Monitoring the twin transition of industrial ecosystems

ELECTRONICS

Analytical report

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Executive summary

Innovative electronics and the electronics industrial ecosystem have a high relevance in the context of the digital and green transition. Electronics is a central underlying technology for digitisation and also plays a significant role in enabling our society and economy to become more environmentally sustainable.

Recently, there has been a significant increase in demand for electronics and semiconductors due to the advancement of digitalisation, automation, and the widespread use of e-mobility. The semiconductor market grew by 9% in 2020 and by more than 25% to about €470 bn in 2021. Europe's contribution to the global semiconductor industry accounts for a share of 9.3%, providing technologies largely at mature nodes. The EU is a powerhouse of advanced manufacturing equipment for the semiconductor industry. In terms of broader electronics technology, the EU is competitive in the electronics for the automotive industry producing ca. 27% of the global automotive electronics, industrial electronics contributing 20% to the global market, and green energy and power electronics. The EU produces 22% of the global aeronautics/defence and security electronics and 19% of the health & care electronics. Europe's strength lies especially in complex, embedded electronics systems and specialised electronics systems. However, the EU has significant weaknesses in design of advanced technologies. Also, the EU has a weaker position in the stand alone and consumer electronics segment.

The electronics industrial ecosystem is characterised by extreme regional specialisation and strong interdependencies throughout the value chain, putting supply at risk in case of disruptions. The EU is increasingly dependent on semiconductors and chips produced in other regions of the world – especially those used for communication electronics, data-processing and computing, including processors.

Large scale production capability and investments in advanced technologies play an important role for the competitiveness of the semiconductor and the electronics industry as a whole. The EU lost a large volume of its production capacities during last decades and needs to mobilise a lot of resources to expand its advanced production capacity. However, there are many competitive small and medium-sized enterprises (SMEs) in the EU that offer specialised electronics for various applications.

The present research on the twin - green and digital - transition of the electronics industrial ecosystem has shown that the EU27 is lagging behind and losing further ground to China and the USA in related technological developments. Tech startups play an important role in providing innovative technologies that drive digital and green transition. Although the EU27 becomes an increasingly important location for electronics tech startups, it remains well behind the USA and China.

Key findings about the green transition

Although some established and new players are taking on new sustainability approaches and business models, the green transition of the EU27 electronics industrial ecosystem is still in its nascent phase. In fact, patent statistics in the field of electronics do not demonstrate a distinct shift towards a green transition. Within this category, there are particularly high dynamics in the development of electronics for solar energy. Some noticeable developments are shown in the field of electronics related to advanced sustainable materials and batteries. According to the survey on the status in the uptake of digital and green technologies in SMEs operating in the electronics ecosystem, recently conducted within the project, only 23% of SMEs have increased investments in green transition and environmental sustainability during the last five years. From these companies, the majority have invested less than 5% of their revenue in green technologies. From all green technologies, the highest adoption by SMEs had energy-saving technologies (14%), renewable energies (12.5%), recycled materials (12.1%), and recycling technologies (11%). Recycled materials were indicated as the most attractive area for future investments. Only 5.1% of all SMEs have adopted the circular design business model.

LinkedIn data indicates that only 9% of electronics professionals have skills relevant for the green transition. Moreover, tertiary graduates in environmental protection technologies make up a very small fraction of the total number of all tertiary graduates varying between 1.4% and 0.1% across EU countries.

Semiconductor manufacturing consumes large volume of natural resources and generates harmful emissions. The electronics industrial ecosystem is responsible for 1% of the total material extraction and for 2.3% of damage to the natural environment caused by all industrial ecosystems, while contributing 1.5% to all industries' total GHG emissions. A lot of sustainability risks are linked to the complexity of the value chain and the limited transparency between players. The consumption of resources and environmental footprint is going to further increase when the production will be ramped up and the chip structure is getting smaller.

A lot of progress has been already achieved through the enforcement of the regulatory framework at the EU, national, regional and local levels. Many companies operating in the electronics ecosystem have made self-commitments to reduce their environmental footprint. A large number of companies relies on sourcing renewable energy and invests in technologies to reduce resource consumption and pollution. North European and Scandinavian countries particularly stand out in building an ecosystem that supports the green transition within the electronics industrial ecosystem.

Key findings about the digital transition

Technologies, such as, augmented and virtual reality, quantum computing, Internet of Things and artificial intelligence (AI) have seen considerable growth within the electronics ecosystem over the period from 2017-2020. A closer look at the technological activities of EU startups reveals a high relevance of sensor and Internet of Things technologies, followed by Integrated Circuit technologies and Artificial Intelligence.

The digital transformation of the companies operating in the electronics industrial ecosystem is at a more advanced stage: according to the survey, 40% of SMEs in the EU27 had increased their investments dedicated to digital technologies over the past five years. Among digital technologies most frequently adopted by SMEs are: cloud technologies (20.6%), online platforms (17.2%), Big Data (11.4%), robotics (10.7%) and AVR (9.6%), whereas Artificial Intelligence has a low uptake of 6%. Digital technologies that companies most frequently plan to adopt are: IoT (6.1%), Big Data (5.9%), and robotics (5.6%). Only 3.9% plan to implement the AI technologies.

Fuelled by public support in major regions, investments in electronics industry considerably increased in recent years. However, compared to the USA, South Korea and Taiwan, the EU27 has undertaken significantly less investment. Investments flowing into electronics startups primarily aim at advanced technologies, such as artificial intelligence, quantum computing and robotics. In line with the global trend, EU tech companies focusing on integrated circuit related and sensor technologies have attracted the largest investments so far.

Across the EU27, the demand for skills that underpin digital transition within the electronics industrial ecosystem is huge. At the same time, the number of students successfully completing degree programmes relevant for the development of advanced industrial electronics ecosystem is declining in many EU countries. Critical job profiles that are the most sought after and difficult to fill are software and design engineers, data scientists and cybersecurity experts. At the same time, there is an increasing shortage of professionals in the electronics production environment and automation. In terms of skills needed, machine learning and AI, data analysis, systems design and system architectures, digital and software skills as well as knowledge of new materials are most critical. The LinkedIn analysis revealed the highest recent growth for computer-aided manufacturing, IoT, machine learning, AI, data analytics and design thinking skills.

1. Introduction

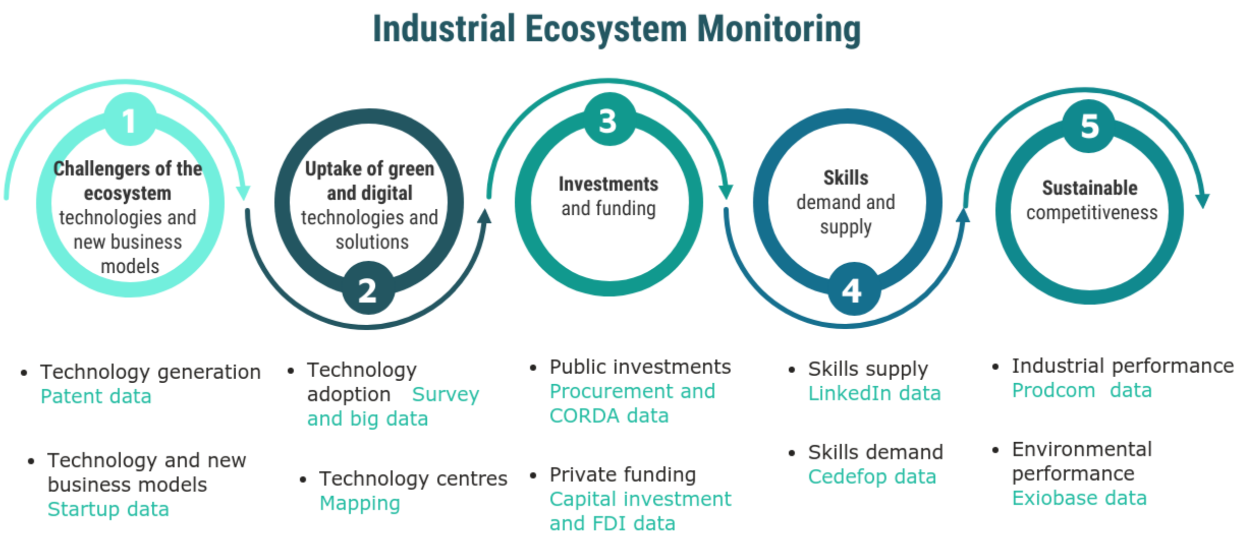
1.1. Objectives

This report has been prepared within the '**European Monitor of Industrial Ecosystems' (EMI)** project, initiated by the European Commission, Directorate General for Internal Market, Industry, Entrepreneurship and SMEs and the European Innovation Council and SMEs Executive Agency (EISMEA). The overall objective of the project is to **contribute to the analysis of the green and digital transformation of industrial ecosystems** and progress made over time.

The EU's updated industrial strategy[1] has identified 14 industrial ecosystems[2] – one of them being **'Electronics'** - that is in the focus of this report. The industrial strategy defined industrial ecosystems as encompassing all players operating in a value chain: from the smallest startups to the largest companies, from academia to research, service providers to suppliers. The notion of ecosystems captures the complex set of interlinkages and interdependencies among sectors and firms across the EU. Industrial transition is driven by technological, economic, and social changes, and in particular by green and digital technologies and the shift to the circular economy. The process is however characterised by complex, multi-level, and dynamic development. To make transition sustainable, technological change needs to be coupled with new business models, the necessary investments, skills, regulatory framework conditions and behavioural change across the ecosystem.

Measuring performance and change is vital to allow policymakers and industry stakeholders to track progress over time and get feedback whether the system is moving in the desired direction. To measure performance, a dedicated **monitoring and indicator framework** has been set up for the purposes of this project with an aim to capture them in regular intervals (see the overview of the monitoring framework in Figure 1).

Figure 1: Overview of monitoring industrial ecosystems and relevant data sources



Source: Technopolis Group, IDEA Consult and Fraunhofer ISI

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[1] European Commission (2020). A New Industrial Strategy for Europe, COM/2020/102 final and European Commission (2021). Updating the 2020 New Industrial Strategy: Building a stronger Single Market for Europe's recovery, COM(2021) 350 final

[2] The 14 industrial ecosystems include: construction, digital industries, health, agri-food, renewables, energy intensive industries, transport and automotive, electronics, textile, aerospace and defense, cultural and creative culture industries, tourism, proximity and social economy, and retail

The indicator framework includes a **set of traditional and novel data sources that allow shedding new light on ongoing transformation patterns.** The novelty of the analysis lies in the exploratory and innovative data sources used across the different chapters. Due to its effort to analyse industrial ecosystems using a more or less standardised set of indicators, the study cannot address all aspects of the green and digital transition. Therefore, additional analysis and industry-specific data sources should be used to supplement a full assessment.

The **methodological report** that sets the conceptual basis and explains the technical details of each indicator is found in a separate document uploaded on the EMI website. Moreover, some of the specific industry codes used throughout this analysis have been also included in Appendix B. The green and digital technologies considered in this study are presented in Figure 2.

Figure 2: Main technologies monitored in the project

Green transformation
Advanced Sustainable Materials
Biotechnology
Energy Saving technologies
Clean Production technologies
Renewable Energy technologies
Solar Power
Wind Power
Other (geothermal, hydropower, biomass)
Recycling technologies
Circular business models

Digital transformation
Advanced Manufacturing & Robotics
Advanced Manufacturing
Robotics
Artificial Intelligence
Augmented and Virtual Reality
Big Data
Cloud technologies
Blockchain
Digital Security & Networks/ Cybersecurity
Internet of Things
Micro- and Nanoelectronics & Photonics
Online platforms

Source: Technopolis Group, IDEA Consult and Fraunhofer ISI

This report contributes to the analysis of the **key pillars put forward in the 'Blueprint for the development of transition pathways'**[3] of the Industrial Forum developed in 2022.

1.2. Definitions

The major goal of this study is to explore the digital and green transition of the EU's electronics industrial ecosystem. The electronics industrial ecosystem represents a system of players, horizontal and vertical links among them as well as framework conditions that support its functioning. According to the definition in the Annual Single Market Report[4], the electronics ecosystem encompasses activities described in the statistical classification of economic activities NACE rev.2[5] as Manufacture of computer, electronic and electrical products (C26), Manufacture of machinery and equipment (C28) and related services. However, the established statistical classification is no longer accurate, as companies in electronics operate across different industrial sectors and can be used only as proxies. All data calculations performed in this study adhered to the definition outlined in the Annual Single Market Report. The electronics ecosystem encompasses a broad area of activities relevant for the development, manufacturing and using all kinds of electronic devices. These span resources and materials, electronic components, electronic boards, stand alone

[3] https://ec.europa.eu/docsroom/documents/49407/attachments/1/translations/en/renditions/native
[4] https://commission.europa.eu/system/files/2021-05/swd-annual-single-market-report-2021_en.pdf
[5] https://ec.europa.eu/eurostat/documents/3859598/5902521/KS-RA-07-015-EN.PDF

and embedded electronics to the broad range of services that support the development and deployment of electronics in different application fields.[6] For the purpose of this study and report, we focus on the 'electronics industrial ecosystem' using this and the definition outlined in the Annual Single Market Report.

Semiconductors, often referred to as chips or microchips[7], are an essential component of electronic devices and a critical technology for modern economies and industries. As major underpinning electronics technology deployed in wide areas of applications, they represent one important technological and industrial focus of this report. Further highly relevant technological field is linked to the term "microelectronics", i.e. the design and fabrication of small structure electronics, such as microprocessors, which can be integrated into electronic circuits. Other microelectronic technologies include sensors, actuators, and memory devices, used in a wide range of applications. Quantum technology is another technological area considered in the context of the electronics ecosystem, as quantum technologies are largely based on electronic components.

1.3. Industrial ecosystem state of play

With the advancement of digitalisation, automation and the proliferation of e-mobility, demand for electronics and semiconductors have boomed recently. The semiconductor market grew by 9% in 2020 and by more than 25% to about €470 bn in 2021.[8] EU27 contribution to the global semiconductor industry was around € 51 bn in 2022 accounting for a world share of 9.3%, which is well below its economic potential.[9] At the same time the EU consumes ca. 20% of the global semiconductor supply, which is set to rise further in the future. In 2022, the global semiconductor market grew by 3.2%, primarily due to the geopolitical crisis and inflation dynamics. Nevertheless, the growth in the EU27 remained double-digit (12.3% in 2022, compared to 27.3% in 2021).[10]

The global semiconductor market for technology fields, essential for digitalisation, such as connectivity (5G/6G), cloud & edge computing, data centres, artificial intelligence, high-performance computing together with personal computer and consumer electronics currently account for more than 75% of the total turnover. However, the EU is largely underrepresented in these technology fields.[11] Continuous increase in the trade for leading edge chips - chips with nodes of 5 nm, 3 nm and beyond - are driven by requirements of advanced technologies, such as artificial intelligence, quantum sensors, or 5G/6G,[12] essential for technological leadership and sovereignty of the EU.

Across the industry, an average revenue growth of 6 to 10% is expected up to 2030. Due to the foreseeable rapid expansion in chips applications, the market for semiconductors is projected to reach the value of around €1 trillion by 2030.[13] About 70% of the total growth is predicted to be driven by three industries: automotive, computation & data storage, and wireless.[14] The strongest-growing segment with a CAGR of about 13% (Figure 3) is going to be automotive semiconductors, fuelled by autonomous driving and e-mobility, boosting its share to 20% in the total semiconductor industry by 2030. The computation and data-storage market is expected to reach a CAGR of 4% to 6%. In the wireless segment, smartphones and 5G would account for the majority of expansion.[15]

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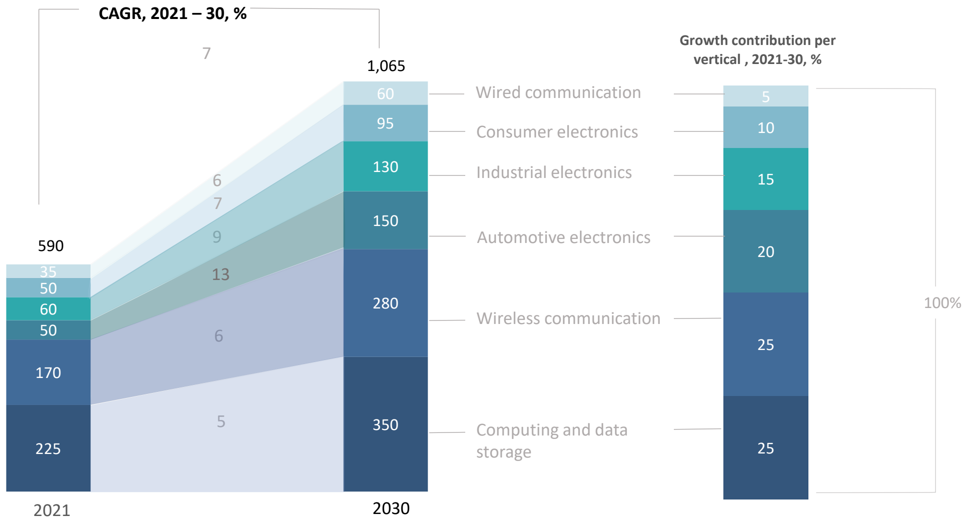
[6] Coulon 2020. Study on the Electronics Ecosystem. European Commission.
[7] Following the definition of OECD, the terms "semiconductors", "integrated circuits (IC)" and "chips" are used interchangeably (OECD 2019), although technically ICs can be understood as a subset of semiconductors. In this report they are sometimes used interchangeably, as many reviewed literature sources used as references in the report also used the terms interchangeably. The industry commonly refers to two broad categories of semiconductors: integrated circuits (ICs), and OSDs: optoelectronics, sensors, and discrete semiconductors.
[8] ESIA 2022: https://www.eusemiconductors.eu/sites/default/files/ESIA_WSTS_AutumnForecast2022.pdf ESIA 2022.
[9] ESIA 2022: https://www.eusemiconductors.eu/sites/default/files/ESIA_WSTS_AutumnForecast2022.pdf
[10] https://www.eusemiconductors.eu/sites/default/files/ESIA_WSTS_PR_2212.pdf
[11] Bitcom 2022. Development of the German and European semiconductor ecosystem. Position Paper.
[12] VDMA 2022. Policy Brief. VDMA 2022.
[13] ESPAS 2022. Global Semiconductor Trends and the Future of EU Chip Capabilities.
[14] McKinsey & Company 2022. The semiconductor decade: A trillion-dollar industry.
[15] McKinsey & Company 2022a. The semiconductor decade: A trillion-dollar industry.

Figure 3: Global semiconductor market value by application fields, indicative, in US$ bn



Source: (McKinsey & Company 2022a)[16]

Global players, such as Bosch, STMicroelectronics, NXP, Intel, Global Foundries, Infineon, Micron, and Osram[17] have R&D and manufacturing operations in Europe. German companies Merck and BASF have significant market shares in supplying advanced chemicals and wafers for semiconductor production.[18] Moreover, the EU has a strong position in developing and making machines for the production of semiconductor components. The Netherlands based company ASML is the largest manufacturer of photolithographic machines essential to semiconductor manufacturing.[19] Further examples are SOITEC - a key player in Silicon On Insulator (SOI) wafers, M+W and Aixtron - a world leaders in advanced tools and technologies, or RECIF - provider of robotic wafer handling technologies.[20] European semiconductor R&D from both industry and academia, is globally highly competitive. Fraunhofer Gesellschaft, IMEC, and CEA-Leti - just to name a few - are among the word class R&D institutions that contribute to the value creation of the semiconductor and electronics industry. However, there are still shortcomings in the EU in the area of transfer and translation of research results into industrial application. What's more, many of the EU innovations are taken up in other parts of the world.[21]

The EU has a good chance to excel in advanced technology called Fully Depleted Silicon On Insulator (FDSOI), highly relevant in the context of digital and green transition. FDSOI is an advanced processing technology for the production of energy-saving while more advanced and powerful transistors. CEA, Soitec, GlobalFoundries and STMicroelectronics are working together to realise the industry's next generation FDSOI fit for structure size of 10 nm, opening further opportunities for higher energy efficiency, yet more compact and powerful technologies. Currently, the STMicroelectronics fab in Crolles in France uses FDSOI manufacturing at 28nm while Globalfroundries in Dresden produces structure sizes of 22 nm for the technology, also used by STMicroelectronics.[22]

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[16] McKinsey & Company 2022a. The semiconductor decade: A trillion-dollar industry
[17] The list is not exhaustive.
[18] ESPAS 2022. Global Semiconductor Trends and the Future of EU Chip Capabilities.
[19] https://www.eetimes.eu/electronics-in-europe-dead-dying-or-reviving/
[20] Coulon, Oliver et al. 2020. Study on the Electronics Ecosystem. European Commission.
[21] European Commission 2022. A Chips Act for Europe.
[22] https://www.elektronikpraxis.de/fd-soi-europaeische-allianz-strebt-naechste-generation-fuer-stromspar-chips-an-a-1110387/

In terms of broader electronics technology, the EU is highly competitive in the electronics for the automotive industry producing ca. 27% of the global automotive electronics and industrial electronics contributing 20% to the global market.[23] The EU produces 22% of the global aeronautics/defence and security electronics and 19% of the global health & care electronics[24]. Europe's strength lies especially in complex, embedded electronics systems and specialised electronics systems used in vehicles, aircraft, automated industry and medical technology.[25]

Europe has a very strong position in power electronics, microelectromechanical systems (MEMS) and sensors for broad application fields, considered as a large asset to mitigate the risks of technological dependency.[26] Sensors in combination with AI are important technologies for smart automation, as they allow robots and automated machines to learn and adopt to perform different tasks. They also enable collaborative work of robots alongside human workers, which opens new opportunity for efficiency gains. Many companies in the EU have a leading position in the development and production of "more than Moore" technologies.[27] However, the EU has significant weaknesses in design, in particular, in processors.[28] Also the EU has a weak position in the stand alone and consumer electronics segment. Overall, the EU's share in the global production of electronic systems has been continuously declining in the last decade.

The semiconductor industry relies on massive capital investments and large scale production to remain competitive. The fast technology evolution and the necessity to invest in very costly new equipment to be able to fabricate next generation electronics makes its manufacture heavily capital intensive and highly concentrated. However, SMEs have a strong part in the EU, especially in areas, such as circuit design and integration, photonics, sensor technologies and electronics industry equipment. Many SMEs in the EU countries are globally highly competitive providing speciality electronics for a variety of applications. The demand for application-specific microelectronics products is particularly high for industrial, medical and automotive industries. These products are usually produced and sold in small quantities, making their manufacturing economically unattractive for large companies. Young companies and start-ups developing and experimenting with new technologies and business models also constitute an important part of the ecosystem. Small and innovative companies contribute to and drive the green and digital transition providing the necessary technologies.

With the European Chips Act in 2021 the EU has launched a number of initiatives that aim at strengthening the region's position as a technological leader and advanced production site in the semiconductor industry while becoming more resilient from external shocks. Further important goal of the Chips Act is to promote the digital and green transition throughout relevant technologies and applications. To achieve these goals, the Act is going to mobilise more than € 43 billion of private and public investments by 2030. The funding is accompanied by policies and measures to establish the necessary framework conditions. Many global players, such as TSMC, Intel, Infineon, Globalfoundries, Broadcom, Bosch, and STMicroelectronics have announced plans to invest across the EU. Since the announcement of the EU Chips Act, the EU has attracted over € 90 billion investment in the semiconductor sector (as of September 2023).

1.4. Complexity of the value chain: Status Quo

This section provides an overview of the complexity of the semiconductor value chain in terms of activities and interdependencies as well as the positioning of the EU in it.

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[23] Coulon, Oliver et al. 2020. Study on the Electronics Ecosystem. European Commission. Coulon 2020.
[24]Coulon, Oliver et al. 2020. Study on the Electronics Ecosystem. European Commission.
[25] ZVEI 2021. Semiconductor Strategy for Germany and Europe. The current situation, analysis, and goals. .
[26] https://www.eetimes.eu/why-mems-and-sensors-are-importaGlobal nt-in-europe/
[27] Bitcom 2022. Development of the German and European semiconductor ecosystem. Position Paper.
[28] European Commission 2022. A Chips Act for Europe.

The value chain of semiconductors can be divided into three major stages: 1) Design, 2) Front-End Fabrication, and 3) Assembling, Testing and Packaging. All stages rely on upstream inputs, such as supply of raw materials and machinery. For all three stages the R&D is highly relevant. The established value chain of semiconductor industry is the result of the regional specialisation and economies of scale. As such it, is highly fragmented and concentrated. The value chain involves a complex network of suppliers across the globe.

1.4.1. Raw materials

The semiconductor industry relies on a variety of raw materials, such as Silicon, rare earth elements, Platinum group metals, Gallium, and Germanium. The EU is the net importer of metals for the production of semiconductors.[29] Along with the basic raw material Silicon, the industry increasingly deploys new materials, such as Gallium Nitride and Silicon Carbide. China accounts for 71% of global Silicon production and 98% of global Gallium. The EU imported in 2020 only 11% of its Silicon and 27% of Gallium from China. The majority of these basic materials can be sourced from within Europe.[30] Further resources required for the fabrication of semiconductors are chemicals and inert gases, such as neon, of which Ukraine has been a major supplier. So, the EU relies on raw materials, which are subject to geopolitical or other risks, including sustainability and environmental impact related risks.

The EU is home to some leading suppliers of specialist materials and chemicals broadly used in the semiconductor industry, such as Siltronic, SOITEC, BASF, Linde, Merck and Air Liquide.

1.4.2. R&D and design

The EU is among major regions with the highest relative investment rates in R&D of the semiconductor sector. Yet the worldwide largest funders in absolute terms are not from the EU. Those involve companies like Intel (US), Samsung (South Korea), Broadcom (US), NVIDIA (US), TSMC (Taiwan), SK Hynix (South Korea), Micron (US), and AMD (US).

Design represents nearly 30% of the total value of the semiconductor value chain. Companies that focus on the design of semiconductors are called "fabless". The global fabless market grew significantly in the last decades. The most successful fabless firms are from the USA and Taiwan. Chinese global share of fabless companies accounts for ca. 15%. The EU's capacity to design decreased heavily in the last decades. Its global share declined from 4% to 1% in the last ten years. The USA is currently the market leader in semiconductor design accounting for 68% of the global total. In the EU27, the capabilities in leading-edge design is largely missing. The EU companies mostly use IPs of US origin.[31] Moreover, the sustainability of semiconductors is formulated at the design stage. Therefore, limited design capacities of the EU is of great concern and has negative impact on the green and digital transition of the region.

1.4.3. Machinery and equipment

The EU as a whole has a strong position in the supply of advanced and cost intensive manufacturing equipment for the semiconductor industry. Its share in the global market accounts for 21%. The Dutch company ASML has over 60% market share of the equipment used for deep ultraviolet lithography (DUV) and 100% in extreme ultraviolet (EUV) lithography market, which is a key technology in advanced node manufacturing.[32]

[29] Ciani and Nardo 2022. The position of the EU in the semiconductor value chain: evidence on trade, foreign acquisitions, and ownership. European Commission.
[30] Council of the European Union 2022. The semiconductor ecosystem. Global features and Europe's position.
[31] European Commission 2022. A Chips Act for Europe.
[32] https://www2.deloitte.com/xe/en/insights/industry/technology/semiconductor-chip-shortage-supply-chain.html

1.4.4. Front-end fabrication

Companies that perform large scale manufacturing of semiconductors are called foundries. The largest foundries focusing on the production of advanced semiconductors are TSMC (Taiwan), Globalfoundries (US), UMC (Taiwan), and Samsung (South Korea). About 75% of global semiconductor manufacturing capacity is concentrated in East Asia and 100% of the world's most advanced semiconductor manufacturing capacity is currently located in Taiwan (92%) and South Korea (8%).[33] In the EU27, there are over 50 semiconductor fabs located in many different member states, including Germany, France, Ireland, Italy, Austria, Netherlands, Belgium, Hungary, Czech Republic, and Sweden. Most of them produce at mature nodes on 150 mm and 200 mm wafers; only a limited number of fabs located in the EU have the capacity to produce at smaller nodes, such as Intel in Leixlip (IE) (14 nm), GlobalFoundries in Dresden (DE) (22 nm), and STMicroelectronics in Crolles (F) (28 nm). The EU holds a market share of 7% in the global semiconductor manufacturing market.[34]

The integrated device manufactures (IDM) perform essential design and manufacturing steps in-house. The most notable IDMs are located in the US (e.g. Intel, Micron, Texas Instruments), South Korea (Samsung, SK Hynix) and Japan (Toshiba). Large IDMs, such as Intel and Samsung, offer foundry services to third-party semiconductor vendors.[35] In the EU, there is a number of smaller IDMs, such as STMicroelectronics (France-Italy), Infineon (Germany) and NXP (Netherlands).[36]

1.4.5. Assembly, packaging and testing

Being originally a largely labour intensive activity, the global market for assembly, testing, and packaging of semiconductors is largely concentrated in Asian countries - Taiwan, China, and low wage countries like Philippines, Malaysia, Vietnam. Currently, the EU share of the global assembly, packaging and testing market is ca. 5 %.[37]

1.5. Value chain interdependencies

The semiconductor industry has become increasingly consolidated within many of the value chain segments over the past 20 years. As a result, expertise and production capacities are highly concentrated in certain markets, which has created a web of interdependencies.[38] Production of end products often involves complex and numerous supply chain steps and long distance travels across the globe.[39] This results in not only significant supply risks, but also poses serious environmental challenges. Additionally, several ties of the supply chain are extremely concentrated, which means that customers are left with limited or no alternatives creating single points of failure in supply. For instance, TSMC in Taiwan and Samsung in South Korea are the only foundries capable of manufacturing the most advanced chips (at nodes below 5 nm). East Asia is also the most important region for back-end manufacturing (assembly, test and packaging).[40] For compound semiconductors, there is a strong dependence on the USA.[41] Currently, there are more than 50 points in the global semiconductor value chain representing potential single points of failure. They make up more than 65% of the global semiconductor market value.[42] With this, the current supply chain is far from being resilient.

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[33] https://www.semiconductors.org/strengthening-the-global-semiconductor-supply-chain-in-an-uncertain-era/
[34] https://www2.deloitte.com/xe/en/insights/industry/technology/semiconductor-chip-shortage-supply-chain.html
[35] OECD 2023. Measuring distortions in international markets. The semiconductor value chain.
[36] Council of the European Union 2022. The semiconductor ecosystem. Global features and Europe's position.
[37] https://www2.deloitte.com/xe/en/insights/industry/technology/semiconductor-chip-shortage-supply-chain.html
[38] McKinsey & Company 2022b. Strategies to lead in the semiconductor world.
[39] For instance, producing a single chip requires up to 1500 process steps. Some process steps during wafer fabrication, such as oxidation and coating, lithography, etching and doping, can be repeated hundreds of times, depending on the specific chip (European Commission 2022).
[40] European Commission 2022. A Chips Act for Europe.
[41] ZVEI 2021. Semiconductor Strategy for Germany and Europe. The current situation, analysis, and goals.
[42] European Commission 2022. A Chips Act for Europe.

Europe is increasingly dependent on semiconductors produced in other regions of the world – especially those used for communication electronics, data-processing and computing, including processors.[43] Important technological trends, such as autonomous driving, smart cities, and artificial intelligence, rely not only on advances in semiconductor technology and especially in the field leading edge technologies[44], but also on a stable supply chain. Supply chain analyses revealed that that EU companies in semiconductors are heavily dependent on suppliers and/or customers located outside the EU. A study of Ciani and Nardo 2022 found that around 80% of suppliers to European semiconductor firms are headquartered outside the EU.

1.6. Impact of recent crises

Since the beginning of the COVID-19 pandemic, the electronics ecosystem has been exposed to the prolonged crisis caused by component shortages. In 2021 there were severe supply chain disruptions in electronic components. Shortages have resulted from a combination of different factors: rapidly growing demand, long manufacturing cycles, supply inflexibility, temporary semiconductor factory closures, supply chain disruptions during the COVID-19 crisis, and geopolitical tensions.[45] This demonstrated the fragility of the supply chain and risks associated with increased dependencies of critical technologies and products on distant suppliers. With semiconductors being major technology across sectors and everyday activities in Europe, the supply crisis has had severe effects on economy and society. Uncertain trade dynamics motivated several players to increase their semiconductor stock levels, further magnifying the gap between supply and demand. The shortage was so concerning that it prompted some large technology companies and major automotive OEMs to move chip design in-house - a trend that could have major implications for the market.[46] Shortages of components have had dramatic implications in a number of economically and socially critical areas, such as medical devices, devices for broadband communications and components for the automotive sector, just to mention a few.[47]

Current Russian military aggression against Ukraine has severe economic implications, including the electronics industrial ecosystem. Ukraine is a major supplier of raw materials that are critical to semiconductor manufacturing: neon, palladium, C4F6 and inert gases required for the semiconductor lithography process. Disruptions in the supply of neon and other noble gases trigger shortages and cost increase. Another cost effect is associated with the rise in price and disruption in the supply of natural gas, used as a source of power within semiconductor manufacturing processes, and longer air freight routes, due to flight bans over Russia. Russia was an important exporter of metals widely used in electronics, like aluminium, nickel and copper. Shortage of these metals can have further impact on operating costs.[48]

Shortages are unlikely to dissolve in the near future particularly with view to rising demands in numerous application areas. Therefore, consistent strategies and measures are necessary to provide semiconductor supply security. At present, inflation poses an additional challenge. According to the recent survey of semiconductor industry representatives carried out by Accenture, considerations around semiconductor sovereignty and geopolitics will have the greatest impact on semiconductor innovation in the near future.[49]

[43] https://www.eetimes.eu/eu-signs-e145bn-declaration-to-develop-next-gen-processors-and-2nm-technology/
[44] "Leading edge" is most commonly referred to the most advanced technology nodes that allow the smallest structure sizes, currently of less than 5 nm. However, a lot of innovative semiconductor technologies critical to the ongoing and emerging technological trends include nodes larger than 5 nm. In this context, the concept of "leading edge" semiconductors can be extended to consider innovative semiconductor technologies with larger nodes critical to advance digital and green transitions (Bitcom 2022).
[45] ESPAS 2022. Global Semiconductor Trends and the Future of EU Chip Capabilities.
[46] McKinsey & Company 2022b. Strategies to lead in the semiconductor world.
[47] For example, supply chain disruptions and component shortages in the automotive electronics led to production cuts and laying off workers in the automotive industry across Europe (European Commission 2022).
[48] European Commission 2022. A Chips Act for Europe.
[49] Accenture 2023. The Pulse of the Semiconductor Industry. Balancing resilience with innovation.

2. Challengers of the industry: green and digital technological trends

Key findings

The electronics industrial ecosystem and the twin transition has a two-way relationship: innovative electronics underpins the digital and green transformation of other industries, and electronics takes advantage of digital and environmental technologies themselves.

The European Union is lagging behind and also losing further ground to China and the USA in terms of technological developments on many indicators:

- The *EU share in the world patent applications in fields related to the electronics industrial ecosystem decreased over time, whereas China constantly and massively increases its patenting activities* in the area dominating global technology development.
- A more detailed patent analysis reveals a strong upward trend in the total inventive electronics related activities of the EU27 linked to the digital transition. Nevertheless, *digital transformation and to some extent even the green transformation is dominated by the USA* related to electronics.
- The USA is the major region with the highest density of electronics tech startups linked to the twin transition. The *EU27 is an increasingly important location for electronics tech startups*, however, it is lagging behind USA and China, the latter taking over leadership.

Important digital and green technological trends that drive development in electronics are linked to various domains such as the **transition of energy systems, power supply, electric and autonomous mobility and batteries, advanced and intelligent automation coupled with sustainability requirements**. Technologies such as, **augmented and virtual reality** (metaverse), **quantum computing, Internet of Things and artificial intelligence (AI)** have seen considerable growth rates within the electronics ecosystem’s patent activities over the period from 2017-2020, indicating the contribution of electronics to these fields.

As part of the digital transition, a closer look at the technological activities of **EU startups reveals a high relevance of sensor and Internet of Things technologies, followed by Integrated Circuit technologies and Artificial Intelligence**.

The green transition within the EU electronics ecosystem is still at an early stage. Patent statistics in the field of electronics do not demonstrate a distinct shift towards a green transition. Within this category, there are particularly high dynamics in the development of **electronics for solar energy.** Much smaller, however notable, is the share of patenting activities in the field of electronics related to **advanced sustainable materials and batteries**. In the EU27, **startups play a key role in driving the green transition in electronics**. Also, some established players are taking on new sustainability approaches and business models. However, the transition to circular business models needs further efforts.

In recent years, there has been a steady growth of startups dealing with **recycling technologies and new recycling management strategies, advanced materials as well as printed and organic electronics.** This development indicates a growing relevance of green technologies.

Across the EU27, Germany, France, and the Netherlands accommodate the largest number of startups operating in the electronics industrial ecosystem linked to the digital and green transition. North European and **Scandinavian countries stand out in building an ecosystem that supports the green transition**. The Eastern European startup scene is gaining momentum. However, the most Eastern EU countries belong to the low performing countries.

A range of digital and emerging technologies offer potential to advance technological progress underpinning economy and social life while simultaneously help identify, mitigate and even reverse environmental damage. Leveraging these technologies and engineering new solutions are key to address economic challenges, climate change and achieve Sustainable Development Goals (SDGs).[50] They include major technologies, such as **Internet of Things, artificial intelligence, renewable energy technologies, digital twins, 5G, edge computing, automation technologies, etc. For all these technologies semiconductors and electronics systems play a key enabling role.** To achieve long-term sustainability and resilience goals within the digital transformation of industrial ecosystems, experts consider as fundamental to give sufficient attention to the full technology stack, from infrastructure to microchips and edge/cloud architectures, suitable data governance and a human-centric approach to technologies.[51]

According to industry insiders and technology experts, the electronics industry is likely to be driven by the following trends in the near future[52]:

- **Metaverse**: a spectrum of digitally enhanced applications both in private and business life using technologies, such as VR, AR, apps driving new experiences, digital assets underpinned by 5G and cloud technology.[53]
- **Sustainability**: technologies and practices that lead to more sustainable consumer products, environmentally friendly manufacturing processes, transportation, product usage and end-of-life. Optimising sourcing materials while reducing waste are at the forefront.
- **Mobility**: electric and autonomous vehicles are the main trends that will power the development of electronics in relevant application areas. Traditional modes of transportation are most likely to be complemented by drone delivery.
- **Digital health**: semiconductor innovations enabling digital health products become increasingly important. In particular, advanced wearable devices are expected to have high growth potential.

In addition, experts from the European Semiconductor Industry Association (ESIA)[54] pointed out to the following areas as main drivers of the future semiconductor market: **Industrial Applications; Quantum computing and AI, and Cybersecurity**.

Without doubt, important technological trends that drive and will drive in the near future technological developments in electronics are linked to the transition of energy systems and power supply, electric and autonomous mobility, advanced and intelligent automation coupled with sustainability requirements. The further digital transition of all economic and social spheres itself requires advanced electronics and operating systems. At the same time, new technological trends are placing unprecedented demands on the electronics industry.

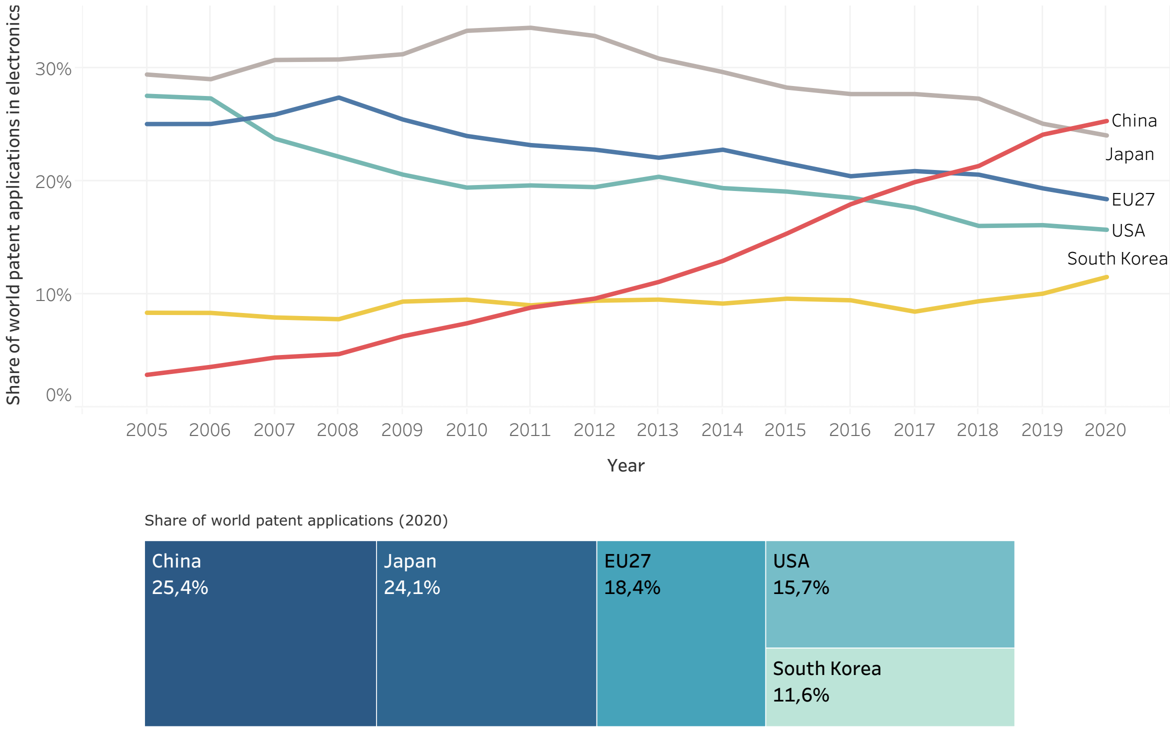
2.1. Technology generation in the ecosystem

For the analysis of technological developments within the electronics industrial ecosystem, patenting activities related to the specific sectoral activities have been tracked. The methodology is based on transnational patents[55] (i.e. PCT/WIPO filings or direct applications at the EPO, excluding double counts), using an extended version of the EPO's Worldwide Patent Statistical Database. Technologies relevant to ecosystems were defined using keywords to identify relevant applications across classes. The detailed methodology is presented in the EMI methodological report. The patent application analysis results were

[50] ITU 2019. Turning digital technology innovation into climate action. Turning digital technology innovation into climate action.
[51] CEPS 2022. THE NEW INDUSTRIAL STRATEGY FOR EUROPE. CEPS Forum on the Future of European Industry.
[52] Accenture 2023. The Pulse of the Semiconductor Industry. Balancing resilience with innovation.
[53] https://www.accenture.com/us-en/blogs/intelligent-operations-blog/metaverse-continuum-set-to-redefine-how-the-world-operates
[54] https://www.eusemiconductors.eu/esia/about-esia
[55] Frietsch and Schmoch 2010 2010. Transnational patents and international markets. Scientometrics, Volume 82.

enhanced by insights generated through comprehensive literature review. The analysed data reveals a **clear downward trend in the EU27's share of patent applications in electronics within the total world patent applications** (please see the line graph in Figure 4). **China dominates and constantly increases its patenting activities in the area with a share of 25.4% of world patent applications in 2020.** Similarly, Japan holds a very strong (second strongest) position in corresponding patenting activities. South Korea and Taiwan also increased their shares of patent applications[56]. As the growth of electronics industry is expected to boost in the future, patent activities are likely to grow as players will attempt to protect and monetise their technological inventions.

Figure 4: Trends in the share of patent applications in world total in the field of the electronics industrial ecosystem in 2010-2020 and global comparison in 2020



Source: Fraunhofer calculations, Patstat

A detailed patent analysis was performed to explore digital and green transition trends within the technological developments related to the electronics industrial ecosystem. The analysis is based on the 2022 edition of the OECD REGPAT database. A text mining algorithm was used to search for key words and their specifications in the patent description as well as in the Cooperative Patent Classification nomenclature. The classification of green transition technologies builds upon the OECD green patents classification, combined with additional technologies relevant to the ecosystems. The identification of digital transition technologies is based on the earlier work on Industry 4.0[57] and includes additional technologies relevant to the ecosystem.

The data indicates strongly increased patenting activities in the electronics areas related to digital transition between 2015 and 2019 (

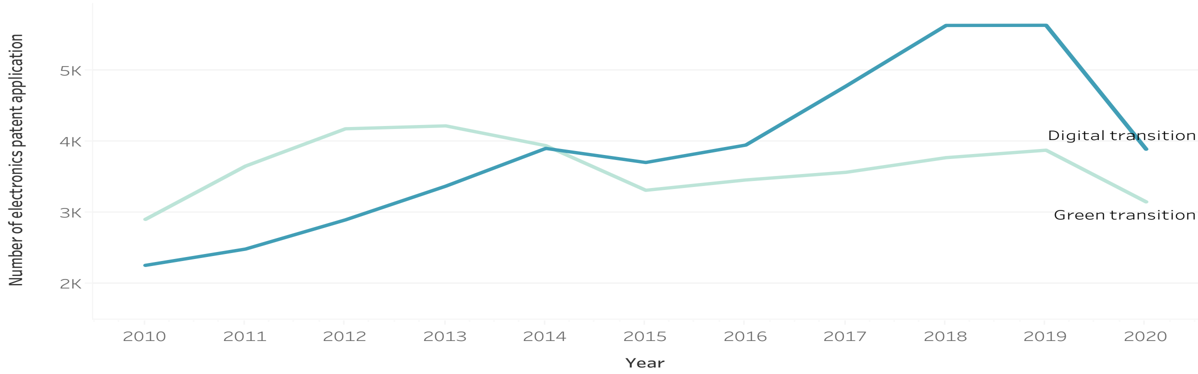
Figure 5), driven by advances in technologies. However, inventing activities in electronics related to the green transition demonstrate a mixed and less pronounced dynamics: between 2010 and 2012 the growth of patent filing accelerated at a fast rate. From 2013, the trend reversed until 2015. Since 2015, there has been a moderate increase of patenting activities in green electronics. These developments seem to reflect the price trends of fossil

[56] https://www.iam-media.com/article/data-reveals-patenting-in-semiconductors-tear-asia-accelerating-its-output

[57] Balland and Boschma 2021. Mapping the potentials of regions in Europe to contribute to new knowledge production in Industry 4.0 technologies.

fuels: a steep fuel price increase between 2005 and 2011 has been followed by rising inventing activities in electronics that support green transition. The falling fossil fuel price between 2012 and 2016 is likely to have negatively impacted the development of green technologies. The reasons for a drop in 2020 are related to the start of the Covid-19 pandemic.

Figure 5: Trends over time in digital and green transition related patent applications connected to the electronics industrial ecosystem



Source: Balland, 2022 based on PATSTAT

2.2. Digital technological trends

A broad deployment of advanced digital technologies in the European electronics ecosystem is essential to sustain global competition. Therefore, a wide adoption and use of digital and automation technologies is characteristic for a modern electronics industry. Moreover, there is an increasing trend for intelligent and autonomous machinery and processes. This requires a wide range of connected devices and systems, such as Industrial Internet of Things (I-IoT), secure edge computing devices, advanced sensors, real time and low latency communication, enabled by 5G interconnectivity.[58] As digitisation progresses, cybersecurity becomes a major topic across sectors. This necessitates continuous innovation to better equip digitised systems against existing and new attacks. Further key requirement of such interconnected systems and tools is secure data exchange and storage, which drives demand for edge computing. AI, machine and deep learning techniques are increasingly deployed to enable data-informed efficient planning, control and optimisation of resources and processes. Through integration and intelligent operations, the described technologies can help improve sustainability across the production facilities and supply chain as well as help increase transparency for users.

2.2.1. Contribution of innovative electronics to the digital transition

There is a broad range of innovative electronics necessary to accelerate and support digital and sustainable processes. They include different microelectronic components that enable a number of functionalities supporting digital and green transformation, such as digital integrated circuits (IC) for data processing, analogue ICs for signal conversion and processing, and semiconductor memories. The development of **new generation 5G/6G mobile communication networks** drives **demand for microelectronic components**, which enable highest frequencies, low latencies, high processing speeds and technologies for wireless communication and low energy consumption. The expansion of **cloud services and exponential increase in data volumes** also require advanced semiconductor technologies. With growing use of AI technologies and high-performance computers, the

[58] European Commission 2022. A Chips Act for Europe.

demand for specialised chips with an enhanced computing power and low energy consumption is also increasing. Further technologies of key relevance are in-memory computing for AI applications, optical semiconductors for communication, sensor technology and data visualisation, new power semiconductors for electrification and energy transition, new memory technologies as a replacement for flash below 40 nm, quantum sensor technology and quantum computing.[59] **Silicon photonics is a fast growing area with applications in high-performance computing, sensors and data centers.[60]** Embedded systems - integrated and intelligent computer systems that combine hardware and software designed to perform a specific function - represent further key focus of advanced microelectronics technology to support digital and green transition. To meet sustainability targets, these systems rely on innovative microelectronics technology, for instance, energy-saving chips.

The contribution of innovative electronics technology to the digital transition is reflected by the patent statistics of related technologies (Figure 6). In the last years, technologies such as, **augmented and virtual reality (including immersive technologies), and quantum computing have seen considerable growth rates** and accounted for the largest share in total selected advanced technologies.

The high share in patenting activities can be also explained through the primary relevance of innovative electronics for the development of these technologies. Augmented and virtual reality is a technology linked also to the metaverse; hence patent applications indicate innovative activity in this area. A significant relative fraction in patenting activities is related to the Internet of Things that widely uses different electronics technology, including sensors, actuators and communication technology. AI applications require advanced and specialised semiconductors, especially processors for deep learning or machine learning workloads. This is a main driver for the massive increase of inventive activities in this field of technology, as patent statistics demonstrate. Nanotechnology is a further key technology with high potential to contribute to the digital and green transition. **Digitalisation is driving the demand and development of cybersecurity and cloud computing technology as well as next generation digital mobility technologies**, as patent data highlight. Apart from this, development of new and improved electronics supports the digital transition through contributing to and advancing the blockchain technologies, additive manufacturing, smart grids and autonomous robots.

[59] ZVEI 2021. Semiconductor Strategy for Germany and Europe. The current situation, analysis, and goals.
[60] Siemens 2022. Digital transformation for smart semiconductor manufacturing. Addressing the opportunities and challenges inspired by technology and digital solutions. .

Figure 6: Patents distribution by digital and green transition related technologies within the electronics ecosystem (over the period from 2017 to 2020)

Technologies	EU27 tech share within all tech in electronics	EU27	USA	China
Digital transition				
Augmented reality	11,6%			
Quantum computers	7,8%			
Internet of Things	5,9%			
Artificial intelligence	4,7%			
Nanotechnology	4,4%			
Cybersecurity	3,8%			
Autonomous vehicles	2,9%			
Cloud computing	2,6%			
Blockchain	1,4%			
Additive manufacturing	1,2%			
Smart grids	0,6%			
Autonomous robots	0,4%			
Green transition				
Solar energy	40,8%			
Advanced Sustainable Materials	3,4%			
Green buildings	3,3%			
Batteries	1,8%			
Air & Water pollution reduction	1,0%			
Green transports	0,9%			
Hydrogen	0,4%			
Efficient power & combustion	0,3%			
Biotechnology	0,2%			
Other energy storage	0,2%			
Wind energy	0,2%			
Biofuels	0,1%			
Nuclear energy	0,1%			
Waste management	0,1%			
Greenhouse gas capture	0,0%			
Recycling technologies	0,0%			
Geothermal energy	0,0%			
Marine & hydro energy	0,0%			
Water related adaptation technologies	0,0%			
	Legend			
		Low share		High share

Source: Balland, 2022 based on PATSTAT

2.3. Green technological trends

2.3.1. Contribution of innovative electronics to the green transition

Innovative electronics is one of the most important technologies facilitating the green transition. Innovative electronics come with a large variety of sustainability advantages enabling energy efficiency, extended product life cycle, preserving natural resources, and also providing essential technologies to generate and use energy from clean sources. The market research Global Market Insights forecasts the global eco-friendly electronics market to reach the value of € 421 billion by 2027, indicating a growing relevance of sustainable electronics.[61] According to the estimations by Goldman Sachs, the deployment of advanced semiconductors can help conserve 10.7% of the global energy (equivalent to 3.27 million GWh) in 2030.[62] For example, the Samsung's second generation 3nm process node reduces the power consumption by up to 50%, while improving performance by 30% and reducing

[61] https://energy5.com/the-rise-of-energy-efficient-electronics-a-win-for-the-environment
[62] Goldman Sachs 2022. Accelerating the Energy Transition: Metrics and tools to measure progress.

the area by 35%.[63] Goldman Sachs Global Investment Research found that through enabling more energy efficient and sustainable products semiconductors help avoid five times more CO^2 compared to the amount emitted during their manufacturing.[64]

Innovations in electronics enable the development of more sustainable technologies including high-efficiency solar cells, lightweight lithium-ion batteries, technologies for water management and treatment, environmental remediation and higher efficiency in manufacturing.[65] The latter involves the reduction in energy and other resource consumption, waste generation and improved cost effectiveness. LEDs are another semiconductor technology, which led to considerable energy savings in the last decade. LEDs use at least 75% less energy and last much longer than incandescent lighting. Real-time data generated by advanced sensors harnessed in different Internet of Things application contexts help realise greater energy and resource efficiency, detect anomalies, and improve quality of products, processes and services to end users. Semiconductors largely contribute to the decarbonisation of the transport sector being essential components of electric vehicle and autonomous cars in the future. Materials, such as Gallium Nitride and Silicon Carbide, substitute traditional silicon contributing to higher thermal conductivity, faster electron mobility and superior performance of semiconductors.[66] For example, Silicon Carbide based power semiconductors enable 70% to 90% less energy loss compared to silicon-based chips, allowing longer ranges by ca. 20% and faster charging by more than 50% for electrical vehicles.[67] Renewable power generation, transmission and use are to a large extent empowered by a steady improvement of semiconductor and other electronics technologies. They enable harnessing, converting, transferring and storing renewable energy as electricity and subsequently moving it onto the electric grid with minimal loss of power.[68]

New developments are underway to facilitate the next generation of sustainable and smart electronics that will further significantly improve the environmental impact of electronics. They involve sustainably designed nanomaterials, sustainable wearable electronics, displays, electronic materials, new manufacturing techniques and end-of-life processes. Integrating advanced digital technologies along the electronics value chain, such as AI supported digital twins, help optimise products, processes and their sustainability parameters. However, as technologies advance, the energy consumption also increases. A recent study shows that the information and computing technology is going to account for up to 20% of the global energy consumption by 2030.[69] Although the technology improvements contribute to improved energy-efficiency, in turn mitigating the environmental effects, the sheer amount of the energy consumption and limited access to renewable energy across regions can result in considerable environmental footprint. Furthermore, hardware manufacturing and use continues to constitute a large portion of ICT's carbon footprint.[70]

2.3.2. Technological trends

The green transition relies to a large extent on innovative, energy efficient, and sustainable electronics. Many companies in the EU develop new solutions that support the transition to the environmentally friendly economy. In the energy sector, the efficient production and transmission of electrical power is key to reaching the objectives of the European Green Deal.[71] The **EU has particular strengths in this field providing innovative power**

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[63] https://www.inceptivemind.com/samsungs-3nm-chips-reduce-power-consumption-45-percent/25296/
[64] Goldman Sachs 2022. Accelerating the Energy Transition: Metrics and tools to measure progress
[65] Fan 2023. Materials and technology innovations towards sustainable electronics. Nature materials. Fan 2023.
[66] https://electronics360.globalspec.com/article/20060/balancing-semiconductor-innovation-vs-sustainability
[67] https://www.polarcapitaltechnologytrust.co.uk/static/documents/Technology_and_Climate_Change_2022.pdf
[68] https://earth.org/semiconductors/
[69] Gupta et al. 2022. Chasing Carbon: The Elusive Environmental Footprint of Computing. IEEE Micro, Volume 42, Issue 4.
[70] Gupta et al. 2022. Chasing Carbon: The Elusive Environmental Footprint of Computing. IEEE Micro, Volume 42, Issue 4.
[71] https://ec.europa.eu/greendeal

electronics that improve efficiency of power generation, transmission and control of energy. Furthermore, the EU27 has a strong position in the **Fully Depleted Silicon on Insulator (FDSOI) chip architecture** that enable higher efficiency, better performance, lower power consumption as well as easier integration of additional features, such as connectivity and security. The technology has a broad adoption in different application areas, such as automotive, IoT, 5G/6G and Industry 4.0.[72] Another major topic of interest for electronics players represents advanced compound materials, which enable innovative electronics with better performance and efficiency attributes and provide opportunities to meet sustainability goals.[73]

As patent statistics show (Figure 6), there is a **particularly high dynamics in the development of electronics for solar energy.** As mentioned above, power electronics is a key technology for efficient renewable power generation, use and distribution. For the green transition of the electronics ecosystem, the availability of environmentally friendly materials for electronics are essential. This involves the development of biocompatible and biodegradable conductive polymer composites, organic materials, green solvents, as well as novel recyclable and circular materials. The trend is reflected by a relatively high share of patenting activities in the field of electronics related to advanced sustainable materials. Furthermore, there is a wide range of electronics technology for the application in buildings that help lower their environmental impact. **Electronics play an important role in making batteries more efficient and accelerating the electrification of mobility**, and hence a lot of inventive activities are dedicated to the development of electronics contributing to battery technology innovations. It has to be noted that the patent analysis here does not include all patent applications related to batteries but only those that happen linked to the electronics industry. Innovative electronics also help reduce air and water pollution. Apart from this, electronics contribute to green transports[74], hydrogen, efficient power and combustion, biotechnology, wind energy and energy storage, biofuels and many other technologies that support green transition, as reflected by patent application statistics.

2.4. Twin transition driven by innovative startups

Innovative young companies that develop new technologies and experiment with new business ideas play an important role in the long-term industry dynamics. Startups operating in the electronics industrial ecosystem are covering a broad range of technologies that support the digital and green transition. As a rule, they fill smaller innovative niches that are less capital intensive. Apart from being one driving force for innovations in digital technologies, startups provide valuable solutions that enable and support the green transition. For example, the Silicon-Saxony based LuxChemtech has developed technologies to recycle silicon and other semiconductor materials and return them to the manufacturing cycle.[75] Big tech companies in Europe like Bosch, Infineon, ASML, NXP semiconductors support and partner with innovative startups to develop sustainable solutions. The international semiconductor business association SEMI has started an initiative to seek out and partner with the world's top startups to bring new sustainability technologies to semiconductor operations.[76]

To study current trends in technological and innovative startups operating in the electronics industrial ecosystem, data tracked by *Crunchbase*[77] *and Net Zero Insights* were analysed.

[72] https://www.soitec.com/en/press-releases/leading-semiconductor-players-to-advance-next-generation-fd-soi-roadmap-for-automotive-iot-and-mobile-applications

[73] Lemos 2022. Unlocking Compound Semis' Economy-Driving Potential. In: *EE Times Europe* November 2022.

[74] This category was defined as vehicles and transportation technologies that are specifically designed to reduce emissions or increase fuel efficiency. The most popular technologies are electric vehicles, hybrid vehicles, and alternative fuels. Here we directly use the CPC Y02T tag for "climate change mitigation technologies related to transportation".

[75] https://www.kfw.de/stories/economy/startups/luxchemtech/

[76] https://www.semi.org/en/blogs/semi-news/startups-for-semiconductor-sustainability-semifinalists-announced-at-semicon-west-2021-hybrid

[77] www.crunchbase.com and https://netzeroinsights.com/

Net Zero Insights is a database specialised in capturing sustainability driven startups, while Crunchbase data is used to analyse trends in technologically driven startups.

The data analysis reveals a dynamic electronics tech startup landscape in the major regions during the last years. The USA is the major region with the highest density of electronics startups. The EU27 is further important location for innovative tech startups, however, it is lagging behind USA and China in terms of access to venture capital, which has been partly compensated for by public funding lately. China has strategically supported its startup ecosystem in recent years by inducing investments in startup companies that resulted in explosive growth of startups in different strategically important fields, including AI and semiconductors. The recent unprecedented rise in tech startups makes China one of the largest and fastest growing location for electronics startups worldwide. As such, **China is increasingly positioning itself as one of the biggest electronic ecosystems.**

Electronics technology startups established after 2015 were the most active in a number of digital and green transition related fields such as sensors, Internet of Things, integrated circuits AI, photonics and process technology, advanced materials, and recycling (Figure 7):

Figure 7: Type of technologies and services within electronics tech startups (established after 2015) in the EU27, USA and China

Technology	EU27	United States	China
Sensor	346	434	160
Internet of Things	239	322	142
Artificial Intelligence and Big Data	145	252	78
Photonics technology	91	123	65
Integrated Circuit	87	235	189
Recycling	71	98	3
Process technologies	62	99	82
Cloud-based and other software	60	69	16
Advanced materials	55	100	62
Organic and printed electronics	44	68	30
Wearable electronics	33	84	32
Energy saving technologies	29	41	20
Embedded systems	25	24	2
Power electronics	21	24	22
Next generation computing	21	22	0
Quantum computing	15	18	4
Blockchain	5	10	3

Source: Technopolis Group based on Crunchbase and Net Zero Insights, 2022

Sensors: Startups related to sensor technologies represent the largest group among all electronics startups. The sensor startup market in the EU and other regions is on the rise, as sensor technologies are key in different applications related to the digital and green transitions. The US startup landscape demonstrates the strongest entrepreneurial activity in this field. The EU as a whole is also well positioned in terms of innovative sensor technologies. Sensors, such as LIDAR and radar are indispensable in automotive applications, pushing out in other applications, such as security screening and imaging, and smart home.[78] Many startups in Europe are specialising in these fields. MEMS sensors is also a frequently targeted technological focus of startups in Europe. Advanced CMOS sensors for the use in different application fields and technologies including Augmented

[78] Silicon 100 2020. 100 Startups Worth Watching. EE Times.

Reality, computational photography, biomedical imaging, digital healthcare is another important topic for startups activities in Europe and other regions. Overall, sensors are required for different connected devices making them a critical technology to be broadly used within the context of the Internet of Things. A number of startups is working on building smart platforms that use AI and sensors to optimise energy usage. Further area of activities for the startups in the EU is the development of sensors for the control and monitoring of emissions as well as detection of dangerous substances. Another important topic is platforms that help manage, track and analyse data generated by sensors. Biosensors to monitor health condition and track vitals are among further technologies pursued by startups.

Internet of Things: With the increased connectivity across all sectors and areas of our life and the advent of 5G/6G communication/connectivity, technologies that underpin Internet of Things (IoT) represent a strong focus for many electronic startups. US' startups have the strongest position in this area, followed by the European startup scene. The growth of Chinese startups has shown a very dynamic development leading to unprecedented increase of startups in many fields, including IoT. Strong entrepreneurial activity of startups related to IoT is linked to sensor technologies, as sensors are key components in the IoT applications. Many electronics startups focus on designing sensors to fit the specialised needs of IoT devices for specific purposes. A large number of startups are developing smart devices for a wide range of different applications, such as smart cities, smart home and industrial automation. Many companies develop hardware design, software, and systems integration to go along with products and applications within IoT. Further main area is the application of IoT for smart metering of emissions.

Integrated circuit technologies: Within this category, startups are included that focus on designing IC for different purposes. For instance, chips specifically designed for AI, HPC (high performance computing) chips, memory devices, micro-controllers, microprocessor, analog device, diode, etc. Automotive chips represent an important topic for European startups in this area. Advanced semiconductor technologies for vehicles with autonomous driving capabilities are expected to drive growth of automotive semiconductors in the near future offering opportunities for startups.

Artificial Intelligence and Big Data: Interest in AI semiconductors has been growing since 2016, and so did the investments in startups. US is leading since the early 2000s, creating many AI semiconductor startups. Investment in China began to grow rapidly in 2015. The total investment in Chinese startups in 2021 exceeded €3 bn, making up 55% of the global investment of the year.[79] AI impacts the semiconductor industry in two ways. First, there is a rising demand for innovative AI-capable electronics components, and second, leveraging AI helps improve the product manufacturing and design processes.[80] Many startups are offering hardware-based acceleration technologies that run neural networks. Another group of startups focuses on AI techniques to optimise the design of new chips. For instance, machine learning-driven solutions can be used to identify design problems and analyse the root causes of failures.[81] A lot of activities are linked to developing AI-based solutions for semiconductor manufacturing and AI semiconductors.

Photonics technologies: further major topic in which European electronics startups engage. Advances in photonics have an impact on a wide range of industries. Demand for integrated photonic devices is also driven by the quantum technologies, specifically quantum computing and communication.[82] Consequently, there is an increasing number of startups focusing on developing new solutions within the field photonic quantum technology. Some startups are working on fibre optics and optical sensing. Although there

[79] https://www.edge-ai-vision.com/2022/07/the-ai-semiconductor-market-2021/
[80] SrartUs insights 2023. Electronics Manufacturing. Trend Report. SrartUs insights 2023.
[81] https://www.startus-insights.com/innovators-guide/semiconductors-trends-innovation/#advanced-materials
[82] https://www.eetimes.eu/quantum-photonics-startup-secures-e1-45m-in-seed-funding/

was entrepreneurial activity in field of laser technologies during the period 2010-2014, this has decreased in the following period.

Process technologies: this startup category comprises companies developing process technologies, including wafer processing, packaging and assembly, metrology and inspection, yield management and optimisation. In the EU, there is a number of startups focusing on development of packaging technologies as well as startups developing and providing metrology and inspection solutions for semiconductor manufacturing. However, the data reveals a stronger entrepreneurial dynamic for related activities in China and the US. Overall, new advanced IC packaging technologies that provide greater integration in increasingly miniaturised packages, enable semiconductor manufacturers' better customisation and improve yields hold high potential for startups.

Advanced materials: Startups are developing silicon alternatives and other semiconductor materials or composites, such as graphene, nanomaterials, GaN, and SiC for higher performance and efficiency. Many semiconductor startups in Europe are pursuing "more than Moore" innovations by leveraging novel materials. Advanced materials are widely used in different application areas impacting high potential markets like: electric vehicles, charging infrastructure, renewable energy, industrial power suppliers, 5G and communications.[83] They also offer environmental benefits through enabling higher energy efficiency and resulting energy savings, reduced emissions during manufacturing process.[84]

Recycling technologies: In recent years, there has been a steady growth of startups in the US and Europe dealing with recycling technologies and new recycling management strategies as well as implementing new business models to promote recycling of electronics. Among them are startups that launch online marketplace for refurbished electronics, or selling second-hand electronic items or offering other recycling services. An increasing number of startups enter the market that develop and provide technology and process development solutions for electronics materials recycling, remanufacturing and re-use. There are also many startups developing recycling technologies focused on capturing, processing and recycling of electronic waste.

Cloud-based and other software: a number of startups in Europe specialise in developing Electronic Design Automation (EDA) tools. A number of US-startup focus for example on the development of software supporting the manufacturing processes of electronics. Further group of startups provide cloud software and cloud-based platforms. For instance, cloud-based platforms that combine data generated in chip-embedded software agents with machine learning techniques to predict failures.

Printed and organic electronics: Printing electronics components on a semiconductor substrate are not only offering large potential to reduce the overall cost of the manufacturing process, but also to reduce environmental impact through the use of sustainable materials. Further, the advancements in printing technologies also contribute to the flexible hybrid electronics field. So, there is a number of startups and scale-ups, which develop solutions for advanced printing technologies and flexible electronics.[85] Printed electronics open up opportunities for designing new types of electronic products to be applied in intelligent packaging, wearables, precision agriculture, and diagnostics.[86] In addition, the need to reduce environmental impact induces manufacturers to opt for organic electronics. Also, designing circuits with microbial components or producing

83 https://www.avnet.com/wps/portal/us/resources/article/the-substantial-benefits-of-silicon-carbide-and-gallium-nitride-in-power-electronics/

84 https://www.allaboutcircuits.com/news/gan-goes-green-three-ways-gan-is-good-for-the-planet/

85 https://www.startus-insights.com/wp-content/uploads/dlm_uploads/2022/01/Electronics-Manufacturing_Trend_Report_StartUs-Insights.pdf

86 https://www.vttresearch.com/en/sustainable-electronics?utm_campaign=BTO%20Newsletter&utm_medium=email&_hsmi=243642107&_hsenc=p2ANqtz--lbQjvOznnXN2oZZo7CEWvLOc_4tux8q2NAlCfbEKznwMFz0ZWMKD_qcfckQAj7vwhqU_3_mVo6k3BM62N0iIU7uAHLe4LAYklOF-N4ad4U7iXIuY&utm_content=243464709&utm_source=hs_email

devices with **biodegradable and recyclable materials** is expected to grow in importance and create new business opportunities for companies.[87]

Energy saving technologies: There are innovative entrepreneurial activities in Europe dedicated to developing technologies that enable energy efficiency improvements or new low-power electronics. For example, the Finnish company Minima Processor[88] offers an ultra-low voltage technology that enables up to 20x energy efficiency improvement in digital processors. Another example is the Swedish semiconductor company Xenergic[89], which has developed provider of extreme low power SRAM devices.

Embedded systems: Embedded systems are in high demand to support transition to connected world. Owing to new technological requirements, the designing and manufacturing of such systems constantly undergo changes to improve performance, security, and connectivity capabilities. Further, in manufacturing facilities, these systems are used to increase machine control and monitoring.[90] Data captured on Crunchbase demonstrate strong entrepreneurial activities related to embedded systems particularly in the US and Europe.

Next Generation Computing/Novel architectures: new technologies, such as AI, drives the development of next generation computing. Innovative startups contribute to this trend by developing non-volatile memory chips, integrating heterogeneous 3D-enabled designs, and using nanotechnology to develop novel processor architectures. Additionally, simple and easily scalable architectures can help reduce power usage and manufacturing costs while improving performance.[91]

Quantum technologies: The EU27 boasts a large number of startups related to quantum technologies (in total 199 according to data on Crunchbase but not all related to electronics). Quantum computers need electronic components and specialised control and readout electronics. The EU27 has a dedicated quantum fund from Paris-based VC firm Quantonation, and Germany announced in February 2023 a new €1bn fund for deep tech and climate tech growth-stage companies, including quantum.[92]

Further areas of activities for startups operating in the electronics industrial ecosystem are **health devices** and **power electronics**.

Another similar analysis of 1 112 electronics startups and scaleups across the globe by StartUs Insight identified ten major trends that impact the electronics manufacturing industry.[93] **Advanced materials that address miniaturisation, better performance and sustainability requirements as well as organic electronics** are among the top trends that drive the innovative electronics startups worldwide. Besides, AI and the Internet of Things enabling smart manufacturing practices play an important role for the electronics industry. Hence, a lot of startups focus on developing innovative solutions in these technological fields. Further important growth drivers for electronics startups include technologies, such as advanced circuit packaging, embedded systems, technologies, enabling printed electronics, miniaturised electronics, 3D printing and immersive technologies.[94]

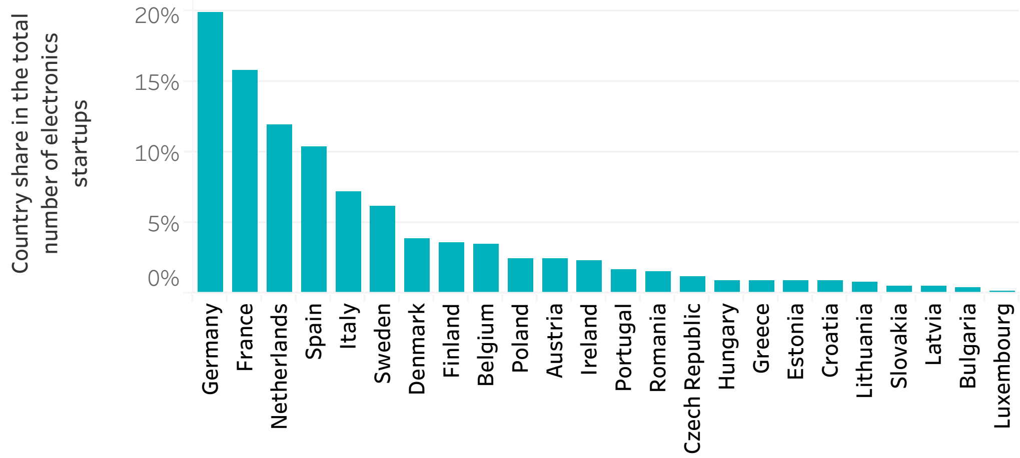
2.4.1.1. Country patterns

According to the data captured on Crunchbase, Germany, France, and the Netherlands accommodate the largest number of startups operating in the electronics industrial

[87] https://www.startus-insights.com/wp-content/uploads/dlm_uploads/2022/01/Electronics-Manufacturing_Trend_Report_StartUs-Insights.pdf
[88] http://www.minimaprocessor.com/
[89] http://www.xenergic.com
[90] https://www.startus-insights.com/wp-content/uploads/dlm_uploads/2022/01/Electronics-Manufacturing_Trend_Report_StartUs-Insights.pdf
[91] https://www.startus-insights.com/innovators-guide/semiconductors-trends-innovation/#advanced-materials
[92] https://sifted.eu/articles/europe-quantum-startups-mapped/
[93] StartUs insights 2023. Electronics Manufacturing. Trend Report.
[94] StartUs insights 2023. Electronics Manufacturing. Trend Report.

ecosystem (Figure 8). Spain and Italy are also among EU countries with large number of startups. These countries have large semiconductor hubs attracting talents and providing business development support. Adjusted for population and GDP, the Netherlands is the absolute champion in terms of the number of startups related to electronics industrial ecosystem, followed by Sweden, Denmark, Finland, Belgium, Estonia and Lithuania. Eastern Europe startup scene is gaining momentum. The region builds on strong academic environment, such as Czech Technical University in Prague, Brno University of Technology, Warsaw University of Technology, Budapest University of Technology and Economics, Vilnius Gediminas Technical University, to mention just few) and the network of research institutes. However, the most Eastern EU countries belong to the low performing countries.

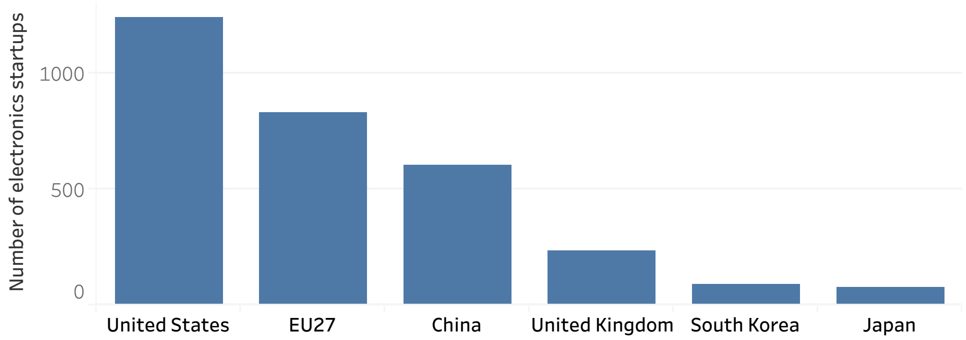
Figure 8: Electronics startups founded after 2010 across the EU MS



Source: Technopolis Group, based on Crunchbase, 2022

Historically, Europe has been less attractive location for startups compared to the USA due to the difficulties to raise funds and realise their full potential (e.g. scale-up). However, in recent years, there has been a positive upward trend, as the EU and some national governments have intensified their efforts to provide a better legal framework and financial incentives to support innovative star-ups. US and APAC remain the main regions with vibrant semiconductor startup ecosystems.[95] Although the EU hosts a smaller number of startups focusing on these areas, it has a good potential to develop digital and green innovations.

Figure 9: Electronics startups across the EU and main international competitors (founded after 2010)



Source: Technopolis Group, based on Crunchbase, 2022

As the demand for innovative electronics required to meet Digital and Green Transition as well as the overall targets set out in the Chips Act is immense, the EU has to intensify its efforts in generating and implementing new technologies. The innovation needs along the entire value chain of electronics as enabling technology that supports the Twin Transition

[95] Kearney 2021. Europe's urgent need to invest in a leading-edge semiconductor ecosystem. Kearney 2021.

are significant. So far, the EU as a whole has fallen shorter in terms of innovative activities that drive the transition, compared to its major competitors, primarily United States and China. The latter is increasingly establishing itself as a technological leader in many areas relevant for the Digital and Green Transition, as statistics on innovative activities dynamics highlights. Especially to meet its ambitious Green Transition goals, the EU relies on radical innovations. Startups and scaleups represent an important source of innovation within the electronics industrial ecosystem and need more targeted support. For the EU it is of paramount importance not only to increase its innovative capacity as quickly as possible, but also to develop the ability to timely scale up and translate the R&D results into industrial application.

3. Uptake of green and digital technologies and business models

Key findings

A business survey was conducted as part of the project about the status in the uptake of digital and green technologies and related business models in SMEs operating in the electronics ecosystem. The results reveal the following insights:

- Only 23% of SMEs have increased investments in green transition and environmental sustainability during the last five years. From these companies, the majority (41%) have invested less than 5% of their revenue in these technologies.
- From all green technologies, the highest adoption by SMEs during the last 5 years exhibit: energy-saving technologies (14%); renewable energies (12.5%); recycled materials (12.1%), and recycling technologies (11%).
- Clean production technologies that help reducing water and material use, minimise waste and increase operational efficiency have been adopted by 8.1% of SMEs.
- Recycled materials are the most attractive area for the future investments of SMEs - 5.9% of respondents indicated that they plan to adopt recycled materials in the near future.
- Circular business models are adopted by a small share of companies: 9.9% are involved in design for higher durability activities; 8.8% provide repair and maintenance services and 8.5% have adopted renting & leasing business models. Much smaller share of companies 5.1% have adopted the circular design business model.

Following the results of the survey on the digital transformation of SMEs operating in the electronics ecosystem:

- 40% of the survey respondents had increased their investments dedicated to digital technologies over the past five years;
- Among digital technologies most frequently adopted by SMEs are: cloud technologies (20.6%), online platforms (17.2%), Big Data (11.4%), robotics (10.7%) and AVR (9.6%). Artificial Intelligence has a low uptake of 6% among SMEs in the electronics ecosystem.
- Digital technologies that SMEs plan to adopt are: IoT (6.1%), Big Data (5.9%), robotics (5.6%). Only 3.9% plan to implement the AI technologies.

Technology centres are at the core of industrial ecosystems and have been mapped specifically within this project. They strengthen the industrial ecosystems by providing R&D expertise, accelerating innovation, supporting technology uptake and improving collaboration. Among EU27 countries that host a considerable number of technology centres and address the electronics industrial ecosystem are Germany, France and Spain.

With the objective to monitor the status in the uptake of digital and green technologies and related business models, this study adopted a mixed-method approach including a **business survey and text mining of company websites**. The survey was based on using Computer Assisted Telephone Interviewing (CATI). The final sample included 8 987 companies in all industrial ecosystems and 300 interviews for the electronics industrial ecosystem in particular. The mainstage fieldwork was conducted between 15 January and 31st May 2023. The survey respondents come from a mix of micro-enterprises (less than 10 employees), small enterprises (10-50 employees) and medium-sized enterprises (50-250 employees).

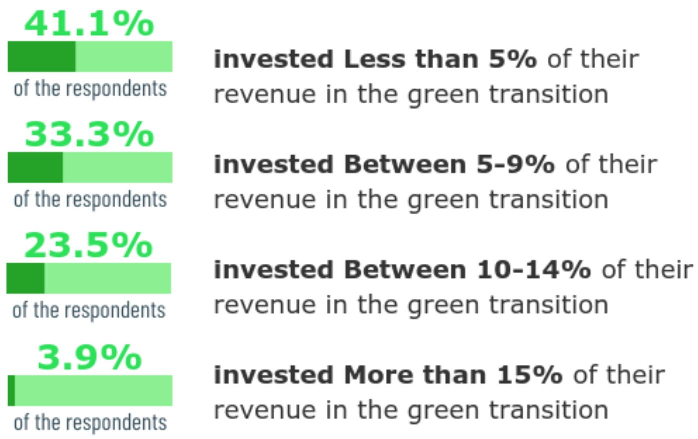
The results of other existing surveys have been also taken into account such as the Flash Eurobarometer 498 on SMEs, green markets and resource efficiency, and the ICT-usage in enterprises survey[96]. The different time of the field work for each survey can give some insights about progress even if the questions were not exactly the same. The Flash Eurobarometer 498's field work took place in November-December 2021. The last ICT usage survey results date from 2020.

3.1. Green transformation of SMEs

As part of the EMI survey, respondents were asked whether they **had increased their investments dedicated to the green transition** and environmental sustainability during the past five years, and **only 23% of the respondents answered** positively, which is among the lowest results of all industrial ecosystems. Similarly, the Flash Eurobarometer in 2021 found that **only 7% of the SMEs surveyed in the electronics ecosystem had a concrete strategy in place to reduce their carbon footprint and become climate neutral** or negative, although 21% was planning to prepare one.

A further question was related to the percentage in terms of the revenue that SMEs invested in green transformation on average annually. The responses show that 41% **invested less than 5% of their revenue** (see Figure 10).

Figure 10: Share of revenue invested in green transformation by SMEs in the electronics ecosystem on average annually



Source: Technopolis Group and Kapa Research, 2023

The detailed survey results demonstrate that SMEs in the electronics ecosystem have been most active in adopting energy saving technologies followed by renewable energy. The least cited green technologies include biotechnology and hydrogen (see Figure below).

[96] https://ec.europa.eu/eurostat/cache/metadata/en/isoc_e_esms.htm

Figure 11: Adoption of green technologies in the electronics ecosystem

	Answer	
Technology	Already using	Planing to adopt
Energy-saving technologies	14,0%	2,0%
Renewable energies	12,5%	3,2%
Recycled materials	12,1%	5,9%
Recycling technologies	11,0%	1,4%
Additive manufacturing	9,2%	0,0%
Clean production technologies	8,1%	3,1%
Carbon capture technologies	5,9%	0,7%
Advanced sustainable materials	5,9%	0,7%
Biotechnology for sustainability	4,0%	0,3%
Hydrogen	2,2%	0,3%

Source: Technopolis Group and Kapa Research, 2023

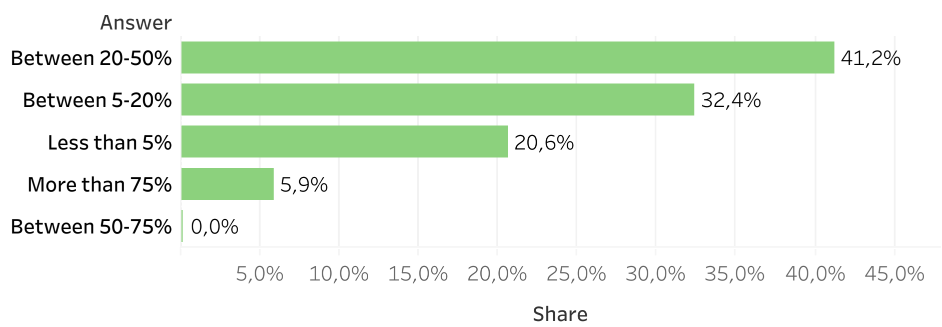
Energy saving technologies

The EMI survey results indicate that **14% of SMEs in electronics have adopted energy saving technologies over the past five years**. Energy saving technologies have been defined at industrial level as systems, machinery, thermal systems, electrical systems, or industrial design features of the production processes or operations that increase the energy efficiency of buildings, transport and production processes. In a broader definition, however, there are more companies that put in place measures to optimise their energy use. According to the results of the Flash Eurobarometer 498, **63% of the SMEs in the electronics industrial ecosystem undertook actions to save energy.**

Renewable energy

Renewable energies have been adopted by **12.5% of the respondents**, nonetheless a large share of the SMEs that switched to renewables used these energy sources between 20-50% within their total energy consumption according to the survey results.

Figure 12: Share of renewable energy use within total energy consumption by electronics SMEs surveyed in the EU27



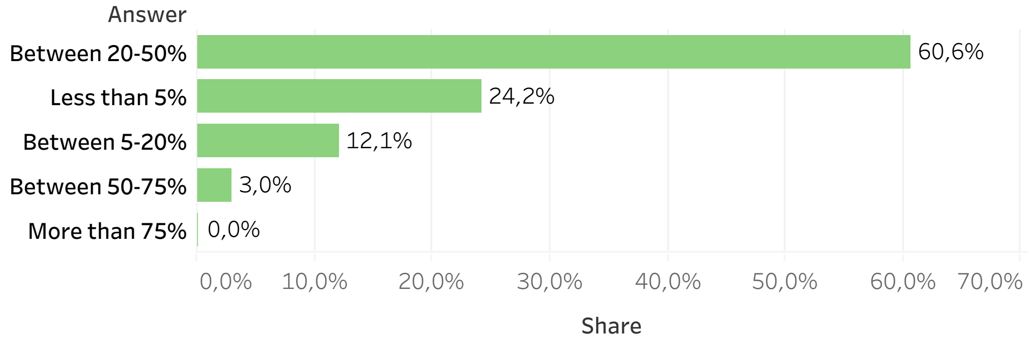
Source: Technopolis Group and Kapa Research, 2023

Recycling

Recycling is very important for the electronics industry, as it can help conserve natural resources, such as metals, minerals, and plastics that are used to make electronic products. Electronic devices and electrical equipment contain materials that pollute the environment and e-waste can release harmful metals, such as mercury, lithium, lead and barium into our soil[97]. In the EU, the issue of e-waste has been addressed by the introduction of the Waste Electrical and Electronic Equipment Directive[98].

Despite the many initiatives that address the e-waste challenge, the use of recycled materials has been indicated only by 12% of the survey respondents and the adoption of recycling technologies by 11% of the SMEs. Those that recycle, however, do so between 20-50% of their products (see Figure 13).

Figure 13: What is the share of recycled materials that you use within your products/production? (share of respondents in electronics that use recycled materials)



Source: Technopolis Group and Kapa Research, 2023

Clean production

Clean production technologies that help reducing water and material use, minimise waste and increase operational efficiency have been adopted by **8.1% of the respondents** in the EMI survey.

Circular business and service models

Sustainable electronics solutions across the value chain and electronics life cycle open up new business opportunities for companies serving different industries. However, it is only a small share of SMEs that have adopted circular business models as found by the EMI survey. The results show that 9.9% of the respondents pay attention to design for durability. Repair and maintenance services have been indicated by 8.8% of the respondents.

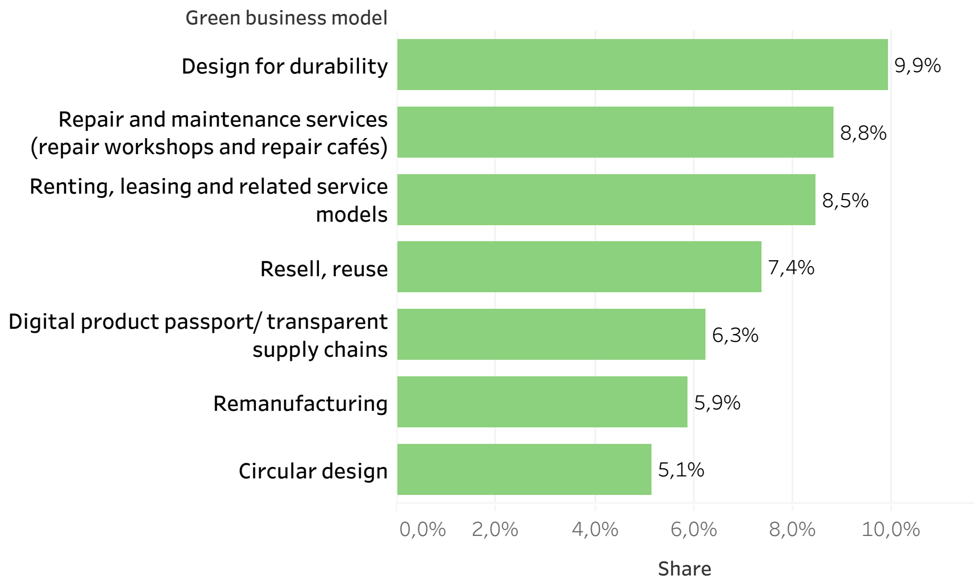
Startups are key players driving the green transition, albeit many established players in the EU take on new sustainability approaches and business models. Meanwhile, there is a range of business practices and models being adopted by an ever-increasing number of companies in the electrical and electronic equipment sectors. They involve the following:[99]

- design and production of *electronic products to improve the durability, reparability* and sustainability through selection of proper materials, high quality components, and modular design;

[97] European Parliament 2020. E-waste in the EU: facts and figures, https://www.europarl.europa.eu/news/en/headlines/society/20201208STO93325/e-waste-in-the-eu-facts-and-figures-infographic.
[98] https://environment.ec.europa.eu/topics/waste-and-recycling/waste-electrical-and-electronic-equipment-weee_en
[99] CEPS 2021. Barriers and enablers for implementing circular economy business models: Evidence from the electrical and electronic equipment and agri-food value chains (CEPS Research Report).

- *reuse, repair, refurbishment and remanufacturing* to increase products' lifetime. However, such "re-valuing" practices are still very limited due to complex designs, software restrictions and high repair costs.
- *product-as-a-service and leasing models*: customers obtain temporary access to a product via leasing or pay-per-use schemes. As a result, the number of some devices put on the market might decrease while product utilisation rises.[100]
- collection and recycling at the end-of-life phase of electronic devices.

Figure 14: Adoption of green business models and non-technological solutions by electronics SMEs in the EU27



Source: Technopolis Group and Kapa Research, 2023

The **transition to circular business models within the European electronics ecosystem is still at a very early stage. The EMI survey found that it is only 9.9% of the electronics SMEs** that apply design for durability principles and 8.8% indicated the provision of repair and maintenance services.

Resell and reuse business models have been adopted by 7.4% of the respondents and remanufacturing has been mentioned by 5.9% of the SMEs.

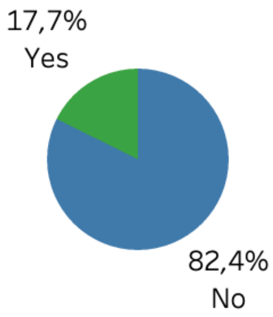
Examples of European companies that embarked on sustainability strategies are ASML and Nikon. Specifically, ASML's Return4Reuse programme seeks to reuse old equipment, while ensuring progressively sustainable use of materials across processes and the value chain through refurbished products. According to company's information, they reused nearly 4 million kg of materials in 2020. Nikon, which also manufactures semiconductor lithography systems, engages proactively in the 3Rs of reducing, recycling, and reusing.[101]

[100] https://www.polyce-project.eu/about/
[101] https://www.azom.com/article.aspx?ArticleID=20788

Environmental standards

When asked about the certification on any environmental standards, it is **17.7% of the respondents indicated that they had been certified** (see Figure 15) by a third party.

Figure 15: Share of survey respondents indicating that they have obtained a third-party verified environmental certificate

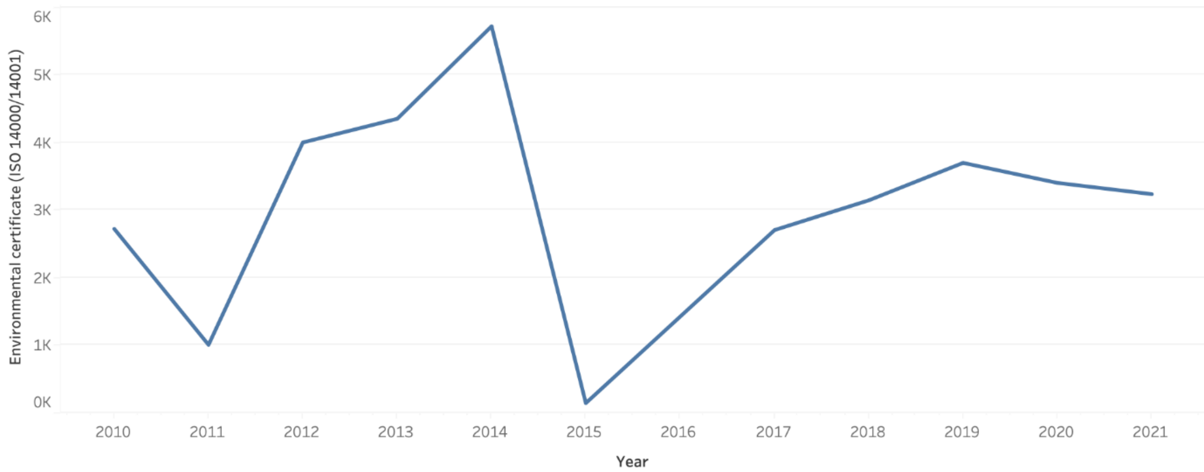


Source: Technopolis Group and Kapa Research, 2023

To monitor the use of environmental standards, the indicator of ISO 14001 provides further insights. ISO 14001 is a set of standards that any company can follow to implement an effective environmental management system. By adopting the good practices suggested by the standard, firms can substantially reduce their environmental footprint. The number of environmental certificates issued in the industry indicates the progress towards the application of environmentally friendly business practices and production methods. For the purposes of this report, ISO data were accessed via the ISO survey of certifications to management system standards[102].

The analysis of the data shows that electronics companies obtained less and less ISO environmental certificates over time. The annual ISO survey indicates that there were 3 238 certificates issued to electronics companies in the EU27 in the year 2021, which number has decreased compared to 4 003 certificates issued in 2012.

Figure 16: Number of environmental certificates issued for companies active in the electronics industrial ecosystem



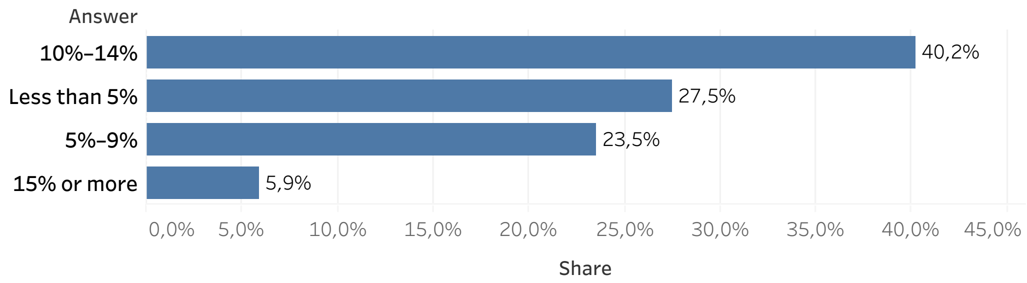
Source: Technopolis Group, 2022 based on ISO

[102] ISO (2022) ISO Survey of certifications to management system standards. Accessed on https://isotc.iso.org/livelink/livelink?func=ll&objId=18808772&objAction=browse&sort=name&viewType=1

3.2. Digital transformation of SMEs

Digital transformation has been less of a concern for SMEs in the EII industrial ecosystem compared to green objectives as analysed above, given the fact that only **40% of the survey respondents indicated that they had increased their investments dedicated to digital technologies over the past five years**. A further question was related to the percentage in terms of revenue that SMEs had invested in digital transformation on average annually. The responses show that **the largest share of the respondents (40%) invested between 10-14% of their revenue** in digital technologies, which is relatively good result.

Figure 17: Share of revenue/income invested in digital transformation in electronics on average annually



Source: Technopolis Group and Kapa Research, 2023

The level of adoption of specific digital technologies relevant for the ecosystem is presented in Figure 18. Cloud technologies were indicated as the most relevant, followed by the use of online platforms, big data, and robotics. Blockchain has been the least adopted among the digital technologies monitored in this project.

Figure 18: Adoption of digital technologies by SMEs in the electronics ecosystem following the EMI survey results

	Answer	
Technology	Already adopted	Planing to adopt
Cloud technologies	20,6%	4,3%
Online platform	17,2%	4,0%
Big data	11,4%	5,9%
Robotics	10,7%	5,6%
AVR	9,6%	2,0%
IoT	6,6%	6,1%
Digital twin	6,3%	2,0%
Artificial Intelligence	6,0%	3,9%
Blockchain	4,8%	1,9%

Source: Technopolis Group and Kapa Research, 2023

Cloud technologies in this project have been defined as the **use of cloud-based software and related cloud platform services. The results show that 20.6%** of the respondents in the EMI survey covering the electronics industrial ecosystem adopted these technologies. According to Eurostat statistics[103] 26.8% of the companies belonging to the sector of manufacturing of computer, electronic and optical products bought high cloud-computing services such as CRM (customer relationship management) software and accounting software in 2020.

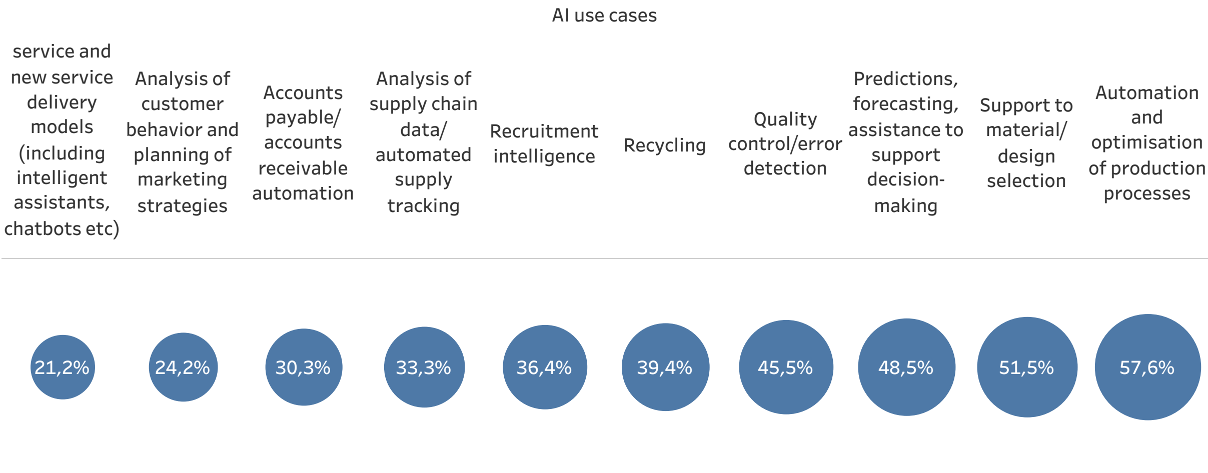
[103] https://ec.europa.eu/eurostat/databrowser/view/ISOC_CICCE_USEN2__custom_7147881/default/table?lang=en

Online platforms are used by 17.2% of the SMEs in the ecosystem, which reflects developments in the field of e-commerce. The electronics industrial ecosystem has been increasing their online sales over the past decade as also shown by the related Eurostat statistics on e-commerce. According to Eurostat data[104], 22.3% of enterprises that manufacture computer, electronic and optical products had e-commerce sales in 2022.

Big data and related data analytics have been adopted by **11.4% of the SMEs** in the ecosystem as found by the EMI survey. Eurostat[105] concludes that 15.5% of the companies in the manufacturing computer, electronic and optical products (10 persons or more) analysed big data internally from any data source or externally in 2020.

Artificial Intelligence has a low uptake of 6% among SMEs in the electronics ecosystem. The related indicator in Eurostat[106] that measures the use of AI by enterprises by economic activity found that **16.9% of enterprises in manufacturing of computer, electronic and optical products** (10 persons or more) adopted at least one Artificial Intelligence technologies in 2021.

Figure 19: Use cases of AI among electronics SMEs

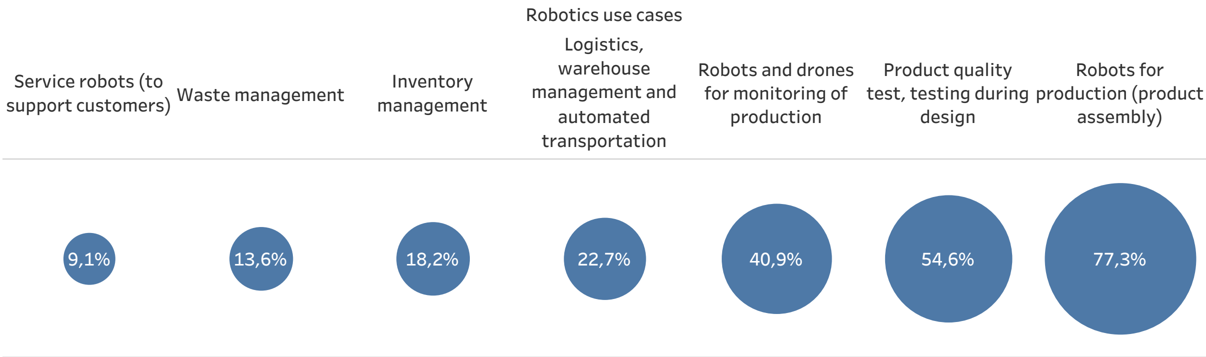


Source: Technopolis Group and Kapa Research, 2023

Robotics technologies are used by 10.7% of the SMEs participating in the EMI survey. Eurostat[107] indicates that **3.6%** of the enterprises in manufacturing of **computer, electronic and optical products** (10 persons or more) used industrial or service robots in 2022. The two statistics indicate the difference in adoption rate between SMEs and large firms (included in the Eurostat figures), but also the difference in the definitions of industries, since the electronics ecosystem is broader than the NACE categories captured in Eurostat. SMEs in the EMI survey indicated that they use robotics most for production and product assembly, followed by product quality testing and robots and drones for monitoring production.

[104] https://ec.europa.eu/eurostat/databrowser/view/ISOC_EC_ESELN2__custom_7153352/default/table?lang=en
[105]https://ec.europa.eu/eurostat/databrowser/view/ISOC_EB_BDN2__custom_7152869/default/table?lang=en
[106] https://ec.europa.eu/eurostat/databrowser/view/ISOC_EB_AIN2__custom_7152872/default/table?lang=en
[107] https://ec.europa.eu/eurostat/databrowser/view/ISOC_EB_P3DN2__custom_7153061/default/table?lang=en

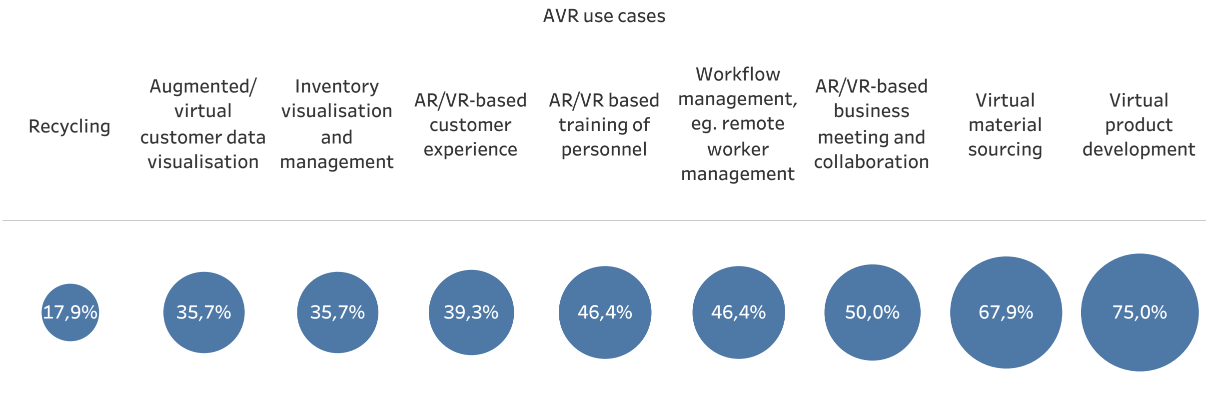
Figure 20: Use cases of robotics among electronics SMEs



Source: Technopolis Group and Kapa Research, 2023

Augmented and virtual reality (AVR) has been adopted by 9.6% of SMEs in the sample. The use cases indicate that AVR was used most often for virtual product development and virtual material sourcing. AVR-based collaboration with supply chain partners has been also indicated by half of the respondents that adopted this technology.

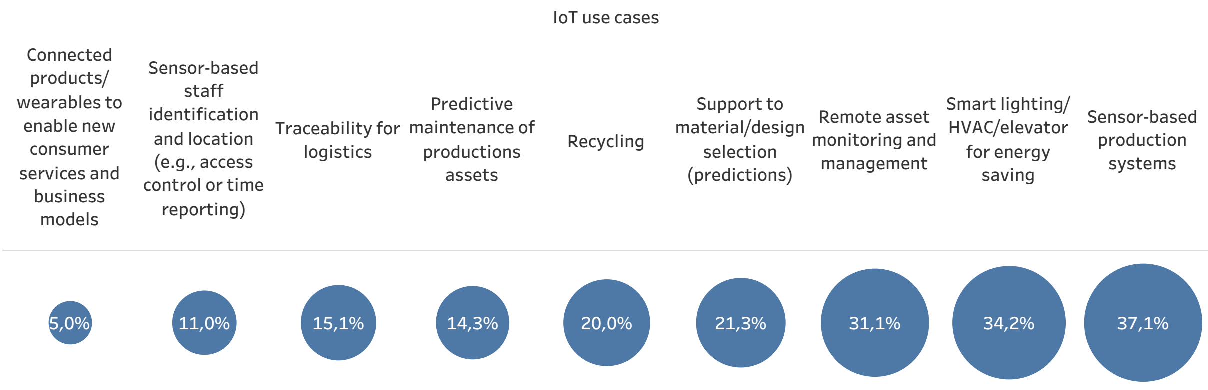
Figure 21: Use cases of augmented and virtual reality (share of SMEs within those that already use IoT)



Source: Technopolis Group and Kapa Research, 2023

Internet of Things (IoT) technologies were indicated by 6.6% of the SMEs in the survey. IoT was used most often as part of sensor-based production systems and as smart devices to improve energy saving.

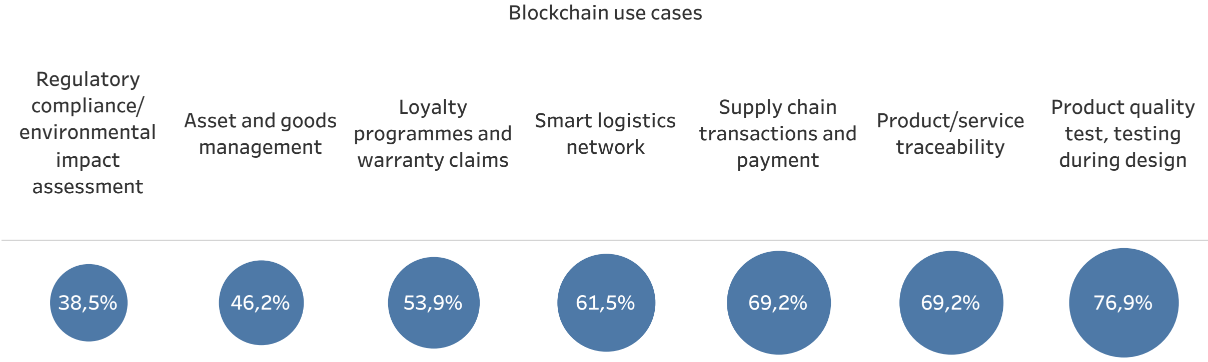
Figure 22: Use cases of Internet of Things (share of SMEs within those that already use IoT)



Source: Technopolis Group and Kapa Research, 2023

Blockchain technologies have an uptake of 4.8% among electronics SMEs. These technologies were applied most often for product quality testing and product traceability. Blockchain solutions can help companies in the electronics ecosystem also to better manage information along the supply chain and for instance record price, date, location, quality, standards, and other relevant information. This contributes to better traceability of the material supply chain.

Figure 23: Use cases of blockchain among electronics SMEs



Source: Technopolis Group and Kapa Research, 2023

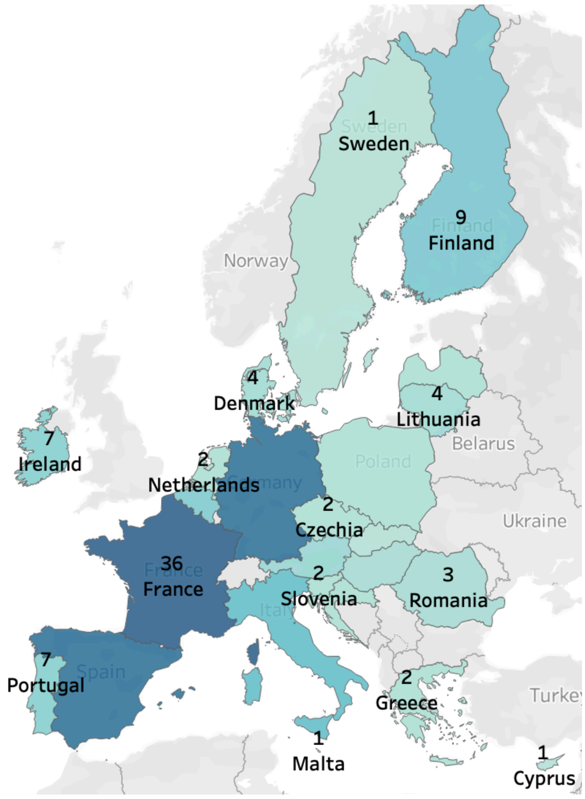
Digital twins create a virtual replica of a physical product, process or system and allow for real time analysis. The EMI survey found that **6.3% of the SMEs** implemented a digital twin.

3.3. Technology centres supporting technology uptake

Innovation actors are at the core of industrial ecosystems and gathering and sharing information about them in a structured way is crucial to detect gaps, improve collaboration, foster innovation, and strengthen innovation ecosystems. Within this project, systematic information is collected on technology centres that are key actors in innovation ecosystems due to their technical expertise and their ability to bring together and steer collaboration among various types of actors in their own ecosystems and beyond (please see the technology centres mapping tool on the EMI website).

Figure 24 presents the number of technology centres that are active in the electronics industrial ecosystem and shows that France is the country with the highest number of technology centres in Europe (36), followed by Germany (32) and Spain (32). The top five is further complemented by Italy (12) and Belgium (8). These countries might host additional technology centres active in electronics, which are currently not registered to the technology centres mapping.

Figure 24: Technology centres per country - electronics industrial ecosystem



Source: Analysis based on Advanced Technologies for Industry Technology Centre Mapping, 2023

The following examples serve to illustrate the activities and scope of technology centres active in electronics, their links with the broader ecosystem as well as examples of recent activities in which they are involved. They include the following three cases: IMM - Institute for Microelectronics and Microsystems (IT), EDI - Institute of Electronics and Computer Science (LV) and RISE - Printed, Bio- and Organic Electronics (SE).

Box 1: Example Technology Centre: IMM - Institute for microelectronics and microsystems (IT)

Name of the Centre	**IMM - Institute for microelectronics and microsystems (IT)**
Location and scope	
The Institute for microelectronics and microsystems (IMM), is a centre located in Catania, Sicily, with secondary offices in other Italian cities: Roma, Bologna, Lecce (Puglia), Agrate Brianza (Lombardia), as well as another secondary office in the University of Catania. IMM is specialised in materials science, process development, device manufacturing and systems integration. It works in three main research application fields: Micro and Nano electronics, Functional materials and devices, and Photonics. These application fields are, at the same time, supported by four technological areas: syntheses, micro and nano fabrication, characterisation, and modelling. The centre works in partnership with small and medium-sized enterprises, large industries, international research institutes, and with Italian and foreign universities such as STMicroelectronics, Enel Green Power, Leonardo, LPE and several SMEs operating in the regions where the offices are located. IMM is a member of the Technological Districts "Micro and Nanosystems'' in Sicily and "High Technology Network" in Emilia Romagna.	
Main services and equipment	

IMM offers a wide range of services in material science, microelectronics, and MEMS research activities: • Characterisation services in Structural Characterisation by electronic microscopy and X-Ray scattering techniques, Metrology and Electrical characterisation, Sensor's and Microsystems characterisation and Optical characterisation • Technological Processes & Support in Research and Development • Packaging, design and simulation services. • Support in Research and Development. • Training of Bachelor, Master and PhD students and coordination of the activities of graduate and undergraduate students in close cooperation with universities. To offer these services, the IMM is equipped with facilities that include a 3D Printing Lab, characterisation facilities, technological facilities, and packaging facilities, among others.
Recent projects related to the green and digital transition in electronics
• **Lab4MEMS** aims to feature a Pilot Line for innovative technologies on advanced Micro-Opto-Electro-Mechanical Systems (MOEMS). It deals with micro-electromechanical system (MEMS) merged with micro-optics, which involves sensing or manipulating optical signals on a very small size scale, using integrated mechanical, optical, and electrical systems. MOEMS includes a variety of devices including optical switch, array of micro-mirrors, optical cross-connect, lasers and micro lens amongst others. MOEMS includes two major technologies: MEMS and Micro-optics, which features device miniaturisation and wide applications in integrated platforms of sensors, actuators and data processing and control. • The aim of the **RISEN** project is to develop and demonstrate contactless, non-destructive, automated sensors to identify, select and label trace materials. Data will be gathered in real-time, processed and sent to a 3D augmented crime scene investigation system to produce an interactive 3D model of the scene, to be available at any time for several purposes in the criminal justice system. The identified traces will be digitally marked and inventoried, and a digitalised chain of custody will be established in real-time implementing mechanisms that assure data integrity over its lifecycle.

Source: Advanced Technologies for Industry Technology Centre Mapping, 2023 and IMM, 2023 https://www.cnr.it/en/ and https://www.bo.imm.cnr.it/unit/projects

Box 2: Example Technology Centre: EDI – Institute of Electronics and Computer Science (LV)

Name of the Centre	**EDI – Institute of Electronics and Computer Science (LV)**
Location and scope	
The Institute of Electronics and Computing (EDI) was founded in 1960 as a state research institute under the supervision of the Latvian Ministry of Education and Science with the aim of promoting a knowledge-based economy in Latvia and becoming a reputed centre in the development of electronics sciences and IT in Europe. Nowadays EDI has a scientific staff of more than 80 professionals and total personnel of more than 100 people. The research carried out in the centre is aligned with the key areas of the Latvian Smart Specialisation Strategy: Information and Communication Technologies and Intelligent Materials, Technologies, and Engineering Systems. EDI works in cooperation with Latvian research institutes and universities, such as the Latvian University, the University of Geodesy and Geoinformatics and the Riga Technical University. It also has partnerships with foreign universities, for example, the Finnish Geodetic Institute,	

Tampere University of Technology, TIMA laboratory in Grenoble and the Shanghai Astronomical Observatory, among others.
Main services and equipment
EDI provides services in: • Technology consulting • Society & Security • Space Technologies • Future Health • Smart Mobility • Smart Production • Artificial Intelligence Among its equipment, EDI has research laboratories such as: • The **Signal processing laboratory**, specialised in digital signal processing systems, including the development of concrete techniques in analog-to-digital signal conversion. • The **Space technology laboratory**, which develops technologies for high-precision event timing and development and implementation of image processing algorithms. • The **Robotics and machine perception laboratory**, to do research in industrial automation, environment monitoring, and integrity control systems, as well as to create computer vision algorithms for classification, object detection and image segmentation tasks. • The **Cyber-Physical Systems laboratory**, which explores research questions for systems that sense, analyse, decide, and interact with the real, physical world.
Recent projects related to the green and digital transition in electronics
• The objective of **PowerizeD** project is to develop technologies of digitalised and intelligent power electronics, in order to enable sustainable and resilient energy generation, transmission and application. • The **AI4CSM** aims to develop advanced electronic components and systems (ECS) and architectures for future mass-market ECAS vehicles. This fuels the digital transformation in the automotive sector, supports the mobility trends and accelerates the transition towards a sustainable green and digital economy. • **EdgeAI** is an initiative for the European digital transition. The EdgeAI project ensures that Europe has the necessary tools and skills to strengthen its edge AI design and development capabilities. The project supports the development of edge AI vertical solutions.

Source: Advanced Technologies for Industry Technology Centre Mapping, 2023 and EDI, 2023 https://www.edi.lv/en/projects

Box 3: Example Technology Centre: RISE – Printed and Organic Electronics (SE)

Name of the Centre	**RISE – Printed and Organic Electronics (SE)**
Location and scope	
RISE is an independent, state-owned research institute. It is one of the 43 companies that is completely or partially owned by the Swedish state.RISE has more than 3,000 employees, researchers, technicians, and other experts, who work all over the country and in a number of foreign subsidiaries.	

The main goal of RISE is to develop innovative, competitive, and sustainable products, processes, and services in partnership with the academic, private, and public sector and supporting various companies. RISE is specialised in many industrial ecosystems such as automotive, chemicals, construction, manufacturing, or electronics. In relation to the last one, RISE focuses on sensors systems, electrical interference, and environmental resistance.
Main services and equipment
RISE provides services to many sectors. Related to electronics, RISE offers the following services: • Evaluation, development and certification services of systems and products such as passenger vehicles, machines, radio and mobile telephone equipment and other IT equipment. • Reliability and safety evaluations of electronic hardware. • Synthesis and characterisation of organic materials. • Modelling and simulation of sensors and sensor systems. • Support to industrial clients globally with know-how and labs to make use of academic research results within the fields of power electronics, printed electronics, photonics, wireless sensors and sensor networks, flexible electronics and bio electronics, and corrosion protection, among others. • Support to startups and established companies in developing smart and innovative applications of graphene and 2D materials. • Environmental testing of packaging and products by doing mechanical and climatic testing. • Guidance in conducting risk analysis. • Business development services. • SME coaching related to electronics.
Recent projects related to the green and digital transition in electronics
• The **HyPELignum** project aims to proof that consumer electronics and internet of things solutions can be made more sustainable, by combining additive manufacturing and wood-based materials. The project will create an energy-efficient microchip for sensing systems as well as analyse new forms to recycle wood and reuse electronic materials. • **SIO Grafen EMC** project seeks to find more environmentally friendly solutions for electromagnetic compatibility (EMC) in industry by replacing metal-based materials with graphene-based ones. • The overarching objective of **Greener Electronics** project is to reduce the environmental impact creating new solutions for Swedish electronics. For this purpose, the project intends to create and disseminate innovative technology and other measures related to lower resource impact from the manufacture, use and recycling of electronics.

Source: Advanced Technologies for Industry Technology Centre Mapping, 2023 and RISE, 2023 https://www.ri.se/en/what-we-do/projects

4. Investment and funding

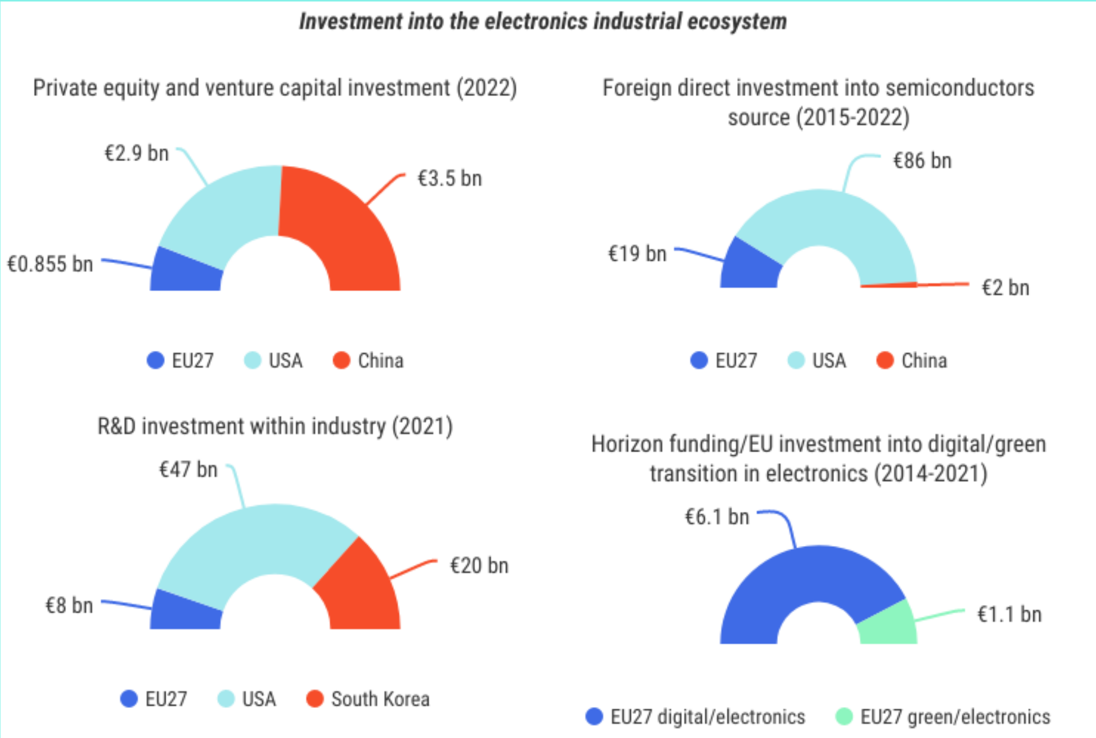
Key findings

Fuelled by public support in major regions, investments in electronics industry considerably increased in recent years. **Following the USA, South Korea and Taiwan, the EU27 had considerably less investment in R&D on semiconductors.**

In 2022, EU27 electronics tech companies that can be linked either to digital or green transition attracted €855 m. The same value was significantly higher both in the USA (€3.5 bn) and in China (€2.9 bn).

Along with renewables and cleantech, the electronics sector attracted the highest FDI worldwide in 2022, driven by the massive capacity expansion in the semiconductor industry. **In the period from 2015 to 2022, the EU27 had a volume of €6 bn intra-EU, €54 bn inward and a lower volume of €18.1 bn outward foreign direct investment in the field of the electronics industrial ecosystem. FDI into the EU peaked in 2021 with a record volume of €25 bn.** EU27 countries represent a major destination for FDIs.

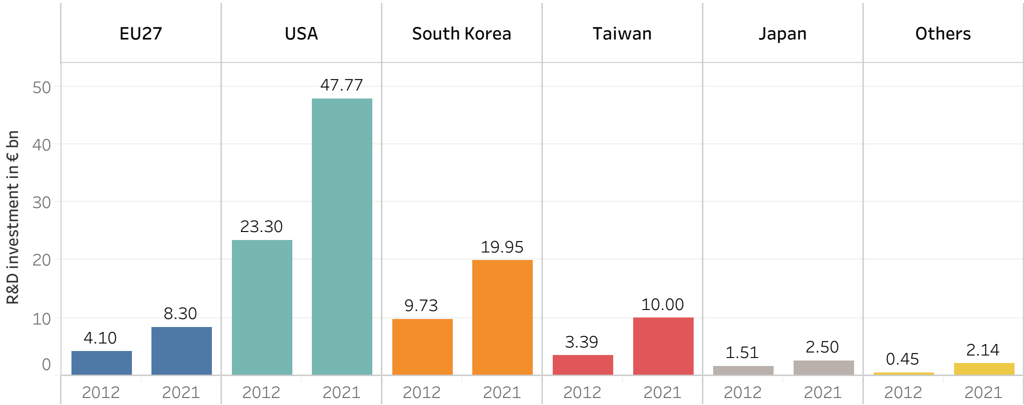
Investments flowing into electronics startups primarily aim at advanced technologies, such as **artificial intelligence, quantum computing and robotics**. In line with the global trend, **EU tech companies focusing on integrated circuit related technologies have attracted the largest investments so far, along with investments in sensor startups**. Overall, the number of seed-and growth-stage funding rounds has also increased in recent years. Across the EU27, German green and digital transition startups operating in the electronics industrial ecosystem have raised record amounts of funds during the last years. The Netherlands stands out as a thriving tech startup landscape reaching high levels of total funds raised compared to other European countries. Along with Germany, France is having one of the highest funding rounds in the EU27.



Source: Technopolis Group calculations, 2023

Semiconductor R&D and manufacturing is extremely capital intensive and requires huge and - due to the rapid technological evolution - frequent investments. Compared to the United States and South Korea, the EU27 strongly underperforms in terms of R&D investment on semiconductors.

Figure 25: R&D investment in the semiconductors sector in 2012 and 2021



Source: EU Industrial R&D Investment Scoreboard, 2022, https://research-and-innovation.ec.europa.eu/document/3a5ac686-8151-4041-9b37-41f2ca4c4121_en

Electronic companies all over the world have increased their spending on digitalisation since the pandemic started. With the European Chips Act[108], the EU has started an unprecedented level of public and private investments in semiconductor-related activities. It is expected to significantly support public and private investment in regional fabrication facilities.

In the EU, R&D in electronics is also supported by the EU research, development and innovation programmes. Horizon 2020 was the European Union's multiannual research and innovation programme for the period 2014-2020, with a budget of almost €80 billion. **According to data from the Community Research and Development Information Service (CORDIS), the programme funded 875 projects** classified under NACE code C26 Manufacture of computer, electronic and optical products, **with a total funding of €8.94 bn.**

Among the funded projects, those related to the digital transition were the most common, with ICT projects accounting for 85% of the total funding. Zooming into the technologies being applied and/or further developed within the projects, advanced manufacturing (including ICA and mechanical engineering) and robotics were the most common technologies applied and/or developed, with 161 projects identified. For instance, PRODUCTIVE4.0 was a €106 million project focused on digital automation, supply chain network solutions, data transparency, and product lifecycle management. Projects involving artificial intelligence were the second most common, with a total funding of €1.6 million.

Additionally, 78 projects with a sustainability focus received a total funding of €1.1 bn, representing 15% of the total funding. As an example, the project TRANSFORM (Trusted European SiC Value Chain for a Greener Economy) sought to provide European downstream market players with a source of SiC components and systems based on a fully European value chain, from substrates to energy converters.

[108] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/european-chips-act_en

4.1. Venture capital and private equity investment in digital and green tech companies within the electronics ecosystem

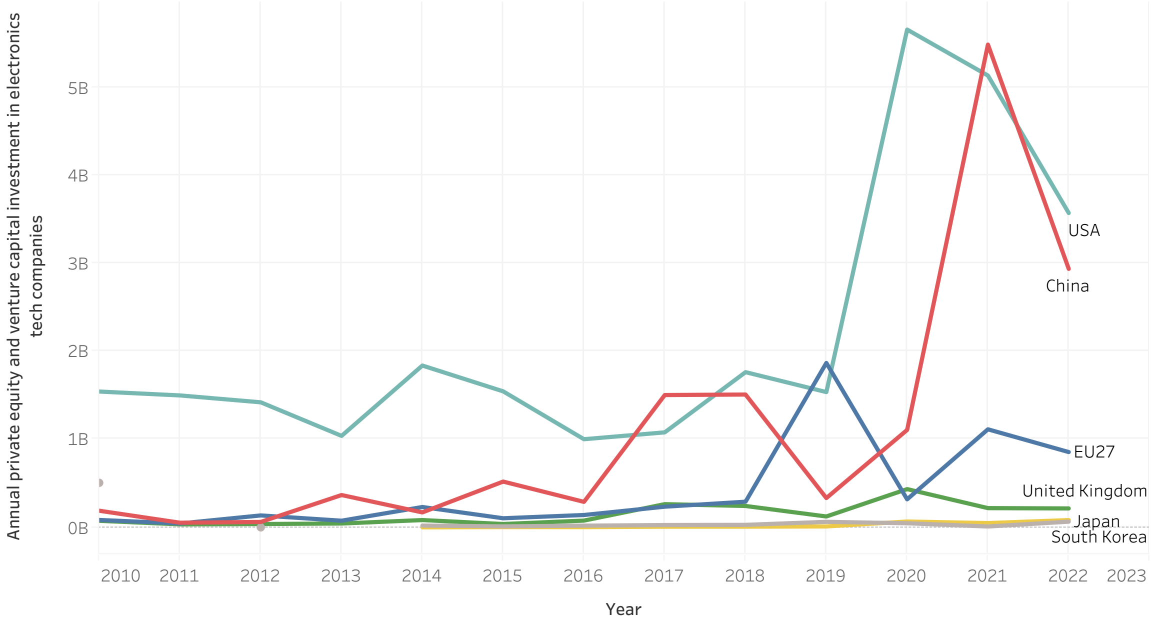
As the production capacity in the EU has been declining since 1990s, so did capital investments in the European semiconductor sector. As a result, the EU's investments accounted for a fraction of the expenditure in other regions, primarily Asia Pacific and North America. Many SMEs and startups in the EU27 had difficulties attracting the necessary investments for R&D and scale up. This led to a stagnating growth of the European electronics industrial ecosystem and its ability to develop and implement cutting-edge technologies.[109] Fuelled by public support in major regions, investments considerably increased in recent years.

Crunchbase and Net Zero Insights data indicates that after a stagnating development of private equity and venture capital investment in EU's electronics tech companies for many years, there had been a **sharp increase in 2018 followed by a drop in 2020. Since then, the funding is on rise again.**

Figure 26 displays the annual funding trends in electronics tech companies linked to the twin digital and green transition. **The volume of funding both in the USA and China is considerably higher** in particular since 2020. China boasted a continuous growth since 2016 and the USA had a steep increase in funding since 2019.[110] One of the main reasons for the significant increase of investments in tech companies is the need for innovative electronics to meet the growing requirements of AI. The increasing demand of the automotive sector, developments in quantum computing, digital health, and space technologies are driving the growth and investment in startups. Recent trade tensions and supply chain disruptions additionally contribute to shifting the focus on self-sufficiency and nationalisation - trends, from which young and small tech companies also benefit.

In 2022, EU27 electronics tech companies that can be linked either to digital or green transition attracted €855 m. The same value was significantly higher both in the USA (€3.5 bn) and in China (€2.9 bn).

Figure 26: Annual private equity and venture capital investment in electronics tech companies since 2010



Source: Technopolis Group calculations based on Crunchbase, 2022

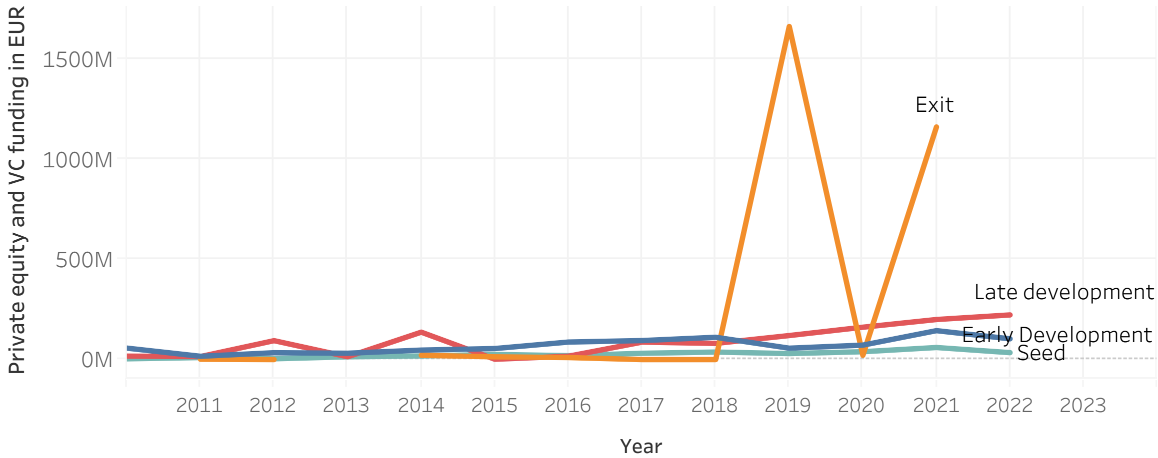
[109] European Commission 2022. A Chips Act for Europe.
[110] As data for 2022 is incomplete at this point in time (February 2023), it does not allow a final assessment for funding in 2022.

A similar recent analysis that took into account a broader range of investment types and without zooming into the digital and green transition found similar discrepancies between the EU and its global competitors. In this analysis, China received the highest investments making up 60% of all global investments, followed by the USA. Europe's share accounts for around 14% in total investments.

The electronics segment that raised the highest investments is IC design, followed by semiconductor materials, and ADAS (advanced driver assistance systems).[111]

Figure 27 presents the picture of annual private equity and VC funding into EU27 electronic startups per main investment type. Funds for early development rounds show a moderate growth since 2011, whereas funds for late development have been increasing significantly after a drop in 2015 and 2016. A high exit value since 2021 indicates that investors receive the multiple of the sum originally invested, when the companies are sold or go public. For example, Qualcomm acquired a two-year-old semiconductor startup, Nuvia for €1.3 bn. Automotive sensor companies, Luminar, Aeva, Aeye, Ouster and Innoviz all went public at valuation of around €1 bn or more.[112]

Figure 27: Private equity and venture capital investment into European electronic startups per main investment type (2010 onwards)

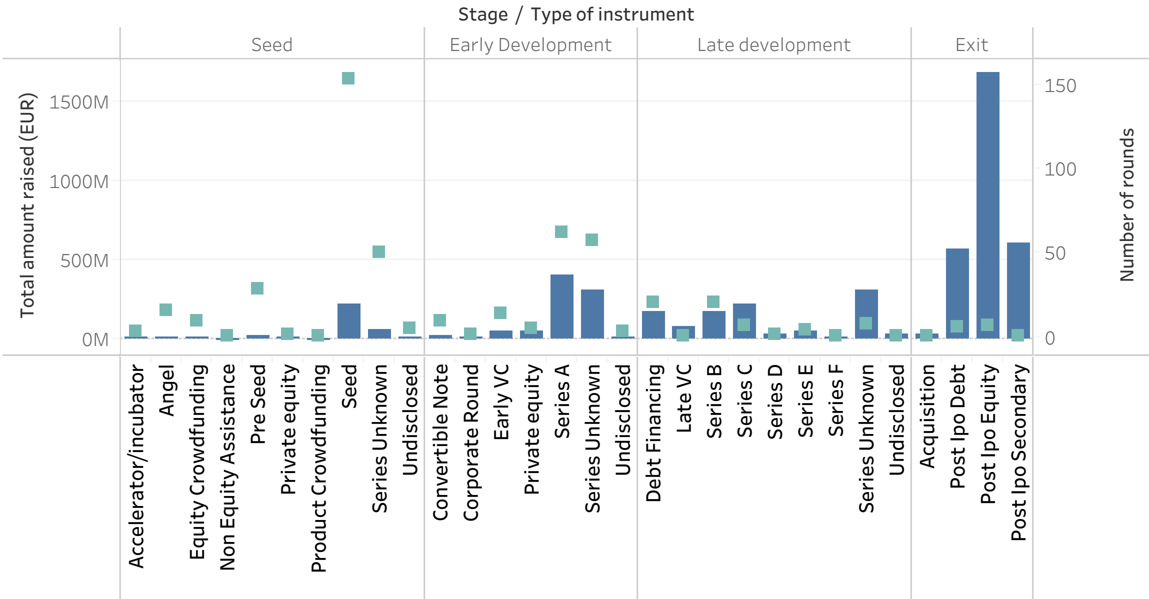


Source: Technopolis Group calculations based on Crunchbase and Net Zero Insights, 2022

In many cases, the exit means an acquisition by an established company as it is well-understood. Seeking for new ideas and innovations, large technology companies often partner and invest in startups and/or buy them. The chances for successful startups to be acquired are high. Many startups actively pursue this strategy, which is not unproblematic in terms of possible negative effects on innovation. Evidence suggests that in the absence of the possibility of an acquisition, new firms generally opt for bolder and more radical innovations. Also, when purchased by an established company, a small tech company is getting less innovative, as radical innovations are associated with greater risks.[113] On the whole, this strategy stifles the innovation potential of many tech companies.

[111] https://www.eetimes.eu/tracking-2022s-us38b-in-semiconductor-investments-for-startups/
[112] https://semiwiki.com/general/297730-semiconductor-startups-are-they-back/
[113] https://insight.kellogg.northwestern.edu/article/the-desire-to-be-acquired-is-stifling-innovation-at-startups

Figure 28: Private equity and venture capital investment by stage and type of instrument into EU electronic startups



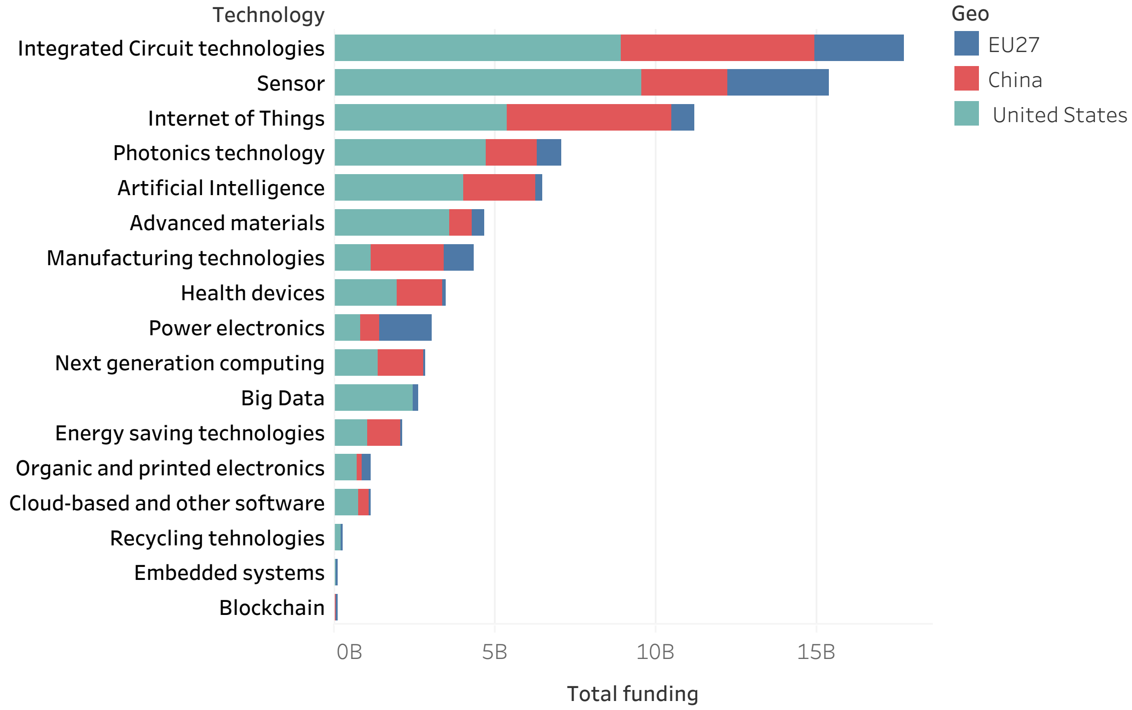
Source: Technopolis Group calculations based on Crunchbase and Net Zero Insights, 2023

Figure 29 provides an overview of the total funding received by each type of technology at EU27 level. In line with the global trend, **EU tech companies focusing on integrated circuits related technologies have attracted the largest investments so far, along with investments in sensor startups.** Overall, the number of seed-and growth-stage funding rounds for EU startups has also increased in recent years. The rising amount of growth-stage funding rounds is considered a good sign for the fast-developing EU startup scene. This trend can encourage founders to have good chances when focusing on scaling their companies.[114]

In terms of geographical location of the companies raising investments, USA stand out as the region with the highest investments (Figure 29), followed by Chinese companies, which obtained considerable funding despite having been involved in less funding rounds than European startups. The investment value for European countries accounts for only a fraction of Chinese and US-American funding during 2015 and 2022 but is expected to gain momentum in the near future.

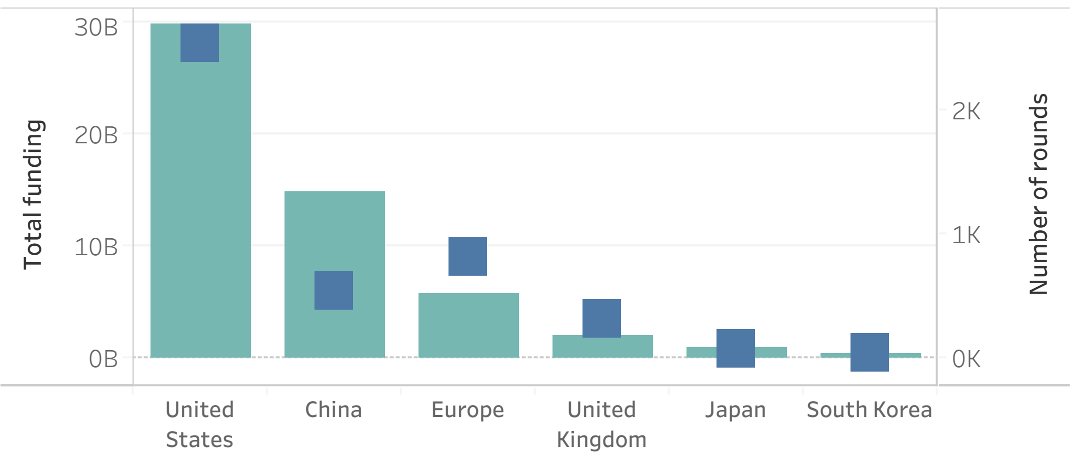
[114] https://www.mckinsey.com/industries/technology-media-and-telecommunications/our-insights/europes-innovation-wunderkinds-the-rising-b2b-startup-ecosystem

Figure 29: Distribution of private equity and VC investment by type of technology



Source: Technopolis Group calculations based on Crunchbase and Net Zero Insights, 2023

Figure 30: Total private equity and VC investment figures in electronics tech by country for funding rounds after 2015



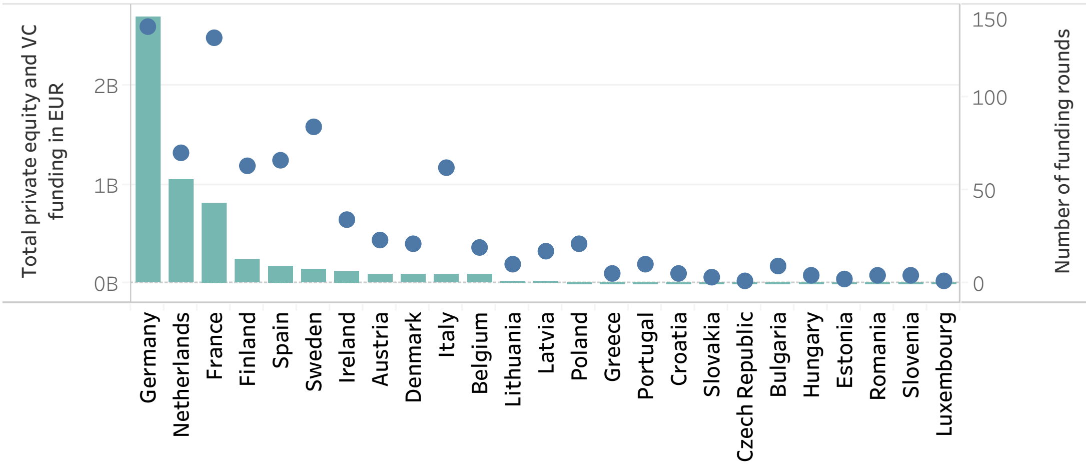
Source: Technopolis Group calculations based on Crunchbase and Net Zero Insights, 2023

Across the EU27, German green and digital transition startups operating in the electronics industrial ecosystem have raised record amounts of funds over the period from 2015-2022 (Figure 31). The Netherlands stands out as a rich and thriving electronics tech startup landscape. For example, per capita, the Netherlands has the highest density of AI startups related to electronics in the EU. Investments in Dutch tech are rising not only thanks to more funding rounds, but also the growing size of rounds.[115] France is following suit, having one of the highest funding rounds in the EU27. North European countries focus a lot on design, R&D intensive activities as well as activities related to the development of green and sustainable solutions. In Finland, for instance, electronics startups play an important

[115] https://sifted.eu/articles/dutch-startups-deeptech-funding/

role in digital and sustainability developments, reflected by a large number of startups in these areas.

Figure 31: Private equity and VC funding in electronics tech startups per EU country (2015-2022)

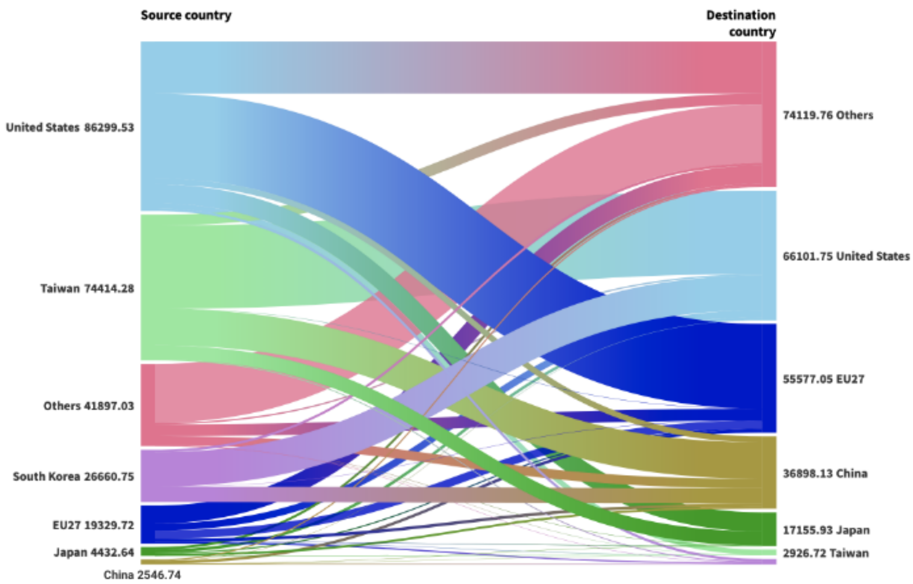


Source: Technopolis Group calculations based on Crunchbase, 2023

4.2. Foreign direct investment in semiconductors and other electronic components

Semiconductors and other electronic components attracted the highest foreign direct investment (FDI) worldwide in 2022 following renewables and cleantech, which trend has been driven by the massive capacity expansion within the industry. **Globally, FDI in semiconductors reached of over €85 bn in 2022**[116], being unleashed by unprecedented public support in major regions. EU27 countries represent one of the major destination regions for FDI, but it is also an important source country. Globally, the United States has been the largest FDI investor in semiconductors followed by Taiwan and South Korea. China is mainly a destination country in this field and less a source of FDI.

Figure 32: Worldwide foreign direct investment in semiconductors in € m over the period from 2010-2022



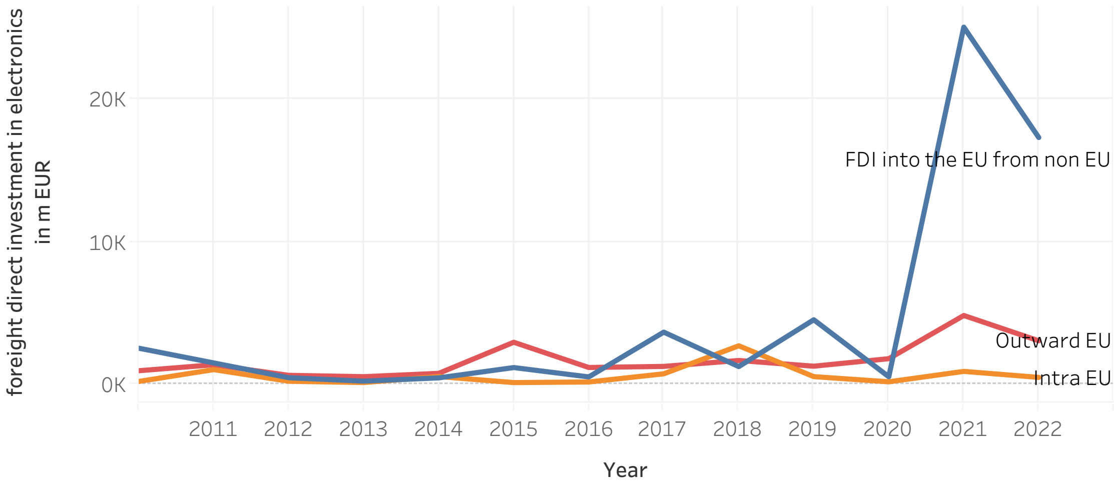
Source: Technopolis Group calculations based on fdiInsights

[116] https://www.fdiintelligence.com/content/data-trends/the-2022-investment-matrix-81976

Over the period from 2015 to 2022, the EU27 had a volume of **€6 bn intra-EU, €54 bn inward and a lower volume of €18.1 bn outward foreign direct** investment in the field of semiconductors and electronics. FDI into the EU peaked in 2021 with a record volume of €25 bn (Figure 33).

Intel is the most active foreign investor in Europe, planning to invest around €80 bn in the EU over the next decade.[117] Germany is the leading recipient of semiconductors and electronic components FDI in Europe.[118] Although to a lesser extent compared to the FDI into the EU countries, there has been also a significant increase in the EU outward investments recently.

Figure 33: Foreign direct investment in the EU27 in semiconductors



Source: Technopolis Group calculations based on fdiInsights

High investment dynamics is expected to continue in the near future due to mobilisation of considerable public support of the electronics industrial ecosystem, the demand for innovative technologies and the need to optimise processes and resources while reducing costs. Startups and scale-ups are going to get some direct support under the European Chips Act, through a combination of new and repurposed funding.[119]

Overall, investments in new and advanced electronics technologies are going to remain at a high level. Companies developing advanced technologies, such as AI, quantum computing and design-improved semiconductors are expected to continue to attract investments.[120] Given the high need of innovations in digital and green technologies and the necessity to strengthen the innovation position of EU in the electronics industry, innovations and investments in them remain of fundamental importance for Europe. Difficulties is accessing venture capital represent a serious barrier for technological advances in electronics that drive the digital and green transition.

117 https://tradeandinvestmentpromotion.com/intel-announces-initial-investment-of-over-e33-bn-for-rd-and-manufacturing-in-eu/
118 https://www.investmentmonitor.ai/features/intel-europe-semiconductor-fdi-investment/
119 https://sciencebusiness.net/news/Digital/The-Ecosystem-EU-Chips-Act-starts-to-shape-innovation-landscape
120 https://www.eetimes.eu/tracking-2022s-us38b-in-semiconductor-investments-for-startups/

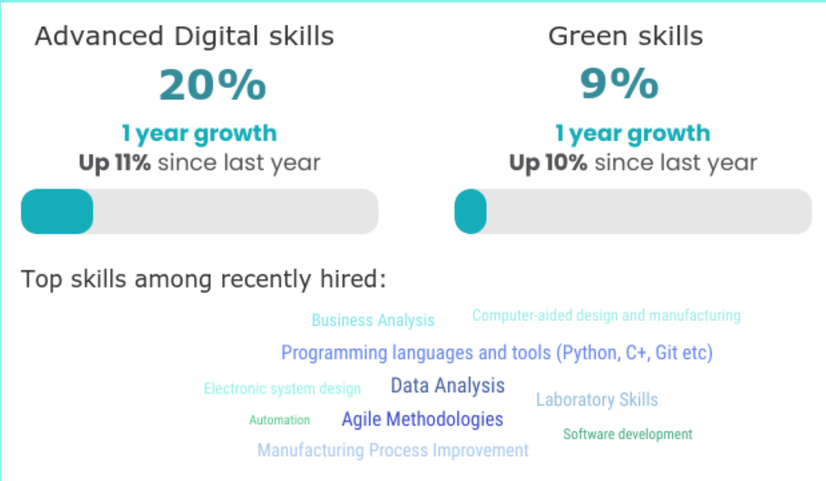
5. Skills

Key findings

Across the EU27 the demand for skills that underpin digital and green transition within the electronics industrial ecosystem is huge. At the same time, the number of students successfully completing degree programmes relevant for the development of advanced industrial electronics ecosystem is declining in many EU countries. Statistics on tertiary education graduates indicate that in the **disciplines most relevant for the digital and green transition of the electronics industrial ecosystem, there has been a notable downturn trend** in the relative distribution of those for many EU countries. Moreover, **tertiary graduates in environmental protection technologies make up a very small fraction of the total number of all tertiary graduates** varying between 1.4% and 0.1% across EU countries. Women are largely underrepresented in most STEM fields.

In terms of the current skills profile of professionals on the labour market, the analysis of LinkedIn data reveals that the electronics industrial ecosystem has the highest share of professionals with advanced digital skills across all other industries in focus. The analysis suggests that within the registered professionals on LinkedIn employed in the electronics ecosystem, **20% claimed having advanced digital skills** such as Internet of Things, cloud, AI, robotics etc. A share of **9% of electronics professionals have skills relevant for the green transition** including most skills related to low carbon and renewable energy technologies. Skills with the highest growth are computer-aided manufacturing, IoT, machine learning, AI, data analytics and design thinking.

Figure 34: Share of professionals employed in the electronics ecosystem with digital and green skills as captured by LinkedIn and the top skills with the highest annual growth among electronic companies in the EU27



Source: Technopolis Group calculations based on LinkedIn data, 2023

As empirical evidence suggests, the most critical job profiles that are the most sought after and the most difficult to fill are software and design engineers, along with data scientists and cybersecurity experts. At the same time, there is an **increasing shortage of professionals in the electronics production environment, and automation specifically**. In terms of skills needed, machine learning and AI, data analysis, systems design and system architectures, digital and software skills as well as knowledge of new materials are most critical.

This section aims at analysing trends in the supply and demand of skilled professionals relevant for the green and digital transition based on data from different sources combining systematically collected data by official statistics, like Eurostat and experimental data from LinkedIn and Cedefop. LinkedIn data enables to identify trends in the development and supply of skilled professionals in advanced technologies related to both digital and green transition. To harvest the data from LinkedIn, keywords capturing skills in each advanced technology category were defined and validated by industry and technology experts. They were subsequently used to construct queries for searching the database. Cedefop Skills intelligence provides insights into jobs and skills requested in online job advertisements by its dataset 'Skills in online job advertisement'. This dataset currently covers 28 European countries and was developed based on the collection and analysis of more than 100 million online job ads from July 2018 onwards.

Skills that the electronics industrial ecosystem mostly require are related to STEM (Science, Technology, Engineering and Mathematics) disciplines. Green skills have been defined as skills related to environmental protection and services, low carbon technologies, renewable energy, the circular economy and clean production technologies. (Advanced) digital skills have been defined in the context of digital technologies specified by the project, notably in artificial intelligence, cloud computing, connectivity, robotics, Internet of Things, augmented and virtual reality, and blockchain.

Ambitious societal projects and technological trends, such as tackling global warming, automation and AI, autonomous driving, require progress in semiconductor technology, for which skills are critical.[121] At the same time the number of students successfully completing electrical and electronics engineering studies and the subsequent Ph.D is declining in many EU countries. Consequently, major players of electronics industrial ecosystem are struggling to attract enough talent to meet their tech-industry needs. Against the backdrop of the planned expansion and ramping up of advanced semiconductor sector in the EU, the challenge is a most pressing one.

5.1. Existing green and digital skills among electronics industry professionals

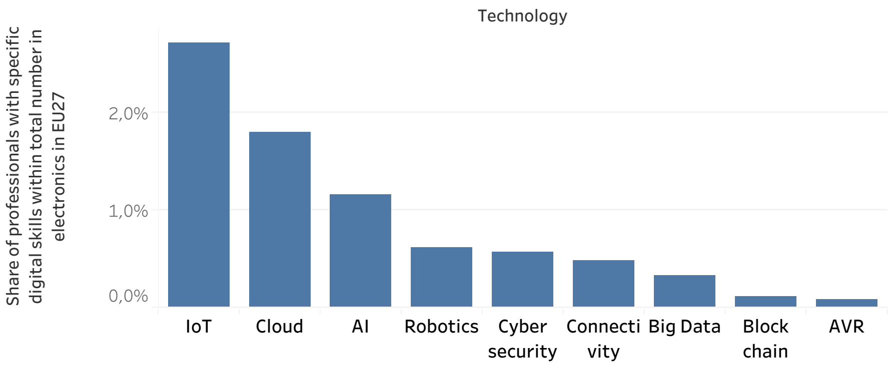
The market supply of labour is represented by the number of workers/professionals of a particular type and skill level who are willing to supply their labour to companies. LinkedIn data can measure this supply by providing insights about the **number of professionals on the market with green and digital technological skills relevant to the electronics industrial ecosystem** (Figure 35). Data have to be interpreted in the light of the use of LinkedIn within people employed in the electronics industry and country differences in representativeness need to be taken into account (please see more information in Annex B on methodologies).

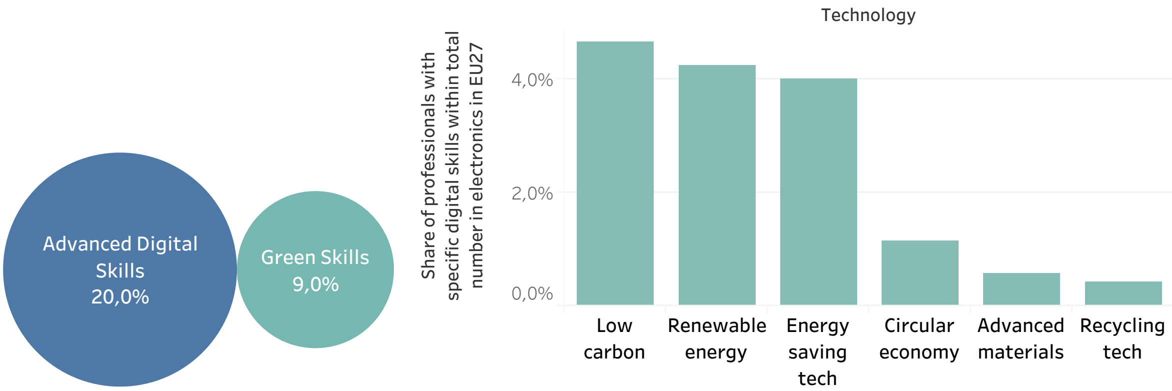
The analysis suggests that within the registered professionals on LinkedIn employed in the electronics ecosystem, **20% claimed having advanced digital skills such as Internet of Things, cloud, AI, robotics etc**. Electronics had the highest share of advanced technology skilled people among all other industrial ecosystems that indicates both the enabling role and the progress in digitalisation of the industry.

LinkedIn data indicates that **9% of electronics professionals have skills relevant for the green transition**. Low carbon and renewable energy are among the highest share that reflects not only the green transition of the electronics industry but its role in advancing the green transition of other sectors. Interestingly recycling technology related skills are possessed only by a small share of professionals, which calls the attention that more needs to be done to advance the recycling of electronic components.

[121] Rae 2022. Let's Get Vocal About European Chip Prowess. In: *EE Times Europe* (November 2022).

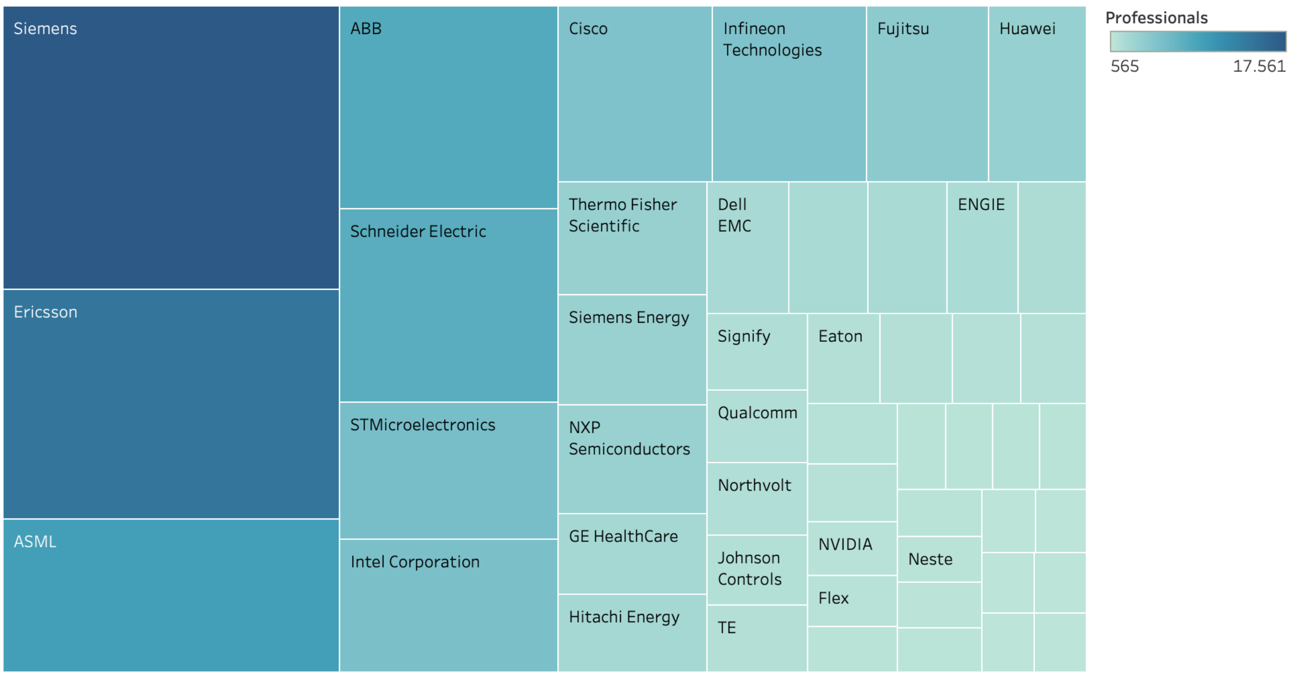
Figure 35: Share of professionals employed in electronics with green and advanced digital skills and with a profile on LinkedIn





Source: Technopolis Group calculations, 2023

Figure 36: Electronics companies in the EU27 with the highest share of both digitally and green skilled workers on LinkedIn



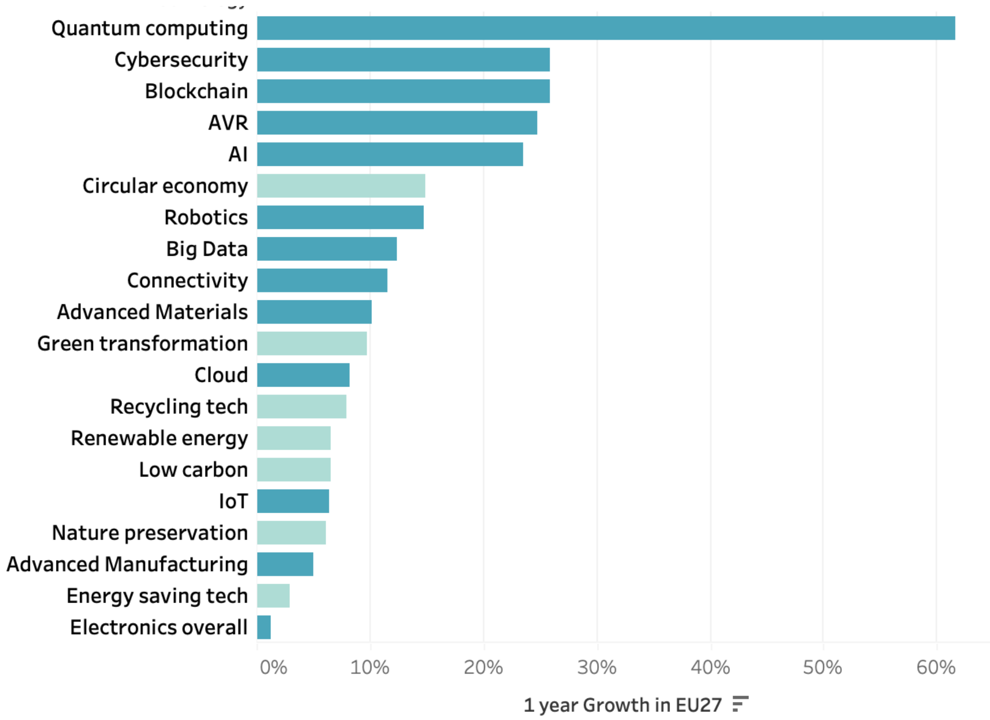
Source: Technopolis Group calculations, 2023

Progress over time

The change in the number of professionals with advanced digital or green skills have to be put in the context of the overall employment patterns. The total number of professionals in electronics on LinkedIn has decreased during 2020-2021 but has slightly increased from 2021 to 2023 (annual 1%). Compared to this, the share of professionals with digital or green skills has witnessed a steady growth over the past years: the **number of advanced digitally skilled professionals grew by 11% and green skills 10% within EU electronics over the period from 2021-2023 on LinkedIn**.

Within the advanced digital and green technologies in the focus of this report, skills related to several technologies are developing dynamically in the EU27. Among the selected digital and green technologies, it is found that **quantum computing technologies are gaining ground** although the overall number of workers with these skills remains limited (this explains the high growth rate). R&D and industrial activities related to quantum technologies are increasing year over year. Further fast expanding technological skills refer to **cybersecurity, blockchain, augmented and virtual reality and artificial intelligence**.

Figure 37: Annual change in the number of professionals in electronics with specific advanced digital and green technological skills (technologies that are specifically tracked within this project)



Source: Technopolis Group calculations, 2020 and 2022

A different analysis of the fastest growing skills among professionals employed in companies belonging to the electronics industrial ecosystem, the analysis of LinkedIn data reveals that expertise in **data analysis and programming** have been growing the most over the past years (Figure 39). Different advanced skills are required to ensure a smart digitisation and automation of electronics industrial ecosystem. For the connection between the physical and the digital world, the application of data analysis tools is necessary. Of central importance are capabilities that allow to achieve optimisation and interaction of the processes in R&D, design, production, logistics and the provision of services.

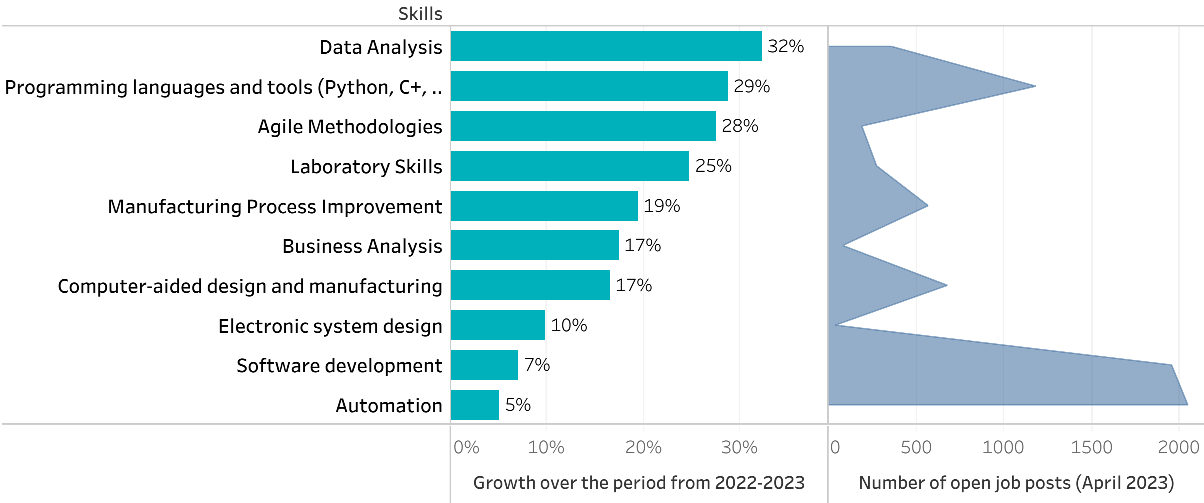
Skillsets that had further high growth are related to **computer-aided design and computer-aided manufacturing** such as three-dimensional interactive applications, 3D modelling and product lifecycle management. CAD/CAM (computer aided design) and (computer assisted manufacturing) systems are highly relevant, since they will allow to design, simulate, and monitor models of products and processes. Correspondingly, related skills in CAD, 3D design and manufacturing, process improvement and quality assurance are in high demand, as reflected by LinkedIn data. Furthermore, the electronics industrial ecosystem continues to require different skills to address the industrial and manufacturing needs, such as skills in semiconductor fabrication, mechanical engineering, FTIR and UV/Vis spectroscopy, just to name a few.

Programming skills that are also underpinning artificial intelligence grew as well. For example, engineers often use Python, MATLAB® and Simulink® product families to design and simulate signal and image processing systems and control systems by capturing algorithms and system models.

Software development more in general is dynamically expanding reflected also in the number of open job posts.

The **growing skills around manufacturing process improvement, agile methodologies, business analysis** can reflect ongoing restructuring within the broader semiconductor industry.

Figure 38: Skills with the highest growth rate among the professionals working in companies in the electronics industrial ecosystem in the EU27 and with a profile on LinkedIn



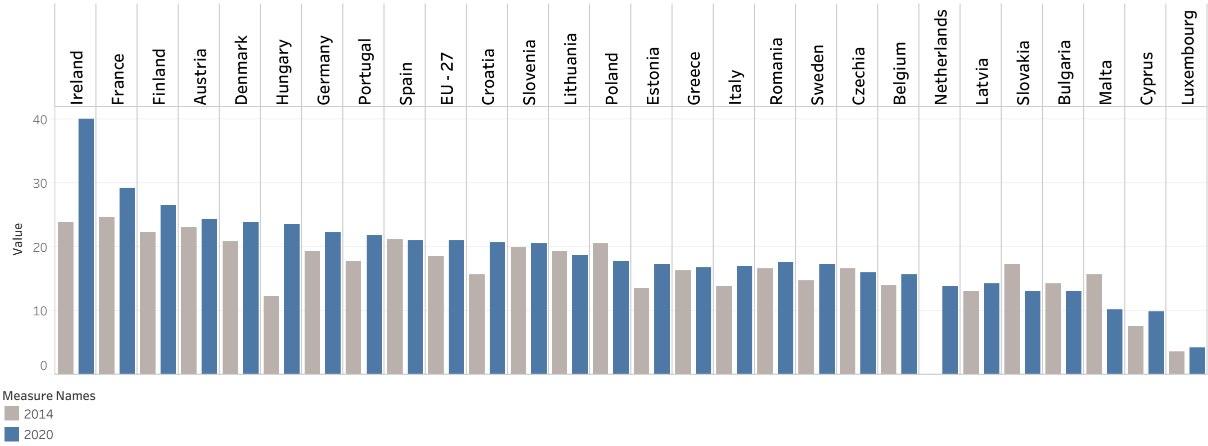
Source: Technopolis Group calculations based on LinkedIn data, 2023

Country patterns

Skills with the greatest demand within the electronics industrial ecosystem are closely linked with STEM disciplines. A meaningful comparison between countries can be obtained if STEM graduates are considered alongside the total number of respective age cohort. The indicator for the EU27 is 20.9 STEM graduates per thousand young people in 2020. Among the highest-ranking countries with an indicator of over 20 per thousand, are Ireland, France, Finland, Austria, Denmark, Hungary, Germany and Portugal (Figure 39). While those that are lagging furthest behind, with an indicator of fewer than 14 per thousand, are the Netherlands, Bulgaria, Slovakia, Malta, Cyprus and Luxembourg. A number of countries display a significant expansion in STEM graduates since 2014. In Hungary, the share of STEM graduates in 2020 was 93% higher, compared to 2014. Further countries that notably increased their share in STEM disciplines in 2020 compared to 2014 are Ireland (+67%), Croatia and Cyprus (+ 31%), Estonia (+28%), Portugal and Italy (+22%), and Luxemburg (+20%). Countries with STEM growth above the EU average (+13%) involve Finland (+19%), France (+18%), Sweden (+17%), Germany (+16%), and Denmark (+15%). In a number of EU countries there has been a noticeable decline in the supply of STEM graduates in last years. These are: Malta (-36%), Slovakia (-24%), Poland (-14%), and Bulgaria (-8%). Women are largely underrepresented in the most STEM fields. Only in Romania, Poland, Greece and Estonia they account for around 40% of all STEM graduates.

At the other extreme are countries where women make up less than 27% of all STEM graduates: Finland, Luxembourg, Belgium and Germany.[122]

Figure 39: Graduates in tertiary education, in STEM disciplines per 1000 of population, aged 20-29



Source: Eurostat

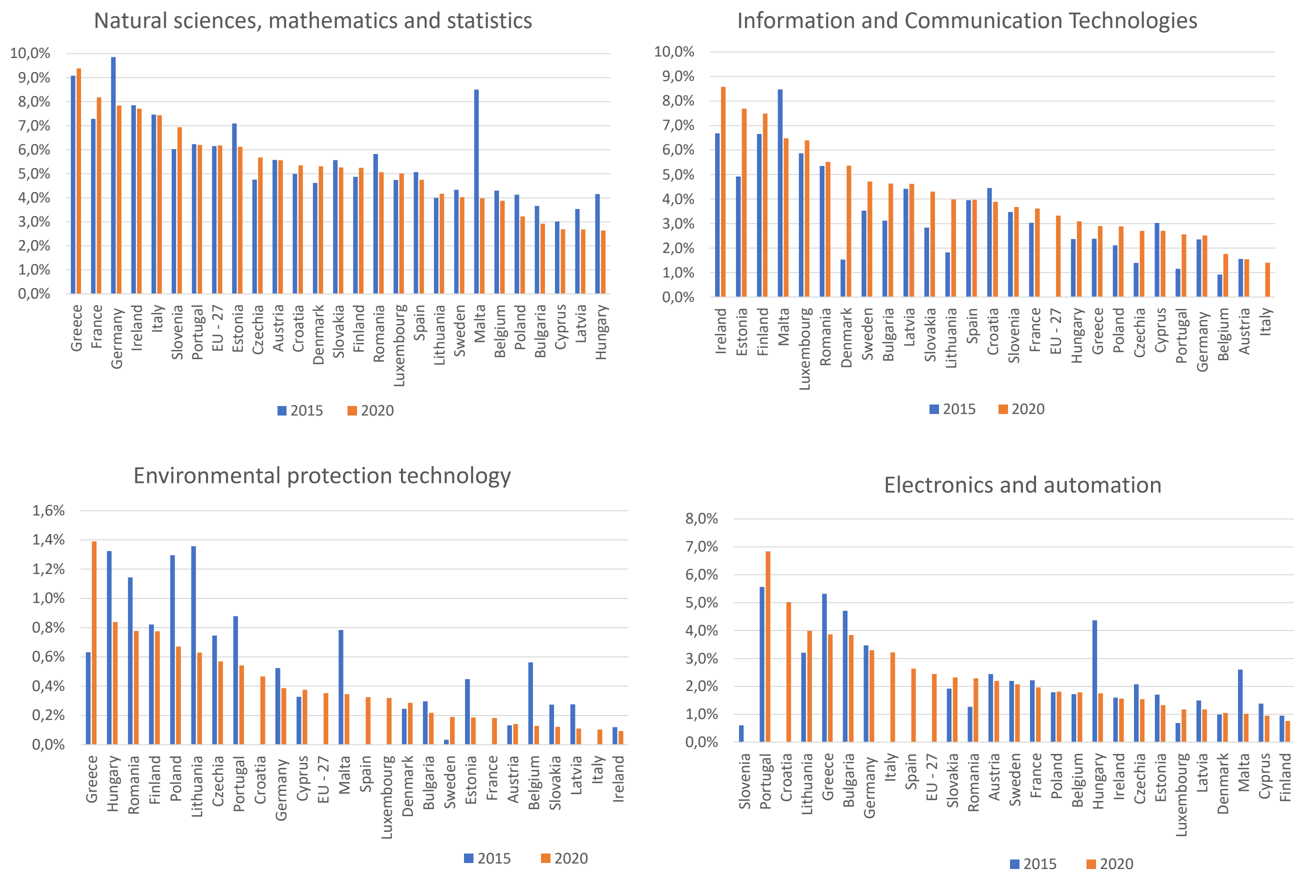
When looking at the dynamics of the tertiary education graduates' statistics in the disciplines most relevant for the digital and green transition of the electronics industrial ecosystem, there has been a notable downturn trend in the relative distribution of those for many EU countries (Figure 40). In the field of natural sciences, mathematics and statistics, the relative share of tertiary graduates dropped sharply in 2020 compared to 2015 in (descending order) Malta, Hungary, Latvia, Poland, Germany, and Bulgaria. Only Czechia, Denmark, Slovenia and France have some noticeable positive shift in favour of the proportion of graduates in natural sciences, mathematics and statistics in 2020 compared to 2015. Tertiary graduates in environmental protection technologies make up a very small fraction of the total number of all tertiary graduates varying between 1.4% and 0.1% across countries. Their relative share decreased further in most of the EU-countries in recent years. Also, in the highly relevant for the modern electronics industrial ecosystem disciplines in the field of electronics and automaton, the relative share of graduates decreased in recent years in most of the EU-countries. Only in the area of ICT disciplines, the relative proportion of tertiary graduates was higher in 2020 for most EU-countries compared to the share in 2015. However, in many EU-countries, such as Italy, Austria, Belgium, Germany, Portugal, Cyprus, Czechia, Poland and Greece, the fraction of ICT graduates compared to the total number of tertiary graduates is extremely low. Against the background of the present digitisation needs and the unprecedented demand in advanced IT technologies and skills, this appears particularly problematic. Conversely, for some EU-countries a relatively high share of ICT specialists supply is characteristic, including Ireland, Estonia, Finland, Malta, and Luxembourg.

Overall, there is a constant rising demand for software development professionals in the EU. The most important drivers of demand are the digital transformation and automation.[123] In many EU countries, the software industry has recently benefitted from the influx of ICT professionals from Belarus, Russia and Ukraine.

The above analysis reveals a severe shortage of skills in many disciplines relevant for the digital and green transition.

[122] https://www.umultirank.org/blog/In-which-European-countries-are-STEM-graduates-most-highly-recognised/
[123] https://plgbc.org.pl/wp-content/uploads/2021/09/100-most-important-trends-in-the-cee-economies.pdf

Figure 40: Share of tertiary education (levels 5-8) graduates in total number of all tertiary education graduates



Source: Eurostat

5.2. Demand for skills based on Cedefop data

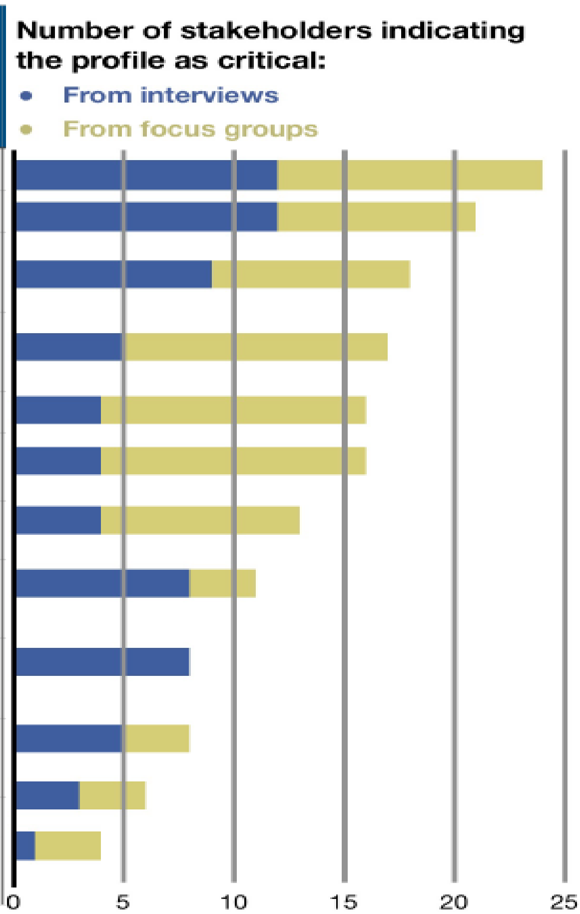
A recently released report, based on comprehensive survey results conducted by the METIS project[124], revealed that the absolute majority of the respondents (96%) representing microelectronics industry in Europe systematically encounters (at least) some extent of mismatch between the skills provided and the skills needed by their organisation.[125]

According to the study, the **most critical job profiles that are the most sought after and the most difficult to fill are software and design engineers** (system design engineers, digital design engineers and analogue design engineers). The design related skills are among the most critical skills with rapidly widening supply shortage due to the increasing demand. The demand for and shortage of software and design engineers, but also **data scientists and cybersecurity** experts have grown considerably in the last years. At the same time, there is an increasing shortage of professionals in production environment, such as **test, application and process engineer, as well as maintenance and robotic engineers.** In terms of skills needed, machine learning and AI, data analysis, systems design and system architectures (SoC, SiP, SoP, complex ASIC), digital skills and software skills (especially embedded software programming), and knowledge of new materials were identified as most critical (Figure 41).

[124] The four year METIS project (EU project) was launched in November 2019 and coordinated by SEMI Europe. The project investigated skill needs of the European microelectronics industry. It describes the skill needs and new job profiles in demand of the European microelectronics industry.
[125] Coulon 2022. METIS Report on Skills Strategy, Skills Anticipation and Monitoring. Microelectronics Pact for Skills.

Figure 41: Most needed skills in EU microelectronics

N°	Skill / Knowledge	Alternative names
1	Systems architectures	System engineering
2	Data analysis	Big data
3	Artificial Intelligence / Machine learning	Especially for software engineers, test engineers and design engineers
4	Knowledge of applications	
5	Quality / reliability	
6	Hardware / Software (HW/SW) integration	Hardware / Software co-design
7	Security	Security-by-design / Cybersecurity
8	Knowledge of new materials	Knowledge of new materials and their applications
9	Software skills	Shift from hardware to software affecting most of the profiles
10	Analog design	Analog / Analog IC / Mixed-signal / RF-IC design
11	Environmental awareness	
12	Social inclusion and diversity	



Source: (Coulon 2022), METIS-Study

Skills demand in the electronics industrial ecosystem has been analysed following the skills intelligence insights of Cedefop. This dataset covers the EU27 Member States (and UK) and is based on the collection and analysis of more than 530 online job advertisement sources (424 distinct websites) which are open-access sites. The dataset provides information on most requested occupations and skills across European countries based on established international classifications, e.g., ISCO-08 for occupations, ESCO for skills, and NACE rev. 2 for sectors.

Specific to the electronics industrial ecosystem[126], **there were 1 178 771 unique job advertisements from companies between 2019-2022.** The number of online job advertisements within electronics in EU27 countries amounts to 397 457 in the year 2022. Skills have been analysed related to the green and digital transitions. The European multilingual classification of Skills, Competences, Qualifications and Occupations (ESCO) is used as follows:

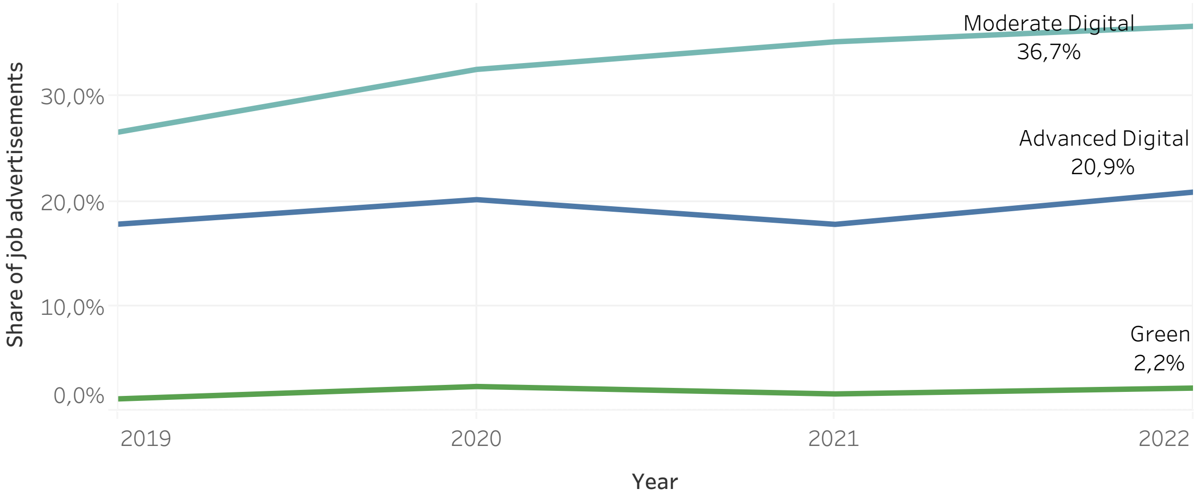
- **Green transition related skills** (ESCO v1.1.) are those knowledge and skills which reduce the negative impact of human activity on the environment. The labelling of skills and knowledge concepts as green follows a methodology based on a 3-step process, which combines human labelling and validation, and the use of machine learning algorithms.
- **Moderate and Advanced Digital skills** (ESCO v1.1.1 which is currently being updated) are competences which involve the confident, critical and responsible use of, and engagement with, digital technologies for learning, at work, and for

[126] In the case of the electronics industrial ecosystem the dataset was filtered for the NACE C26 industries.

participation in society. The labelling of skills and knowledge concepts follows a 5-steps methodology, which combines human labelling and validation with the use of machine learning. Within digital skills, we distinguish between moderate digital skills (that do not include basic Microsoft office skills but include specialised software used in the industry, the use of statistical software etc) and advanced digital skills (a category that is filtered for digital technologies highlighted in the methodological report including AI, big data, robotics, IoT, cloud, augmented and virtual reality, blockchain).

The share of online job advertisements that required any form of **moderate digital skills (excluding basic IT office skills) was 33.07%** over the period from 2019-2022 (36,7% in 2022), while this percentage was **19.32% for advanced digital skills** (20.9% in 2022). Requirements related to the **green transition** appear less often on the advertisements notably in a very small share **1.82%** of the cases. Both the number and share of job ads with digital and green skills requirement increased over time.

Figure 42: Share of online job advertisements that demand digital and green transition related skills in the electronics industrial ecosystem within the total number of electronics job ads



Source: Technopolis Group calculations based on Cedefop data, 2023

In terms of geographical coverage, the top countries are also the ones having the highest share of online job advertisements that contain transition skills with France leading (35.36%) followed by Italy (28.63%) and Germany (13.96%).

The more sought after advanced digital skills (top 5) are:

- Computer programming
- Robotics
- Databases
- Online analytical processing
- Object oriented modelling

The green skills are significantly more limited compared to digital, notably 8 632 job advertisements in 2022. Among these, the more sought-after green skills are:

- Energy efficiency
- Environmental legislation
- Emission standards

6. Green performance of the ecosystem

Key findings

Semiconductor manufacturing consumes large volume of natural resources. Harmful to the environment emissions from semiconductor industry are generated during various phases of the value chain. Growing production of semiconductors requires even more resources. The consumption of resources is also increasing when the chip structure is getting smaller. Hence, to reduce environmental footprint during the production is of crucial importance in the EU and companies need to undertake efforts to reduce raw materials used, energy and chemical usage as well as to improve recycling and reuse. Many companies have made self-commitments to reduce their environmental footprint.

In terms of greenhouse gas emissions, the electronics ecosystem contributed with **1.6% to the total GHG emissions of all industrial ecosystems**, most part originating from manufacturing of electronic components. The electronics industrial ecosystem was **responsible for 1% of the total material extraction of all industrial ecosystems** as the analysis of Exiobase data suggest. In terms of **land use and water consumption**, the impact of the industry on the environment grew steadily over the past years. The electronics industry has also a significant **impact on biodiversity**, both directly and indirectly. This indicator shows that it has **increasingly contributed to damage to the natural ecosystem over the past years.** Electronics was responsible for 2.3% of all damage caused by all industrial ecosystems.

Despite the support from policymakers the transition to a circular economy in various sectors including electrical and electronic equipment is still at a very early stage. **In 2019, the EU27 was responsible for the second largest share of e-waste globally and was the leading region in terms of generation of e-waste per capita.** In the EU ca. 40% of waste electrical and electronic equipment (WEEE) is collected and enters official treatment. In the EU, recycling of WEEE mainly focuses on the recovery of base metals, such as aluminium, copper, gold, silver and steel, which are easier to extract.

Figure 43: Environmental impact summary table

Environmental impact	Change from 2010 to 2021 (CAGR)
GHG emissions	-0.03%
Material use	-1.2%
Land use	+2.8%
Water use	+3.1%
Damage to the environmental ecosystem	+3.3%

Source: Technopolis Group calculations based on Exiobase, 2023

It is widely acknowledged that digital technologies have significant potential to help address environmental challenges and enable the shift toward a circular economy (CE).[127] Digitalisation contributes a lot to the 'dematerialisation' of many aspects of social and economic life and provides tools for climate change mitigation and adaptation. However, **digital technologies are responsible for 4% of global GHG emissions, which is more than the amount of pollution caused by aviation**. Their negative implication on natural environment is primarily linked to the huge energy consumption required to run digital technologies.[128] But not only the rising energy consumption is a serious ecological issue. Being a very fast developing technology, electronics produces the world's fastest growing waste stream[129] creating negative environmental effects and pollution that cause damages of human health and endanger biodiversity.[130]

The relationship between electronics and the environment is complex. On one hand, innovative electronics can provide solutions that contribute to sustainability. However, the manufacturing process for modern electronics requires large amounts of resources, such as energy and water, and involves the use of hazardous chemicals and gases. Additionally, there are significant emissions and waste generated throughout the production and disposal of electronics.

6.1. Environmental footprint of the electronics ecosystem

This report draws upon data from Exiobase and Eurostat with the aim to measure trends in the environmental impact of industrial ecosystems (Exiobase 3.8[131]). Whilst Eurostat represent the official statistics, Exiobase is a legitimate source of information referred to for example by the European Environmental Agency[132], the EC/JRC community[133], Eurostat[134], and by the European Commission to propose the regulation on carbon border adjustment mechanisms[135]. Pressure to environments refer to trade-embodied resources utilisation, and trade-embodied impacts. Resources utilisation is captured with four main dimensions are considered for cross-industry comparisons: embodied Land use, embodied Water consumption, embodied Materials Consumption, and Energy mix supplied to the industrial activity. In terms of impacts, there are two dimensions monitored: Air emissions (incl. GHG) and damage to the ecosystem.

The electronics industrial ecosystem consumes huge resources. In terms of greenhouse gas emissions, the electronics ecosystem contributes to **2% of the total GHG emissions of all industries**, most part originating from manufacturing of electronic components (see Figure 44). Its negative impact stayed stable over time.

Harmful to the environment emissions from semiconductor industry are generated during various phases of the value chain:[136],[137]

[127] ITU 2019. Turning digital technology innovation into climate action. Turning digital technology innovation into climate action.
[128] ITU 2019. Turning digital technology innovation into climate action. Turning digital technology innovation into climate action
[129] PACE 2021. Circular Economy Action Agenda for Electronics.
[130] PACE 2019. A New Circular Vision forElec tronics. Time for a Global Reboot. World Economic Forum.
[131] Exiobase is a time series of environmentally extended multi-regional input-output (EE MRIO) tables. EXIOBASE 3 (3.8.2) [Data set]
[132] EEA 2022. Visit 12/10/2022. https://www.eea.europa.eu/data-and-maps/data/external/exiobase
[133] Beylot et al. 2019. Assessing the environmental impacts of EU consumption at macro-scale. Journal of cleaner production, 216. Beylot et al. 2019.
[134] Remond-Tiedrez, I. and Rueda-Cantuche, J.M 2019. EU Inter-country Supply, Use and Input-output Tables: Full International and Global Accounts for Research in Input-output Analysis (FIGARO). Luxembourg: Publications Office of the European Union.
[135] EC (2021) REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL. Establishing a carbon border adjustment mechanism. COM(2021) 564 final.
[136] This breakdown can vary by fab/production facility based on various factors, including the amount of renewable energy used and the extent to which process-gas-abatement systems have been implemented (McKinsey & Company 2022d).
[137] IMEC 2022. The green transition of the IC industry; McKinsey & Company (2022d): Keeping the semiconductor industry on the path to net zero.

- **Raw material sourcing and processing**: Extraction of key raw materials broadly used in the semiconductor manufacturing, such as barium, gold, silver, lithium, tin, nickel and cobalt is the starting point of the environmental impact of the industry. Mining is often linked to the massive disturbance of ecosystems and habitat degradation. Further negative effects may occur, such as erosion and pollution of soil and water through using hazardous chemicals and the dissolution of heavy metals. In addition, smelting and refining are responsible for significant air emissions, water pollution and slag. Apart from having adverse environmental impacts, a lot of mining takes place in other parts of the world, including African countries, Indonesia, Philippines, Russia, China and Latin America under violations of human and workers' rights.
- **Manufacturing:** environmental risks during fabrication of electronics are linked to the use of chemicals, toxic substances and gases. According to the Electronics Watch, more than 400 chemical products are used in semiconductor manufacturing, some of them contain harmful ingredients, such as carcinogens, for example sulfuric acid, catechol, and naphthalene.[138] Many toxic substances are used in electronics manufacturing as a whole, such as benzene, lead, and arsenic, which when leaching out into soil, air, and water have detrimental effects on the environment and health.[139] Moreover, the production of semiconductors involves use of process gases and chemicals used during wafer etching, chamber cleaning, and other tasks. Common gases used are the highly potent greenhouse gases NF_3, PFCs, NFCs, and N_{20}, which have a high global warming potential (GWP).[140] Around 35% of the overall emissions generated during production of semiconductors are related to process gases and chemicals. Their consumption rises when the size of nodes shrinks.[141]

  Further negative environmental impact is related to the **electricity consumption to run production capacities**. It arises directly from the use of electricity, steam, heating, and cooling equipment. Around 45% of all emissions during processing and manufacturing are associated with electricity consumption. Besides, the **manufacturing processes require huge amounts of water**. According to a report of UNESCO, the global electronics industry, including semiconductor manufacturing, consumes ca. 12% of the world's total water supply.[142]

- **Downstream emissions** are associated with emissions generated through the usage of end products and waste streams that are generated at the end of lifecycle of electronic devices. In 2019, Europe was responsible for the second largest share of e-waste globally and was the leading region in terms of generation of e-waste per capita.[143] E-waste is among the fastest growing waste streams and make up to 20% of the total emissions generated during the entire lifecycle of electronics. A large negative impact is linked to the widespread use of plastics made of fossil fuels in the electronics and the limited recycling opportunities of plastics.

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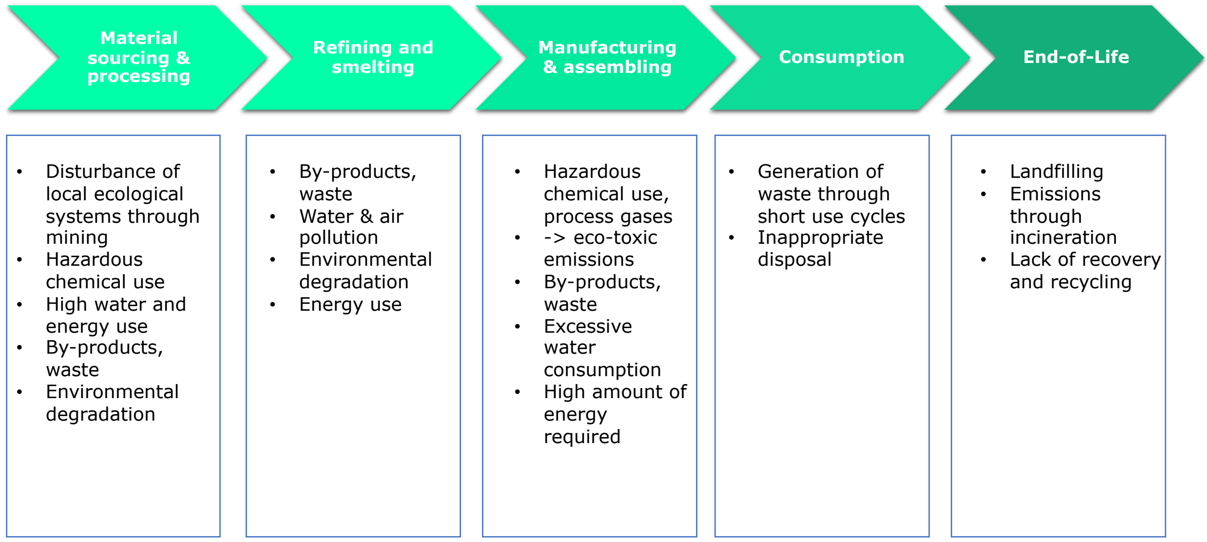
[138] Electronics Watch 2020. THE CLIMATE CRISIS AND THE ELECTRONICS INDUSTRY: Labour Rights, Environmental Sustainability.
[139] https://thesustainabilitycooperative.net/2022/03/24/are-electronics-bad-for-the-environment/
[140] NF_3 has a global warming potential that is 17.000 times more potent than CO2 (IMEC 2022).
[141] McKinsey & Company 2022c Sustainability in semiconductor operations: Toward net-zero production.
[142] UNESCO 2022 State of groundwater resources. The United Nations World Water Development Report.
[143] Rizos and Bryhn 2022. Implementation of circular economy approaches in the electrical and electronic equipment (EEE) sector: Barriers, enablers and policy insights.

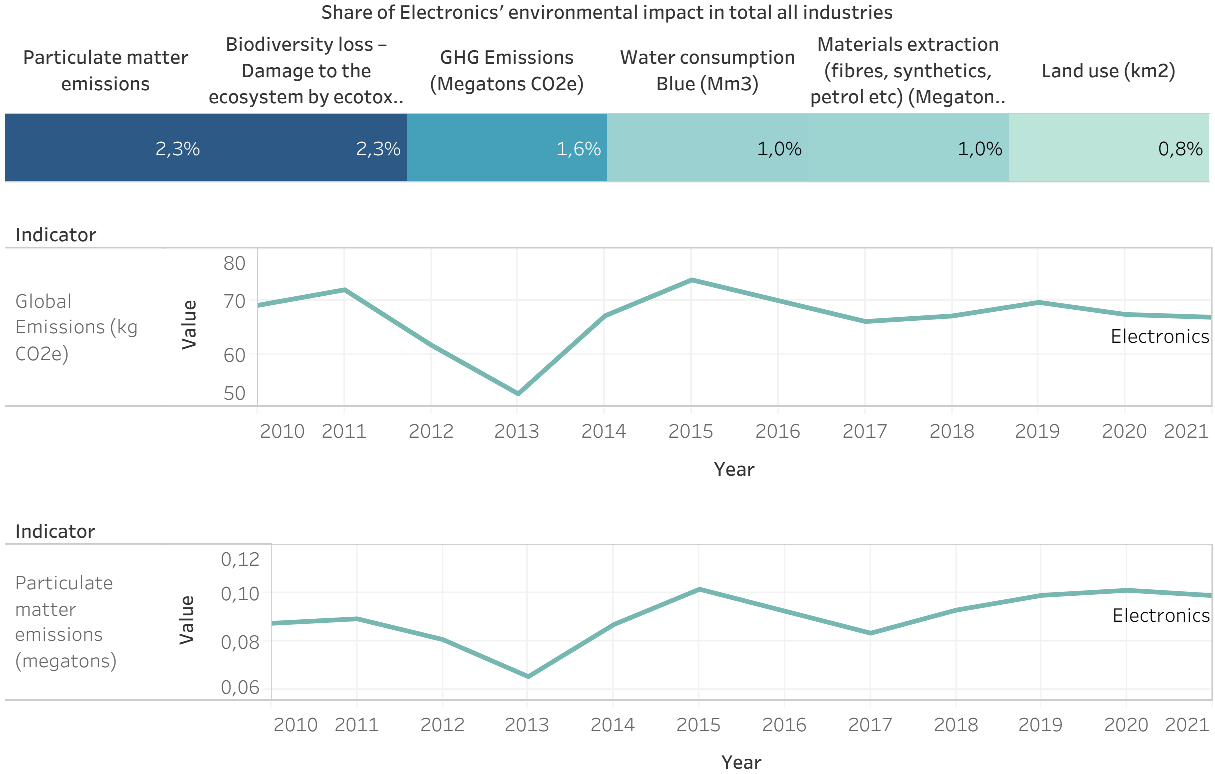
Figure 44: Environmental risks along the value chain of electronics

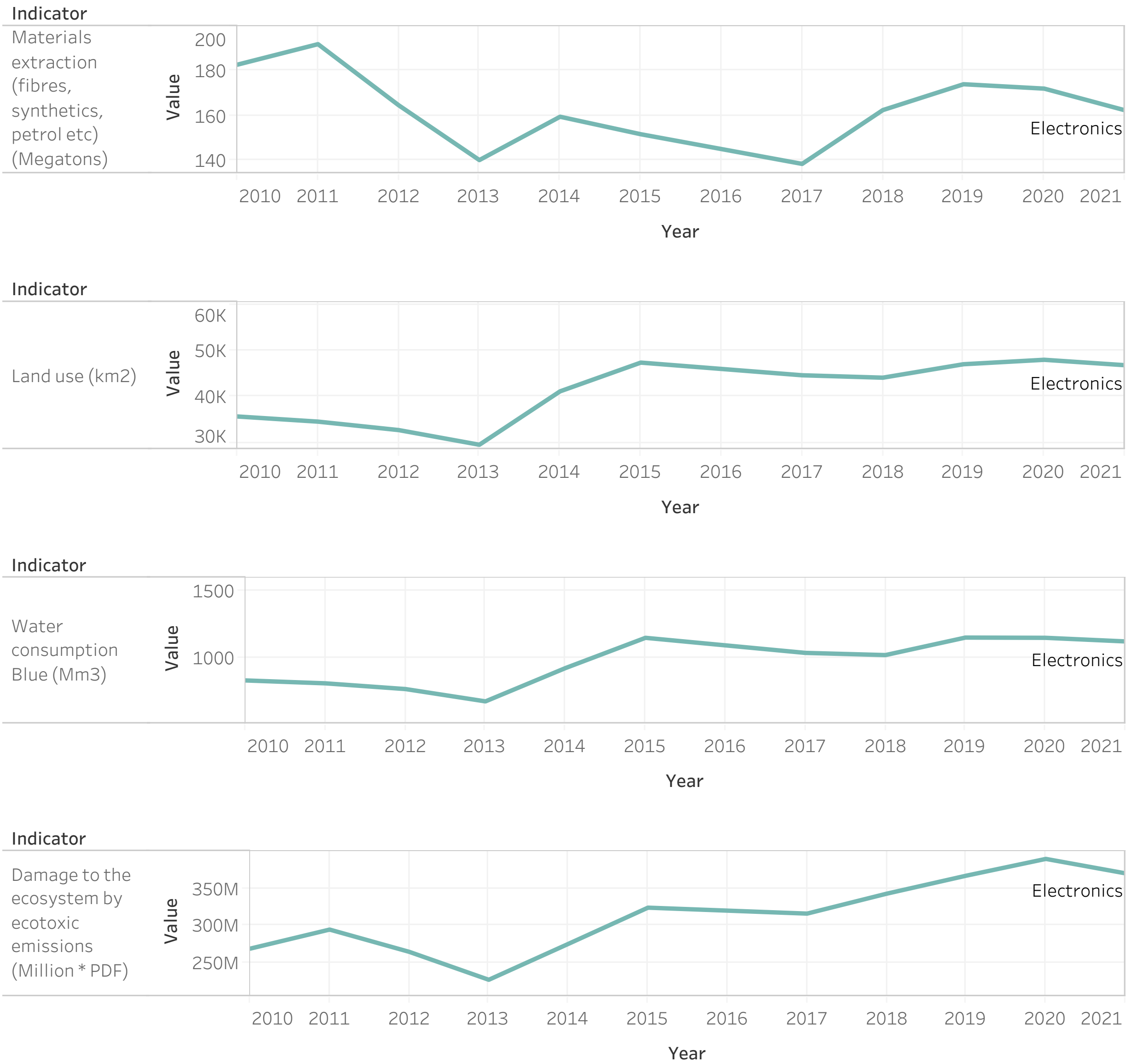


Source: own elaboration

The Figure below shows the summary of green performance indicators at EU level and its change from 2010 to 2021.

Figure 45: Environmental indicators that capture the environmental impact of the electronics industry, including both production and consumption accounts based on Exiobase data between 2010-2021





Source: Technopolis Group, 2022, based on Exiobase data

Resource use:

The electronics industrial ecosystem was **responsible for 1% of the total material extraction of all industrial ecosystems in 2021** as the analysis of Exiobase data suggests.

In terms of **land use and water consumption**, the impact of the industry on the environment grew steadily over the past years.

Biodiversity loss:

The electronics industry has a significant **impact on biodiversity**, both directly and indirectly. This indicator shows that it has **increasingly contributed to damage to the natural ecosystem over the past years.** Electronics was responsible for 3.5% of all damage caused by all industrial ecosystems.

6.2. Transition to circular economy

While being a major enabling technology for the green transition, especially empowering the provision of technology to reduce and optimise energy consumption, the large amount of energy and other resources, such as water, required during the production cycle of electronics represents a serious environmental challenge. With the growing demand of small node chips and the planned expansion of production capacities, the challenge of the extensive resource consumption is going to further exacerbate as their production is particularly energy and water intensive.[144] Compared to the production of a 28-nanometre with that of a 2-nanometre pattern, the electricity consumption for the latter is higher by a factor of 3.46, the consumption of ultra-pure water by a factor of 2.3 and greenhouse gas emissions by a factor of 2.5 per wafer.[145] However, the new generation of microprocessor chips with smaller nodes consumes around 30% less power, while improving performance and delivering additional density gains, compared to proceeding models.[146] Despite this significant offset, to reduce environmental footprint during the production is of crucial importance for the EU and companies need to undertake efforts to reduce raw materials used, energy and chemical usage as well as to improve recycling and reuse. Many companies operating in the electronics ecosystem have made self-commitments to reduce their environmental footprint. Recent survey of electronics companies in Europe on sustainability[147] demonstrated that the majority of companies have already undertaken some measures related to climate protection (56%) and pollution prevention (55%). 34% indicated that they are engaged in circular economy related activities. The efforts to improve ecological footprint are also driven by increasing customers' and end users' demand for sustainable solutions.

The use of renewable energy, water treatment, conservation and recycling would considerably minimise the environmental impact. In the EU, many companies operating in the ecosystem rely on the renewable energy sourcing and deployment of new technologies and techniques to reduce the overall resource consumption. Access to renewable energy is one of the major factors for companies to decide where to build new production sites. Many of them set a target to become carbon neutral by 2030 or later.[148] Overall, the EU semiconductor industry is taking stricter measures to reduce the emission of fluorinated greenhouse gases (F-gases) compared to other world regions. According to ESIA, the European semiconductor industry achieved 42% emission reduction of perfluoro compound gases[149] from 2010 to 2020.

As was demonstrated before, a lot of sustainability risks are linked to the complexity of the value chain and the limited transparency between players. Suppliers in other regions are often prone to keep confidential the framework conditions under which the materials are sourced, and components processed. Estimated 40% of globally traded chemical products in semiconductor manufacturing are not properly labelled and don't reveal the necessary information about possible harmful substances.[150] Many countries and the EU as a whole have established extraterritorial legislation to regulate the global activities of domestic companies and many multinational companies have adopted corporate responsibility to address sustainability risks.[151] Hence, companies in the EU, and other advanced countries, increasingly adopt measures to monitor and enforce social and ecological sustainability standards among suppliers. These include various instruments, such as codes of conduct,

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[144] For example, the leading global manufacturers of advanced semiconductors TSMS and Samsung produced in 2020 ca. 15 and 13 million tons of carbon respectively. TSMS uses more than 193,000 tons of water per day or 70 billion litres of water per year: https://earth.org/semiconductors/

[145] https://future-markets-magazine.com/en/markets-technology-en/semiconductor-production-set-to-become-greener/

[146] European Commission 2022. A Chips Act for Europe.

[147] Electronica 2022. Trend Index 2022. Sustainability in the electronics industry.

[148] https://www.eetimes.com/semiconductor-manufacturing-on-the-way-to-net-zero/

[149] Perfluorocompound gases include all compounds used in semiconductor industry: perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF6), and nitrogen trifluoride (NF3) Therefore, the reference to.

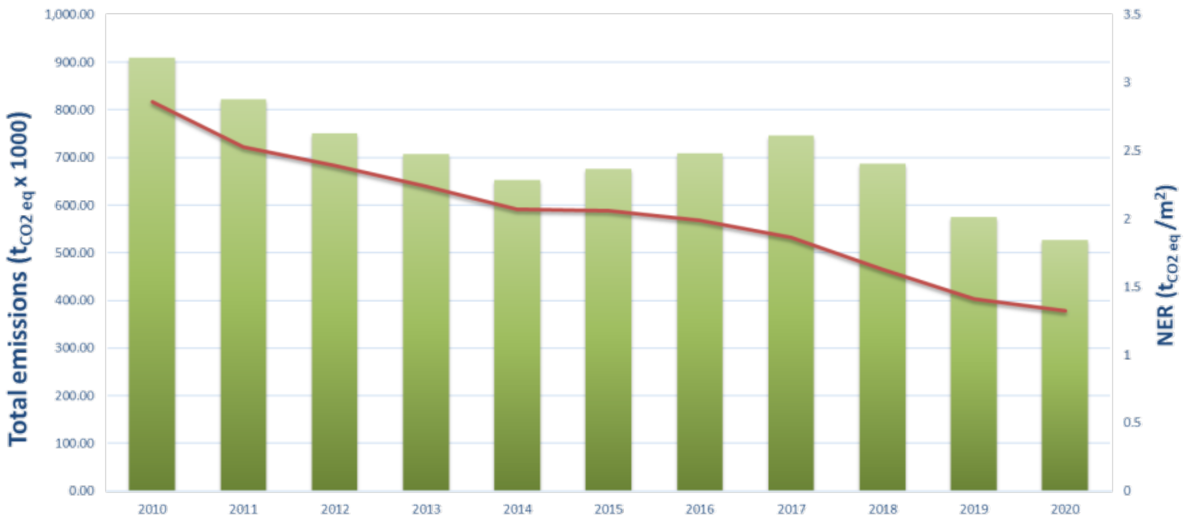
[150] Electronics Watch 2020. THE CLIMATE CRISIS AND THE ELECTRONICS INDUSTRY: Labour Rights, Environmental Sustainability.

[151] Evans and Vermeulen 2021 Governing electronics sustainability: Meta-evaluation of explanatory factors influencing modes of governance applied in the electronics value chain. Journal of Cleaner Production. Volume 278.

product traceability, supplier auditing and reporting, sustainable procurement, as well as sustainability certifications and labels.[152]

Moreover, the EU has introduced a number of instruments to improve the sustainability in the electronics sector. Among them are the EU directives on the Restriction of Hazardous Substances in Electrical and Electronic Equipment, the Ecodesign Directive and the Directive on Waste Electrical and Electronic equipment outlining requirements for the design of electronic products, their fabrication and end-of-life management.

Figure 46: European semiconductor perfluoro compound gas emissions 2010-2020



Source: ESIA[153]

In the EU ca. 40% of WEEE (waste electrical and electronic equipment) is collected and enters official treatment. High complexity of electronic devices, which negatively impacts the cost-effectiveness of recycling and recovering processes and lack of fully developed WEEE management infrastructure are major reasons for low collection and recycling rates. In the EU, recycling of WEEE mainly focuses on the recovery of base metals, such as aluminium, copper, gold, silver and steel, which are easier to extract. The recycling efficiency of these metals is above 50% owing to the availability of well-established industrial processes. At the same time, the recovery of other metals such as gallium, germanium, indium and rare earths is still challenging resulting in very low recycling rates of around 1%.[154]

Despite the support from policymakers, the transition to a Circular Economy in various sectors and industrial ecosytems, including electronic industrial ecosystem, is still at a very early stage. A lot of progress has been achieved through the enforcement of the regulatory framework at the EU, national, regional and local levels. Yet there is still a lot of room for improvements and considerable efforts need to be undertaken to improve the scope and speed of the green transition.

[152] Evans and Vermeulen 2021 Governing electronics sustainability: Meta-evaluation of explanatory factors influencing modes of governance applied in the electronics value chain. Journal of Cleaner Production. Volume 278.
[153] https://www.eusemiconductors.eu/sites/default/files/ESIA_PR_PFCEmissionReductions.pdf
[154] CEPS 2021. Barriers and enablers for implementing circular economy business models: Evidence from the electrical and electronic equipment and agri-food value chains.

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Appendix B: Methodological notes

Crunchbase and Net Zero Insights

Industrial classifications (industry tags) selected for the analysis included:

- Electronics
- Semiconductors
- in addition a key word search in the business descriptions.

Survey

The table below presents the overview of the sub-sectors included in the sampling frame, with corresponding sections according to NACE industrial classification. The survey respondents come from a mix of micro-enterprises (less than 10 employees), small enterprises (10-50 employees) and medium-sized enterprises (50-250 employees). In terms of geographical coverage, the survey has a balanced coverage of all EU countries.

Table 1: Survey sampling strategy

NACE		Sample size of the survey
C26	Manufacture of computer, electronic and optical products	300

Source: Technopolis Group and Kapa Research, 2023

Foreign direct investment data analysis

fDi intelligence[155] tracks cross-border greenfield investment both intra EU, extra EU and globally, covering the electronics industrial ecosystem among other industries. It provides real-time monitoring of investment projects, capital investment and job creation with powerful tools to track and profile companies that are active investors in the field. The data source tracks projects that are expected to create new jobs and do not cover merges and acquisitions.

Table 2: Concordance between NACE and FDI Intelligence data

NACE		Code in FDI Intelligence
C26	Manufacture of computer, electronic and optical products	Electronics, Semiconductors

Source: Technopolis Group and Kapa Research, 2023

TED data analysis

Table 3: Concordance between NACE and TED

NACE		CPV values
C26	Manufacture of computer, electronic and optical products	

Source: Technopolis Group and TED

[155] https://www.fdiintelligence.com/

Environmental certificates

ISO annual surveys report the number of companies/organisations with environmental certificates. Environmental certificates were the ISO 14000, which was updated requiring more stringent standards and practices in the year 2015. The new standard was then named ISO 14000/2015. Holders of the ISO 14000, starting from the year 2015, had to be re-certified to gain the new ISO14000/2015 certificate. New sustainability and environmental practices had to be put in place; with organisational change and financial requirements implied. Accreditation bodies had also to adopt new verification procedures, with their corresponding time lag. This may explain the drop in number of certified companies/organisations from 2015 to 2017.

Exiobase

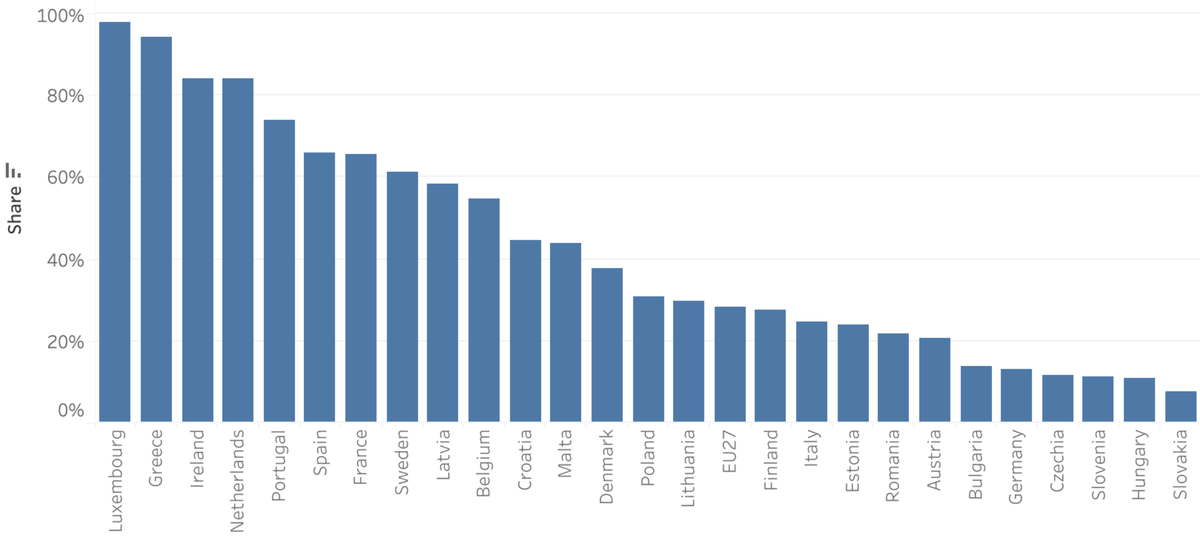
Exiobase is a time series of environmentally extended multi-regional input-output (EE MRIO) tables. Its coverage is by country and industry from 1995 to 2021 and has EU and extra rest of the world coverage. Source: Stadler, Konstantin, Wood, Richard, Bulavskaya, Tatyana, Södersten, Carl-Johan, Simas, Moana, Schmidt, Sarah, Usubiaga, Arkaitz, Acosta-Fernández, José, Kuenen, Jeroen, Bruckner, Martin, Giljum, Stefan, Lutter, Stephan, Merciai, Stefano, Schmidt, Jannick H, Theurl, Michaela C, Plutzar, Christoph, Kastner, Thomas, Eisenmenger, Nina, Erb, Karl-Heinz, … Tukker, Arnold. (2021). EXIOBASE 3 (3.8.2) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.5589597

LinkedIn's representativeness

To perform a representativeness analysis of LinkedIn, the available industry-specific dataset has been compared to Eurostat figures regarding the active population. Nevertheless, there are several limitations in conducting a robust representativeness analysis due to the fact that the two datasets have different origins, classification systems resulting in mismatches in the definition of some categories[156]. There are 149 industries available on the LinkedIn platform and categories are allocated according to the individual choice of the user or the affiliation to a company registered on LinkedIn as a company profile. The LinkedIn data is therefore broadly less representative of the entire population, however it provides insights on the current trends and developments and can be used as such.

Figure 47: Representativeness; the number of professionals in electronics industry and on LinkedIn compared to Eurostat SBS statistics

[156] See for details the ATI Methodological report: https://ati.ec.europa.eu/reports/eu-reports/advanced-technologies-industry-methodological-report



Source: Technopolis Group calculations based on LinkedIn vs Eurostat - annual enterprise statistics for special aggregates of activities (NACE Rev. 2)

Green skills – keywords used: Cleantech, Sustainability, Sustainable Development, Sustainable Business, Energy Efficiency, Clean Energy Technologies, Renewable Energy, Wind Energy, Biomass, Biomass Conversion, Solar Energy, Solar Power, Urban Forestry, Forest Ecology, Sustainable Communities, Organic Farming, Organic Gardening, Urban Agriculture, Organic Food, Waste Management, Waste Reduction, Recycling, Water Treatment, Water Resource Management, Water Purification, Green Marketing, Green Printing, Environmental Biotechnology, Environmental Science, Environmental Engineering, Environmental Management Systems, Environmental Protection, Wastewater Treatment, Ecology, Circular Economy, Zero Waste, Waste to Energy, Plastics Recycling, E-Waste, Carbon Reduction Strategies, Carbon Footprinting, Carbon Neutral, Energy Retrofits, Biodiversity, Biodiversity Conservation, Nature Conservation, Advanced Materials, Nanomaterials, Biomaterials, Reuse, Separation Process, Sorting, Equipment Repair, Natural Resource Management, Sustainability Reporting, Green Development, Sustainable Cities, Energy Conservation, Energy Management, Environmental Awareness, Environmental Impact Assessment, Environmental Compliance, Leadership in Energy and Environmental Design (LEED), Environmental Policy, Green Technology, Sustainable Design, Sustainable Architecture, Environmental Consulting, Maintenance and Repair, Solar PV, Solar Cells, Wind Turbines, Wind Turbine Design, Carbon Capture, Low Carbon Technologies, Low Carbon, Renewable Fuels, Renewable Energy Systems, Renewable Resources, Integrated Water Resources Management, Natural Resources, Biodiesel, Bioplastics, Waste Treatment, Waste Water Treatment Plants, Electric Vehicles, Hybrid Electric Vehicles, Multi-modal Transportation, Energy Efficiency Consulting, Recycled Water, Adaptive Reuse, Ecodesign, Life Cycle Assessment, Energy Optimisation, Alternative Fuels, Green Building, Green Infrastructure, Green Purchasing, Biodegradable Products, ISO 14001, EMAS, Environmental Standards

Digital skills – keywords used: data analytics, , online platforms, digital payment, Cybersecurity, Intrusion Detection, Malware Detection, Cloud Security, Cybercrime Investigation, Cyber Threat Intelligence (CTI), Cryptography, DLP, Malware Analysis, IDP; Vulnerability Assessment, Certified Information Security Manager (CISM), Computer Forensics, Cloud Infrastructure, Cloud Services, Google Cloud Platform (GCP), SAP Cloud Platform, SAP HANA, Everything as a Service (XaaS), Software as a Service (SaaS), Platform as a Service (PAAS), Infrastructure as a Service (IaaS), Private Clouds, Hybrid Cloud, Cloud Computing, Edge Computing, High Performance Computing (HPC), Serverless Computing, Robotics, Robot, Robotic Surgery, Human-robot Interaction, Drones, Connected Devices, Internet of Things (IoT), Robotic Process Automation (RPA), Wireless Sensor Networks, Embedded Systems, Cyber-Physical Systems, Smart Cities, Artificial Intelligence (AI), Biometrics, Cognitive Computing, Computer Vision, Deep Learning, Machine Learning, Natural Language Processing (NLP), Natural Language Understanding, Natural Language Generation, Reinforcement Learning, Speech Recognition, Supervised Learning, Unsupervised Learning, Big Data Analytics, Hadoop, Real-time Data, Yarn, Teradata Data Warehouse, Blockchain, Ethereum, Bitcoin, Cryptocurrency, Crypto, Distributed Ledger Technology (DLT), Hyperledger, Augmented Reality (AR), Virtual Reality (VR), Mixed Reality, Computer-Generated Imagery (CGI), Connectivity, M2M, 5G, SD-WAN, Home Automation, Flexible Manufacturing Systems (FMS), Smart Manufacturing, Smart Materials, Quantum Computing, Smart Devices, Intelligent Systems, Big Data, Computer-Aided

Design (CAD), Computer Science, MATLAB, C (Programming Language), Python (Programming Language), Digital Strategy, Digital Printing, Digital Marketing, Online Journalism, Revit, Building Information Modeling (BIM), JavaCard, R (Programming Language), Digital Imaging, Digital Media, C++, Collaborative Robotics, Industrial Robotics, Medical Robotics, Mobile Robotics, AutoCAD, Automation, Autodesk 3ds Max, Lumion, Data Analysis, Data Mining, 5G Core, Integrated Security Systems, Cloud Applications, Cloud Computing IaaS, Cryptocurrency Mining, CryptoAPI, Automated Machine Learning (AutoML), Machine Learning Algorithms, Virtual Reality Development, Virtual Data Rooms, Intelligence Systems, Robot Programming, Predictive Analytics, Data Lakes, Blockchain Analysis, Digital Publishing, Enterprise Software, Software Development, SAS (Software), SAP Products, SAP ERP, Online Payment, Online Payment Solutions; Online Travel, Online Marketing, Online Business Management, Online Advertising, Online Gaming, Web Services, Mobile Applications, Mobile Marketing, Java Database Connectivity (JDBC), Data Warehousing, Statistical Data Analysis, Data Modeling, Databases; Electronic Data Capture (EDC), Data Centers, Oracle Database, SAP Solution Architecture Data Entry, Data Management, Data Mapping, Web Applications, GIS Applications, Oracle Applications, Visual Basic for Applications (VBA), Computer Hardware, Computer Maintenance, Computer Network Operations, Computer Networking, Computer Graphics, Online Communications, Social Media Marketing, Digital Direct Marketing, Digital Illustration, Digital Video, Digital Photography, Xero, GPS Applications, GPS Devices, GPS Tracking, GPS Navigation, Microsoft Power Apps, Social Networking Apps, Google Apps Script, Social Media, E-Commerce, Data Intelligence, Online Platforms, Mobile Payments