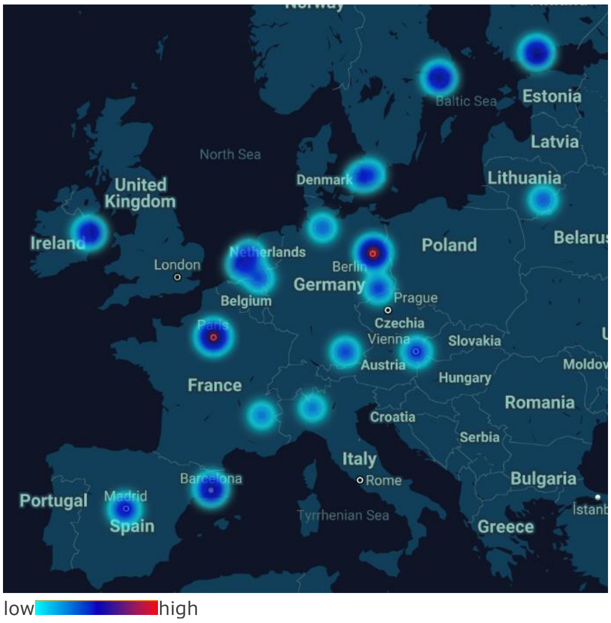
Figure 14: Startup creation in the electronics industry in Europe



Source: Technopolis analysis based on Crunchbase and Dealroom data

Zooming in at a city level (Figure 15), among the leading entrepreneurial locations in EU27 – measured according to significance in startups/spinoff creation – are Munich, Paris, Stockholm, Barcelona, Dublin, Madrid, Vienna and Delft.

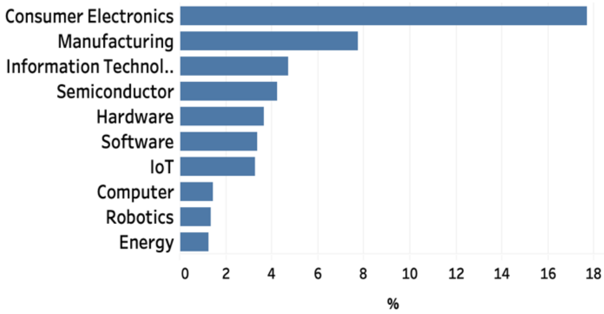
Figure 15: Key city startup hubs in Europe



Source: Technopolis analysis based on Crunchbase and Dealroom data using geolytics map

A significant share of startups in the electronics industry are specialised in consumer electronics, as outlined in Figure 16, which displays the specialisations among launched startups and spinoffs. Other specialisation areas of importance are manufacturing, IT, semiconductors, hardware, software and IoT.

Figure 16: Specialisation of startups in the electronics sector



Source: Technopolis analysis based on Crunchbase and Dealroom data

Startups in the EU that received the highest funding in the past three years are active in the areas of photonics and image sensors, batteries, automotive, mobility, healthcare and AI.

[28] For this section's analysis of startup and spinoff creation, startups are defined as established during the past 10 years. It implies that the visualisations of startup/spinoff creation are based on startups launched during the period of 2009 to 2019.

Startup creation in the field of hardware and semiconductors for AI has been concentrated in Germany, France, Netherlands and Italy within the EU27 (see Figure 17), although the largest investment deals were concluded in France.

71 startups in the US and 69 in the EU27 have been identified through the Crunchbase and Dealroom databases. These companies have been founded after 2005 and develop chips, hardware and any other semiconductor related product for artificial intelligence. EU startups focus more often on AI in the IoT (e.g. chips with microcontroller levels), while US counterparts on chips used in datacentres as observed from the list. The startups have been captured by analysing business descriptions and category labels, but a more thorough analysis would be necessary for deeper insights[29].

In the market there are 3 main application areas for AI accelerator chips:

1) Training machine learning models (e.g. Google Tensor Processing Units which support TensorFlow, and NVidia Graphics Processing Units for training).

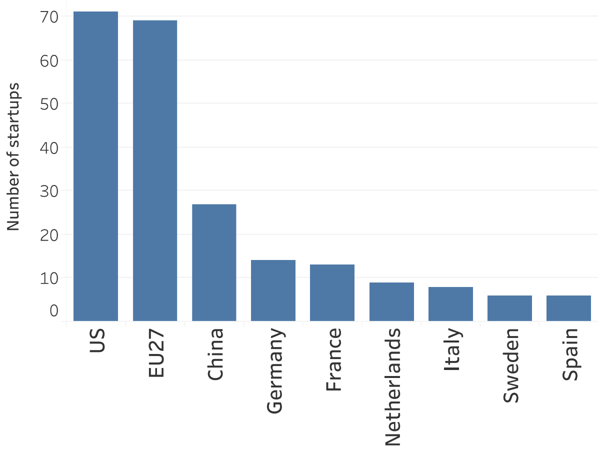
2) Inference on the cloud (e.g. Altera, Intel, Tencent are building chips for datacentres that are dealing with requests from apps that are being used by thousands of clients at the same time) - To develop such applications one needs field-programmable gate array (FPGA) technology to provide low latency streaming. Europe is not strong in this area since it does not have many FPGA manufacturers.

3) Inference at the edge – for example in smartphones, self-driving cars, drones, robots. This is where there are numerous startups and these are all producing application-specific integrated circuits targeting specific applications such as image processing. European startups are especially active in this field.

Examples of AI chip startups include the French 'Another Brain' that develops AI-enabled chips for autonomous learning; the Italian GreenWaves Technologies a fabless semiconductor firm that designs ultra-low power embedded solutions for image, sound and vibration AI processing in sensing devices; the German MatchX that manufacturers LPWAN + AI hardware and software, delivering IoT Edge AI solutions.

In the US, Cerebras is a computer systems company dedicated to accelerating deep learning by developing AI chips and a Wafer-Scale Engine (WSE). Kneron is another San Diego-based artificial intelligence chip maker.

Figure 17: Startup creation in the field of hardware and semiconductors for AI (2005-2019)



Source: Technopolis analysis based on Crunchbase and Dealroom data

[29] The startups have been captured within the category 'Artificial Intelligence', 'Semiconductor' and 'Electronics' of Crunchbase, with a keyword search for "chip";"hardware";"Graphcore";"semicon";"storage";"memory";"accelerator", respectively "deep learning"; "artificial intelligence"; "machine learning"; "natural language"; "AI" and further manual data checks.

4. Skills supply and demand

Key messages

Among the advanced technologies within the focus of this report, the **most dominant technological skill** of currently employed professionals in the electronics industry **relates to IoT,** followed by Cloud technologies, AI, Advanced Materials and Robotics. Nevertheless, the number of professionals with these skills is still relatively very low and there is a serious talent shortage in the industry.

The EU Member States with the highest share of professionals with specific technological skills in IoT, cloud technologies or artificial intelligence are **Germany, France, the Netherlands and Italy**.

In terms of the recent hires, the most relevant skills include engineering, programming, design, Matlab and Python, which reflects the need for **software development, data management and security,** all important drivers behind AI and IoT. In electronics design in particular, there is a strong demand for professionals with **analogue and digital circuit basics** skills.

The most sought-after skills by employers include **Big Data and AI, followed by Security**, Robotics and Cloud as captured through the analysis of job advertisements by electronics companies.

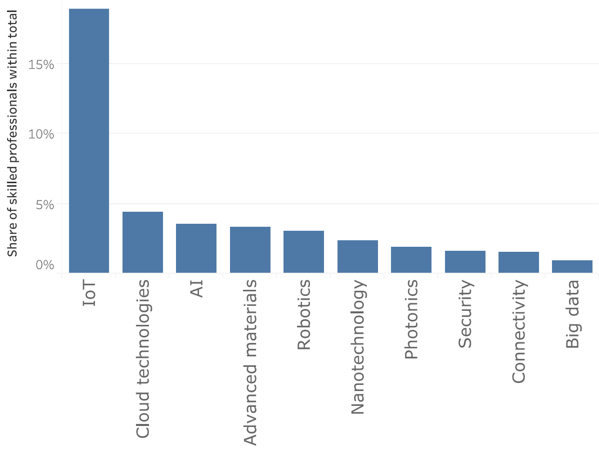
4.1 Supply of new technological skills - prominence of IoT

In this section, we present the findings of the analysis of skilled professionals as captured by LinkedIn. To harvest the data from LinkedIn, keywords capturing skills by advanced technology have been defined and queries have subsequently been constructed to filter the database by location and industry. Data have been captured in two data points (November and December 2019). The analysis has been conducted for the EU27, but we display the national figures only for those where the country data included enough observations.

Given the scale and speed of advances in electronics value chains, there is a strong need for a highly skilled workforce to underpin growth in industries and the take-up of technologies. As outlined in section 2, the electronics industry is confronted by numerous technology shifts, which bring both new opportunities and new challenges for the electronics industry in Europe to adapt to. From an advanced technology perspective, Figure 18 shows the distribution in the current supply of technological skills in the electrical and electronic manufacturing sector according to an analysis of LinkedIn[30] data.

Among the advanced technologies within the focus of this report, the most dominant technological skills (see Figure 18) relate especially to IoT, but also cloud technologies and AI, while Advanced Materials and Robotics are prominent too. In contrast, while IoT skills are also relatively important in the semiconductors sector, this is followed by skills relevant for Advanced Materials and Nanotechnology.

Figure 18: Share of professionals with technological skills in the electronics industry within total professionals as captured by LinkedIn, EU27, 2019



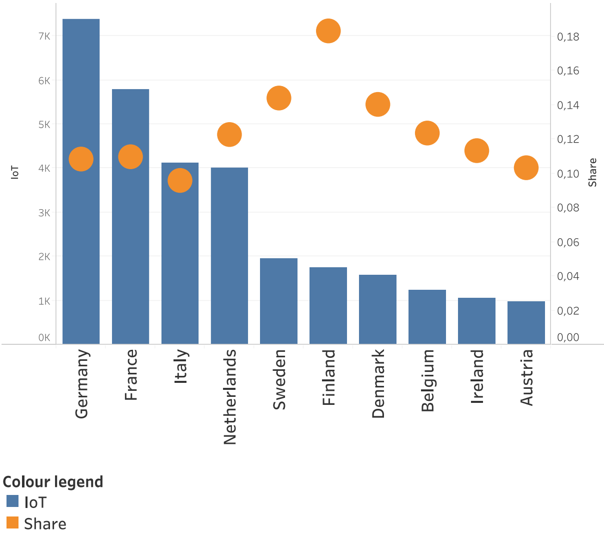
Source: Technopolis Group based on LinkedIn analysis

Figure 19 and 20 visualises the graphical concentration of two examples, notably IoT and AI

[30] To harvest the data from LinkedIn, keywords capturing skills by advanced technology have been defined and reviewed by technology experts. Queries have subsequently been constructed to filter the database by location and industry. Weights have been applied to account for the differences across countries in terms of the representativeness of the data.

skills in electrical and electronic manufacturing and semiconductors.

Figure 19: Number of professionals and share in total with IoT skills among top 10 EU countries (2019)



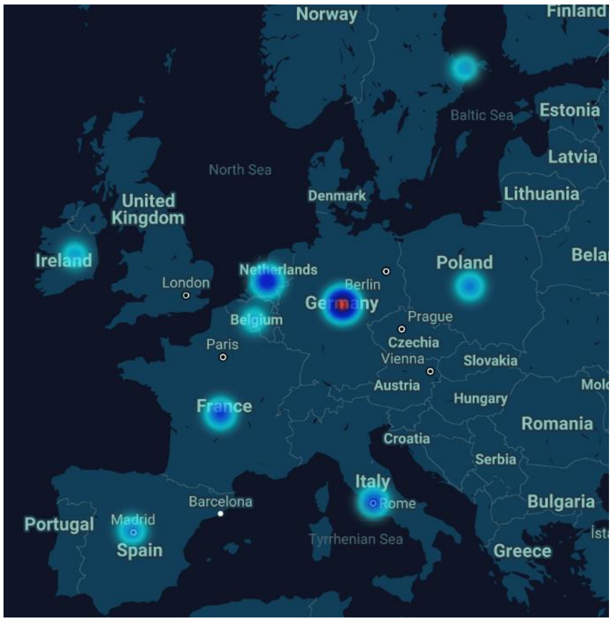
Source: Technopolis Group analysis based on LinkedIn

The top five EU Member States with the highest number of professionals with specific technological skills in IoT are Germany, France, Italy, the Netherlands and Sweden. Nevertheless, if one looks at the share of IoT skills within the total number of professionals, it is the Nordic countries at the top, namely Finland, Sweden and Denmark.

Focussing on the same supply figure for technological skills relevant for AI, the top five countries that possess the highest number of professionals are Germany, the Netherlands, France, Italy and Poland.

In terms of the share of AI professionals within the total number of electronics professionals, the ranking changes somewhat and results in Ireland, Germany, Poland, the Netherlands and Belgium being the top five.

Figure 20: Concentration of professionals with AI skills in the electronics industry in EU27



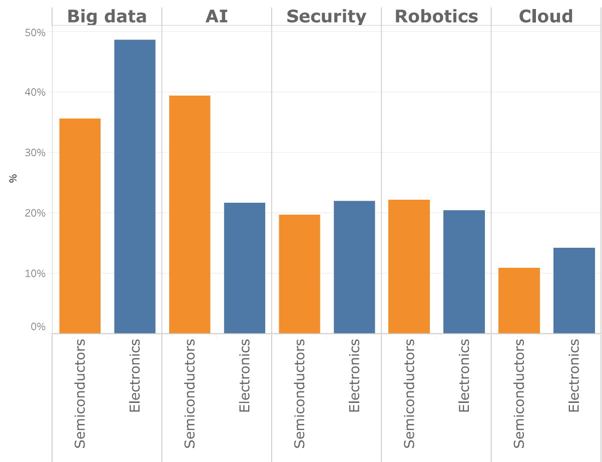
low high

Source: Technopolis Group based on LinkedIn analysis using geolytics map

4.2 Demand for new skills, especially big data and AI

Turning to the demand for new technological skills, the number of professionals with skills in Big Data witnessed the highest growth rate from 2018 to 2019 in the electrical and electronics manufacturing sector. In comparison, AI achieved the highest one-year growth rate in the field of semiconductors. Beyond Big Data and AI, also skills related to security, Robotics and Cloud technologies were also highly sought after by employers in electrical and electronics manufacturing and semiconductors in 2019. Figure 21 provides a mapping of high-growth skills areas for both electrical and electronics manufacturing and semiconductors.

Figure 21: One-year growth of top 5 skills (2018 – 2019)

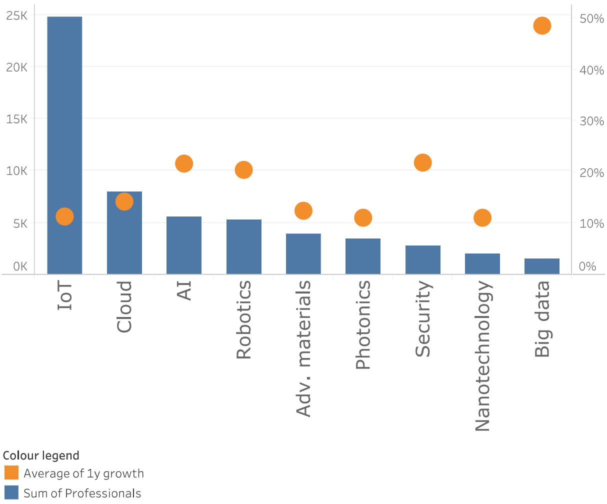


Source: Technopolis Group based on LinkedIn analysis

Although technological skills relevant for Big data faced the most notable growth from 2018 to 2019, the technology skills possessed by the largest number of EU27 professionals in the electronics industry are IoT, Cloud technologies and AI.

In the following figures, the 2018-2019 growth trends for technological skills are outlined for both electrical and electronics manufacturing (Figure 22) and semiconductors (Figure 23).

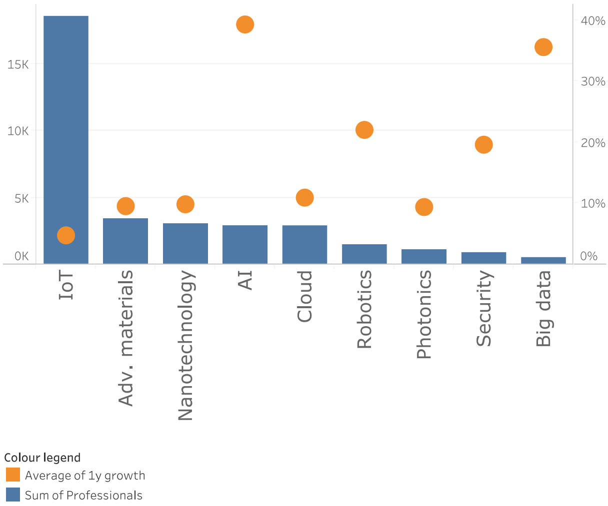
Figure 22: Number and growth rate of professionals with specific technological skills in electrical & electronic manufacturing (2019)



Source: Technopolis Group based on LinkedIn analysis

In the area of semiconductors (see Figure 23), beyond technological skills relevant for IoT, Advanced Materials and Nanotechnology also recur among employees, with respectively 10% and 9% of professionals having these skills.

Figure 23: Number and growth rate of professionals with specific technological skills in semiconductors (2019)



Source: Technopolis Group based on LinkedIn analysis

Besides the analysis of the technologies within the focus of this report, the skill demand by electronics industry firms hiring through LinkedIn has been also investigated using the skills taxonomy of LinkedIn.

In terms of the most recent hires by electronics firms in Europe, professionals possess skills such engineering, Java, C++, C, SQL, Software Development, Matlab and Python, which reflects the fact that there are some very specific skills needed for electronics in terms of analogue and digital design. Furthermore, the driver for AI and IoT is software data management and security skills. In electronics design in particular, there is a strong demand for professionals with analogue and digital circuit basic skills. Among technologically advanced countries with growing demand for system expertise in electronics (e.g. Germany), the demand for domain-specific knowledge combined with software or data analytics skills is, however, very difficult to meet.

5. Future outlook: challenges and opportunities

5.1 Technological advancements creating new demand

The preceding sections have emphasised how electronics is used in an increasingly broad range of settings and applications areas. Not only is the fast-paced electronics market faced by technology-intensive manufacturing activities and a growing complexity of electronics products, it is also becoming more and more exposed to price pressures and shorter innovation cycles. Furthermore, electronics and semiconductors are pervasive in many areas; on one hand the big drivers are IoT, big data and AI, while on the other hand it is electronics that provide the hardware and platforms to enable these technologies.

Digital transformation of the automotive, energy or medical industries is creating increasing demand for new types of electronics and electrical engineering such as for sensors and chips. Advanced manufacturing technologies and robotisation lead to the integration of ICT, mechanical and electrical engineering, opening business opportunities for the suppliers of hardware components to manufacturers[31]. In particular, IoT/IIoT is a driver of the electronics industry through the need for electronic components such as cabling for data or wireless interfaces. Although there are a wide range of new opportunities, innovative electronics companies will need to turn more towards high value-added services.

5.2 Data economy shaping new business models and the need for security

The data economy combined with software technologies generate both challenges for existing business models to adapt and opportunities for electronics companies to leverage data and value creation. Future business models are anticipated to have a dependency on data and data analytics as well as on delivering services based on data. The growth in data also induces a need for security and privacy. As shown in the analysis of skills demand, while skills related to big data and AI faced the highest growth rate from 2018 to 2019 by employers, it was followed by security. The protecting of critical and sensitive business and operational data is expected to drive cybersecurity spending among electronics companies.[32]

5.3 High investment needs

While technology advances and the data economy creates new demand and business opportunities, the semiconductor industry is also among the most R&D intensive industries. Industry-wide investment rates in R&D&I and production equipment are in the region of 15-20% of sales[33]. This induces high investment needs for companies and countries in order to keep up with the global competition. In addition, new production technologies to maintain Moore's Law and to increase the wafer size further requires additional investments; for instance, the cost of a new foundry reached approx. €12.5 bn in 2015[34]. European companies in the microelectronics sector however perform strongly on investments in R&D, also powered by public funding for basic research, including the existence of research technology organisations (IMEC, Fraunhofer and CEA-Leti among others) with excellence in R&D and in numerous technologies.[35]

5.4 Fragmentation and internationalisation

The trend of fragmentation and internationalisation of the semiconductor value chain relates to different factors[36]: 1) a strive for cost reduction with the implication that production increasingly moves to countries with lower labour cost. 2) the migration of consumer good production to Asia tends to simultaneously also pull related semiconductor production to Asia. 3) the speed of technological advancement induces companies to focus on core competences. 4) the significant and increasing costs of building fabs limit the set of companies that can pay for building new factories. As a consequence of the fragmentation and internationalisation of the

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[31] https://www.cbi.eu/market-information/electronics-electrical-engineering/trends/

[32] IBM. (2019). *Electronics Industrial IoT Cybersecurity. As strong as its weakest link. Creating value, pursuing innovation, and optimizing operations*.

[33] SIA & Nathan Associates. (2017). *Beyond Border: The Global Semiconductor value chain*.

[34] Fraunhofer IMW. (2018). *Global Competition in Microelectronics Industry from A European Perspective: Technology, markets and implications for industrial policy* and Armasu, L. (2015). *Samsung's New 14 Billion Chip Plant To Manufacture DRAM, Processors in 2017*.

[35] European Commission. (2019). *Study on the Electronics Ecosystem – Overview, Developments and Europe's Position in the World. Final Report. SMART 2016/0007*.

[36] DTI. (2012). *Study on Internationalisation and Fragmentation of Value Chains and Security of Supply: Case study on semiconductors*. European Commission, DG Enterprise and Industry.

supply chain, European semiconductor producers have offshored their semiconductor factories outside the EU, also with an eye to focus on niche markets. Next to this, the significant decrease in market share for the production of consumer electronics for European companies, has lowered the incentives for semiconductor producers to make investments in technology fabs in the EU[37]. In order to address fragmentation, there is a need for coordinated support, which can be encouraged at EU-level.

5.5 Impact of future wireless technologies

Future wireless technologies (5G and 6G) will impact the electronics industry to a large extent. 5G technology will improve the ways internet-connected devices are used and enable new market opportunities. But the transition will require sizable infrastructure investments. The growth in data and IoT is foreseen to lead to a shift from cloud technologies to edge computing for industrial application domains, to thereby facilitate processing capacity at the edge closer to devices and reduce the amount of data being transferred into the cloud to be processed. Edge computing responds to the need for more real-time computing power at local level to thereby facilitate the functioning of IoT/IIoT devices.

5.6 Legislation driving new trends

The Green Deal together with environmental and security-related legislation shapes the demand patterns for certain electrical products. Several EU Directives have been issued in recent years that accelerate the development of renewable energy sources, including power electronics for electric vehicles and advanced sensors (e.g. impact processing for autonomous cars) and OLED lighting. Political measures are expected to continue driving power electronics and the share of electronics in automotive in the short and long term.

5.7 Need for upskilling

The employment growth forecast for Europe may not be substantial, and it is restricted by a significant skills gap hindering companies from taking advantage of the technologies available. It is also foreseen that traditional jobs will disappear leading to new job definitions (data management experts, AI specialists, etc). The METIS project[38] listed some main skill needs for the microelectronics sector, including the need to align VET provision and occupational profiles with emerging technologies (e.g. AI) and support SMEs in finding employees with skills to develop next generation solutions. Lastly, future engineers will likely also need to be versed in horizontal areas, such as ethics, privacy, energy management, etc.

[37] European Commission. (2019). *Study on the Electronics Ecosystem – Overview, Developments and Europe's Position in the World. Final Report. SMART 2016/0007*.

[38] METIS. (2020). *The Challenge*. Retrieved April 2020, from metis4skills.eu: http://www.metis4skills.eu/the-challenge

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https://www.cbi.eu/market-information/electronics-electrical-engineering/trends/

About the 'Advanced Technologies for Industry' project

This report has been prepared in the framework of the Advanced Technologies for Industry (ATI) project, initiated by the European Commission, Directorate General for Internal Market, Industry, Entrepreneurship and SMEs and the Executive Agency for Small and Medium-sized Enterprises.

The EU's industrial policy strategy promotes the creation of a competitive European industry. In order to properly support the implementation of policies and initiatives, a systematic monitoring of technological trends and reliable, up-to-date data on advanced technologies is needed. To this end, the Advanced Technologies for Industry (ATI) project has been set up. The project provides policymakers, industry representatives and academia with:

- Statistical data on the production and use of advanced technologies including enabling conditions such as skills, investment or entrepreneurship;
- Analytical reports such as on technological trends, sectoral insights and products;
- Analysis of industrial value chains and policy needs;
- Analysis of technological trends in competing economies such as in the US, China or Japan;
- Access to technology centres and innovation hubs across EU countries and city mapping.

You may find more information about the 16 technologies here: https://ati.ec.europa.eu.

The project is undertaken on behalf of the European Commission, Directorate General for Internal Market, Industry, Entrepreneurship and SMEs and the Executive Agency for Small and Medium-sized Enterprises (EASME) by IDC, Technopolis Group, Capgemini, Fraunhofer, IDEA Consult and NESTA.

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