European Commission

Monitoring the twin transition of industrial ecosystems

DIGITAL INDUSTRIAL ECOSYSTEM

Analytical report

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1. Executive Summary

Measuring performance and monitoring change within an industrial ecosystem are vital components that enable policymakers and industry stakeholders to track progress over time and obtain valuable feedback on whether the system is moving in the desired direction. This report is a contribution to the ‘Monitoring European Industrial Ecosystems’ project, initiated by the European Commission's Directorate General for Internal Market, Industry, Entrepreneurship, and SMEs, in partnership with the European Innovation Council and SMEs Executive Agency (EISMEA). Its primary objective is to present the current state and the advancements achieved over time in terms of the green and digital transition of the digital industrial ecosystem.

For each of the fourteen industrial ecosystem, a pathway for the green and digital transition, i.e., a **transition pathway**, is or will be developed. For the digital industrial ecosystem, this transition pathway is covered by the **Digital Decade Compass and policy programme.** The Digital Decade policy programme, with concrete targets and objectives for 2030, will guide Europe’s digital transformation in skills, infrastructure, business and government. This policy programme sets up an annual cooperation cycle, based on an annual cooperation mechanism involving the Commission and Member States, to achieve the common objectives and targets. In 2019, the digital industrial ecosystem employed 6.6 million people, and the value added was roughly EUR 674 billion. While, compared to the other industrial ecosystems, the digital industrial ecosystem is somewhere in the middle as regards employment and gross added value, in 2018, the ecosystem included 1.2 million firms, of which 99.8% were SMEs.

When the **COVID-19** crisis hit, it boosted the penetration of Information and Communications Technology (ICT) and digital adoption. For instance, due to the need for telework, online schooling & shopping, the demand for digital infrastructure increased substantially. However, at the same time, like in many other sectors, demand decreased (e.g., demand for hardware for the automobile sector) and supply chains were disrupted, slowed down or even stopped in many countries. Other challenges facing the digital industrial ecosystem include **under investment** and the dependence on other industrial ecosystems as well as world regions for key value chain components to support the industrial ecosystem. In addition, **insufficient levels of digital skills** in other industrial ecosystems hamper the prospects of future growth in the digital industrial ecosystem, despite considerable potential. The uptake of **digital technologies can enable a carbon-neutral EU**, however clashes related to energy consumption, resource use and recyclability persist.

In this project, the green and digital transition of industrial ecosystems have been analysed based on a tailored monitoring framework and dataset. The data include startup data, patent applications, trade and production data, investment data, online job advertisements and job profiles. The methodology of the data calculations is included in report on the conceptual and methodological framework.

Key findings about the digital transition

Technologies underpinning the digital industrial ecosystem include advanced manufacturing and robotics, as a lead technology, followed by artificial intelligence, big data, cloud technology, photonics, digital security, blockchain and internet of things (IoT). Datasets on patents, information on Technology Centres active in digital technologies as well as trade dependencies among technologies give insight into the **interrelationship between the industrial ecosystems and their underlying digital technologies**.

Trends in the evolution of **patent applications of advanced technologies related to the digital transformation as a share in the world total patent applications** show that China is increasing its efforts in digital technology patenting, whereas the EU27 and the USA are showing a decreasing trend in digital patenting over the period 2010 to 2020. Looking at patent applications in digital technologies reveals that the EU27 has the highest share of patent applications in advanced manufacturing technologies, followed by the Internet of Things. At the same time, a weakness in AI and big data is noted. AI and IoT are highlighted as particularly crucial technologies for their potential to produce efficiency and cost reduction in view of digital transformation of businesses.

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. The **Technology Centre Mapping** comprises information 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 ecosystem and beyond. A total of 159 Technology Centres active in the digital industrial ecosystem are identified in the mapping, with Spain, France and Germany hosting the highest number of Technology Centres in this domain.

As one aspect of resilience against potential crises, **trade dependency** on non-European imports of relevant goods is established for the digital industrial ecosystem and put **in relation to Europe's own production capacities**. For the digital industrial ecosystem, advanced manufacturing and robotics technologies are identified to be at the core, however, have lower dependencies than for the remainder of the digital domain. The auxiliary technologies dependencies are far more pronounced, especially for AI and big data.

Key findings about the green transition

There is a strong **interplay between the digital and green technologies, forming the core of the twin (green and digital) transition**. The green technologies included in this study that are particularly related to the digital industrial ecosystem include energy saving technologies and renewable energy technologies, which both rely on digital technologies for optimisation (energy saving and energy distribution). Analysis in the report zoom in on skills and startup analyses to assess the interplay between green technologies and the digital industrial ecosystem.

Skills data analysed build upon LinkedIn data, which is the largest professional network platform, which can be used for the identification of skilled professionals in advanced technologies and active in digital and green transition. **3.5% of professionals registered on LinkedIn indicate to have one type of green skill**. The most common green skills in the digital industrial ecosystem include sustainability, computer repair, environmental awareness, maintenance and repair, and renewable energy. Skills such as sustainability, environmental awareness, and renewable energy can be related to understanding and implementing sustainable practices and integrating eco-friendly principles into the industrial ecosystem. For the digital industrial ecosystem, 9 532 591 unique job advertisements were found from companies between 2019-2022 in the EU27. The **share of online job advertisements that required any form of green transition related skill was 1.9%.**

Looking at startup data, the link between the digital and green transformation have been captured by analysing **digital tech startups as part of the digital industrial ecosystem with a focus on the green transition** based on data sourced from the Crunchbase and Net Zero Insights databases. Looking at the absolute number of tech startups with an environmental objective, AI is the most common technology with a solution for the green transition. From the perspective of the technology, the start of technology driven start-ups with the highest proportion of green objectives arise from IoT based start-ups.

2. Introduction

2.1 Objectives

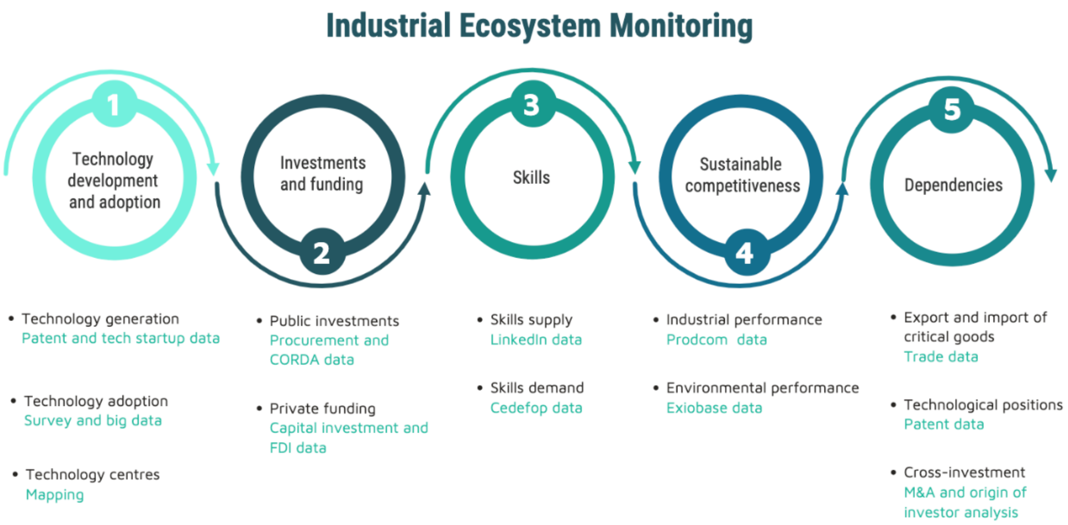
This report has been prepared within the '**Monitoring European industrial ecosystems'** project, initiated by the European Commission, Directorate General for Internal Market, Industry, Entrepreneurship and SMEs and the European Innovation Council and SMEs Executive Agency (EISMEA). The overall objective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

The EU's updated industrial strategy from May 2021 has defined 14 industrial ecosystems[1] – one of them being **Digital** - that is in the focus of this report. Industrial transition is driven by technological, economic, and social changes, and in particular by digital technologies and the shift to a green and circular economy. The process is however characterised by complex, multi-level, and dynamic development. To make transition sustainable, technological change alone is not sufficient. Systemic changes across value chains of industries and other levels of the socio-economic fabric – such as user practices, governance, policies, regulations infrastructure and industrial networks – are required.

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 and the main technologies to be monitored in the Figure below).

The **methodological report** that sets the conceptual basis and explains the technical details of each indicator is found on the EMI website. Some of the specific industry codes used throughout this analysis have also been included in Appendix B.

Figure 1: Overview of the monitoring and indicator framework



Source: Technopolis Group, IDEA Consult and Fraunhofer ISI

[1] construction, digital industries, health, agri-food, renewables, energy intensive industries, transport and automotive, electronics, textile, aerospace and defence, cultural and creative culture industries, tourism, proximity and social economy, and retail

Figure 2: Main technologies monitored in the EMI 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'**[2] of the Industrial Forum developed in 2022.

2.2 Definition of the ecosystem

This section highlights the definitions used to **delineate the digital industrial ecosystem**.

According to the European Commission's Annual Single Market Report 2021, the digital industrial ecosystem "covers ICT Manufacturing, Services (excluding telecommunications), and Telecommunications.[3]

In terms of NACE classifications, the digital industrial ecosystem typically covers:

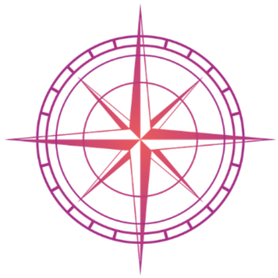
- J62 – J63: Computer programming, consultancy, and information service activities
- J61: Telecommunications
- J58: Publishing activities
- Partially C26: Manufacture of computer, electronics and optical products
- Partially S95: Repair of computers and personal and household goods

For each of the fourteen industrial ecosystem, a pathway for the green and digital transition, i.e., a **transition pathway**, is or will be developed. For the digital industrial ecosystem, this transition pathway is covered by the **Digital Decade Compass and**

[2] https://ec.europa.eu/docsroom/documents/49407/attachments/1/translations/en/renditions/native
[3] European Commission (2021) Annual Single Market Report 2021 https://commission.europa.eu/system/files/2021-05/swd-annual-single-market-report-2021_en.pdf

policy programme[4]**.** The Digital Decade policy programme, [5] with concrete targets and objectives for 2030, will guide Europe's digital transformation in skills, infrastructure, business and government. This policy programme sets up an annual cooperation cycle, based on an annual cooperation mechanism involving the Commission and Member States, to achieve the common objectives and targets.

Figure 3: Targets of The Digital Decade policy programme for 2030



Source: EC (2021). Europe's Digital Decade[6]

2.3 Industry state of play

In 2019, the digital industrial ecosystem employed 6.6 million people, and the value added was roughly EUR 674 billion. While, compared to the other industrial ecosystems, the digital industrial ecosystem is somewhere in the middle as regards employment and gross added value, the ecosystem has known the **largest employment growth and gross value added growth** between 2015 and 2019.[7] Furthermore, in 2018, the ecosystem included 1.2 million firms, of which 99.8% were SMEs.[8] Within the digital industrial ecosystem, the NACE category 'computer programming, consultancy and information service activities' (J62, J63) contribute most to the ecosystem's employment and added value.[9]

The **total production value for the digital industrial ecosystem** gives insight into the production performance of the overall ecosystem as delineated by the NACE 2 classification and weights identified in the Annual Single Market Report.[10] Data on production from Eurostat, notably Prodcom statistics, reveal the total values of production of manufactured goods carried out by enterprises located in EU27 over 14 years (from 2008 until 2021).[11]

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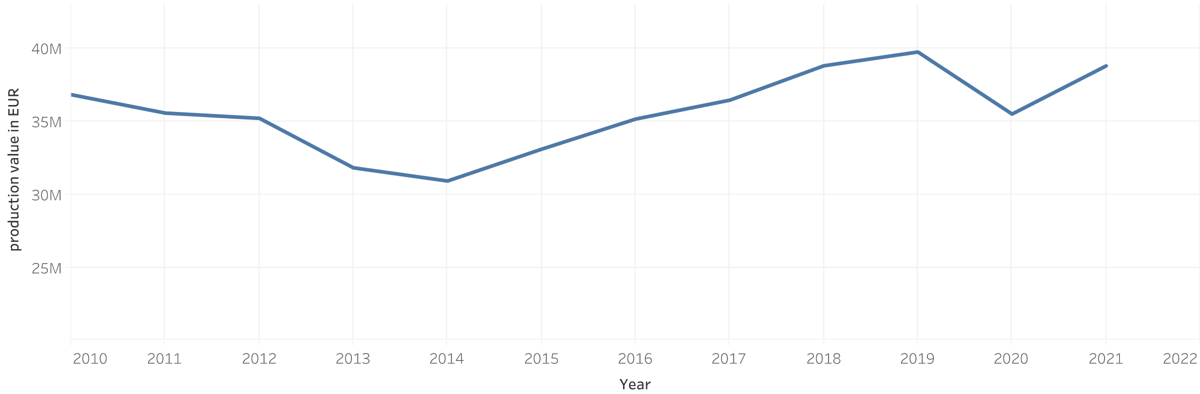
[4] European Commission (n.d.) Transition pathways for European industrial ecosystems https://single-market-economy.ec.europa.eu/industry/transition-pathways_en
[5] European Commission (n.d.) Europe's Digital Decade https://digital-strategy.ec.europa.eu/en/policies/europes-digital-decade
[6] European Commission (n.d.) Europe's Digital Decade https://digital-strategy.ec.europa.eu/en/policies/europes-digital-decade
[7] European Commission (2022) Annual Single Market Report 2022. https://ec.europa.eu/docsroom/documents/48877
[8] European Commission (2021) Annual Single Market Report 2021. https://commission.europa.eu/system/files/2021-05/swd-annual-single-market-report-2021_en.pdf
[9] European Commission (2021) Annual Single Market Report 2021. https://commission.europa.eu/system/files/2021-05/swd-annual-single-market-report-2021_en.pdf
[10] European Commission (2021) Annual Single Market Report 2021.
[11] Eurostat Prodcom https://ec.europa.eu/eurostat/web/prodcom/data/database

Results depicted in Figure 4 present the weighted sum of production of manufactured goods aggregated at NACE 2-digit level for the EII industrial ecosystem (thousands of euros).

The year 2020 clearly depicts a dip in the production related to the digital industrial ecosystem, attributed to the COVID-19 pandemic, however a swift recovery in 2021 illustrates the short-lived impact overall. Other notable trends include a downward trend in 2009 (economic crisis), almost lasting until 2014, after which a clear and positive trend is visible. The overall stability of the production values from 2008 to 2021 are evident for the ecosystem.

Figure 4: Production performance of digital industrial ecosystem in EUR thousands for 2010-2021



Source: IDEA Consult based on Eurostat [prom]

When the **COVID-19 crisis** hit, it boosted the penetration of Information and Communications Technology (ICT) and digital adoption. For instance, due to the need for telework, and schooling, online shopping, consumer interaction, the demand for digital infrastructure increased substantially. However, at the same time, like in many other sectors, demand decreased (e.g., demand for hardware for the automobile sector) and supply chains were disrupted, slowed down or stopped production in many countries. During later COVID-19 waves, the digital sector was not negatively impacted.[12] In fact, in 2020, more than 1 million ICT specialists entered the market, businesses provided more fully digitised products and services, and bought more cloud computing services.[13] Overall, the COVID-19 pandemic has radically changed the role of digitalisation in our society and economy and accelerated its pace. Digital technologies are regarded as imperative for working, learning, entertaining, socialising, shopping, and accessing everything from health services to culture.[14]

Challenges for the industry

There are challenges facing the **digital industrial ecosystem** and challenges for **digital transformation** in other sectors in general. The digital industrial ecosystem is suffering from **under investment** and the dependency from other regions for critical parts of the supply chains.[15] In addition, the **EU is dependent** on other regions, notably Asia and the US, for key digital capacities, such as hardware (e.g. fibre, electronic components, raw materials), computing power or software (e.g., data processing, cloud and edge computing).

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[12] European Parliament. Policy Department for Economic, Scientific and Quality of Life Policies. (2021). Impacts of the COVID-19 pandemic on EU industries. https://www.europarl.europa.eu/RegData/etudes/STUD/2021/662903/IPOL_STU(2021)662903_EN.pdf

[13] European Commission (2022) Digital Economy and Society Index (DESI) 2022. https://ec.europa.eu/newsroom/dae/redirection/document/88764

[14] European Commission (n.d.) Digital Principles. https://futurium.ec.europa.eu/en/digital-compass/digital-principles

[15] European Commission (2021) Annual Single Market Report 2021. https://commission.europa.eu/system/files/2021-05/swd-annual-single-market-report-2021_en.pdf

Looking at the challenges related to the overall digitalisation of the industry, the **Digital Economy and Society Index** (DESI) 2022 results show that while most of the Member States are making progress in their digital transformation, the adoption of key digital technologies by businesses, such as artificial intelligence and big data remains low, also among the EU frontrunners.[16] The report indicates that in 2021, only 55% of SMEs reached at least a basic level in the adoption of digital technologies. To reach the Digital Decade target, this percentage should be 90% by 2030. The report also indicates that 34% of enterprises rely on cloud computing (in 2021), 8% use Artificial Intelligence (in 2021), and 14% big data (in 2020), and it points to the large gap between large companies and SMEs in the deployment of these technologies. A common obstacle to a digital transformation is a **lack of understanding of the process and the steps required** to complete it.

Also, **insufficient levels of digital skills** hamper the prospects of future growth across industrial ecosystems, deepen the digital divide and increase risks of digital exclusion as more and more services, including essential ones, are shifted online.[17] There is a general shortage of ICT specialists across industrial ecosystems on the EU labour market and the number of vacancies keeps growing.

In the next years, it is crucial to support reforms and investments in the digital industrial ecosystems, but also in other industrial ecosystems in key areas such as connectivity, the development and deployment of advanced digital technologies (such as AI, blockchain, cloud and edge infrastructure and services), human capital, and the acceleration of the sustainable uptake of digital solutions and a cyber-resilient digital transformation.[18]

As many of the other ecosystem reports show[19], the uptake of digital technologies can enable a carbon-neutral EU. Digital technologies **support and provide functions that can catalyse the green transition**.[20] As a recent JRC report indicates: "*Monitoring and tracking can provide real-time information and be a catalyst for the circular economy. Simulation and forecasting can improve efficiency. Virtualisation of production and consumption changes sectors and reduces environmental impact by moving economic activities online. Using digital technologies, systems management can cope with an increasing complexity while optimising operations*." However, at the same time, the digital and green transition can also clash as digitalisation uses electricity and digital technologies are often resource-intensive and create waste.[21]

[16] European Commission (2022). Digital Economy and Society Index (DESI) 2022. https://ec.europa.eu/newsroom/dae/redirection/document/88764

[17] European Commission (2022). Digital Economy and Society Index (DESI) 2022. https://ec.europa.eu/newsroom/dae/redirection/document/88764

[18] European Commission (2021) Annual Single Market Report 2021. https://commission.europa.eu/system/files/2021-05/swd-annual-single-market-report-2021_en.pdf

[19] Including the Agri-food and Energy Intensive Industries industrial ecosystem reports

[20] Muench, S., Stoermer, E., Jensen, K., Asikainen, T., Salvi, M. and Scapolo, F., Towards a green and digital future, EUR 31075 EN, Publications Office of the European Union, Luxembourg, 2022, ISBN 978-92-76-52451-9, doi:10.2760/977331, JRC129319.

[21] https://joint-research-centre.ec.europa.eu/jrc-news-and-updates/twin-green-digital-transition-how-sustainable-digital-technologies-could-enable-carbon-neutral-eu-2022-06-29_en

3. Digital technologies underpinning the digital industrial ecosystem

The **technologies underpinning the digital industrial ecosystem** include advanced manufacturing and robotics, as a lead technology, followed by artificial intelligence, big data and cloud, photonics, digital security, blockchain and internet of things (IoT). These technologies are the driving force of the digital industrial ecosystem and the digital transition of other industrial ecosystems with a combined force to transform all industries.

As a matter of context, the Digital Economy and Societal Index (DESI) captures the integration and uptake of digital technologies in businesses on a basic to advanced scale. The technologies that are identified for the digital industrial ecosystem are also mentioned there, including big data, artificial intelligence and cloud technologies as advanced technologies. A view on the overall uptake shows that big data is on the rise, increasing to 14% in 2020, from 12% in 2018, whereas cloud (34%) and AI (8%) are captured for the first time in 2020 data.[22]

This subchapter zooms in on the digital technologies underpinning the digital industrial ecosystem. Datasets include patents, and the way in which patenting activities have evolved in the digital industrial ecosystem as well as for several digital technologies. Information on Technology Centres active in digital technologies, their location, and several examples are presented to highlight the capabilities of technology centres to support the digital transition. Trade dependencies of technologies related to the digital industrial ecosystem are also explored to illustrate the interrelationship between the industrial ecosystems and their underlying digital technologies.

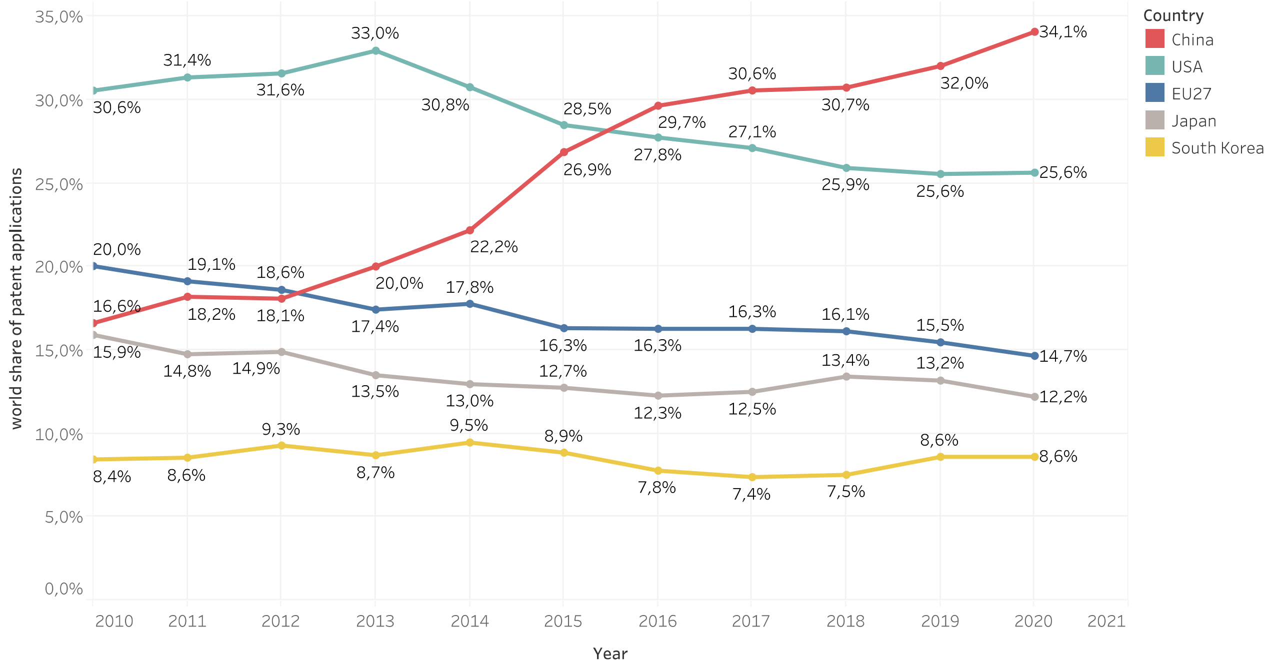
3.1 Patenting activities

Technology developments have been tracked by patenting activities related to the specific sectoral activities based on patent-based classifications. The analysis is based on 'transnational patents' (Frietsch/Schmoch, 2010) (i.e., PCT/WIPO filings or direct applications at the EPO, excluding double counts) and was conducted based on an extended version of the EPO's Worldwide Patent Statistical Database that Fraunhofer ISI implemented locally. Technologies relevant to ecosystems, in this case the digital industrial ecosystem, are defined based on a search that refer to patent classifications (IPC) and/or use keywords to identify relevant applications across classes. The detailed methodology is presented in the EMI methodological report.

Figure 5 presents the trends in the evolution of patent applications of advanced technologies related to the digital transformation (see Figure 2) as a share in the world total patent applications. In general, patents application trends vary depending on world region. China stands out as a country that is, in global comparison, increasing its efforts in digital technology patenting, whereas the EU27 and the USA are showing a decreasing trend in digital patenting over the same period. The decreasing trend observed for Japan is minimal, where South Korea is relatively stable over the period of 2010 to 2020.

[22] Digital Economy and Society Index (DESI) 2022. https://ec.europa.eu/newsroom/dae/redirection/document/88764

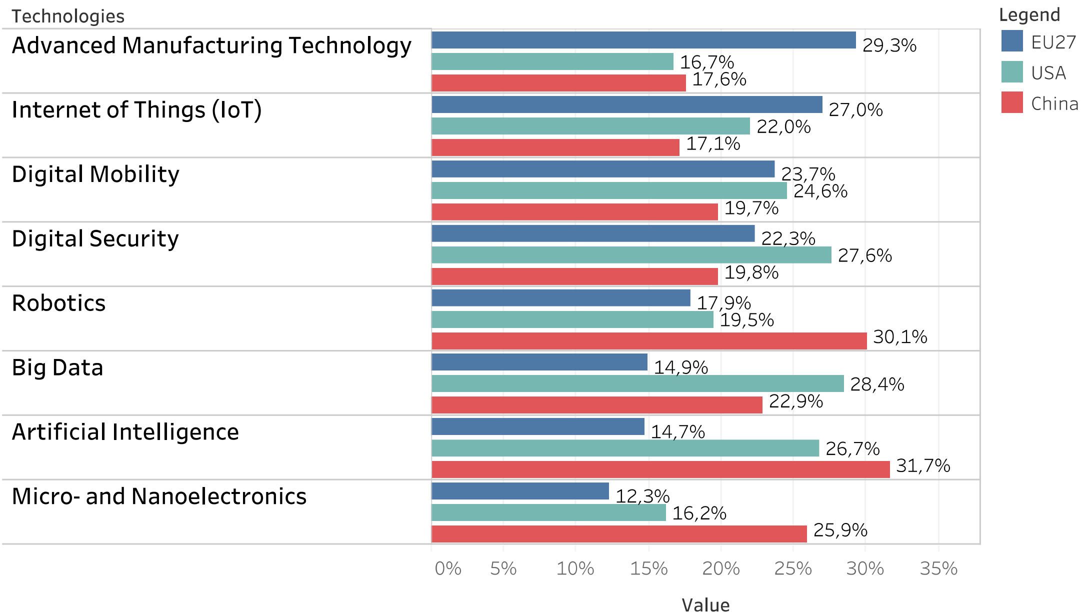
Figure 5: Trends in the EU27 share of patent applications in world total in the field of the digital industrial ecosystem in 2010-2020 and global comparison in 2020



Source: Fraunhofer calculations, PATSTAT

The analysis of patent applications in advanced technologies reveals that the EU27 has the highest share of patent applications in advanced manufacturing technologies, followed by the Internet of Things. At the same time a weakness in artificial intelligence and big data inventions is noted. AI and IoT are highlighted as particularly crucial technologies for their potential to produce efficiency and cost reduction in view of digital transformation of businesses.

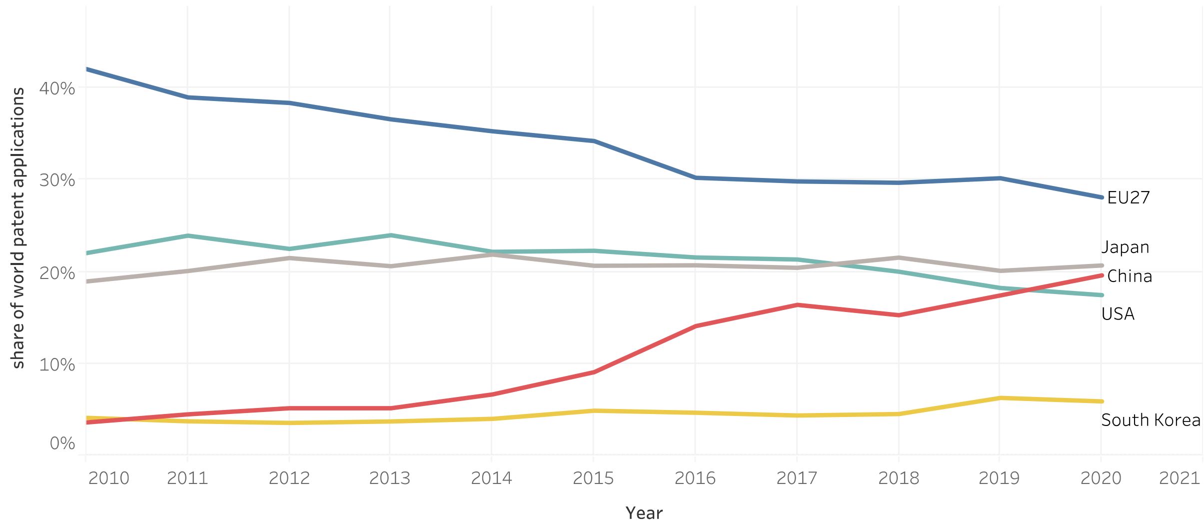
Figure 6: Share of patent applications in world total in digital technologies in 2020



Source: Fraunhofer calculations, PATSTAT

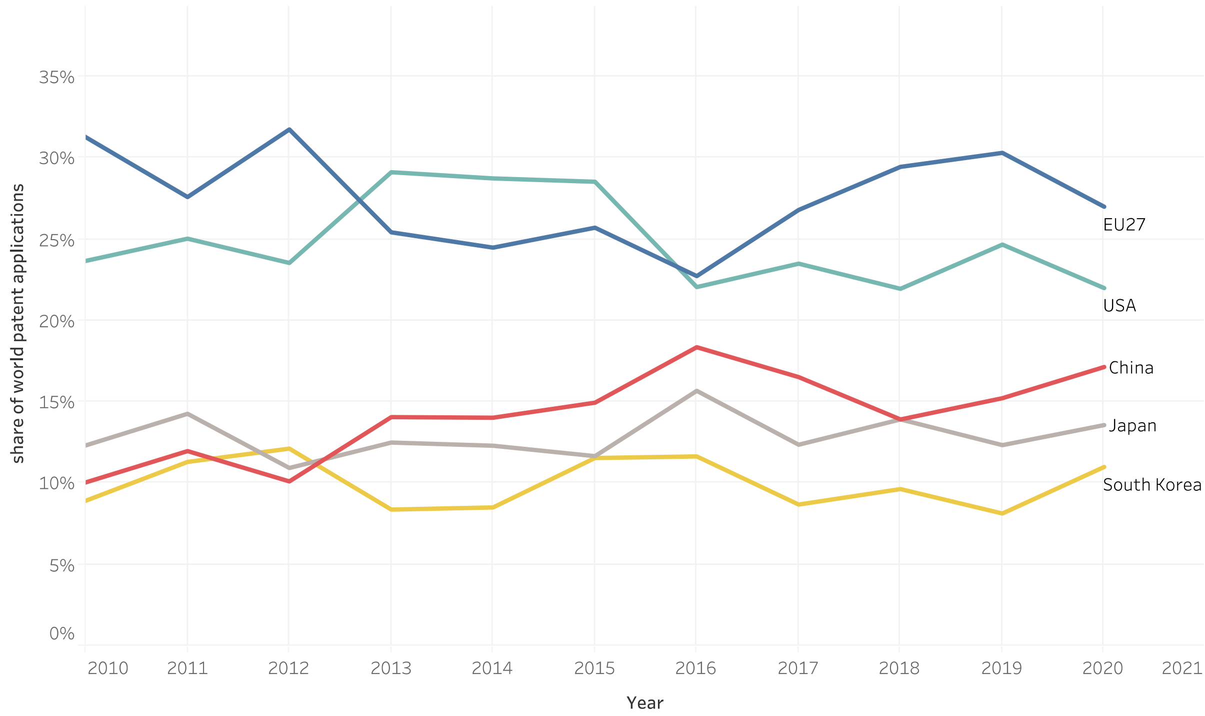
Zooming in on **patenting activities in specific digital technologies**, Figure 7 presents the share of **advanced manufacturing and robotics patent applications** in world total for the EU27 in global comparison. Patents for the EU27 are notably decreasing, compared to China which shows a considerable increase over the same time period from 2010 to 2020. USA also shows a slight decline, compared to a slight increase in South Korea. Patents for Japan in advanced manufacturing technologies and robotics is stable. Similarly, Figure 8 zooms in on patents in **Internet of Things (IoT)** the EU27 in world total in global comparison, with the EU27 and USA showing slight decreases, compared to Japan and China with slight increases. Overall values are comparable stable over the period of 2010 to 2020.

Figure 7: Share of advanced manufacturing and robotics patent applications in world total 2010-2020



Source: Fraunhofer calculations, PATSTAT

Figure 8: Share of Internet of Things patents in world total in global comparison, 2010-2020



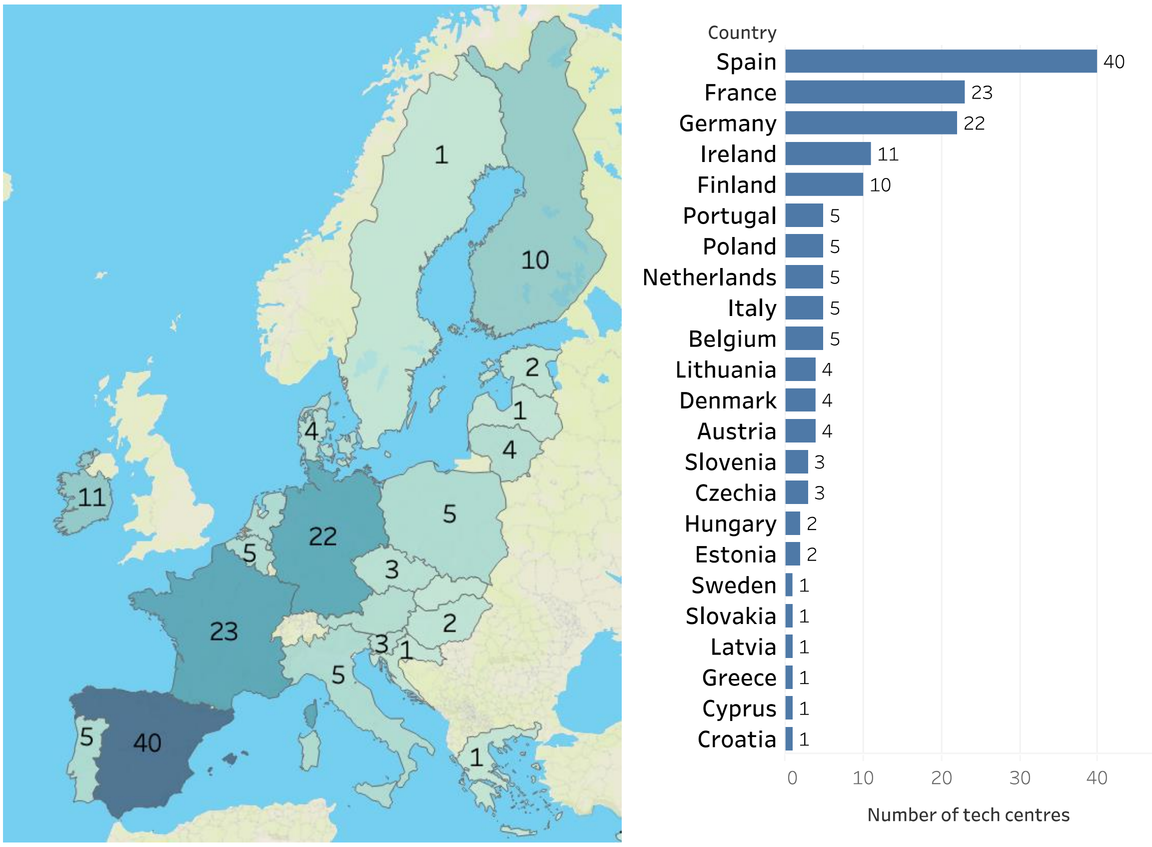
Source: Fraunhofer calculations, PATSTAT

3.2 Technology centres

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. The Technology Centre Mapping[23] comprises information 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.

Figure 9 presents the number of technology centres (TCs) that are active in the digital industrial ecosystem per European country (N=159) and shows that Spain (40) is the country with the highest number of technology centres in Europe, followed by France (23), Germany (22), Ireland (11), and Finland (10). These and other countries might host additional technology centres active in the digital technologies,[24] which are currently not registered to the technology centres mapping.

Figure 9: Technology centres per country – digital



Source: Analysis based on Technology Centre Mapping, 2023

The following examples serve to illustrate the activities and scope of technology centres active in digital technologies, their links with the broader ecosystem as well as examples of recent activities in which they are involved. They include the following three cases: Bcom

[23] Advanced Technologies for Industry Technology Centre Mapping https://ati.ec.europa.eu/technology-centre/mapping allows Technology Centers to apply to join the mapping following validation. As such countries show a different degree of representativeness and the data should be interpreted accordingly.

[24] For the purpose of this analysis, the digital industrial ecosystem involvement was defined by filtering the mapping on digital technologies.

(FR), CIIRC CTU - Czech Institute of Informatics, Robotics and Cybernetics (CZ), and Alexandra Institute (DK).

Box 1: Example Technology Centre: Bcom (FR)

Name of the Centre	**Bcom (FR)**
Location and scope	
Bcom is a private research and technology centre, with headquarters in Rennes, France. It is supported by the government's Investissements d'Avenir program, the Region of Brittany, Rennes Métropole, Lannion Trégor Communauté and Brest Métropole and has branch offices in Paris, Brest, and Lannion. The mission of Bcom is to help businesses develop their competitiveness by creating innovations through the use of digital tools. For this purpose, the Bcom focuses on the following areas of expertise: • Artificial Intelligence, • augmented and virtual reality, • cybersecurity, • images & sound processing, • advanced engineering, • cognitive technologies • 5G & IoT. Bcom has a network of international partners in Europe, North America and Asia including partnerships with Airbus, SNCF, Inria, Orange, and Ekinops, among others.	
Main services and equipment	
Bcom provides services, among others: • **to accelerate and automatise the deployment of interoperable digital infrastructure**, including: - xG Testbed services to carry out technical experimentation, from early stated to field trials. - DICOM-RTV Converter, a software that allows the transport of uncompressed medical videos in real-time together with their associated metadata, in a synchronised way. - The DICOM Library, a software created to upload to the web medical imaging with the objective of nurturing the collaboration between physicians, the providers of the medical imaging application and researchers. • **for data exploitation, and for boosting business processes** through, for example, AI coaching services, and trainings in the deployment of wireless technologies and digital transformation. • **to process and distribute audio, video, or immersive content.** • **to protect users and secure data and content.** • **to provide advanced engineering services**, including software, hardware, and cloud engineering, as well as validation of solutions.	
Recent projects related to the green and digital transition	

Recent projects include:[25] • **EDIH Bretagne**, founded in 2023, aspires to be an important actor for the digitisation of the Brittany region. As part of this project, Bcom proposes different products to assist companies in their cybersecurity, image transfer, forecasting analysis or real-time 3D monitoring of items. • The **5G-OR** demonstration project is aimed at setting up the future generation of a 5G-enabled OR ecosystem to enhance patient outcomes. The utility of 5G is to be proven in four use cases in hospitals in Strasbourg, Berlin, and Mannheim. In the project, Bcom is both a supplier and implementer of the complete 5G infrastructure network. • The **Hexa-X** project seeks to link the physical, digital, and human worlds, strongly rooted in future wireless technology and architectural research. Within this project, Bcom focuses on cybersecurity and Artificial Intelligence, specifically on intra and inter-slice security, on AI and Anomaly Detection and AI and Massive MIMO.

Source: Technology Centre Mapping, 2023 and Bcom, 2023 https://b-com.com/

Box 2: Example Technology Centre: CIIRC CTU - Czech Institute of Informatics, Robotics and Cybernetics (CZ)

Name of the Centre	**CIIRC CTU - Czech Institute of Informatics, Robotics and Cybernetics (CZ)**
Location and scope	
The Czech Institute of Informatics, Robotics and Cybernetics (CIIRC CTU) was founded in 2013 and is part of the Czech Technical University (CTU) situated in Prague. CIIRC CTU is focused on carrying out research in fields such as robotics, artificial intelligence, computer graphics, computer vision and machine learning, designing software ecosystems, and automatic control and optimisation, among others. Some of the key partners of the CIIRC CTU, both universities and industry, are the Austrian Institute of Technology (AIT), Siemens, Skoda, the German Research Centre for Artificial Intelligence, SAP, IBL, Rockwell Automation, and SYBEX. CIIRC CTU is also full member of EIT Manufacturing, and has joined CLAIRE and ELLIS, both European networks on artificial intelligence.	
Main services and equipment	
The main services and equipment offered by the TC include: • **Research & Development** through its different research teams and labs including the Department of Artificial Intelligence, Intelligence Systems, Industrial Informatics, Robotics and Machine Perception and Industrial Production and Automation, among others. • **Technology Transfer services for industry** through licensing of technology, contracted or sponsored research, and consultancy services. • Access to a testbed for advanced industrial production (**Testbed for Industry 4.0**). • **Training, mentoring and event organisation**. **Other services** provided include testing and validation, concept validation and prototyping, strategy development for businesses, digital maturity assessment and brokering/matchmaking as well as ecosystem building.	
Recent projects related to the green and digital transition	

[25] See https://b-com.com/en/discover-us/bcom-galaxy#european-projects

Notable projects carried out by CIIRC CTU include:[26] • **ARISE**: This project seeks to minimise waste in manufacturing processes while at the same time reducing the carbon footprint. It guides European SMEs in efficiently using Artificial Intelligence especially focusing on AI-enabled applications. • **DIH-World**: This project intends to foster the use of advanced digital technologies by European SMEs active in manufacturing. It assists them in reaching global drawing upon the capacities of regional DIHs.

Source: Technology Centre Mapping, 2023 and CIIRC CTU, 2023 https://www.ciirc.cvut.cz/

Box 3: Example Technology Centre: Alexandra Institute (DK)

Name of the Centre	**Alexandra Institute (DK)**
Location and scope	
Alexandra Institute is a non-profit research & development centre located in Denmark. The aim of the Institute is to develop innovative IT solutions for companies in different sectors building on digital technologies including artificial intelligence, cybersecurity, health and welfare, and computer graphics. Throughout its history, the Alexandra Institute has established collaborations with universities (e.g., Aalborg University, Aarhus University, Danish Technological University, Copenhagen University) and clusters (e.g., Clean, Copenhagen Fintech, Vision Denmark, CenSec). Alexandra Institute works with industry partners including customers such as LEGO, Kamstrup, Novo Nordisk, RetinaLyze, and PROLON.	
Main services and equipment	
The main services and equipment offered include: • **Consultancy** services related to digitalisation such as the "Free Expert Check", which consists of a 30-minute video conference service to help clients identify potential blind spots, needs and strengths in their digitalisation strategies. • The **Development Package** service, which is divided into a report with a roadmap for possible solutions, tests of profitability and technical feasibility, a model and simulation of the solution, a minimum viable product, and a commercially viable product. • An **IT testing facility**. • A **User Involvement** service, that offers the possibility to conduct user studies and to design and evaluate user tests to facilitate idea generation in innovation processes.	
Recent projects related to the green and digital transition	
Relevant projects include: [27] • **AI MATTERS:** The AI MAnufacturing Testing and experimenTation network For EuRopean industrieS is a project dedicated to improving the resilience and flexibility of the European manufacturing industries through the improved uptake of artificial intelligence, robotics, as well as intelligent, autonomous systems for flexible production. • **SODA-Scalable Oblivious Data Analytics**: The SODA project enables practical privacy-preserving analytics of information from multiple data assets using multi-party computation (MPC) techniques. The project is demonstrated though a healthcare use case.	

Source: Technology Centre Mapping, 2023 and Alexandra Institute, 2023 https://alexandra.dk/

[26] See https://www.ciirc.cvut.cz/research-education/projects

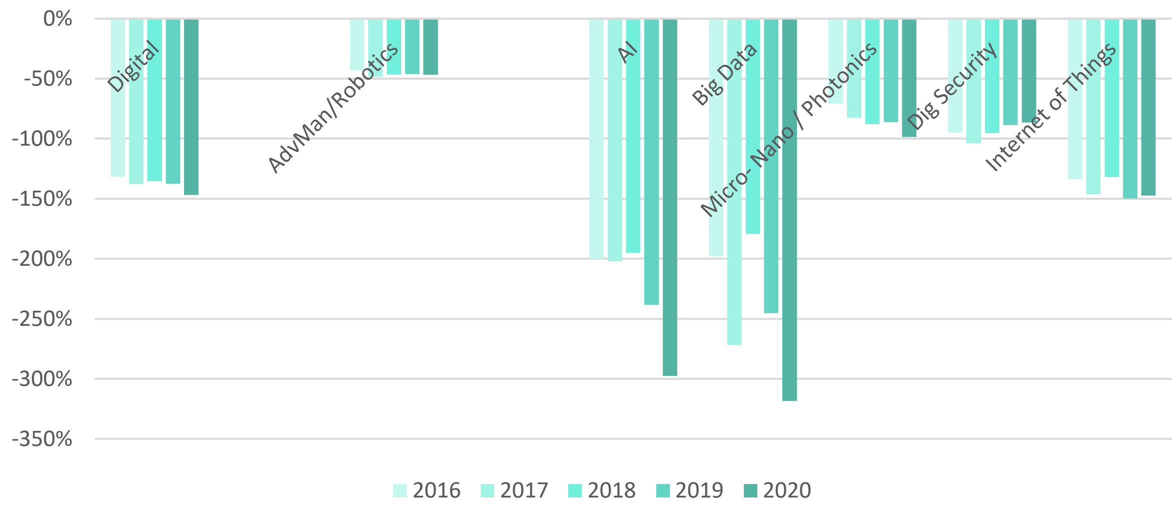
[27] See https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/how-to-participate/org-details/999773278

3.3 Trade dependencies

As one aspect of resilience against potential crises, Europe's vulnerability in specific technology domains is further investigated through quantitative analysis. More specifically, the Union's dependency on non-European imports of relevant goods is established for the digital industrial ecosystem and put in relation to Europe's own production capacities. On this basis, trends in external dependency in relation to own production capacity is visualised and traced. Based on production and trade data, the monitoring of dependency prepares the ground for an in-depth analysis of resilience related issues.

For the digital industrial ecosystem (see Figure 10) we find that imports constitute a comparatively high share when compared with domestic production (the highest across all industrial ecosystems). The sector depends on advanced manufacturing and robotics technologies, which have lower dependencies than for the remainder of the digital domain. The auxiliary technologies related to the digital industrial ecosystem include artificial intelligence, big data, micro- and nanoelectronics, digital security and networks / cybersecurity, and Internet of Things (IoT) where dependencies are far more pronounced, especially for AI and big data.

Figure 10: Ecosystem dependency, key technologies, and auxiliary technologies for the digital industrial ecosystem



Source: Fraunhofer ISI based on production and trade data, UNCOMTRADE, 2023

4. 4. Coupling the green transition and the digital industrial ecosystem

There is a strong **interplay between the digital and green technologies**, forming the core of the twin (green and digital) transition.

The Annual Single Market Report highlights the further interplay between the digital and green transition as pertains to **skills**. Both the green and digital transition put pressure on workers and employers to develop and foster a skills transition, and a failure to meet these needs risks an increasing skills mismatch, leading to an impact on growth, if one or both are mismanaged.[28]

The green technologies included in this study that are particularly related to the digital industrial ecosystem include **energy saving technologies and renewable energy technologies**, which both rely on digital technologies for optimisation (energy saving, and energy distribution).

As such, this chapter **zooms in on the green transition in the digital industrial ecosystem**. Information on skills, as well as startups are presented in the chapters below, highlighting specifically the interplay between the digital and green technologies for the digital industrial ecosystem.

4.1 Skills supply for the green transition

This section aims at analysing trends in the supply of skilled professionals relevant for the green transition of the digital ecosystem as defined by the EU Industry Strategy based on LinkedIn data. LinkedIn is the largest professional network platform with rich information like profile summary, job title, job description and field of study, which can be used for the identification of skilled professionals in advanced technologies and both in digital and green transition. It represents the single most comprehensive source currently available for technology-specific skills related indicators. To harvest the data from LinkedIn, keywords capturing skills by advanced technology have been defined and reviewed by technology experts.

The study adopts the definition of Cedefop for **Green transition related skills** and hence "the knowledge, abilities, values and attitudes needed to live in, develop and support a sustainable and resource-efficient society"[29]. The green skills taxonomy applied in LinkedIn includes skills related to environmental protection, environmental services, resource efficiency, biodiversity, low carbon technologies, renewable energy, the circular economy, waste management, management of food waste, and clean production technologies and business models related skills (the list of keywords that have been used and are possible to track with the algorithm of LinkedIn is included in Appendix B).

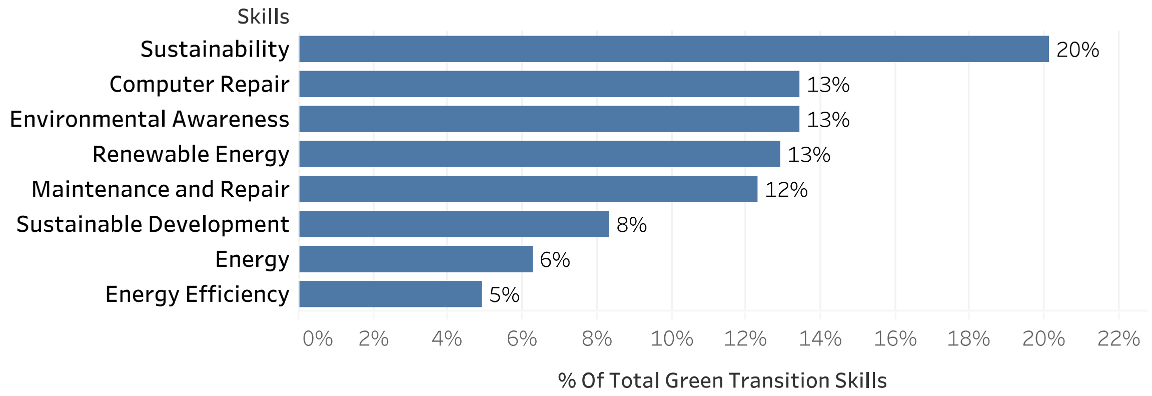
Within the registered professionals on LinkedIn employed in the digital industrial ecosystem, this analysis found that **3.5% of professionals indicate to have one type of green skill.**

The most common green skills in the digital ecosystem include sustainability, computer repair, environmental awareness, maintenance and repair, and renewable energy. Skills such as **sustainability**, **environmental awareness,** and **renewable energy** can be related to understanding and implementing sustainable practices and integrating eco-

[28] European Commission (2022) COMMISSION STAFF WORKING DOCUMENT Annual Single Market Report 2022
[29] Cedefop (2012) Green skills and innovation for inclusive growth, https://www.cedefop.europa.eu/files/3069_en.pdf

friendly principles into the industrial ecosystem. While **computer repair** and **maintenance repair** can be attributed to promoting the circular economy.

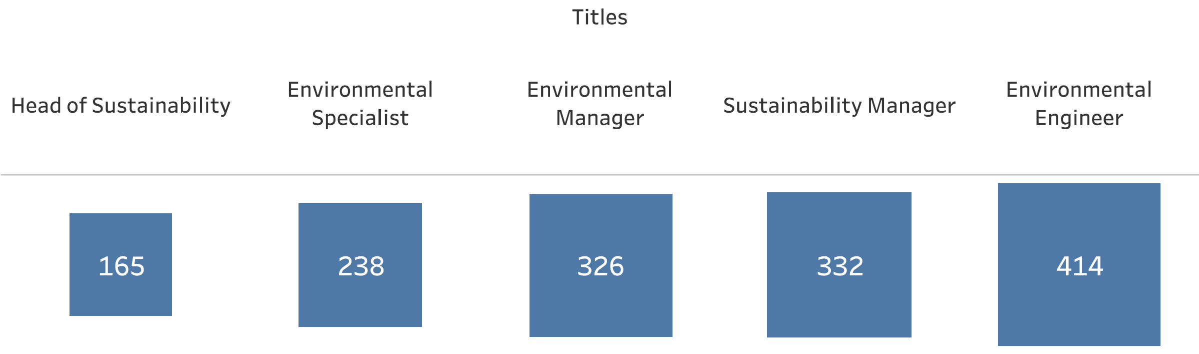
Figure 11: Common type of green transition related skills among professionals employed within the digital industrial ecosystem



Source: Technopolis Group calculations based on LinkedIn, 2023

The most common green job titles in the digital ecosystem include environmental engineer, environmental manager and environmental specialist, sustainability manager and head of sustainability, as presented in Figure 12. The **Environmental engineer, environmental manager, and environmental specialist** job titles are related to environmental management and involve implementing sustainable practices, ensuring compliance with regulations, and addressing environmental challenges. While environmental engineers focus on integrating environmental considerations into engineering projects, environmental managers and environmental specialists oversee environmental policies, assessments, and mitigation strategies within organisations. **Sustainability manager** and **head of sustainability** job titles centre around sustainability initiatives and strategic planning. Sustainability managers and heads of sustainability play key roles in developing and implementing sustainability strategies, driving change, and promoting sustainable practices within organisations. They monitor sustainability metrics, collaborate with stakeholders, and lead efforts to enhance resource efficiency and reduce environmental impact.

Figure 12: Most common type of job titles with green transition skills employed within the digital industrial ecosystem



Source: Technopolis Group calculations based on LinkedIn, 2023

4.2 Skills demand for the green transition

Skills demand in the digital industrial ecosystem has been analysed following the skills intelligence insights of Cedefop, the European Centre for the Development of Vocational Training[30]. This dataset covers the EU27 (plus 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.

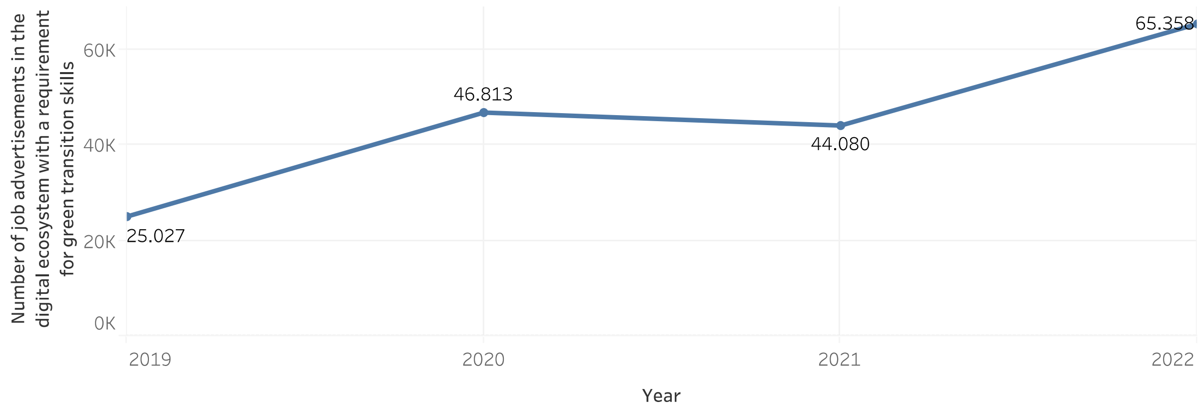
For the digital industrial ecosystem[31], **9 532 591 unique job advertisements** were found from companies between 2019-2022 in the EU27. These job advertisements have been text-mined and the required skills have been analysed from the perspective of the green and digital transitions. The green pre-defined skills are from ESCO v1.1 and the digital are predefined from ESCO v1.1.1 which is currently being updated.

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 (ML) algorithms: 1) Manual labelling; 2) Machine learning classifier; 3) Comparison and manual validation.

The share of online job advertisements that required any form of **green transition related skill was 1.9%**.

Figure 13: Share of online job advertisements that demand green transition related skills within the total number of job advertisements in the digital industrial ecosystem over time



Source: Technopolis Group calculations based on Cedefop data, 2023

The more sought-after green skills include:

- Environmental stewardship and sustainability
- Energy efficiency
- Application of **transport industry management concepts** in order to improve transportation processes, reduce waste, increase efficiency, and improve schedule preparation.

[30] https://www.cedefop.europa.eu/en/tools/skills-online-vacancies
[31] In the case of the digital industrial ecosystem the dataset was filtered for the NACE industries as defined in the Annual Single Market Report: C26, J58, J61, J62, J63, S95).

Zooming in, we can look at some concrete examples from job advertisements included in Box 4 .

Box 4: Concrete examples of job advertisements at the crossroads between the green and digital transition

Energy Strategy Manager, Power & Energy Strategy at a large E-commerce MNC

Skills: Energy efficiency & apply management transport costs

The job ad highlights the significance of energy efficiency and the application of transport management concepts. Candidates are expected to possess a strong understanding of energy management, enabling them to analyse and optimise energy costs within the organisation. They will be responsible for designing and implementing strategies and programs that minimise charging costs and maximise energy asset optimisation. This focus on energy efficiency aims to reduce overall costs and promote environmental sustainability. Additionally, the role calls for individuals who can apply their expertise in transport management to optimise logistics planning and transportation operations. By utilising effective strategies such as route optimisation, load planning, and supply chain management, candidates can enhance transportation efficiency, minimise fuel consumption, and reduce emissions.

Business Unit Profitability and Performance Management at an IT solutions company

Skills: energy efficiency

The job role in the Business Unit Profitability and Performance Management (PaPM) involves providing consulting, implementation, training, and architecture services for profitability and sustainability management based on SAP's analytics solutions. The role focuses on driving the development of SAP PaPM solutions in sustainability, researching environmental and sustainability trends, and synthesising research findings into actionable recommendations. The position requires knowledge in programming languages, a university degree in relevant fields, and industry experience in sustainability. The job emphasises analytical thinking, passion for sustainability, and the ability to work independently and collaboratively.

Sustainability Manager at a Digital Tech Start-up specialised in digital solutions helping companies minimise environmental impact

Skills: Climate Change Impact

The role of Sustainability Manager requires expertise in various areas for this advertisement, including ecosystems, energy efficiency, transportation management concepts, animal welfare, and types of wood. The manager is responsible for assessing and mitigating the environmental impact of companies' activities, with a focus on preserving and protecting ecosystems. They guide companies in implementing energy-efficient practices and technologies to reduce their carbon footprint. The manager also applies transportation management concepts to optimise logistics and minimise emissions in supply chains. They ensure that animal welfare standards are met and promote ethical practices within relevant industries. Additionally, the manager possesses knowledge of different types of wood to promote responsible sourcing and sustainable forestry practices.

Source: Technopolis Group based on data from job advertisements, 2023

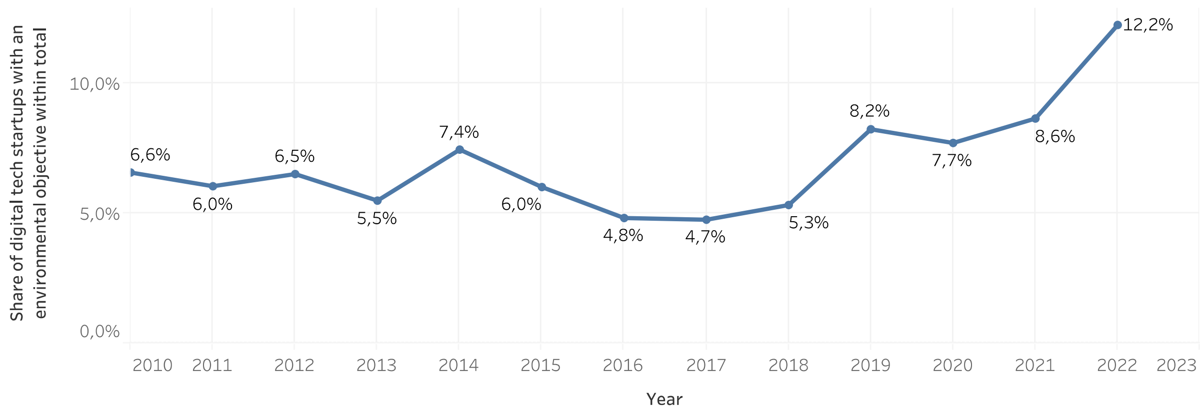
4.3 Digital tech startups with an environmental focus

In this analysis, the link between the digital and green transformation have been captured by analysing digital tech startups[32] as part of the digital industrial ecosystem with a focus on the green transition based on data sourced from the Crunchbase and Net Zero Insights[33] databases. In order to have a sufficient timespan for analysis, we take into account companies established since 2010 until 2022. Environmental focus was defined as including one of the following categories: renewable energy, recycling/waste management, circular economy, low carbon/carbon reduction, energy efficiency, environmental protection, clean production. The detailed methodology is presented in the methodological report of the project.

The analysis presented in Figure 14 shows that the share of digital companies with a green transition objective has increased over time. The examples of startups demonstrate the growing importance of two distinct objectives:

- Realising the potential of digital technologies in reaching environmental targets and the commercialisation of related solutions
- **Mitigating the negative environmental impact of digital technologies** notably in increasing electricity consumption and producing greenhouse gas emissions.

Figure 14: Share of digital tech startups with an environmental/green transition objective within total digital startups



Source: Technopolis Group based on Crunchbase, 2023

When looking at the absolute number of technology startups with an environmental objective, we find that AI tech firms have been the most common to address environmental challenges, clean production or the circular economy. AI is followed by IoT and big data applications (seeFigure 15).

When analysing to what extent IoT, AI, cloud, etc., tech startups have had an environmental objective within their own category, it is observed that IoT tech startups tend to focus on the green transition the most within all IoT firms. In a similar way, IoT is followed by cloud technologies (see Figure 15).

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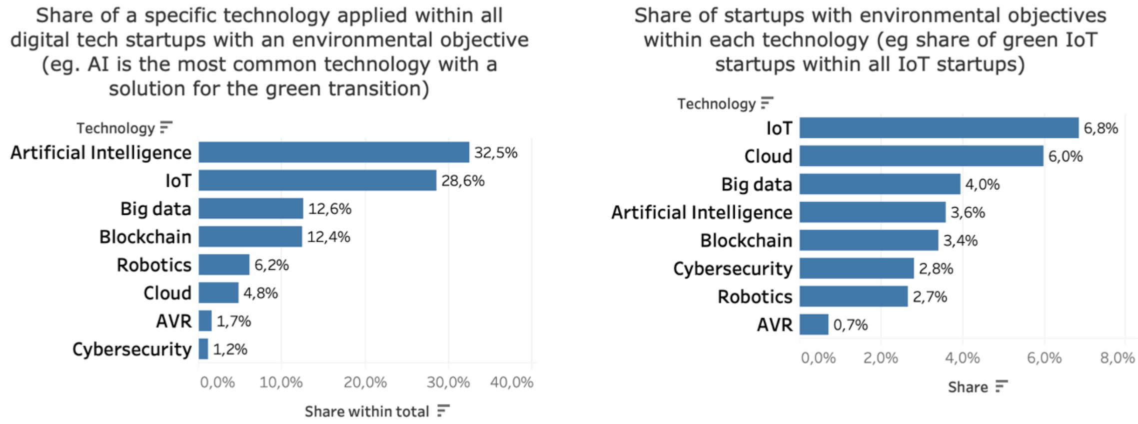
[32] In this study, startups are defined as 'young, innovative, growth–oriented businesses in search of a sustainable and scalable business model' (NESTA, 2015). Tech startups are technology-based startups. More specifically, digital tech startups do not simply develop or adopt digital technologies but digital is an inherent part of their value proposition (Oestreicher-Singer and Zalmanson, 2012; Griva et al, 2023). Environmental startups are another form of young, innovative business that develop and implement products, technologies and services that contribute to environmental sustainability, for example by reducing greenhouse gas emissions, improving energy efficiency, adopting a circular economy approach or providing a service that is ecological (see in Bergset et Klaus, 2015).

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

IoT can facilitate the digitalisation of production processes and business operations including water distribution, preventive maintenance, smart manufacturing and thus contributing to resource efficiency.[34] Cloud technology providers and related data centres consume a lot of electricity and generate global CO2 emissions.

Figure 15: Share of digital tech startups with an environmental objective per type of digital technology in focus



Source: Technopolis Group based on Crunchbase, 2023

Some examples include the following:

- IoT startups develop networks that allow forest owners to monitor, analyse and protect remote forests and detect wildfires.
- Tech firms develop energy-efficient and eco-friendly computing cooling technology for cloud applications that saves electricity and reduces land use. Other tech firms provide solutions for data storage that have a lower environmental impact.
- Artificial Intelligence is applied to increase the uptime and performance of renewable energy sources. Combined with sensors and data streams, AI technology enables solar and wind energy owners to get more energy out of their sources and accelerate the transition to renewable energy.
- Big data analytics (often coupled with AI) help reducing waste by optimising supply chain orders and monitoring consumption patterns. Among the startups, we find examples with an application that helps restaurants reduce their food waste by selling their surplus to consumers at reduced prices.
- Applications also allow sustainability management by calculating the carbon footprint of shipping of goods, development of products, and overall business operations. Data and transparent analysis can help realise impact and urge for action.

[34] Fraga-Lamas, P.; Lopes, S.I.; Fernández-Caramés, T.M. Green IoT and Edge AI as Key Technological Enablers for a Sustainable Digital Transition towards a Smart Circular Economy: An Industry 5.0 Use Case. *Sensors* 2021, *21*, 5745. https://doi.org/10.3390/s21175745

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6. Appendix B: Methodological notes

LinkedIn

Queries have subsequently been constructed to filter the database by location and industry. For the skills analysis of the digital ecosystem the following LinkedIn tags have been used: *Smart Cities; Green Building; Green Infrastructure; Green Purchasing; 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; Waste; 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; Computer Recycling; E-Waste; Carbon Reduction Strategies; Carbon Footprinting; Carbon Neutral; Energy Retrofits; Biodiversity; Biodiversity Conservation; Nature Conservation; Advanced Materials; Nanomaterials; Biomaterials; Polymer Science; Materials Science; Optical Materials; Reuse; Separation Process; Sorting; Automotive Repair; Electronics Repair; Equipment Repair; Computer 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; Car Repair; Machinery Repair; Maintenance and Repair; Solar PV; Solar Cells; Natural Gas; 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; Wastewater Treatment Plants; Electric Vehicles; Hybrid Electric Vehicles; Multi-modal Transportation; Energy Efficiency Consulting; Polymer Composites; Recycled Water; Adaptive Reuse; Ecodesign; Life Cycle Assessment; Energy Optimization; Alternative Fuels; Biodegradable Products; ISO 14001; Solid Waste; Hazardous Waste Management; Corporate Social Responsibility; Biofuels; and EMAS*. In order to capture the number of professionals working in the sector, occupations related to the industrial ecosystem have been taken into account.