Europäisches Patentamt
European Patent Office
Office européen des brevets

Patents and the Fourth Industrial Revolution

The global technology trends enabling the data-driven economy
December 2020

Foreword

In light of the COVID-19 pandemic, the future of the global economy depends more than ever on innovation and creativity. Industries that make intensive use of intellectual property rights not only account for 45% of the EU's GDP and 39% of employment, they are also more resilient to crises (EPO and EUIPO, 2019). In our efforts to pull the global economy out of recession, IP-intensive industries will make a crucial contribution by driving economic growth, largely fuelled by innovation in emerging technologies.

The Fourth Industrial Revolution (4IR) is already triggering sweeping transformations in value creation and consumer behaviour. A constellation of disruptive technologies – the internet of things, cloud computing, big data, 5G communication and, of course, artificial intelligence – is paving the way for a new a data-driven economy.

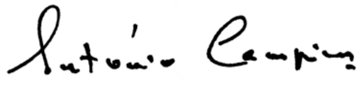
In just three years from now the world will be populated by 29 billion smart connected devices, all capable of collecting and sharing data in real time and making smart, autonomous decisions. In terms of value creation, the boom in 4IR technologies is expected to contribute over two trillion euros to the EU economy by the end of this decade.

As the patent office for Europe, the EPO is at the forefront of these transformations and uniquely positioned to assess their scope and implications. This new study takes a truly global perspective on the technology drivers of the Fourth Industrial Revolution. Drawing on patent data across over 350 distinct technology fields, it provides unrivalled insights into the digital transformation impacting the global economy today.

Overall, the findings point to a world in which the pace of innovation in 4IR technologies has accelerated dramatically over the past decade. Between 2010 and 2018, global patent filings for smart connected objects grew at an average annual rate of almost 20% – nearly five times faster than all other technology fields. By 2018, 4IR technologies accounted for over 10% of global patenting activities, and their growth looks set to continue in the years ahead.

The study also offers key insights into the innovation performance and specialisation profiles of countries and companies in 4IR technologies. On top of identifying those regional clusters that are dominating the data-driven economy, the study also traces developments in areas like transport, healthcare or agriculture where smart, connected devices, are having the greatest impact.

By virtue of its sheer magnitude, the Fourth Industrial Revolution will define the global balance of technology leadership for years to come. Europe's strength lies in the diversity of its innovation ecosystem, the strong performances of smaller countries with highly specialised innovation profiles and its flourishing regional clusters of excellence. While Europe is not growing as fast as other regions when it comes to innovation in 4IR technologies, windows of opportunity remain open. More remains to be done to promote innovation in emerging technologies if Europe seeks to get ahead in the global 4IR race.



António Campinos
President, European Patent Office

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List of abbreviations

4IR	Fourth Industrial Revolution
5G	5th generation of mobile networks
AI	Artificial intelligence
CII	Computer-implemented inventions
CPC	Cooperative Patent Classification
EPC	European Patent Convention
EPO	European Patent Office
ICT	Information and communication technology
IoT	Internet of Things
IPF	International patent families
IPR	Intellectual property rights
IT	Information technology
PRO	Public research organisations
R&D	Research and development
RTA	Revealed technological advantage
UNI/PRO	Universities and public research organisations

List of abbreviations

AL	Albania
AT	Austria
AU	Australia
BE	Belgium
CA	Canada
CH	Switzerland
CN	People's Republic of China
CW	Curacao
DE	Germany
DK	Denmark
ES	Spain
FI	Finland
FR	France
IL	Israel
IN	India
IS	Iceland
IT	Italy
JP	Japan
KR	Republic of South Korea
LI	Liechtenstein
MC	Monaco
MK	North Macedonia
MX	Mexico
NL	Netherlands
NO	Norway
RS	Serbia
SE	Sweden
SG	Singapore
SM	San Marino
TR	Turkey
TW	Chinese Taipei
UK	United Kingdom
US	United States

Executive summary

Purpose of the study

The European Patent Office (EPO) intends this study to guide policymakers, industry and the broader public through a major technology transformation that impacts a wide range of sectors of the economy. Known as the Fourth Industrial Revolution [1] (4IR), this global trend is driven by a constellation of disruptive technologies which together are paving the way to a data-driven economy.

By 2023, it is estimated that more than 29 billion devices will be connected to Internet Protocol networks across the globe, most of which will be creating data in real time. Once combined with other technologies, such as big data, 5G or artificial intelligence, they enable the automation of entire business processes, including repetitive intellectual tasks previously performed by human beings. It is estimated that the cumulative additional GDP contribution of these new digital technologies could amount to EUR 2.2 trillion in the EU alone by 2030, a 14.1% increase from 2017 (European Commission, 2020). Leading innovators in these technologies are already shaping the data-driven economy for the years to come. Meanwhile, others may struggle or even disappear in the wake of 4IR disruptions.

Drawing on the latest information available in published patent documents, the data presented in this study show trends in high-value inventions for which patents have been filed in more than just the inventors' domestic market, by counting international patent families (IPFs [2]). It offers insights into which countries, companies and regional clusters are leading the way in 4IR technologies and thus are best placed to benefit from the data-driven economy in the near future. By highlighting the fields that are gathering momentum and the cross-fertilisation taking place between these fields, this study provides a guide for policy and business decision-makers to direct resources towards value creation in the digital era.

1 Fourth Industrial Revolution is the term used by Klaus Schwab, founder and Executive Chairman of the World Economic Forum, in his recent book on this subject ("The Fourth Industrial Revolution", 1st edition, New York; Crowne Business, 2017.).

2 Each IPF covers a single invention and includes patent applications filed and published at several patent offices. It is a reliable proxy for inventive activity because it provides a degree of control for patent quality by only representing inventions for which the inventor considers the value sufficient to seek protection internationally. The patent trend data presented in this report refer to numbers of IPFs.

About patents and patent information

Patents are exclusive rights for inventions that are new and inventive. High-quality patents are assets for inventors because they can help attract investment, secure licensing deals and provide market exclusivity. Patents are not secret. In exchange for these exclusive rights, all patent applications are published, revealing the technical details of the inventions in them.

Patent databases therefore contain the latest technical information, much of which cannot be found in any other source, which anyone can use for their own research purposes. The EPO's free Espacenet database contains more than 120 million patent documents from around the world, and comes with a machine translation tool in 32 languages. This patent information provides early indications of technological developments that are bound to transform the economy. It reveals how innovation is driving the Fourth Industrial Revolution.

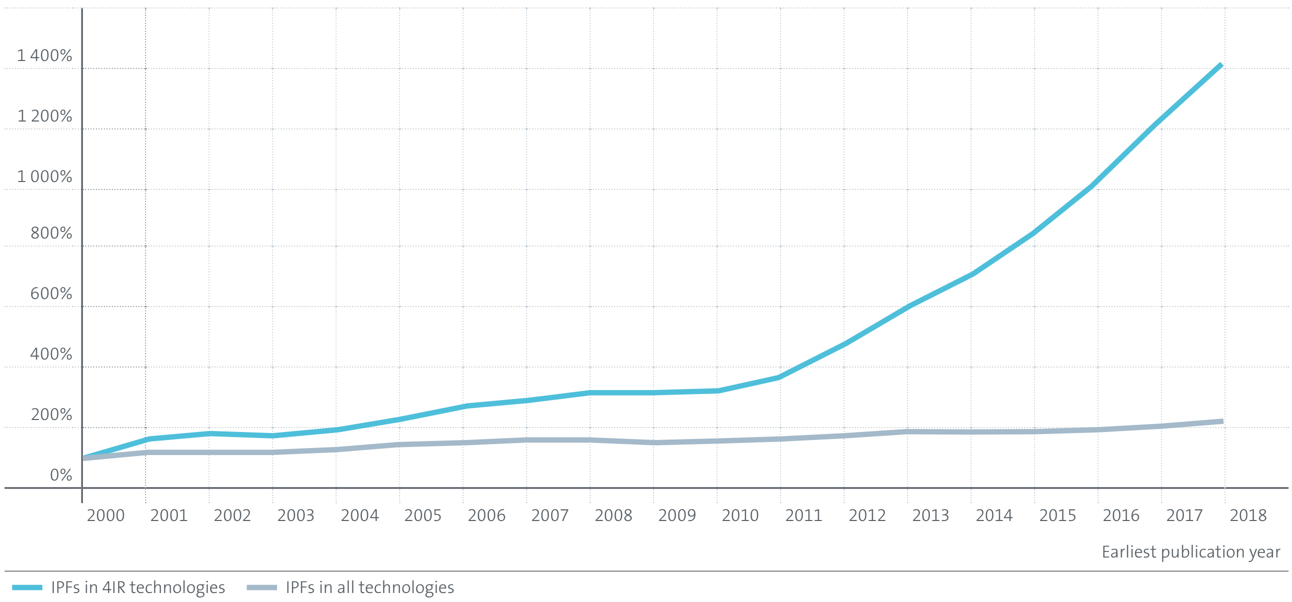
Main findings

Highlight 1: *4IR innovation has dramatically accelerated during the past decade and accounted for more than 10% of global innovation in 2018.*

The pace of global Innovation in 4IR technologies accelerated strongly during the last decade, with an average annual growth rate in patenting close to 20% from 2010 to 2018, compared with 12.8% between 2000 and 2009 (Figure E1). The annual increase in international patent families (IPFs) for 4IR technologies has been nearly five times greater than the growth of IPFs in all fields since 2010 (4.2%). As a result, smart connected objects accounted for more than 11% of all patenting activity worldwide in 2018, with nearly 40 000 new IPFs in 2018 alone.

Figure E1

Global growth of IPFs in 4IR technologies versus all technology fields, 2000-2018

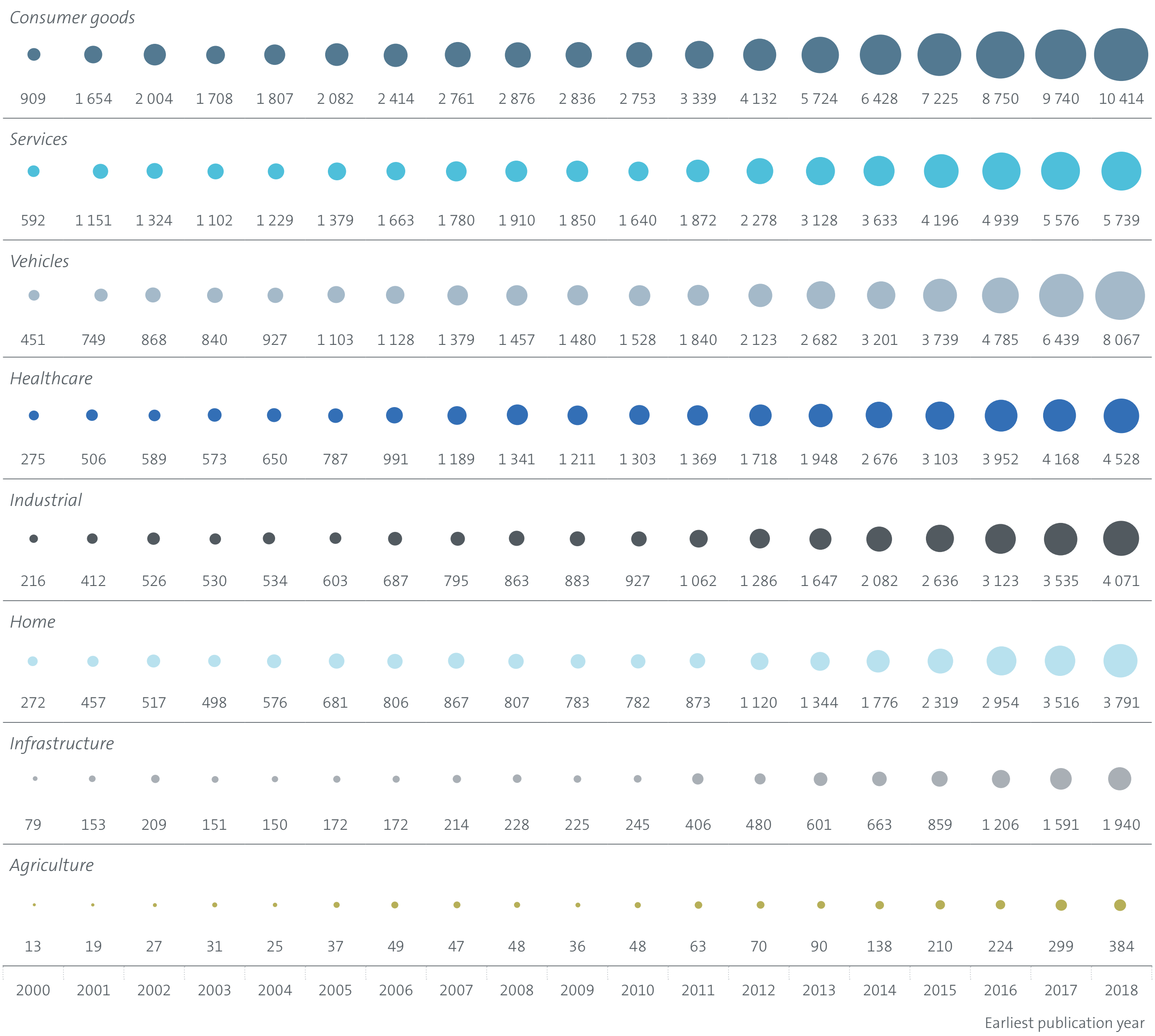


Source: European Patent Office

Similar growth trends are observed in all categories of 4IR technology fields, along with an increasing convergence between those fields. The rise of patenting activities has been especially impressive in connectivity and data management, with up to 14 000 and 11 500 IPFs respectively posted in these two fields in 2018 alone, and annual growth rate of 26.7% and 22.5% respectively between 2010 and 2018. A large variety of application domains have likewise been impacted by 4IR innovation over the same period, from smart industry, agriculture, and infrastructure to smart services (Figure E2). Among them, smart consumer goods (e.g. wearables, entertainment, toys, textiles) generated more than 10 000 IPFs in 2018 alone.

Figure E2

Global growth of IPFs in application domains, 2000-2018



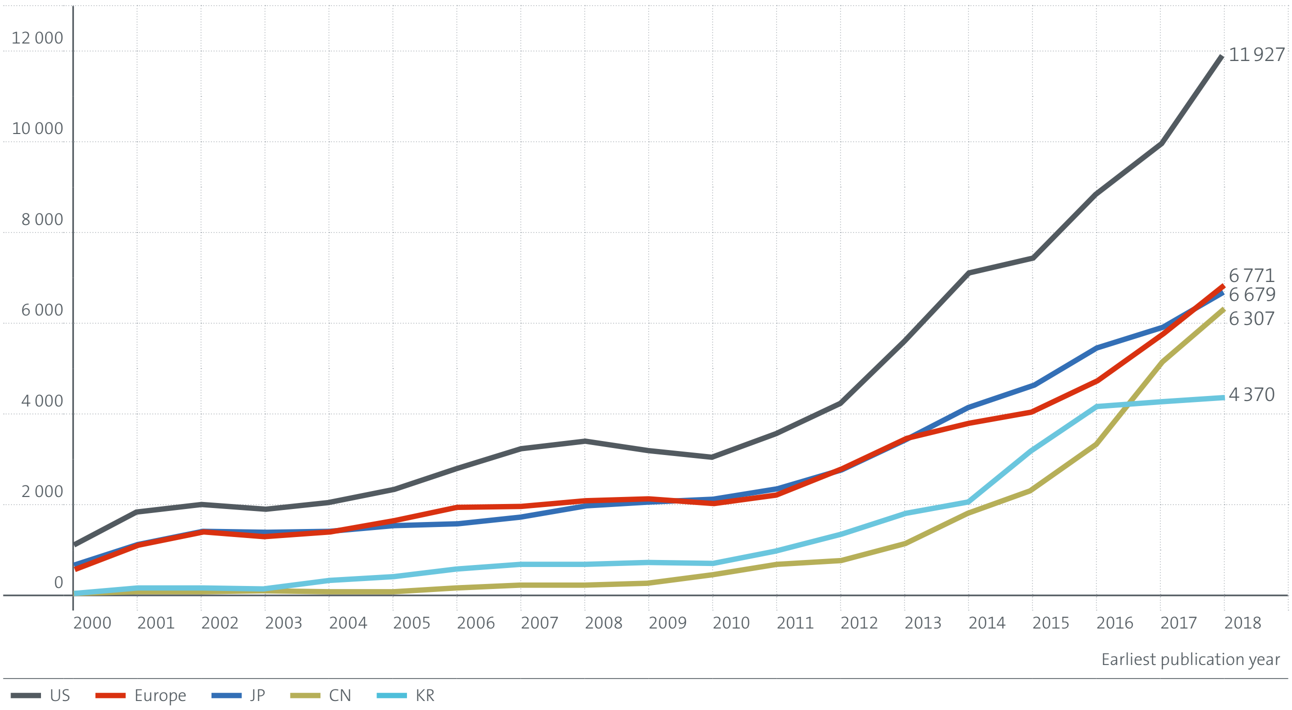
Source: European Patent Office

Highlight 2: *The US remains the world leader in 4IR technology, despite the fast growth of 4IR innovation in Korea and China. Europe*[3] *is losing ground to other global 4IR innovation centres, despite the remarkable performance of small countries such as Sweden and Switzerland.*

The US is by far the most innovative world region in 4IR technologies, with about one third of all the IPFs between 2000 and 2010 (Figure E3) and a strong presence in all technology sectors of 4IR. The US further reinforced this lead after 2010, due to a faster growth of 4IR IPFs (+18.5% annually on average) than in Europe and Japan. Europe and Japan each account for about one fifth of all IPFs in 4IR since 2000. The Republic of Korea and the People's Republic of China account for another 10% each, with a stronger specialisation in the core technology fields of IT hardware, software and connectivity. However, they started from very low levels in the late 2000s and their innovative activities have increased very fast since then (25.2% and 39.3% respectively per year on average).

Figure E3

Growth of IPFs in 4IR technologies by global innovation centres, 2000-2018



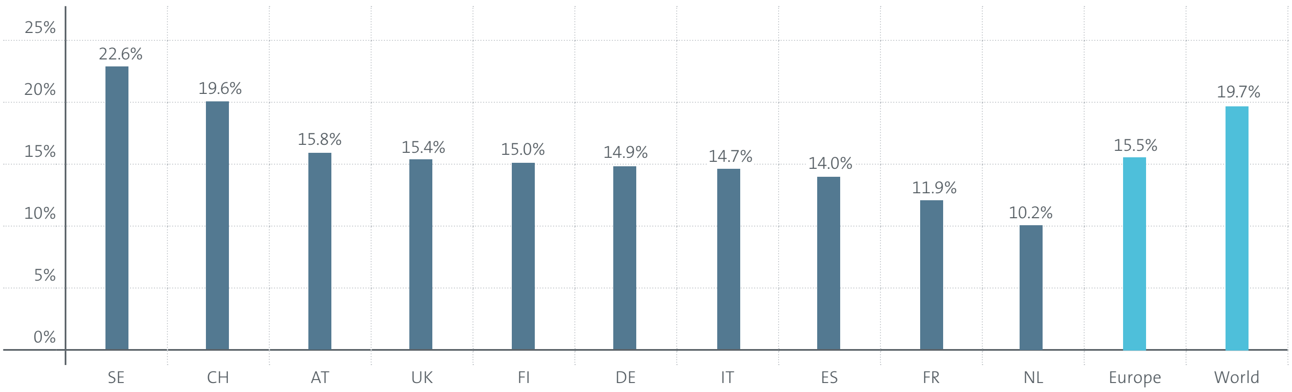
Source: European Patent Office

3 Europe is defined as comprising all 38 member states of the European Patent Organisation.

Germany alone produced 29% of all the IPFs generated in Europe between 2000 and 2018 - more than twice the contribution of the United Kingdom and France, each with 10% of European IPFs. However, the average growth of 4IR innovation in these countries in the past decade has been well below the world average (19.7%). The performance of smaller European countries is all the more remarkable in this context. With 651 and 524 IPFs respectively per million inhabitants over the period 2000-2018, Finland and Sweden show a productivity in 4IR innovation that is comparable to that of Korea (525). From 2010 to 2018, Sweden and Switzerland also posted a growth of IPRs that equals or even exceeds the global average over this period.

Figure E4

Average annual growth of IPFs for 4IR technologies in leading European countries, 2010-2018



Source: European Patent Office

Highlight 3: *The dynamism of national industry champions and regional clusters in 4IR technologies explains the domination of the US and the rise of Korea and China in the 4IR innovation landscape. By contrast, the relative weight of the top European and Japanese 4IR applicants has diminished since 2010, while the main 4IR clusters in Europe and Japan have experienced slower growth in their innovative activities.*

The top 10 applicants in the period 2010-2018 together account for 23.8% of all international patent families (IPFs) for 4IR technologies, up from 18.5% in the period 2000-2009. They feature four US companies, two Korean companies and two European companies, while Japan and China are represented by one company each. Korean companies Samsung and LG dominate the ranking, with 5.2% and 2.9% respectively of all IPFs and similar specialisation in IT hardware, power supply, and smart goods and services. The entry of Chinese company Huawei in the top 10 after 2010 illustrates the fast rise of 4IR innovation in China in recent years. By contrast, top European and Japanese applicants have lost ground to their US and Asian counterparts during the same period.

Table E1

Comparison of top 10 applicants between 2000-2009 and 2010-2018

Ranking 2000-2009			Ranking 2010-2018			
	Company	Share		Company	Share	Change
1	SAMSUNG ELECTRONICS [KR]	2.8%	1	SAMSUNG ELECTRONICS [KR]	5.2%	=
2	SONY [JP]	2.6%	2	LG [KR]	2.9%	+
3	PANASONIC [JP]	2.1%	3	QUALCOMM [US]	2.7%	+
4	SIEMENS [DE]	1.8%	4	SONY[JP]	2.4%	-
5	NOKIA [FI]	1.8%	5	HUAWEI [CN]	2.1%	+
6	PHILIPS [NL]	1.7%	6	INTEL [US]	2.0%	+
7	APPLE [US]	1.5%	7	MICROSOFT [US]	1.8%	+
8	MICROSOFT [US]	1.5%	8	ERICSSON [SE]	1.7%	+
9	CANON [JP]	1.4%	9	NOKIA [FI]	1.5%	-
10	HITACHI [JP]	1.3%	10	APPLE [US]	1.5%	-
	Total 2000-2009	**18.5%**		**Total 2010-2018**	**23.8%**	

Innovative activities are often geographically concentrated into regional clusters, typically in large urban agglomerations with an ecosystem of R&D-performing institutions around leading companies. The top 20 4IR clusters identified in the study constitute the main engines of their respective countries' performance in 4IR innovation and are jointly responsible for more than half (56.3%) of all IPFs in the period 2010-2018. Their ranking (Table E2) is topped by thirteen Asian and US clusters, followed by seven clusters located in Europe and the Middle East, all with different leading companies and 4IR specialisation profiles.

The two main 4IR clusters (Seoul and Tokyo) each account for nearly 10% of IPFs worldwide, and the third one, San José (Silicon Valley), for another 6.8%. All US, Korean and Chinese clusters in the top 10 showed impressive annual growth rates of around 20% between 2010 and 2018, and even 30% for the region of Beijing. By contrast, top clusters in Europe and Japan have experienced a more limited average annual growth, of 8% to 16%, during the same period. In comparison with the very large global clusters observed in other parts of the world, innovation activities in Europe also appear to be distributed between smaller regional clusters located across its different countries.

Table E2

Top 20 global 4IR clusters

Global ranking	Cluster	Country	Share 4IR (2010-2018)	Average growth rate (2010-2018)
1	Seoul	KR	9.9%	22.7%
2	Tokyo	JP	9.8%	10.3%
3	San José	US	6.8%	21.1%
4	Osaka	JP	4.0%	9.1%
5	Shenzhen	CN	3.1%	20.6%
6	San Diego	US	2.9%	20.2%
7	Seattle	US	2.4%	21.5%
8	Beijing	CN	2.3%	30.5%
9	New York	US	2.0%	13.8%
10	Detroit	US	1.5%	25.8%
11	Taipei City	TW	1.4%	16.5%
12	Boston	US	1.4%	12.2%
13	Los Angeles	US	1.3%	13.7%
14	Tel Aviv	IL	1.2%	15.4%
15	Eindhoven	BE/DE/NL	1.2%	8.9%
16	London	GB	1.1%	12.9%
17	Munich	DE	1.1%	16.1%
18	Stockholm	SE	1.0%	15.2%
19	Paris	FR	1.0%	8.5%
20	Stuttgart	DE	0.9%	11.4%

1. Introduction

This study by the European Patent Office (EPO) provides policymakers, industry and the broader public with information about a major global technology trend that is taking place across many sectors of the economy. Known as the Fourth Industrial Revolution[4] (4IR), this trend is driven by a constellation of disruptive technologies – such as big data, artificial intelligence (AI), fifth generation wireless communication (5G) and the Internet of Things (IoT) – which together are paving the way to a data-driven economy.

1.1. What is the Fourth Industrial Revolution?

While previous industrial revolutions have been about replacing human or animal physical effort with machines, or more recently computers, 4IR goes much further. Our ability to collect, share and process massive amounts of data makes it possible to automate complex tasks on an unprecedented scale. Wirelessly connected devices equipped with sensors can now detect changes in their physical environment and harness the power of AI to implement the optimal response *without any human intervention*. From "smart" factories operating autonomously to "smart" goods that foresee consumers' needs, the deployment of connected objects in transport (autonomous vehicles), energy (smart grids), healthcare (robot-assisted surgery), cities and agriculture is profoundly changing the way the economy and society are organised.

Like previous industrial revolutions, 4IR raises major economic and social issues. The automation of routine intellectual tasks changes the nature of human work, and hence the balance of the labour market. It raises profound ethical issues, such as the legal responsibility for decisions made by AI. As staggering amounts of technical and personal data flow through ubiquitous connected objects, cyber risks also become a major threat to businesses and governments alike. Such transformations oblige companies to rethink their business models and to adapt to new forms of competition. Besides investing in the training of the 4IR workforce, policymakers face the challenge of supporting and regulating new digital infrastructures and of creating appropriate legal frameworks to safeguard competition, cybersecurity and consumer rights in the digital age.

The speed and scope of the technical changes documented in this report are set to impact the wealth of nations. Frontrunners in major 4IR technologies such as AI or 5G communication are already shaping the data-driven economy for the years to come. Some parts of the world may secure durable growth by specialising in critical niches of 4IR technology. Others may see entire sectors of their economy struggle or even disappear in the wake of 4IR disruptions.

1.2. About this study

This study focuses on the technologies underpinning 4IR and on the way in which they are shaping the economy. Aimed at decision-makers in both the public and private sectors and building on the insights of a first study published in 2016, it looks at the high-tech drivers and innovation trends behind 4IR on a global scale.

Drawing on the latest information available in published patent documents, the data presented in this report show trends in high-value inventions for which patents have been filed in more than just the inventors' domestic market, by counting international patent families (IPFs). It provides insights into which countries, companies and regional clusters are leading the way in 4IR technologies and thus are best placed to benefit from the data-driven economy in the near future. The data also show the respective technology specialisation profiles of these actors. By highlighting the fields that are gathering momentum and the cross-fertilisation taking place between these fields, they provide a guide for policy and business decision-makers to direct resources towards value creation in the digital era.

This Fourth Industrial Revolution is primarily driven by scientific progress, and therefore by patented inventions. Companies and inventors make use of the temporary exclusivity conferred by patent rights to market their innovations and, in so doing, to recoup their R&D investments. They also increasingly employ patents as leverage in order to exploit their products, whether through licensing contracts or by setting up R&D co-operations. The EPO is responsible for granting patents which can be validated in up to 44 countries. As one of the world's main providers of patent information, it is therefore uniquely placed to observe the early emergence of these technologies and to follow their development over time. The analyses presented in the study are the result of this monitoring.

4 Fourth Industrial Revolution is the term used by Klaus Schwab, founder and Executive Chairman of the World Economic Forum, in his recent book on this subject (Schwab, 2017).

1.3. The technology drivers of the Fourth Industrial Revolution

The term Fourth Industrial Revolution (4IR) is used in this study to denote the full integration of information and communication technologies (ICT) in the context of manufacturing and application areas such as personal, home, vehicle, enterprise and infrastructure. It is, however, more than a mere continuation or even acceleration of the development of ICT, and marks instead a radical step towards a fully data-driven economy.

Technology convergence

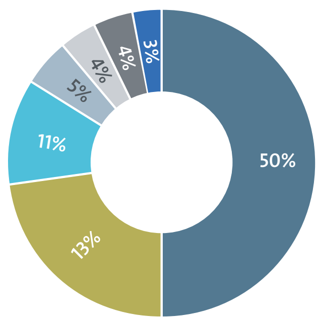
By 2023, it is estimated that more than 29 billion devices will be connected to Internet Protocol networks across the globe, most of which will be creating data in real time (Cisco, 2020). These devices include not only the laptops, smartphones and TVs with which we are familiar, but also a myriad of other smart connected objects that have started to appear more recently: smart watches, glasses and wearables, package trackers, smart meters, smart fridges and windows, smart implants, drones, autonomous vehicles and an increasing number of robots in factories, construction sites and hospitals. All these devices are typically embedded with sensors and processors, and capable of communicating with each other via the Internet of Things (IoT). Because they are increasing faster than personal connections, such machine-to-machine (M2M) connections are expected to account for half of all global connections by 2023 (Figure 1.1).

Connected objects are therefore a major factor in the rapid growth of data traffic. Along with other communication networks from fibre and satellites to Wi-Fi and short-range technologies, the advent of the 5th generation (5G) of mobile networks provides the communication infrastructure for these developments, with 13 times higher speeds than the average current mobile connection by 2023 (Cisco, 2020). The latest 5G networks are designed to support ultra-reliable device-to-device communications for a variety of applications of the IoT, such as the simultaneous connections of several hundreds of thousands of wireless sensors, with low energy consumption. Due to reduced network latency, they also allow for new critical uses of connectivity, such as autonomous driving or remote surgery.

The advent of smart connected objects likewise contributes to the economy's increasing reliance on massive amounts of data. According to IDC (2018), the global data sphere was estimated to be 45 zettabytes [5] in 2019, and is expected to grow to 175 zettabytes by 2025, a quarter of which will be real-time data. The safe and reliable storage of these enormous quantities of data in ways that enable subsequent analytics is thus a critical need. Cloud computing technologies now offer the capability to do so by storing and processing huge amounts of data on networks of remote servers located in multiple data centres. They effectively work as a utility for easily-scalable data services for all types of companies and organisations, using shared resources to achieve economies of scale and making data-accessing mechanisms more efficient and reliable.

Figure 1.1

Global number of connected devices in 2023



Source: Cisco (2020) and European Patent Office

5 One zettabyte corresponds to 1E+12 gigabytes. According to IDC (2018), a datasphere of 45 zettabytes is equivalent to a stack of single-layer Blu-ray discs equal to 23 times the distance from the earth to the moon.

Data-driven value creation

The Fourth Industrial Revolution places data at the centre of the value creation process, by bringing together data from different sources and the systems that create and exploit that data. Smart connected devices have the autonomy to decide how to act or react, based on information that they have collected and received from other devices, and then compared with criteria in their programming. The data sensed by these objects even enable the creation of "digital twins" (i.e. fully digital replicas) for complex machines, factories, supply chains or even living organs, thereby dramatically expanding possibilities for diagnostic, predictive maintenance and real-time optimisation. To understand their full potential, however, it is also necessary to take into account additional developments driven by other enabling technologies.

Progress in data analytics is of fundamental importance to extract value from data. The development of powerful diagnostic systems, and in particular the performance of human-like cognitive functions by artificial intelligence (AI), is dramatically changing this pattern. Tools such as machine-learning and neural networks can process vast amounts of data, recognise objects (e.g. faces), learn languages, create novel designs or detect patterns that were previously impossible for humans to grasp. By making the interpretation of such patterns meaningful for machines as well as for humans, they enable machine prediction, diagnosis, modelling and risk analysis. AI is an essential element for enabling effective use of larger data volumes which can no longer be dealt with manually, and where the algorithms can no longer be efficiently reprogrammed by hand.

Using large data sets, 3D systems make the results of complex models humanly viewable. Together with new interfaces to display such information, they enable applications based on virtual reality in a wide range of situations, from gaming to remote surgery, as well as the flexible design and production of any type of object through additive manufacturing (3D printing). These additional technologies play a critical role in enabling the full exploitation of the information collected by connected objects. Combined in the IoT, they displace the focus of value creation and innovation from traditional engineering towards the automated regulation of any type of system through the collection and analysis of data.

This constellation of 4IR technologies is finding applications in a wide variety of sectors (Table 1.1.) with considerable economic impact. In Europe alone, it is estimated that the cumulative additional GDP contribution of new digital technologies could amount to EUR 2.2 trillion in the EU by 2030, a 14.1% increase over 2017 (European Commission, 2020). By providing the technology infrastructure for the systematic collection, processing and exploitation of data, 4IR technologies will in particular be a key factor in realising the full potential of AI and analytics. According to the McKinsey Global Institute (2018), their deployment can help AI deliver additional global economic activity of around USD 13 trillion by 2030, or about 16% higher cumulative GDP compared with 2018.

Table 1.1

Some applications of the Internet of Things

Setting	Examples
Human	Human devices (wearable and ingestible) to monitor and maintain human health and wellness, disease management, increased fitness, remote health monitoring, telehealth systems
Agriculture	Smart farming, regionally pooled data analysis, predictive maintenance, real-time monitoring, predictive treatment of cattle, optimised use of fertilisers and pesticides
Home	Home controllers and security systems, smart energy (thermostats, HVAC, solar energy production and storage and integration into smart power networks), smart lighting, home automation
Retail environments	Self-checkout, inventory optimisation, food traceability, omni-channel operations, digital signage, in-store consumer digital offers, vending machines, near-field communication payment/shopping
Offices	Energy management and security in office buildings, improved productivity, including for mobile employees and teleworkers, production and asset management, staff identification and monitoring
Factories and worksites	Operating efficiencies, optimising equipment use and inventory, predictive maintenance, health and safety, on-demand production
Cities	Adaptive traffic control, smart grids, smart meters, environmental monitoring, resource and waste management, parking solutions, public infrastructure asset control, public safety and emergency response
Transport	Connected navigation, real-time routing, shipment tracking, autonomous vehicles and flight navigation, transport-sharing, asset and fleet management, freight monitoring, automated public transport, marine and coastal surveillance
Vehicles	Condition-based maintenance, usage-based design, pre-sale analytics, eCall, connected vehicles, services on demand, remote updates, automatic emergency calls
Finance	Remote asset security, insurance telematics, smart ATMs, bank digital signage, risk assessment in house and health insurances, smart contracts

1.4 Outline of the study

The next sections of this chapter introduce the main technology building blocks of 4IR and show how combining them can open up new possibilities for value creation and innovation. Chapter 2 sets out the methodology used in the study to identify and map inventions into the different technology fields underpinning 4IR, while chapter 3 presents the main trends. Chapter 4 focuses on the top patent applicants involved in 4IR. Chapter 5 analyses the global origins of 4IR inventions, while chapter 6 looks more closely at the top 30 4IR innovation clusters on a global scale. The study is illustrated by four case studies highlighting a range of inventions related to the Fourth Industrial Revolution.

BOX 1

Computer-implemented inventions (CII) and artificial intelligence (AI) at the EPO

An important implication of 4IR is that innovation in the enhancement of products and processes is increasingly taking place in the virtual layer of software, rather than in any hardware components. This feature is already familiar in computers and mobile devices, which consumers can update, upgrade or equip with new software without having to buy a new device. With the generalisation of the IoT, the same pattern is set to apply to all sorts of hardware, including vehicles and factories. As a result, most 4IR inventions are computer-implemented inventions.

Computer-implemented inventions are treated differently by patent offices in different regions of the world. In Europe, Article 52 of the European Patent Convention (EPC) excludes computer programs "as such" from patent protection. Inventions involving software can be patented as long as they clearly have a technical character.

Over the years, the case law of the EPO Boards of Appeal has clarified the implications of Article 52 EPC, establishing a stable and predictable framework for the patentability of computer-implemented inventions, including inventions related to artificial intelligence. This framework is reflected in the EPO's Guidelines for Examination.

Like all other inventions, in order to be patentable, computer-implemented inventions must meet the fundamental legal requirements of novelty, inventive step and industrial application. In addition, it must be established that they have a technical character that distinguishes them from computer programs "as such", which are excluded from patentability. In other words, they must solve a technical problem in a novel and non-obvious manner.

The normal physical effects of the execution of a program, e.g. electrical currents, are not in themselves sufficient to lend a computer program technical character, and a further technical effect is needed. The further technical effect may result, for example. from the control of an industrial process or the working of a piece of machinery, or from the internal functioning of the computer or computer network itself (e.g. memory organisation, program execution control) under the influence of the computer program.

The same applies for computer-implemented inventions related to artificial intelligence. While abstract machine-learning algorithms are not as such patentable, patents may be granted for their application to solve a technical problem in a field of technology (e.g. medical image classification) or when they are adapted for a specific technical implementation (e.g. graphics processing unit (GPU), implementation of neural networks).

The EPC thus enables the EPO to grant patents for inventions in many fields of technology in which computer programs make a technical contribution. Such fields include medical devices, the automotive sector, aerospace, industrial control, additive manufacturing, communication/media technology, including voice recognition and video compression, and the computer/processor or computer network itself.

Visit the website of the EPO for more information about the patenting of digital technologies.

2. Methodology

2. Methodology

Patents are an effective means to protect inventions of all types, including those related to 4IR technologies. They can be used to observe the emergence of these technologies at an early stage, and to monitor their development over time. Patent examiners, who assess patent applications on a daily basis, accumulate significant expertise in the related technology fields, so are therefore in a very good position to develop cartographies of all related 4IR technologies and map them to pertinent patented inventions. This chapter provides a description of the 4IR cartography developed by the EPO, the process by which relevant patent applications have been identified and other important methodological aspects that were applied to produce this study.[6]

2.1. Cartography of 4IR inventions

This cartography identifies patent applications that constitute the building blocks of 4IR. It is based on a rigorous selection of inventions that are related to smart and connected devices and which combine features of computing, connectivity and data exchange. These 4IR inventions are further divided into three main sectors, namely "core technologies", "enabling technologies" and "application domains", each of which are subdivided into several technology fields.

The first sector, *core technologies*, corresponds to the basic building blocks upon which the technologies of 4IR are built. It consists of inventions that directly contribute to the three established fields of information and communication technologies (ICT) inherited from the previous industrial revolution: IT hardware, software and connectivity. The table gives a short definition of these core technology fields.

Table 2.1

Overview of core technology fields

Field	Definition	Examples
IT hardware	Basic hardware technologies	Sensors, advanced memories, processors, adaptive displays, smart instruments
Software	Basic software technologies	Intelligent cloud storage and computing structures, adaptive databases, mobile operating systems, virtualisation and blockchain technologies
Connectivity	Basic connectivity systems	Network protocols for massively connected devices, adaptive wireless data systems for short-range and long-range communication

6 A separate Annex on the methodology for identifying 4IR technologies in patent data can be downloaded from epo.org/trends-4IR.

The second sector encompasses *enabling technologies* that build upon and complement the core technologies. These enabling technologies can be used for multiple applications. They have been subdivided into eight technology fields (Table 2.2).

The third sector, *application domains*, encompasses the final applications of 4IR technologies in various parts of the economy. It has been divided into eight different technology application fields (Table 2.3).

Table 2.2

Overview of enabling technology fields

Field	Definition	Examples
Data management	Technological means to create value from data	Diagnostic and analytical systems for massive data, prediction and forecasting techniques, monitoring functions, planning and control systems
User interfaces	Enabling the display and input of information	Virtual reality, augmented reality, speech recognition and synthesis
Core AI	Enabling machine understanding	Machine learning, neural networks, statistical and rule-based systems, AI platforms
Geo-positioning	Enabling the determination of the position of objects	Enhanced geo-location and satellite navigation, device to device relative and absolute positioning
Power supply	Enabling intelligent power handling	Automated generation, situation-aware charging systems, shared power transmission and storage objectives, smart power-saving management
Data security	Enabling the security of data	Adaptive security systems for devices, services and data transmission
Safety	Enabling safety or physical objects	Intelligent safety systems for theft and failure prevention
Three-dimensional support systems	Enabling the realisation of physical or simulated 3D systems	3D printers and scanners for parts manufacture, automated 3D design and simulation, 3D user interfaces

Table 2.3

Overview of technology fields in application domains

Field	Definition	Examples
Consumer goods	Applications pertaining to the individual	Personal health monitoring devices, smart wearables, smart entertainment and sport devices, smart toys and textiles
Home	Applications for the home environment	Smart homes, alarm systems, intelligent lighting and heating, consumer robotics, climate control systems
Vehicles	Applications for moving vehicles	Autonomous driving, vehicle fleet navigation devices
Services	Applications for business enterprise	Intelligent retail, payment and loyalty systems, smart offices
Industrial	Applications for industrial manufacture	Smart factories, intelligent robotics, energy saving
Infrastructure	Applications for infrastructure	Intelligent energy distribution networks, intelligent transport networks, intelligent lighting and heating systems
Healthcare	Applications for healthcare	Intelligent healthcare systems, robotic surgery, smart diagnosis
Agriculture	Applications for agriculture	Climate monitoring systems, greenhouse automation, smart crop and cattle management, smart farming

As indicated in Box 2.1, 4IR inventions can be relevant to one or more technology fields, within one or more technology sectors. If an invention combines features of several 4IR technologies, forming a bridge technology between different 4IR building blocks, the related patent application is classified accordingly in all the relevant technology fields, resulting in overlaps in the numbers at field and sector level.

BOX 2.1

Linking 4IR technology to patent data

The cartography of 4IR technologies was created in three steps.

Step 1: Mapping the cartography to the patent classification scheme

The cartography is based on the in-depth knowledge of EPO patent examiners. Patent classification experts from all technical areas were asked to indicate to which field ranges of the Cooperative Patent Classification (CPC) scheme they would assign 4IR inventions, and to which fields of the cartography these ranges should be attributed. The resulting concordance table contains around 368 CPC field ranges in all technical areas with their respective 4IR technology fields. The cartography was verified by applying ad hoc queries against the EPO's full-text patent database and analysing the results using text mining techniques. Whenever anomalies were identified they were re-assessed by classification experts and corrected/amended where necessary.

Examples

CPC range	Description	4IR fields
G16H10/00 - G16H80/00	Medical informatics	Consumer goods, healthcare
B60K31/00 - B60K31/185	Vehicle control, e.g. automatic speed control	Vehicles

Step 2: Identifying 4IR patent applications

On all patent documents in the identified CPC ranges, a full-text search query was applied to identify documents related to the 4IR definition with the highest degree of certainty placed on true positives. As a general restriction, all documents had to contain the concept of data exchange, even if this was not itself the inventive aspect of the patent application. In addition, further subqueries were defined to include the concepts of communication (e.g. internet, mobile, wireless), computing (e.g. big data, cloud, artificial intelligence) and intelligent devices (e.g. sensor networks, Internet of Things, smart homes).

Step 3: Classifying patent applications to the cartography fields

All the patent documents associated to each field in the cartography were extracted and labelled with said field. Finally, all the retrieved patent documents were combined in a final set of unique patent documents with the corresponding cartography fields. The combination of the cartography fields defined the characteristic 4IR technology fields of the patent application.

Examples

– CPC codes assigned to patent application or cited documents: A61B5/68, B60D1/075
– Corresponding CPC field ranges in 4IR cartography: A61B5/68 - A61B5/6802, B60D1/01 - B60D1/075
– Cartography fields mapped to patent application: Personal, Connectivity, Vehicles

For the purposes of this study, the statistics on 4IR patent applications are based on a simple count method, reflecting the number of patent families, i.e. inventions, assigned to a particular field or sector of the cartography, independently of whether some of these patent families are also classified in other fields or sectors. For example, a patent family assigned to two fields of the same sector is counted as a single invention at sector level and as one invention in each of the technology fields. Accordingly, an invention assigned to two fields in two different sectors is counted as one invention in each of the two technology sectors and as one invention in each of the technology fields.

2.2. Focus on international patent families

Patents are strictly territorial. To protect a single invention in multiple markets, a number of national or regional patents are required. A large number of patents, therefore, does not necessarily mean a large number of inventions. A more reliable measure is to count international patent families (IPFs), each of which represents a unique invention and includes patent applications filed and published in at least two countries. [7] IPFs are a reliable and neutral proxy for inventive activity because they provide a degree of control for patent quality and value by only representing inventions deemed important enough by the applicant to seek protection internationally. A relatively small proportion of applications meet this threshold. This concept enables a comparison of the innovative activities of countries and companies internationally, since it creates a sufficiently homogeneous population of patent families that can be directly compared with one another, thereby reducing the national biases that often arise when comparing patent applications across different national patent offices.

In addition, almost all IPFs are classified according to the Cooperative Patent Classification (CPC) scheme (which is not always the case with applications filed solely at one office). This means that only one scheme is needed to identify relevant inventions and assign them to the different technologies within the cartography, irrespective of where the applications were filed. Each IPF identified as relevant to 4IR technologies is assigned to one or more sectors or fields of the cartography. The analysis covers the period 2000-2018. The date attributed to a given IPF always refers to the year of the earliest publication within the IPF. The geographic distribution of IPFs is calculated using information about the origin of the inventors disclosed in the patent applications. Where multiple inventors were indicated on the patent documents within a family, each inventor was assigned a fraction of the patent family.

Where necessary, the dataset was further enriched with bibliographic patent data from PATSTAT, the EPO's worldwide patent statistical database, as well as from internal databases, providing additional information, for example, on the names and addresses of applicants and inventors, or whether the applicant is a company or a research organisation. In addition, information was retrieved from the Bureau van Dijk ORBIS (2019 version) database and used to harmonise and consolidate applicant names and their addresses. Each applicant name was consolidated at the level of the global ultimate owner according to the latest company data available in ORBIS. If that information was not available, the data was cleaned manually.

2.3. Identification of global 4IR clusters

To identify the regional 4IR innovation clusters, the density-based DBSCAN algorithm (Ester et al. 1996) was applied to the geocoded inventor locations for all relevant IPFs. This algorithm groups together location points with a dense neighbourhood into clusters and has two important advantages. First, it is able to represent clusters of arbitrary shape, and second, it labels location points that do not belong to any cluster as noise. This allows the analysis to focus on the identified innovation clusters and dismiss inventor addresses outside said clusters.

For each IPF, the locations of all unique inventor-address pairs listed in one of the patent applications in the patent family were selected and represented as separate data points. No duplicates of any address were removed, i.e. two different inventors having the same address produced two separate points in the same location. Equally, if the same inventor was listed in multiple patent applications then multiple points were placed in the same location.

The DBSCAN clustering algorithm was then applied to the set of points. Two parameters were required as inputs to the algorithm: the eps radius, which defined the radius of the neighbourhood around each point (i.e. each inventor address), and the minimum number of points in the neighbourhood of a point to consider it as a core point, i.e. a point in a high-density region. The characteristics of the clusters found by the algorithm depend directly on the selection of these two parameters. To find the global 4IR clusters, an eps radius of 40 km and a minimum number of 2 000 data points were selected.

7 An IPF is a patent family that includes a published international patent application, a published patent application at a regional patent office or published patent applications at two or more national patent offices. The regional patent offices are the African Intellectual Property Organization (OAPI), the African Regional Intellectual Property Organization (ARIPO), the Eurasian Patent Organization (EAPO), the European Patent Office (EPO) and the Patent Office of the Cooperation Council for the Arab States of the Gulf (GCCPO).

Case study: Data-driven dairy farming

Case study: Automated milking robots
Company: Lely
Sector: Dairy farming
Invention: Automated milking robot
Country: The Netherlands

The agricultural sector faces fairly daunting challenges: climate change, greater emphasis on sustainability and the environment, and growing workforce pressure as younger generations are drawn towards urban areas, leaving their traditional farming communities behind. Furthermore, with a growing global population, farmers will have to increase their output with fewer resources. It is therefore unsurprising that they are using technology to move towards smarter agriculture and precision farming.

European Inventor Award finalists Alexander van der Lely and Karel van den Berg are pioneers, having spent the last few decades developing milking robots for cows at agricultural machine manufacturer Lely. Global demand for dairy products is on the rise, but conventional milking can be stressful for cows. Traditionally, it is the farmer, and not the animal, that decides when it is time for milking. The Dutch inventors developed a new concept in agribusiness, one that incorporates automation and generates and then leverages data, whilst focussing on animal well-being.

Space-age technology for the farm

The milking robot is called the Astronaut: the cows are connected to high-tech machinery with a single cord but remain free to move, similar to an astronaut on a spacewalk. Each cow has a scannable collar that enables data collection, a robotic arm with sensors that detect teats, a cleaning mechanism and teat cups.

Cows enter the pen when they want to be milked. Once inside, their collars are scanned and the robotic arm starts the procedure. After their teats have been cleaned, the cups lock on to begin milking. While the cow is being milked, it is given feed from an individually controlled diet. The sensors also detect motion and the robot arm is able to move as the cow does. The entire process is aimed at giving the cow autonomy, ensuring lower stress and gentler handling. Human intervention is not needed. However, if the system reports an error, or a particular animal remains in the pen for an unusually long time, a notification is sent to a mobile device.

Big data meets agriculture

Lely's automated milking systems are designed to give farmers data including feeding habits, milk flow, milk quality, animal health and a feed/milk conversion ratio on a per-cow or entire-herd basis. The data feeds into a management system and can then be analysed and used to implement operational improvements.

Compared with conventional methods, a farm with 120 cows can increase its milk production by more than 1 kg per cow per day when milking is done twice a day using the Astronaut. As the cows are sick less often, veterinary costs are lower and the animals require fewer antibiotics.

Slow start, strong finish

While milking robots are not a new field of technology, there were some early challenges. Initially, the inventors found it difficult to fine-tune sensors to detect teats or account for differences in udder shapes or sizes. Then, automation enabled round-the-clock milking, requiring a fundamental shift in practices. Farmers at the time wanted reassurance as switching to all-new machines was a risk. With fewer staff managing the herd, farmers needed to know that spare parts and repair technicians were available in the event of a breakdown. Lely needed to build a support network and create market confidence. The company licensed its patented inventions and, as a result, market awareness improved and adoption rates increased.

Today, some 30 000 Astronauts are used to milk cows in 45 countries. The growing adoption rate of milking robots boosted Lely's turnover by 46% to EUR 606 million in 2019. The company now has 1 600 employees, two production facilities, three research and development departments and a portfolio that includes over 140 patent families. The milking robot market is currently valued at EUR 1.1 billion and is projected to grow to EUR 2.5 billion by the end of 2027, representing a compound annual growth rate of 11.4% between 2020 and 2027.

The farm of the future

Milking robots are just one example of innovation meeting agriculture. Farmers are beginning to test multispectral crop analysis with drones, driverless tractors and AI powered pest detection. The Fourth Industrial Revolution is set to drive an agricultural one.

3. Main technology trends

3. Main technology trends

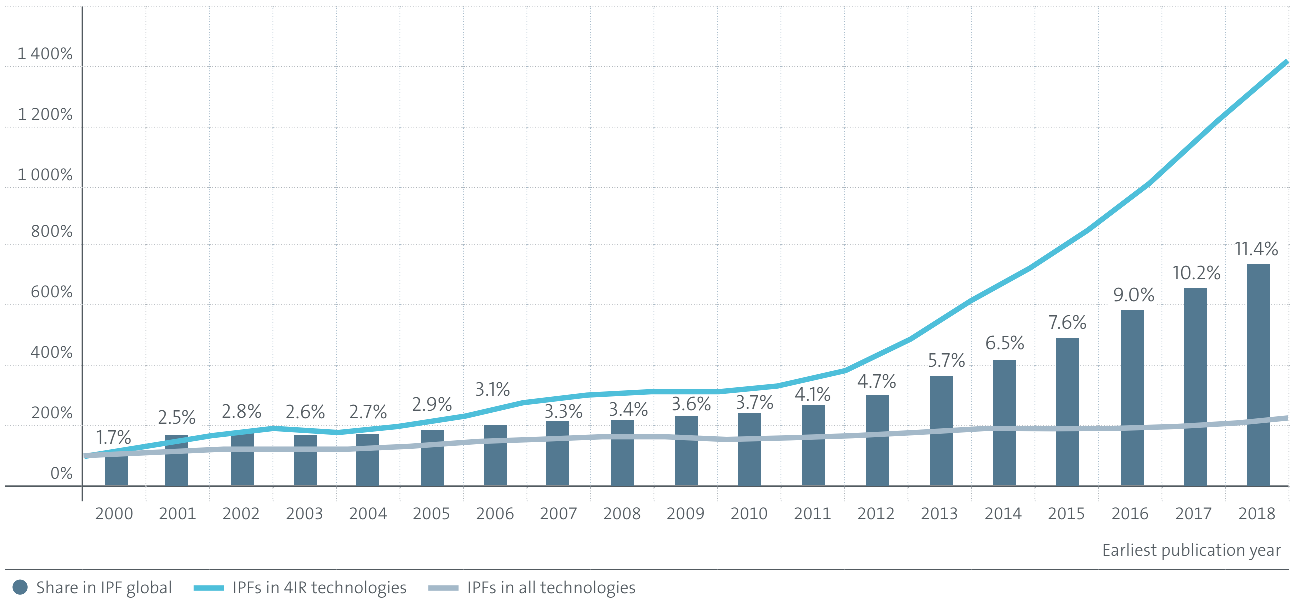
Using the cartography of 4IR technologies described in chapter 2, a total of 264 565 international patent families (IPFs), each corresponding to a 4IR invention patented in two or more jurisdictions or in a regional patent office, were identified globally between 2000 and 2018. This chapter looks at trends in these inventions over the last two decades and across different technology fields and sectors.

3.1. General trends

The pace of global Innovation in 4IR technologies accelerated strongly during the last decade (Figure 3.1), with an average annual growth rate in patenting close to 20% between 2010 and 2018, compared with 12.8% from 2000 to 2009. The annual increase in patent filings for 4IR technologies has been nearly five times greater than the growth of patenting in all fields since 2010 (4.2%). As a result, smart connected objects accounted for more than 11% of all patenting activity worldwide in 2018, with nearly 40 000 new IPFs in 2018 alone.

Figure 3.1

Global growth of IPFs in 4IR technologies versus all technology fields, 2000-2018



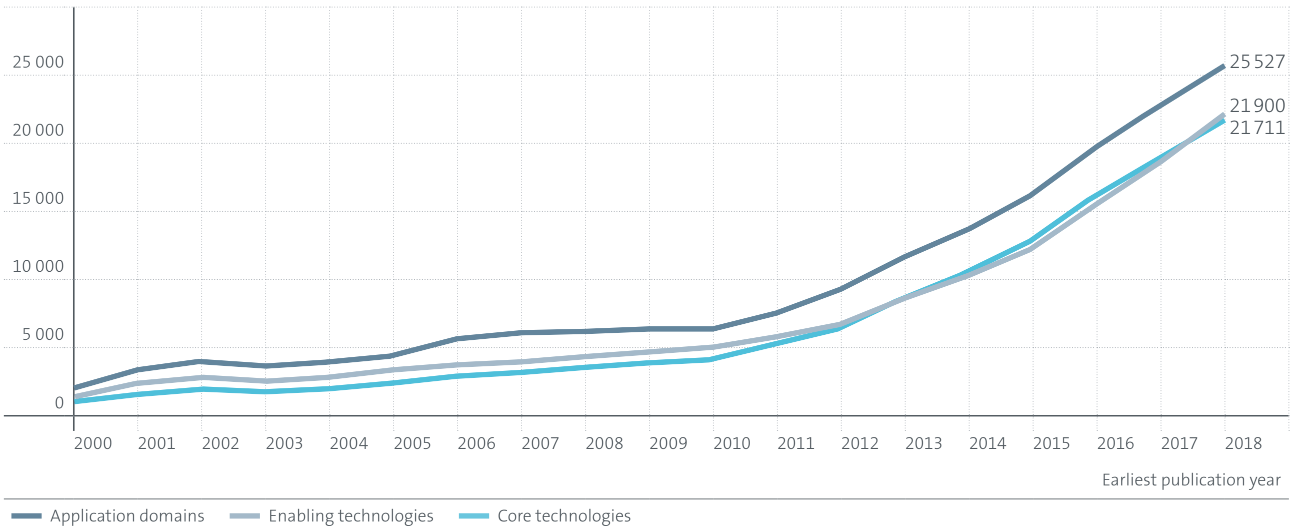
Source: European Patent Office

Similar trends are observed in all three main sectors of 4IR technologies (Figure 3.2). The number of IPFs related to 4IR application domains has been consistently higher than in other sectors during the whole period 2000-2018, with more than 25 000 IPFs counted in 2018 alone. Innovation in core technologies and enabling technologies has generated roughly comparable annual numbers of patented inventions since 2000, posting more than 20 000 IPFs in each sector in 2018.

However, a closer look at the trends after 2010 shows that the number of IPFs has been growing at a faster rate in core technologies (23.0%) than in enabling technologies and application domains (20.3% and 19.0% respectively). This faster growth is more clearly visible in the distribution of IPFs across sectors (Figure 3.3). About 60% of the IPFs for 4IR technologies produced since 2010 pertain to more than one sector, and 11.8% of them are relevant to all three sectors. In this recent period, the increasing share of IPFs related to core technologies has been the main driver of integration with enabling technologies and new application domains.

Figure 3.2

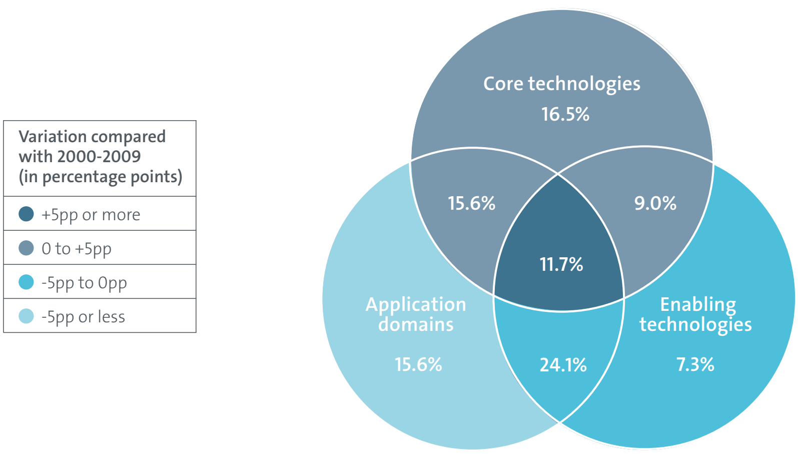
Global growth of IPFs in 4IR sectors, 2000-2018



Source: European Patent Office

Figure 3.3

Distribution of IPFs between the three main 4IR sectors, 2010-2018



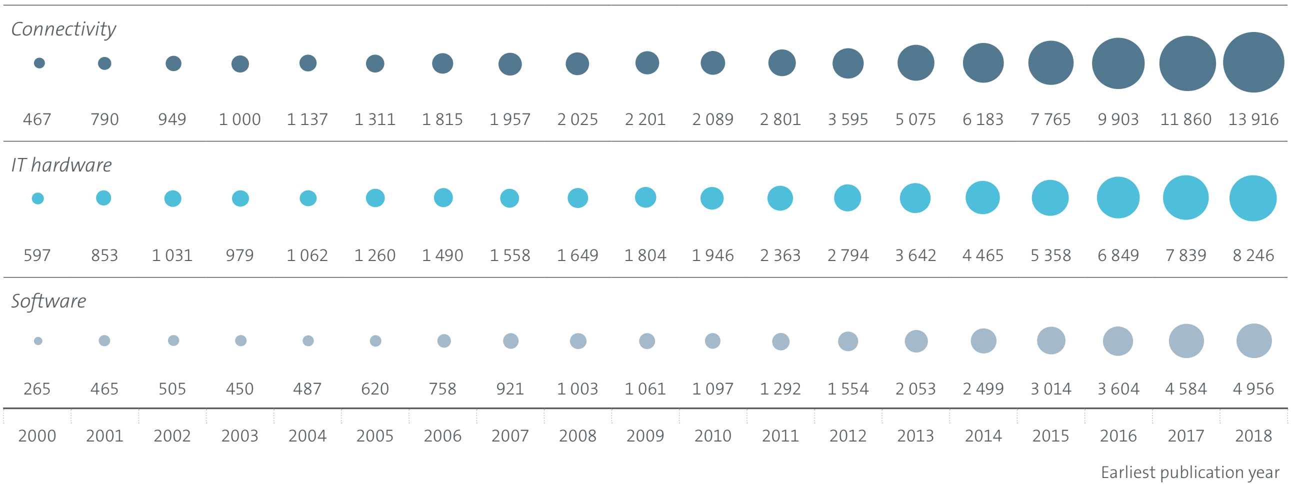
Source: European Patent Office

3.2. Trends by 4IR technology fields

The core technologies supporting the rise of 4IR include IT hardware (e.g. processors, sensors, memories), software infrastructure (e.g. operating systems, databases, cloud computing) and connectivity (e.g. protocols, short- and long-range communication). While all three fields have experienced a strong growth since 2010 (Figure 3.4), patenting activities have been increasing especially fast in connectivity, with an annual growth of 26.7% over this period. This impressive rise in the past decade has been largely driven by the development of 5G, which is providing the missing link for the massive deployment of smart connected objects. With 63 187 IPFs since 2010, connectivity is also the largest of all the 4IR technology fields analysed in this study.

Figure 3.4

Global growth of IPFs in core 4IR fields, 2000-2018



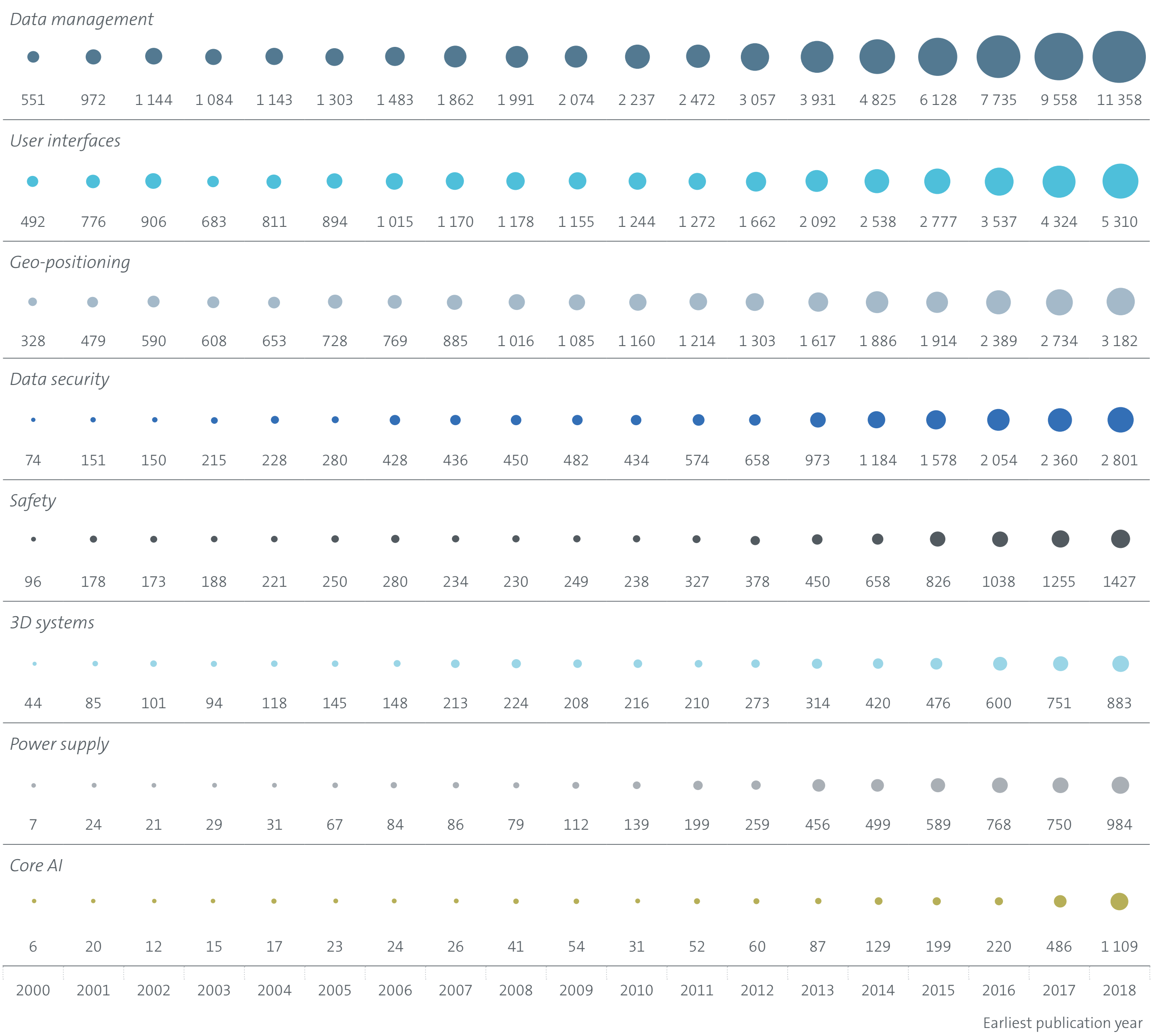
Source: European Patent Office

Overall, innovation in 4IR enabling technologies has increased by 356% since 2010, and a positive growth trend can be observed in all related fields (Figure 3.5). However, much of the growth during this period has been driven by innovation in the field of data management, which encompasses all technologies aiming at exploiting data, from their creation, processing and analysis to feedback execution (see Box 3.1). This field is pivotal in deriving value from the massive amount of data collected by connected objects and is proving to be a key lever for the deployment of 4IR technologies in new application fields. The field of data management has posted an average annual growth of 22.5% since 2010, and in 2018 accounted for more than half of all IPFs related to enabling technologies.

Other dynamic enabling technology fields include user interfaces (24 756 IPFs since 2010), geo-positioning (17 399 IPFs) and data protection (12 616 IPFs). The core technologies underlying artificial intelligence (such as neural networks, deep learning and rule-based systems) show a spectacular increase, with an average annual growth rate of 54.6% since 2010, albeit with relatively low absolute numbers of IPFs so far.

Figure 3.5

Global growth of IPFs in enabling technology fields, 2000-2018



Source: European Patent Office

BOX 3.1

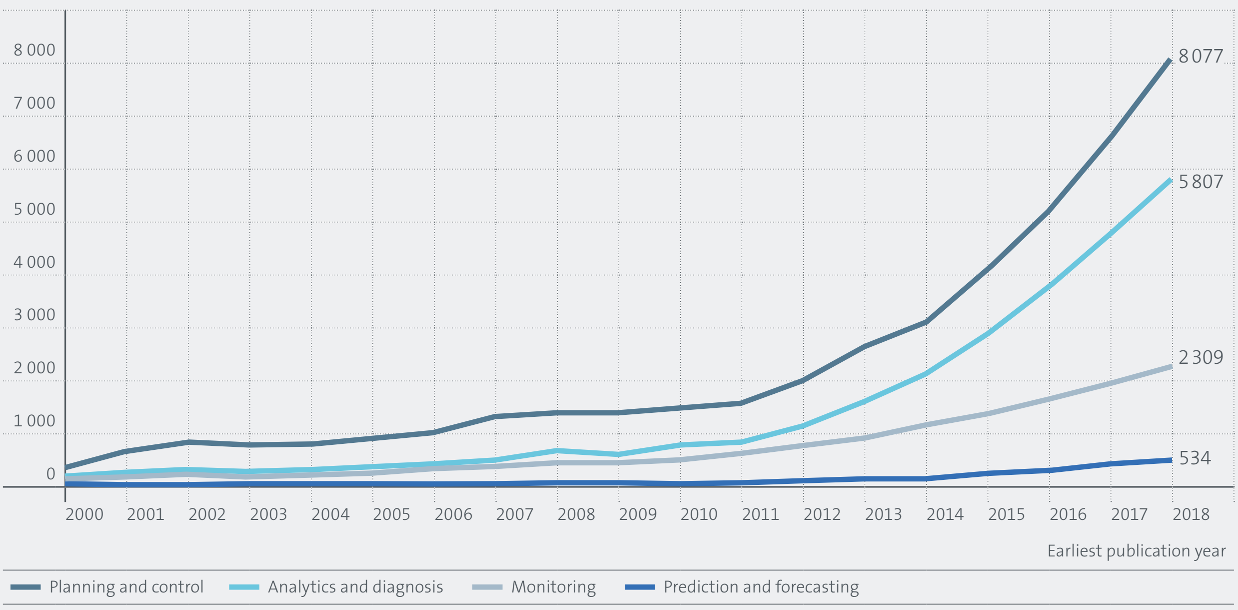
Focus on data management technologies

Data management technologies provide the means to create value out of data, and as such constitute the cornerstone of the Fourth Industrial Revolution. They encompass all steps from the collection, mining and analysis of data to feedback execution in physical devices. It is therefore not surprising that data management represents by far the largest category of 4IR enabling technologies, and is a particularly dynamic field, with an average growth rate of 22.5% since 2010.

The field of data management can be subdivided into four distinct categories, namely monitoring functions (generating data typically by means of sensors), analytics and diagnosis (based on the generated data), planning and control (e.g. automated control systems for entreprises, vehicles or factories), and prediction and forecasting (e.g. wind speed forecasting for managing electric energy production, or business forecasting and optimisation). Figure 3.6 shows the global trends in all four data management subfields between 2000 and 2018. The majority of IPFs, 69%, are related to planning and control, followed by analytics and diagnosis (44%), monitoring (23%) and the smallest subfield, prediction and forecasting (4%). All of them have developed very rapidly since 2010, with average growth rates exceeding 20%, and analytics and diagnosis growing fastest at 27.8% per year.

Figure 3.6

Global growth of IPFs in data management technologies, 2000-2018



Source: European Patent Office

Samsung, with a share of 5%, is very strong in analytics and diagnosis but does not appear in the top five of the other subfields. Microsoft is second in analytics and diagnosis, and first in prediction and forecasting technologies. Interestingly, planning and control and monitoring do not feature any ICT company among the top five applicants. Two automotive companies, Ford and Toyota, are in the lead for planning and control, while Halliburton and General Electric, two multinational conglomerates that are active in many industrial areas, are the top appliants in monitoring technologies. European companies Siemens and Robert Bosch are among the top applicants in planning and control and, in the case of Siemens, analytics and diagnosis.

Table 3.1

Top applicants in subfields of data management technologies, 2010-2018

	Monitoring	Share in subfield	Analytics and diagnosis	Share in subfield
1	HALLIBURTON [US]	3.6%	SAMSUNG ELECTRONICS [KR]	5.0%
2	GENERAL ELECTRIC [US]	3.3%	MICROSOFT [US]	1.9%
3	HITACHI [JP]	2.4%	GENERAL ELECTRIC [US]	1.9%
4	FORD [US]	2.3%	SONY [JP]	1.8%
5	SCHLUMBERGER [CW]	1.9%	SIEMENS [DE]	1.8%

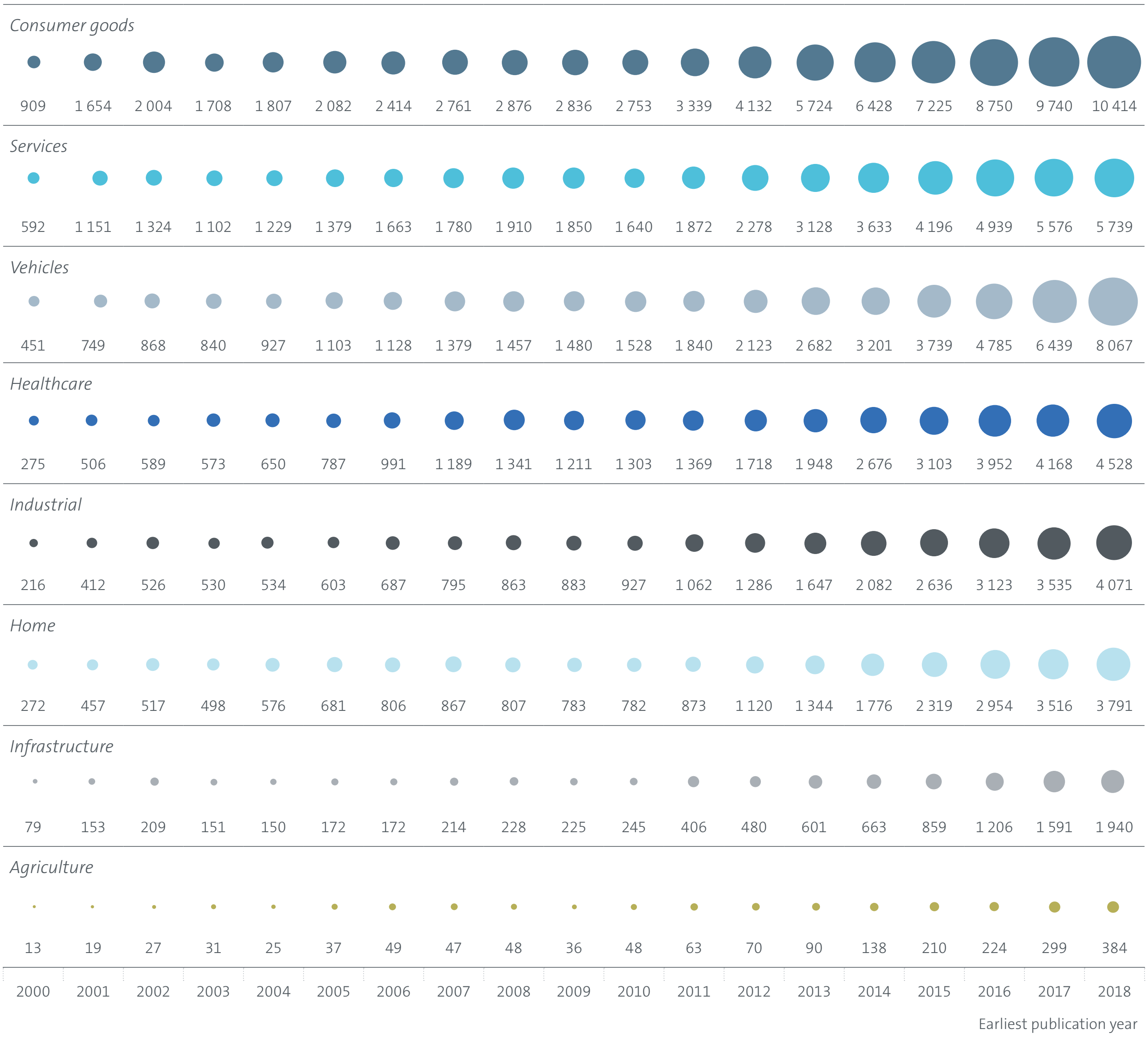
	Planning and control	Share in subfield	Prediction and forecasting	Share in subfield
1	FORD [US]	3.2%	MICROSOFT [US]	2.6%
2	TOYOTA [JP]	2.3%	GENERAL MOTORS [US]	2.3%
3	SIEMENS [DE]	2.3%	FORD [US]	2.0%
4	ROBERT BOSCH [DE]	2.3%	HITACHI [JP]	1.9%
5	MITSUBISHI ELECTRIC [JP]	2.1%	BEIJING DIDI INFINITY TECHNOLOGY & DEV [CN]	1.9%

Figure 3.7 illustrates the diversity of application domains impacted by 4IR technologies, from consumer goods and services to industry, agriculture and infrastructure. Although all of these applications domains have experienced a strong increase in innovation during the last decade, some of them clearly dominate in terms of the volume of patenting activities. The field of smart consumer goods (e.g. wearables, entertainment, toys, textiles) in particular generated the largest number of IPFs in the period 2000-2009, and has remained the most dynamic one since then, recording more than 58 000 IPFs between 2010 and 2018 and over 10 000 IPFs in 2018 alone.

Other very active fields include smart vehicles (with over 8 000 IPFs in 2018), smart services (almost 6 000 IPFs in 2018) and smart healthcare (4 500 IPFs in 2018). Applications of 4IR technologies for the home, industry and healthcare have posted a more regular yet sustained growth in the past decade. An increase in 4IR patenting activities in smart infrastructure (e.g. energy, transport) and agriculture can also be observed in recent years (post-2014), albeit from a low initial level.

Figure 3.7

Global growth of IPFs in application domains, 2000-2018



Source: European Patent Office

Innovation in application domains typically involves a combination of technology bricks from core and enabling technology fields. To make this visible, Table 3.2 shows, for each 4IR application domain, the share of IPFs in that domain that are also classified as relevant to other fields pertaining to either enabling technology fields and/or core technology fields.[8] The first three rows show for instance that 43% of IPFs related to 4IR services and 31% of the smart consumer goods IPFs have a core hardware component, while connectivity is more often involved in application domains such as smart home (53%), infrastructure (37%) and services (34%). The shares of IPFs related to core software technology are lower than in the other two core technology fields and highest for consumer goods (14.2%), home applications (10.9%) and services (10.9%).

Data management is by far the most pervasive enabling technology. It is present in 87% of IPFs related to smart manufacturing, two thirds of infrastructure applications, and more than half of IPFs related to vehicles. Data management technologies are more generally visible in a significant share of IPFs in all application domains. Among the other enabling technologies, geo-positioning is frequently associated with 4IR applications for vehicles and consumer goods, and safety technologies with smart home, vehicle and industrial applications. Nearly 10% of IPFs related to healthcare also include a 3D systems component, for instance for medical imaging or the 3D printing of implants. Data security has the highest share of IPFs in consumer goods (5.9%), services (4.8%), home (3.4%) and infrastructure (3.2%). The two smallest enabling technology fields are power supply and core AI. In terms of IPFs, power supply is relatively more important for consumer goods (2.1%) and healthcare applications (1.7%), whereas core AI shows its highest shares in relation to smart services (1.4%) and infrastructure (1.3%).

Table 3.2

Impact of enabling and core technologies on different application domains, 2010-2018

		Application domains							
		Consumer goods	Home	Vehicles	Services	Industrial	Infrastructure	Healthcare	Agriculture
Core techno-logies	IT hardware	31.1%	14.9%	13.7%	42.8%	8.5%	12.6%	6.6%	6.5%
	Software	14.2%	10.5%	3.9%	10.9%	4.7%	8.6%	1.7%	2.0%
	Connectivity	32.9%	53.2%	11.3%	34.1%	10.3%	36.8%	13.0%	5.6%
Enabling techno-logies	Data management	16.0%	31.2%	54.2%	18.1%	87.1%	66.0%	27.2%	20.3%
	User interfaces	13.7%	6.7%	10.8%	9.1%	4.4%	6.0%	5.8%	1.4%
	Core AI	0.8%	0.7%	0.7%	1.4%	0.8%	1.3%	0.7%	0.9%
	Geo-positioning	16.1%	4.0%	31.2%	3.5%	2.1%	7.2%	1.6%	7.7%
	Power supply	2.1%	0.7%	0.3%	0.8%	0.5%	0.9%	1.7%	0.1%
	Data security	5.9%	3.4%	1.2%	4.8%	1.4%	3.2%	0.9%	0.2%
	Safety	1.0%	19.9%	9.2%	3.2%	15.6%	5.0%	0.8%	0.3%
	3D systems	2.6%	0.4%	0.3%	0.8%	2.7%	0.8%	9.6%	0.5%

8 Table A.1 in the annex provides a complementary perspective. It shows the number of co-occuring IPFs as a share of all IPFs in an enabling and core technology field. For example, it confirms that consumer goods and vehicles are the most important application domains for geo-positioning technologies.

Case study: Galileo satellite signals

Case study:	Galileo global satellite navigation system
Organisation:	Centre National d'Etudes Spatiales (CNES)
Sector:	Satellite navigation
Invention:	Radio signals for better satellite navigation

Many devices connect to the internet via WiFi and Bluetooth (both short-range), whereas longer-range connections often rely on innovations such as low-power wide-area networks (LPWAN). These types of network enable connectivity and positioning over a fairly long range and are energy-efficient, but rely on base stations located on land. This presents a significant limitation in, for example, shipping or in search and rescue operations where precise location data is needed and terrestrial network connectivity is not possible. In these situations, satellite technology is driving 4IR.

In 2017, Laurent Lestarquit (France, CNES), Jean-Luc Issler (France, CNES) Lionel Ries (Belgium, European Space Agency), José Ángel Ávila Rodríguez (Spain, European Space Agency), and Günter Hein (Germany, Universität der Bundeswehr München) were winners of the European Inventor Award for developing the radio signals for Galileo, the world's most accurate global navigation satellite system (GNSS). The system was developed by the European Union primarily for civilian use and to give Europeans their own satellite network that is free of external control. In addition to autonomy, Galileo's precise timing and positioning will enable wider adoption of the geolocated 4IR devices that are currently used in logistics, mobility, agriculture and healthcare. With a "constellation" of satellites overhead all broadcasting their location and an accurate timestamp, any device that has at least four satellites above it can be tracked to within a metre or less.

Sculpting new waveforms

The inventors in this pan-European team faced a number of technical hurdles. They needed to create accurate positioning signals while remaining within the limited frequency range agreed upon in earlier EU-US negotiations. Galileo's signals could not interfere with those of GPS and GLONASS, and they also had to make very low energy demands so as to conserve limited satellite power. To meet these challenges, the team invented two signalling techniques - the Alternative Binary Offset Carrier (Alt-BOC) signal and the Composite Binary Offset Carrier (CBOC) signal.

The Alt-BOC technique effectively packs four signals – two pairs of accurate free-of-charge signals from Galileo's Open Service – into one large one. When the four signals in the Alt-BOC are used together, they offer extremely high accuracy for specialised receivers and are suitable for civil aviation, as well as helping satellites optimise their power consumption.

CBOC is an innovative spread-spectrum technique that creates a new single waveform. This signal allows high-end receivers to accurately calculate positions, but is also compatible with older devices and other GNSS signals.

Look up, look ahead

Galileo is in the Initial Operational Capability phase, with 22 active satellites in orbit. Once fully operational, it will offer six global high-performance services. These include four free-to-use features: the Open Service (OS) for positioning and timing, the precise High Accuracy Service (HAS) to complement OS, the Open Service Navigation Message Authentication (OS-NMA) and the Search and Rescue Service (SAR), as well as the limited Public Regulated Service (PRS) for government-authorised users and the access-controlled Commercial Authentication Service (CAS).

The accuracy of the system benefits a variety of users in a number of ways. The travel and logistics sectors can improve fuel efficiency, save time and reduce operational overheads, farmers can engage in precise or smart farming techniques, urban managers and planners can build smarter, more efficient cities, and car manufacturers conduct further research and development into autonomous driving. This accuracy also inspires innovation: over 1.6 billion smartphones are already Galileo-enabled, and numerous companies are developing compatible receivers, chipsets and modules, as well as innovative services and smartphone apps that rely on accurate positioning.

The second generation of satellites will launch from 2024. The engineers want to ensure that Galileo is robust enough to withstand challenges, but flexible enough to facilitate innovation beyond the Fourth Industrial Revolution.

4. Global applicants in 4IR technologies

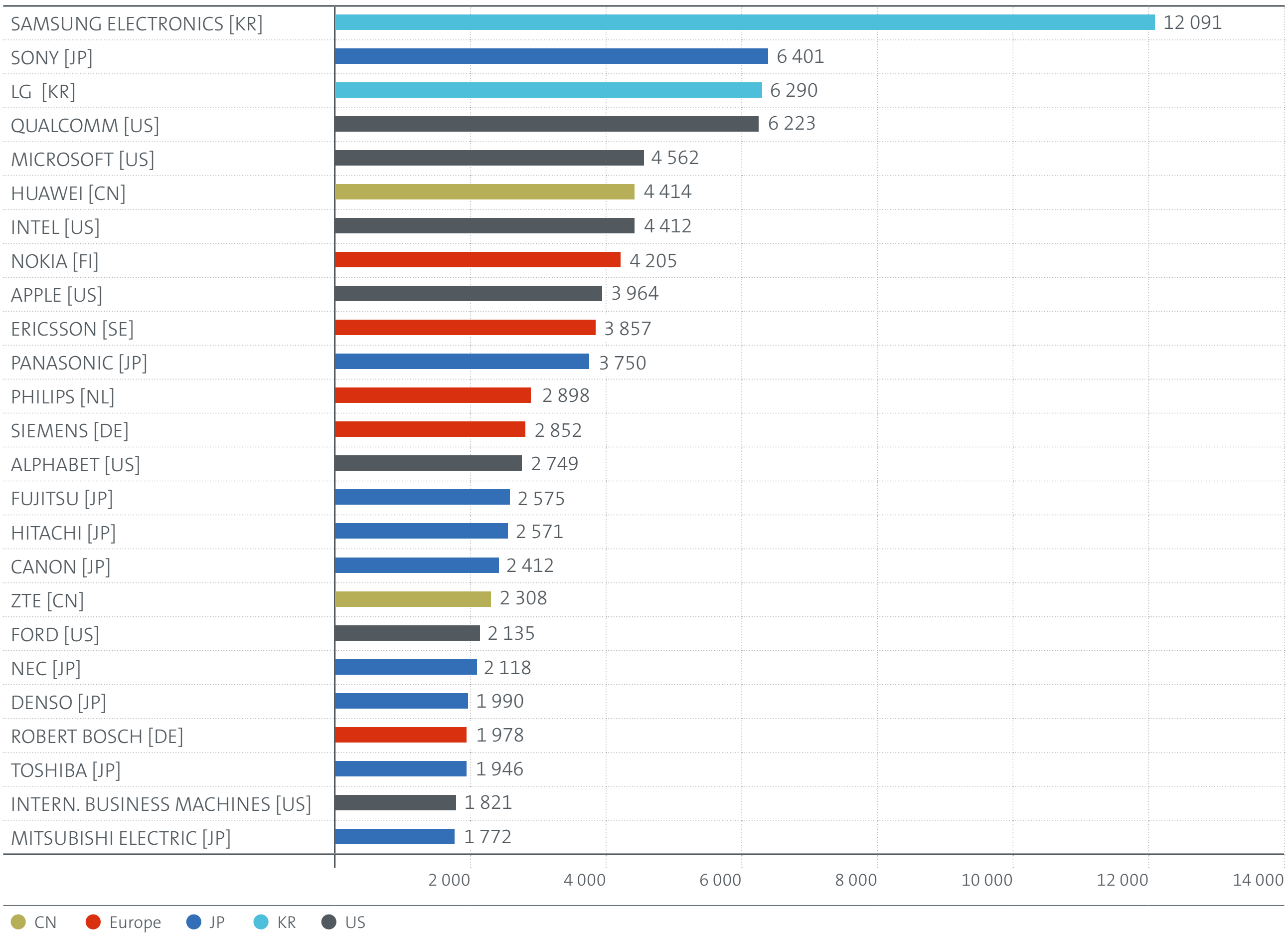
4. Global applicants in 4IR technologies

This chapter focuses on the main applicants in 4IR technologies at the EPO in the period 2010-2018. It reports on their locations and technology strengths and on the geographic distribution of their inventive activities.

4.1. Top global applicants

The top 25 applicants together account for 37.9% of all international patent families (IPFs) for 4IR technologies and feature nine Japanese companies, seven US companies and five European companies. Korea and China are represented by two companies each. Samsung is the clear leader in 4IR technologies with over 12 000 IPFs, which corresponds to 4.6% of all 4IR inventions between 2000 and 2018. In 2018 alone the company contributed over 2 000 IPFs. Samsung is followed, albeit with a wide gap, by three pursuers with similar numbers of IPFs: Sony (6 401), LG (6 290) – both Asian companies – and Qualcomm (6 223), a US company. The list of top 10 4IR applicants is completed by another three US companies, Microsoft (5th), Intel (7th) and Apple (9th), two European companies, Nokia (8th) and Ericsson (10th), as well as one Chinese company, Huawei (6th).

Figure 4.1
Top 25 applicants, 2000-2018



Source: European Patent Office

There have been significant changes in the top patent applicants for 4IR technologies over time. Table 4.1 shows the top 20 companies for the periods 2000-2009 and 2010-2018. In both, Samsung is the company with the highest number of 4IR IPFs. Samsung was not only able to maintain its top position, but even expanded its share from 2.8% to 5.2% between the two periods. LG, the second Korean company, managed to improve its ranking from 17th to 2nd place, while Sony dropped from 2nd down to 4th place. Overall, the concentration of IPFs in 4IR technololgies among the top 20 applicants has significantly increased between the two periods (from 28.2% to 33.5%).

Japanese and European top applicants have lost ground to Korean, Chinese and US companies. Huawei (5th) and ZTE (13th) now appear in the list of top applicants, as well as two European companies, Ericsson (8th) and Robert Bosch (20th). The US companies IBM and Motorala lost shares and disappeared from the list of top 20 applicants, while other US companies, such as Apple, Microsoft and especially Qualcomm, were able to increase or at least maintain their shares in 4IR technologies and were joined by two additonal US companies, Intel and Ford.

Table 4.1

Comparison of top 20 applicants between 2000-2009 and 2010-2018

	Ranking 2000-2009			Ranking 2010-2018		
	Company	Share		Company	Share	Change
1	SAMSUNG ELECTRONICS [KR]	2.8%	1	SAMSUNG ELECTRONICS [KR]	5.2%	=
2	SONY [JP]	2.6%	2	LG [KR]	2.9%	+
3	PANASONIC [JP]	2.1%	3	QUALCOMM [US]	2.7%	+
4	SIEMENS [DE]	1.8%	4	SONY[JP]	2.4%	-
5	NOKIA [FI]	1.8%	5	HUAWEI [CN]	2.1%	+
6	PHILIPS [NL]	1.7%	6	INTEL [US]	2.0%	+
7	APPLE [US]	1.5%	7	MICROSOFT [US]	1.8%	+
8	MICROSOFT [US]	1.5%	8	ERICSSON [SE]	1.7%	+
9	CANON [JP]	1.4%	9	NOKIA [FI]	1.5%	-
10	HITACHI [JP]	1.3%	10	APPLE [US]	1.5%	-
11	QUALCOMM [US]	1.2%	11	ALPHABET [US]	1.3%	+
12	INTERNATIONAL BUSINESS MACHINES [US]	1.2%	12	PANASONIC [JP]	1.2%	-
13	FUJITSU [JP]	1.0%	13	ZTE [CN]	1.1%	+
14	TOSHIBA CORPORATION [JP]	1.0%	14	FORD MOTOR [US]	1.0%	+
15	DENSO [JP]	0.9%	15	FUJITSU [JP]	1.0%	-
16	MOTOROLA SOLUTIONS [US]	0.9%	16	PHILIPS [NL]	0.9%	-
17	LG [KR]	0.9%	17	HITACHI [JP]	0.9%	-
18	NEC [JP]	0.9%	18	SIEMENS [DE]	0.8%	-
19	PIONEER [JP]	0.9%	19	NEC [JP]	0.8%	-
20	MEDTRONIC [IE]	0.8%	20	ROBERT BOSCH [DE]	0.7%	+
	Total 2000-2009	**28.2%**		**Total 2010-2018**	**33.5%**	

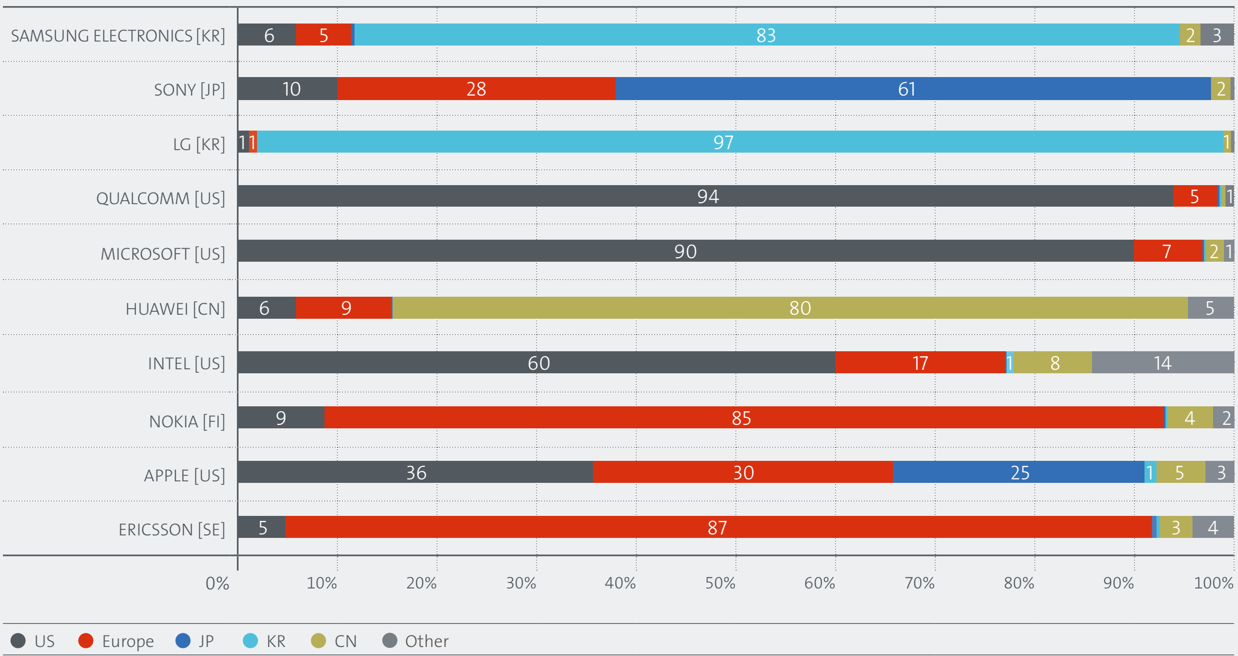
BOX 4.1

Geographic origins of the top applicants' 4IR inventions

Most of the top patent applicants are international companies, with worldwide operations. For each top 10 company Figure 4.2 presents the five most important origins of inventive activity. It shows that there are two types of R&D location strategies. A first group of companies have a majority of inventors concentrated in one country. It includes Samsung, LG, Qualcomm, Microsoft, Huawei, Nokia and Ericsson, each with over 80% of inventions originating from the country or region of the company`s headquarters. Other companies source a large share of their IPFs from other countries. Sony has a strong base of inventors in Europe[9] and the US, Intel relies heavily on inventors from Europe, India and Israel, and Apple enjoys important contributions from inventors in Europe and Japan.

Figure 4.2

Geographic origin of IPFs of top 10 applicants, 2000-2018



Source: European Patent Office

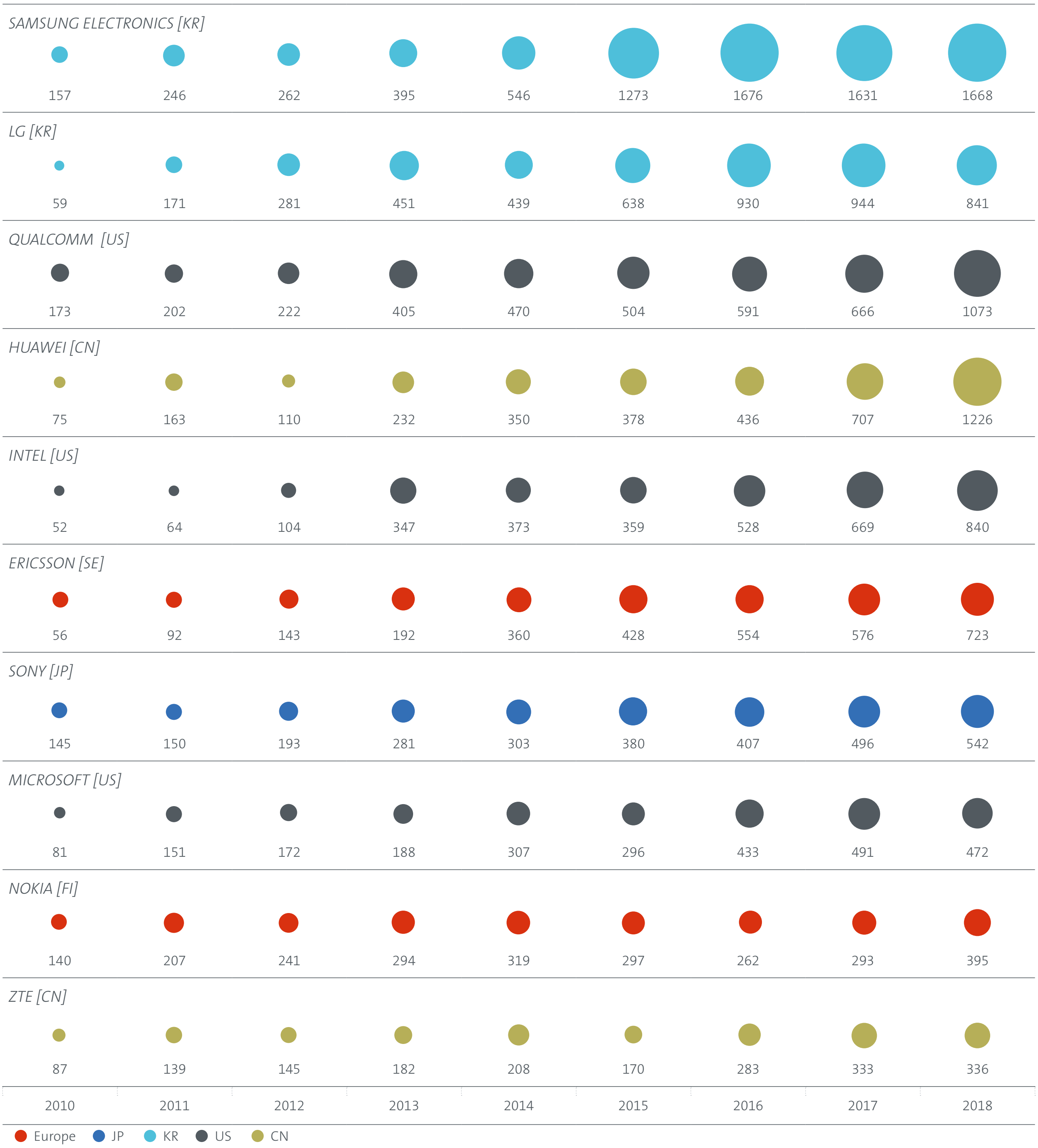
9 Europe is defined as comprising all 38 member states of the European Patent Organisation.

4.2. Top applicants per 4IR sector

The following Figures 4.3-4.5 present the top 10 applicants in each of the three 4IR sectors: core technologies, enabling technologies and application domains. In addition, based on the concept of revealed technological advantage (RTA), Tables 4.2-4.4 provide the companies' specialisation profiles in 4IR technology fields. The RTA index has been calculated over the period 2010-2018, as the share of IPFs in the 4IR field of interest divided by the share of the same company in all 4IR IPFs. An RTA above 1 reflects a company's specialisation in a given technology field while companies with an RTA below 1 are likely to face bigger challenges in developing technological leadership in that field.

Figure 4.3

Top 10 applicants in core technologies, 2010-2018



Source: European Patent Office

Due to the significant overlaps between the three 4IR sectors (see Figure 3.3), many companies appear in the three top applicant lists. Samsung is the clear leader in all three of them. In core technology sectors (Figure 4.3) it took the first position from Qualcomm in 2011 and was able to increase its annual number of IPFs from fewer than 200 in 2010 to more than 1 600 in the years 2016-2018. With an RTA above 1, Samsung is specialised in all three core technology fields, showing a particular strength in IT hardware (Table 4.2). LG is second in IPFs in core technologies over the period 2010-2018 and contributed around 900 IPFs annually in 2016 and 2017. With an RTA above 2, its main technology strength lies in connectivity, whereas its performance in software, with an RTA below 1, is relatively weak.

In 2018, LG was overtaken by Huawei, with over 1 200 IPFs, and Qualcomm, with over 1 000 IPFs, both companies which are strongly specialised in connectivity. Not surprisingly, Microsoft is the company with the highest level of specialisation in IT hardware and software. Swedish company Ericsson ranks 6th, with a strong specialisation in connectivity. Nokia, Sony and Panasonic were among the leading companies in 4IR core technologies at the beginning of the decade, but lost their dominant positions in more recent years, since they were not able to maintain the same high growth rates of some US, Korean and Chinese companies.

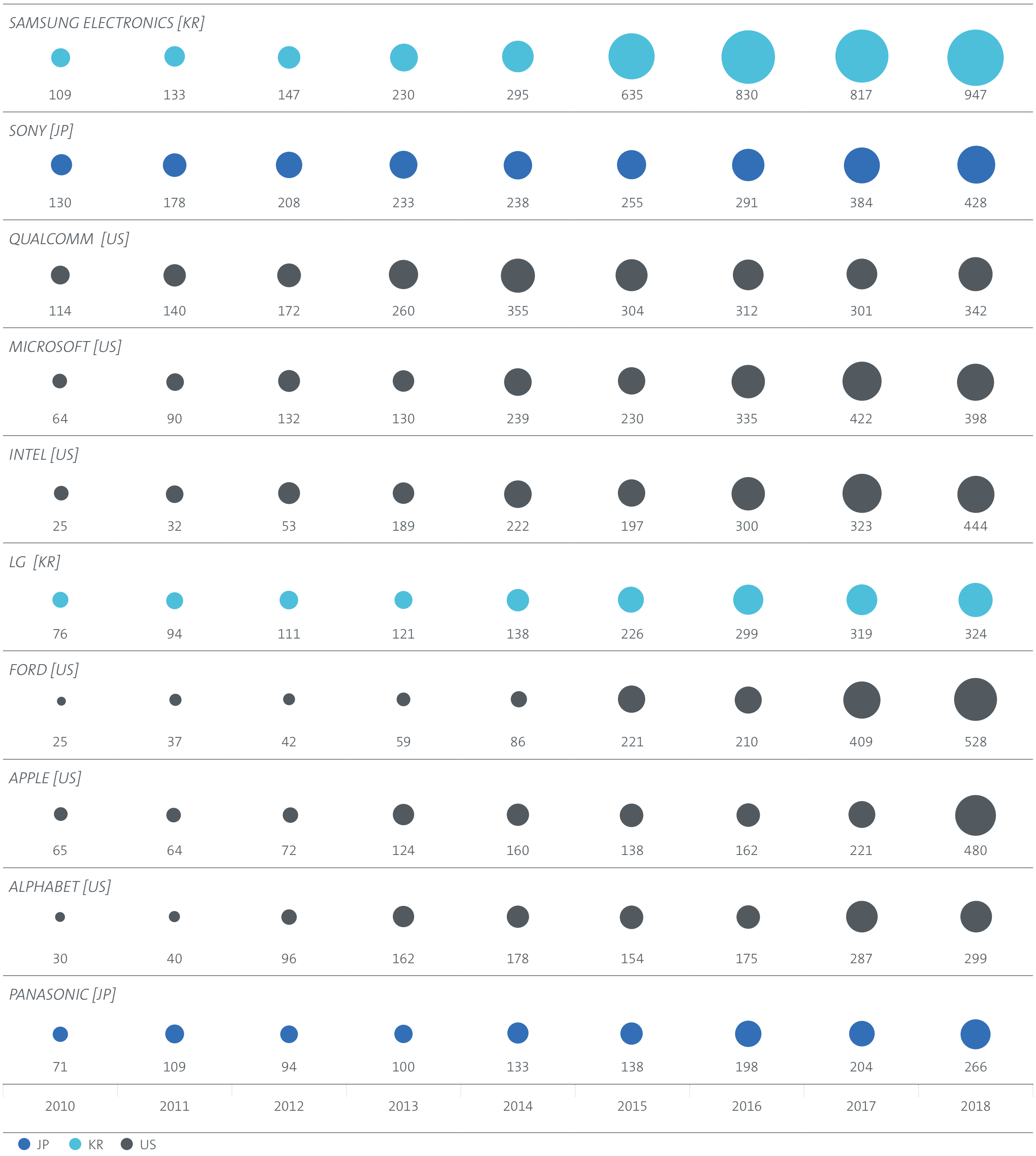
Table 4.2

Specialisation profiles of top 10 applicants in core technologies, 2010-2018

Top 10 2010-2018	IT hardware	Software	Connectivity
SAMSUNG ELECTRONICS [KR]	2.0	1.2	1.3
LG [KR]	1.3	0.5	2.0
QUALCOMM [US]	0.9	1.1	1.8
HUAWEI [CN]	0.5	1.5	2.4
INTEL [US]	1.6	2.1	1.5
ERICSSON [SE]	0.3	1.2	2.7
SONY [JP]	1.6	0.7	0.9
MICROSOFT [US]	2.0	3.0	0.7
NOKIA [FI]	0.9	1.5	2.0
ZTE [CN]	0.4	1.5	2.3

Figure 4.4

Top 10 applicants in enabling technologies, 2010-2018



Source: European Patent Office

Samsung took the lead in enabling technologies in 2015, growing its annual number of IPFs from around 100 in 2010 to almost 1 000 in 2018. Being a global leader in battery technologies (EPO and OECD/IEA, 2020), this Korean company shows high levels of specialisation in power supply technologies. Samsung also has a technological advantage in data security for 4IR. Japan's Sony Corporation, which was the leading company for enabling technologies at the beginning of the decade, was able to maintain its second place, increasing its annual number of IPFs to more than 400 by 2018. Among all enabling technology fields, Sony is particularly specialised in user interfaces, as well as power supply and 3D systems.

These two Asian leaders are followed by six US companies and another Korean company, LG. Indeed, three of them - Intel, Ford and Apple - contributed a larger number of IPFs than Sony in 2018. They have different strengths: Intel shows high specialisation in power supply, core AI and data security technologies, whereas Apple's specialisation profile is more balanced across all fields. Ford, a car manufacturer, shows the highest RTA indices in the fields for safety, data mining and exploration and geo-positioning. There is no European company in the global top 10 for enabling technologies. However, Siemens, Nokia and Robert Bosch are ranked 12th, 13th and 14th respectively at global level.

Table 4.3

Specialisation profiles of top 10 applicants in enabling technologies, 2010-2018

Top 10 2010-2018	Data management	User interfaces	Core AI	Geo-positioning	Power supply	Data security	Safety	3D systems
SAMSUNG [KR]	0.6	0.9	0.9	0.5	2.2	1.4	0.4	0.3
SONY [JP]	0.5	2.2	0.8	0.8	1.2	0.6	0.1	1.1
QUALCOMM [US]	0.3	0.6	0.9	1.9	3.2	1.0	0.1	0.1
MICROSOFT [US]	0.6	2.3	3.3	0.5	0.9	1.6	0.1	0.3
INTEL [US]	0.5	0.6	3.2	0.8	3.4	1.8	0.2	0.3
LG [KR]	0.5	0.8	0.2	0.4	2.2	0.6	1.0	0.1
FORD [US]	2.4	0.8	1.4	2.1	0.1	0.3	3.4	0.4
APPLE [US]	0.8	1.2	0.9	1.1	1.3	1.0	0.6	0.9
ALPHABET [US]	0.6	2.0	2.5	1.2	0.8	1.1	0.5	0.2
PANASONIC [JP]	1.3	1.2	0.5	0.9	0.6	0.6	2.1	0.1

Samsung, LG and Sony are also the three leaders in 4IR application domains. Although Samsung, which is specialised in consumer goods and smart services, contributed over 1 000 IPFs in 2018, this is a decrease of almost 20% compared with the previous two years. Interestingly, a similar relative drop can be observed for LG between 2017 and 2018.

Indeed, Ford and Apple, two companies which significantly increased their contributions in the most recent years, to 634 and 568 IPFs respectively, were the biggest applicants in 2018, after Samsung.

Figure 4.5

Top 10 applicants in application domains, 2000-2018

Source: European Patent Office

With an RTA close to 5, Ford is strongly specialised in smart vehicles, whereas Apple shows no clear specialisation pattern, with smart consumer goods and smart services being the only two application domains with an RTA above 1. The only European company that appears in the top 10 is Philips (8th), which has a very strong technological advantage in smart healthcare. The next three largest European applicants in 4IR technologies are German companies Siemens (12th, with a high specialisation in smart industry, infrastructure, healthcare and vehicles), Robert Bosch (13th, and likewise specialised in smart vehicles and smart industry) and Nokia (15th, with a stronger focus on smart consumer goods).

Table 4.4

Specialisation profiles of top 10 applicants in application domains 2010-2018

Top 10 2010-2018	Consumer goods	Home	Vehicles	Services	Industrial	Infra-structure	Healthcare	Agriculture
SAMSUNG [KR]	1.4	0.9	0.3	1.3	0.4	0.3	0.7	0.0
LG [KR]	1.5	1.1	0.5	1.0	0.5	0.6	0.2	0.1
SONY [JP]	1.6	1.0	0.4	1.3	0.3	0.9	0.7	0.8
QUALCOMM [US]	1.0	0.3	0.5	0.5	0.1	0.2	0.2	0.1
FORD [US]	0.8	1.3	4.9	0.6	1.4	1.6	0.1	0.0
PANASONIC [JP]	1.0	2.0	1.4	1.3	1.3	2.0	0.8	0.4
APPLE [US]	1.1	0.9	0.9	1.0	0.6	0.8	0.7	0.3
PHILIPS (NL)	0.6	0.8	0.1	0.5	0.4	0.2	6.2	0.2
INTEL [US]	1.1	0.5	0.3	0.6	0.2	0.4	0.2	0.1
MICROSOFT [US]	1.0	0.5	0.2	1.2	0.2	0.3	0.2	0.1

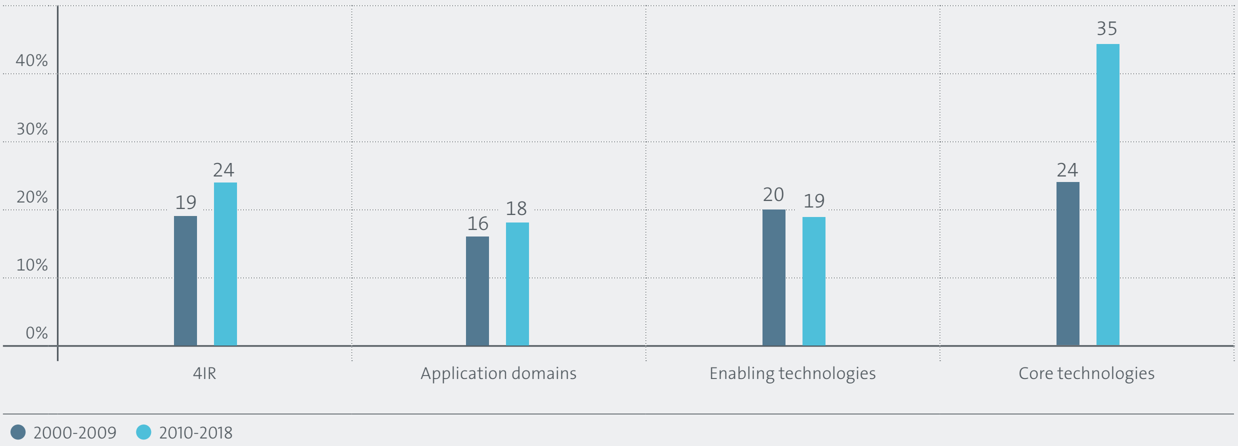
BOX 4.2

Impact of the top 10 applicants in 4IR sectors

Figure 4.6 compares the shares of the top 10 applicants in 4IR technologies and its three sectors between 2000-2009 and 2010-2018. It can be interpreted as a measure of applicant concentration. It shows that the leading companies were able to increase their shares from 19% to 24% between the two periods. However, at sector level it becomes obvious that this is solely driven by core technologies, where the share of the top 10 applicants increased by 11 percentage points, from 24% to 35% of all IPFs. In application domains, it grew by only two percentage points, largely due to the increase in the share of the top applicant, Samsung. In enabling t echnologies, the share actually decreased to 19%.

Figure 4.6

Aggregate share of the top 10 applicants in each 4IR sector in 2000-2009 and 2010-2018



Source: European Patent Office

4.3. Impact of research institutions

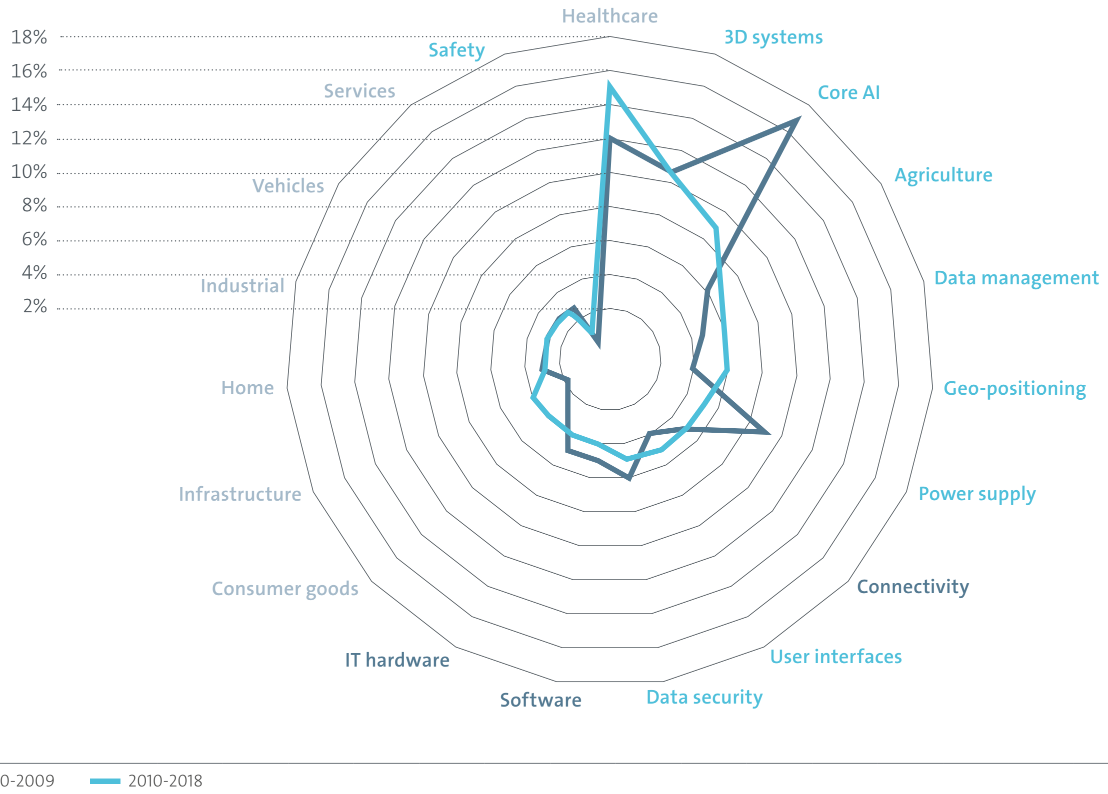
Universities and public research organisations (PROs) are important players in the 4IR innovation ecosystem, generating 5.6% of 4IR patenting between 2000 and 2018. Interestingly, the share of IPFs originating from such research institutions increased between the periods 2000-2009 and 2010-2018 from 5.3% to 5.7%. This is mainly due to rising shares in enabling technologies (from 5.0% to 5.7%) and application domains (from 4.7% to 5.6%). At the same time, the share in core technologies declined from 5.2% to 4.7%.

These observations are in line with the trend towards applicant concentration (Box 4.2). The declining share of IPFs from universities and PROs and the increased concentration measures indicate that innovation in the core technologies sector has reached a certain maturity level and is now largely led by big companies. At the same time, the rising activity of universities and PROs and the relatively low applicant concentration suggest that the sectors of enabling technologies and application domains are still at an earlier phase in their development.

On the 4IR field level (Figure 4.7), the highest relative contributions of universities and PROs can be observed in the enabling technology fields of core AI, 3D systems and power supply, and the application domain of smart healthcare. While the shares in core AI and power supply between the 2000-2009 and 2010-2018 periods fell from 17.2% to 8.8% and from 9.1% to 5.5% respectively, the share in 3D systems remained relatively stable at more than 10%. The share in smart healthcare grew to 14.5% and is now the highest of all the technology fields. Safety (2.2%), smart services (2.6%), vehicles (3.1%) and industry (3.1%) are the fields with the lowest contributions by universities and PROs in the period 2010-2018.

Figure 4.7

Contribution of universities and PROs to 4IR technology fields in 2000-2009 and 2010-2018



Source: European Patent Office

Table 4.5 presents the top 10 universities and PROs together with the 4IR technology fields in which they have developed a revealed technological advantage (RTA > 1.5). The Korean research institute ETRI, with over 1 500 IPFs in 2000-2018, is the clear leader and also belongs to the top 30 patent applicants for 4IR technologies. Its relative technological specialisation lies in the fields power supply, data security and software. The German PRO Fraunhofer Institute, with 636 IPFs, is second and is specialised in user interfaces. The US University of California follows with more than 300 IPFs and relatively high RTA values in the fields of smart healthcare, agriculture, core AI and 3D systems. Two other European research institutions, the French CEA (9th) and the Dutch TNO (10th), two additional US universities, Harvard (6th) and MIT (8th), together with ITRI (4th) from Chinese Taipei, CAICT (5th) from China and another Korean research institution, KAIST (7th), make up the rest of the top 10.

Table 4.5

Top 10 universities and public research organisations, 2000-2018

	Institution	IPFs	Specialisation (RTA > 1.5)
1	ETRI (ELECTRONICS AND TELECOMMUNICATIONS RESEARCH INSTITUTE) [KR]	1566	Power supply, data security, software
2	FRAUNHOFER [DE]	636	User interfaces
3	UNIVERSITY OF CALIFORNIA [US]	334	Healthcare, agriculture, core AI, 3D systems
4	ITRI (INDUSTRIAL TECHNOLOGY RESEARCH INSTITUTE) [TW]	290	-
5	CAICT (CHINA ACADEMY OF INFORMATION AND COMMUNICATIONS TECHNOLOGY) [CN]	281	Core sectors, power supply, connectivity
6	HARVARD UNIVERSITY [US]	229	Healthcare, 3D systems
7	KAIST (KOREA ADVANCED INSTITUTE OF SCIENCE AND TECHNOLOGY) [KR]	185	Healthcare, power supply
8	MIT (MASSACHUSETTS INSTITUTE OF TECHNOLOGY) [US]	179	Healthcare, core AI, geo-positioning, 3D systems
9	CEA (COMMISSARIAT A L'ENERGIE ATOMIQUE) [FR]	169	Core AI, geo-positioning, power supply
10	TNO (Netherlands Organisation for Applied Scientific Research) [NL]	138	Home, data security, connectivity

Case study: Smart glass

Case study: Electronically tintable glass
Company: SageGlass
Sector: Civil construction, green engineering
Invention: Electronically tintable glass
Country: United States

As far back as the 1980s, inventors were working on dimmable, solar control glazing using thermochromic and photochromic glass. Windows constructed from this type of glass are embedded with liquid crystals or photochemically active molecules that respond to heat and light and are therefore able to change colour and transparency. There is one drawback: it is not possible to control these changes in the glass – the response is automatic.

French inventor Jean-Christophe Giron, Vice President of R&D at SageGlass, developed a solution to this problem. He began by researching nanotechnology and looked at materials that change colour when exposed to electricity. Together with his team, he developed smart glass that is electronically tintable and allows the user to decide the level of visible light transmission (VLT).

Each pane is coated in five layers of ceramic material that, in total, measure less than 1/50th the thickness of a human hair. When a low voltage (less than 5 volts DC) is applied to the coating, lithium ions move from one layer to the next and the coating responds by becoming darker. Essentially, the glass behaves like a see-through battery with transparency that varies as the battery loads or unloads. For his ground-breaking invention, Giron was nominated for the European Inventor Award in 2015.

Connected and in control

The process of tinting is highly customisable and managed by an intelligent control system that incorporates a series of sensors. The system can integrate with smart devices or existing building management systems, so that users can control the VLT via a wall switch, mobile app or voice control device such as the Amazon Echo. Automated tinting is available thanks to an algorithm that makes adjustments based on light data collected from the sensors. It is also possible to control individual zones – while one room could be set to be fully tinted, an adjacent one could allow a greater flow of light.

The high degree of customisation makes smart window systems attractive to a variety of users. A museum may want to shield artefacts from the damaging effects of solar radiation, but still provide a natural light source for visitors. The ability to independently control zones enables offices to continually adjust VLT as the position of the sun in the sky changes in relation to a building's facade, helping regulate temperature whilst ensuring that occupants can enjoy the views and light from outside.

Smart glass, smarter buildings

Buildings account for approximately 40% of global energy consumption. While blinds and shades prevent light from entering a building, they do not block all heat. Heating, ventilation and air conditioning (HVAC) systems still need to regulate interior temperatures, increasing energy consumption and related emissions.

SageGlass panes are energy-efficient. It takes less power to operate 180 square meters of smart glass that it does to run just one 60W light bulb. In winter, the electrochromic glass uses the sun's energy to heat up rooms. In summer, it darkens to prevent rooms from overheating. By limiting VLT with controllable glass, buildings can reduce electricity, heating and air-conditioning expenditure by up to 20%.

A view on the future

The European Union established a legislative framework to promote green building. The Energy Performance of Buildings Directive covers policies and measures that will help national governments to improve the energy performance of buildings. Similar directives and schemes have been implemented outside the EU.

SageGlass has been installed in over 700 building projects since 2003. The global electrochromic glass market was valued at EUR 1.1 billion in 2019 and is forecast to grow to EUR 2.1 billion by 2027, at a compound annual growth rate of 9.0% over the next seven years. While the glass is tintable the outlook is clear: the combination of policy and cost savings is driving interest in this field.

5. Global geography of 4IR innovation

5. Global geography of 4IR innovation

This chapter reports on the geographic origin of 4IR innovation, as identified by the locations of the inventors of international patent families (IPFs) for 4IR technologies. It focuses on the main 4IR innovation centres on a global scale. For the purposes of this chapter, Europe is defined as comprising all 38 member states of the European Patent Organisation.

5.1. Global innovation centres

Innovation in 4IR technologies has been largely dominated by the US, Europe and Japan, which together accounted for more than 70% of all IPFs in the period 2000-2018 (Table 5.1). The US is by far the most innovative world region in 4IR technologies, with about one third of all the IPFs over this period. The US already had a lead in 4IR technologies before 2010, which was further reinforced in the following decade thanks to the faster growth of 4IR innovation (+18.5% annually on average since 2010) than in Europe and Japan (Figure 5.1).

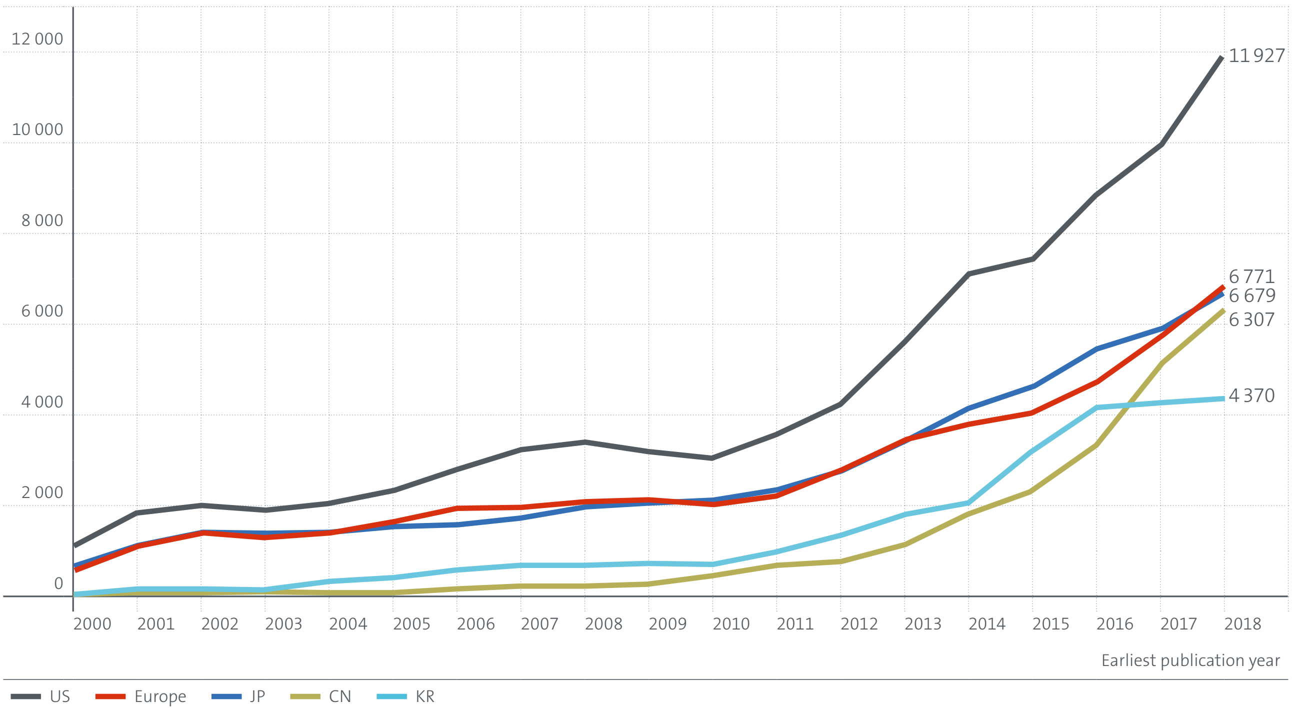
Table 5.1

Distribution of IPFs by global innovation centres, 2000-2018

	Number of IPFs	Share of IPFs	Number of IPFs per million inhabitants
World	264 565	100%	33.9
US	85 650	32%	258.8
Europe	52 626	20%	95.4
JP	51 245	19%	405.2
KR	26 956	10%	525.8
CN	23 140	9%	16.1
Other countries	24 948	9%	4.7

Figure 5.1

Growth of IPFs by global innovation centres, 2000-2018



Source: European Patent Office

Europe and Japan each account for about one fifth of all IPFs in 4IR technologies since 2000. Both regions also have similar growth patterns since 2000 (with average annual growth rates of 15.5% and 15.8% respectively since 2010). However, the number of IPFs relative to the population is much higher in Japan (with more than 400 patent families per million inhabitants on average between 2000 and 2018) than in Europe (with fewer than 100 patent families per million inhabitants over the same period). This denotes a much higher innovation intensity in Japan, which is second only to Korea (525 IPFs per million inhabitants) in this respect. The Republic of Korea and the People's Republic of China each account for about 10% of all IPFs since 2000. However, they started from very low levels in the late 2000s and their innovative activities have increased at a very high rate since then (25.2% and 39.3% respectively per year on average). China in particular generated more than 6 300 IPFs in 4IR technology in 2018, nearly on a par with the performance reported for Japan and Europe. By contrast, the number of IPFs in Korea reached a plateau in 2017 and 2018, at around 4 300 IPFs per year. This dynamic reflects that of Korea's two top applicants, Samsung and LG, who contributed 62% of the country's IPFs in 4IR between 2010 and 2018.

For those seeking to understand their country's comparative advantage in more detail, Table 5.2 reports the RTA index of the main global innovation centres in 4IR sectors and fields. For this purpose, the RTA index has been calculated over the period 2010-2018, in each case as the share of IPFs originating from a given innovation centre in the 4IR field or sector of interest, divided by the share in all IPFs in 4IR technologies originating from that same innovation centre. An RTA above 1 reflects the innovation centre's specialisation in a given 4IR technology field or sector. Conversely, innovation centres with a lower RTA in a given technology face a bigger challenge in developing the technological leadership needed to add significant value to their economy in future decades.

The US does not show a clear specialisation pattern at the 4IR sector level, which indicates that its leadership in 4IR innovation is evenly spread across all categories of 4IR technologies. However, it has developed particularly strong advantages in certain fields, including core software technology (e.g. operating systems, databases, cloud computing), core artificial intelligence (e.g. neural networks, deep learning, rule-based systems), 3D systems and the healthcare application domain. The fact that the first three fields are all related to software technology clearly denotes a very strong US leadership in this domain.

Europe and Japan show comparable patterns, with a relatively low contribution to innovation in core technologies and stronger specialisation in enabling technologies and application domains. Japan's relative performance is outstanding in enabling technology fields such as data management (by far the main field of enabling technologies in terms of patenting activities) and user interfaces, whereas European countries appear to be more specialised in safety, 3D systems and geo-positioning (see case study on Galileo on page 34). Both innovation centres also stand out in 4IR applications for vehicles, which reflects the strength of the automotive industries in their respective economies. Japan also shows a strong specialisation in smart services, and Europe in smart agriculture (see case study on automated milking robots on page 23).

Table 5.2

Specialisation of global innovation centres by 4IR technology fields, 2010-2018

Core technologies	**US**	**Europe**	**Japan**	**R. Korea**	**P.R. China**
Number of IPFs 2010-2018	30 939	18 165	15 845	15 890	14 194
			Revealed technology advantage:		
All core technologies	1.0	0.9	0.8	1.3	1.2
IT hardware	1.0	0.7	1.1	1.5	0.8
Software	1.2	0.9	0.6	0.9	1.3
Connectivity	0.9	1.0	0.7	1.3	1.5

Enabling technologies	**US**	**Europe**	**Japan**	**R. Korea**	**P.R. China**
Number of IPFs 2010-2018	32 905	21 096	21 018	9 552	9 864
			Revealed technology advantage:		
All enabling technologies	1.0	1.1	1.1	0.8	0.9
Data management	1.0	1.1	1.3	0.7	0.7
User interfaces	1.0	0.8	1.4	1.0	0.9
Artificial intelligence	1.6	0.8	0.6	0.6	0.9
Geo-positioning	1.0	1.2	1.1	0.6	0.8
Power supply	0.9	0.9	0.8	1.7	1.2
Data security	1.1	1.1	0.5	1.0	1.3
Safety	1.0	1.3	1.1	0.7	0.7
3D systems	1.4	1.3	0.6	0.6	0.4

Application domains	**US**	**Europe**	**Japan**	**R. Korea**	**P.R. China**
Number of IPFs 2010-2018	42 410	26 136	26 216	14 029	11 847
			Revealed technology advantage:		
All application domains	1.0	1.0	1.1	0.9	0.8
Consumer goods	0.9	0.9	1.1	1.3	1.0
Home	1.0	1.0	0.9	1.0	1.0
Vehicles	0.9	1.3	1.3	0.6	0.7
Services	1.1	0.8	1.1	1.1	0.9
Industrial	1.1	1.1	1.3	0.5	0.7
Infrastructure	1.0	1.1	1.1	0.6	1.0
Healthcare	1.4	1.2	0.7	0.6	0.4
Agriculture	1.1	1.5	0.8	0.3	0.5

The revealed technology advantages in each 4IR sector or field are calculated as the share of an innovation centre's IPFs in that sector or field, divided by the share of the same innovation centre's IPFs in all 4IR technologies.

The Republic of Korea and the People's Republic of China are the only global innovation centres with a technology advantage in core technologies (1.3 and 1.2 respectively at sector level). The strengths of both innovation centres in core technologies reflect those of their respective industry champions (see chapter 4). Korea appears to be highly specialised in IT hardware and *connectivity*, due to the innovation performance of Samsung and LG in these fields. China excels in connectivity and software, in which companies like Huawei and ZTE have become world leaders.

By contrast, both innovation centres generally show a lack of specialisation in enabling technologies and application domains, with a few important exceptions, however. Both are strong innovators in power supply technologies, and China also stands out in the field of data security. The Republic of Korea has a strong specialisation in smart consumer goods (the main application domains in terms of patenting activity) and to a lesser extent also in smart services.

BOX 5.1

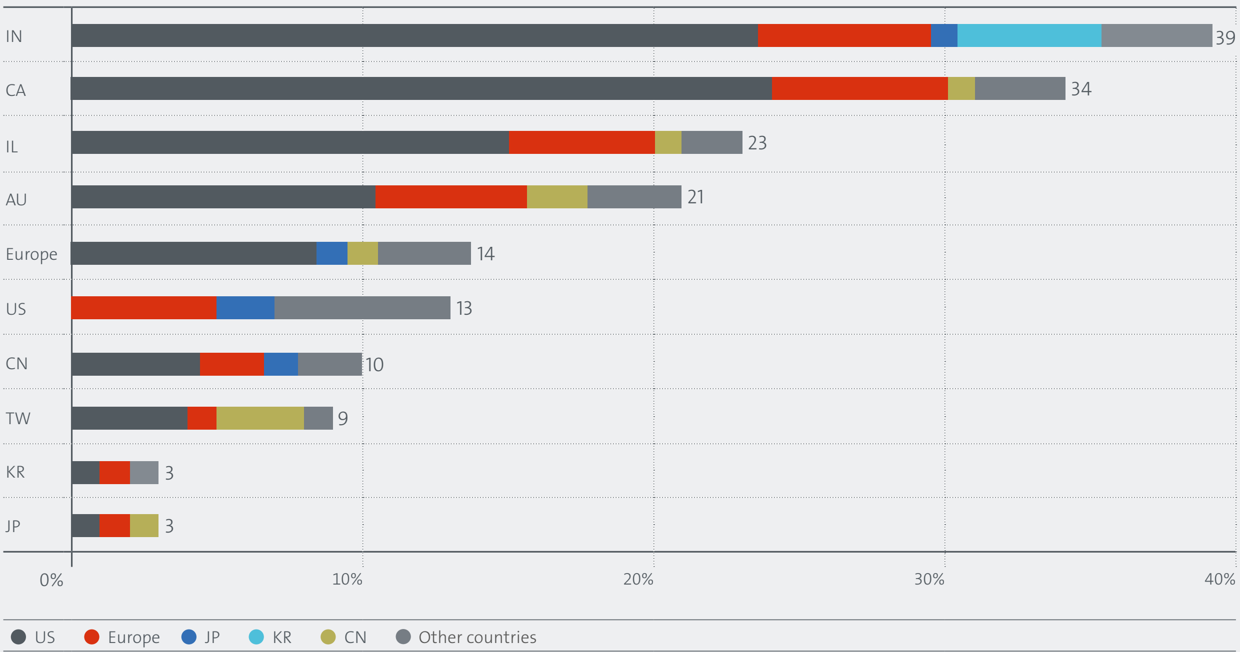
Cross-border collaboration in 4IR innovation

Some 11% of the IPFs related to 4IR technologies originate from teams of inventors located in different countries. The location of these teams provides information on international networks of R&D co-operation, making it possible to identify the countries that are most involved in these networks. Figure 5.2 shows that, on a global scale, India and Canada stand out in this respect, as up to 39% and 34% of their respective IPFs were co-invented in the period 2010-2018. Israel (23%) and Australia (21%) are likewise frequently engaged in cross-border R&D collaboration for 4IR innovation. The US is by far the main partner for all these countries, and in particular for Canada and Israel.

The main global innovation centres show different profiles with respect to international co-inventions. The US and the block of European countries are the most open to collaboration with foreign R&D partners, each with about 14% of international co-inventions. They are also each other's most important partner. By contrast, Japan and South Korea are hardly engaged in such collaboration, with just 3% of co-invention each. China is in an intermediate position, with 10% of co-inventions in 4IR technologies during the period 2010-2018.

Figure 5.2

Share of IPFs co-invented with other countries, 2010-2018



Source: European Patent Office

5.2. Focus on Europe

Innovation in 4IR in Europe is dominated by Germany, which alone contributed about 6% of all IPFs on a global scale in the period 2000-2018 (Table 5.3). This represents 29% of all the IPFs generated in Europe over this period, and more than twice the contribution of the United Kingdom (2.8%), the next country in the European ranking. France comes third with 12.5% of all European IPFs (2.5% of global IPFs). Despite their relatively small sizes in terms of population and GDP, Sweden (2% of global IPFs), the Netherlands (1.5%), Finland (1.4%) and Switzerland (0.7%) are significant contributors to 4IR innovation and are positioned ahead of Italy (0.7%) and Spain (0.4%) in the ranking. Austria is another small country in the ranking, with a contribution to 4IR innovation (0.4%) that is comparable with that of Spain despite having one fifth of Spain's population. With 651 and 524 IPFs respectively per million inhabitants over the period 2000-2018, Finland and Sweden show a remarkable innovation performance in 4IR technologies, at the same level as Korea (525).

Since 2010, the average growth in 4IR innovation in Germany (14.9%), the United Kingdom (15.5%), Austria (16%) and Finland (14.9%) has been on a par with the European average (15.5%) – and as such well below the world average over the same period (19.7%). France, the Netherlands and Spain have likewise lost ground to other innovation centres, including within Europe, with average annual growth rates of 11.7%, 10.2% and 14.0% respectively between 2010 and 2018 (Figure 5.3). The dynamism of 4IR innovation in Sweden (22.6%) and Switzerland (19.6%) is all the more remarkable in this context. Sweden in particular posted a growth in IPRs that exceeds the global average over this period, thanks in particular to a strong performance in connectivity technologies.

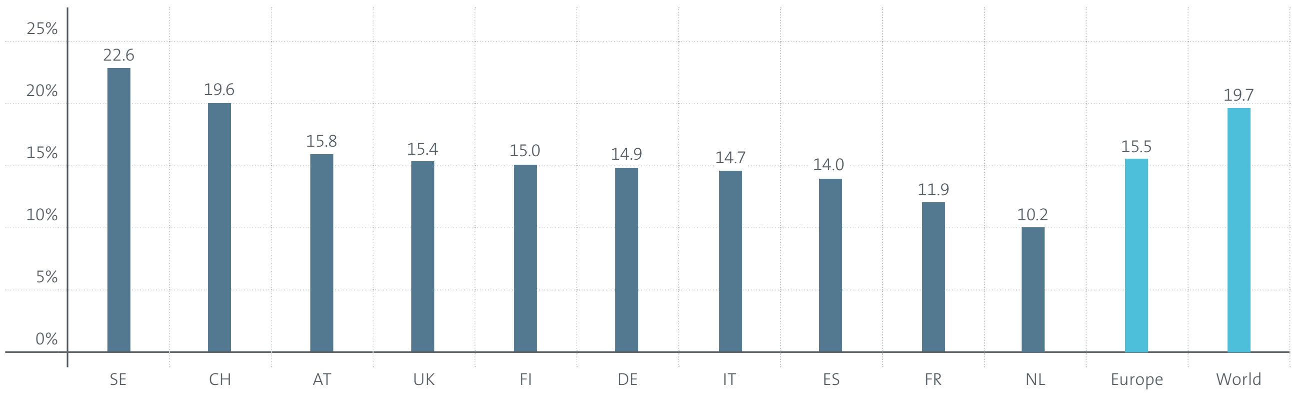
Table 5.3

Distribution of IPFs by European countries, 2000-2018

	Number of IPFs	Share of IPFs in the world	Share of IPFs in Europe	Number of IPFs per million inhabitants
DE	15 440	5.8%	29.3%	184.3
UK	7 508	2.8%	14.3%	110.6
FR	6 562	2.5%	12.5%	100.5
SE	5 296	2.0%	10.1%	524.4
NL	4 076	1.5%	7.7%	237.9
FI	3 608	1.4%	6.9%	651.1
CH	1 842	0.7%	3.5%	212.8
IT	1 827	0.7%	3.5%	30.2
ES	1 092	0.4%	2.1%	23.4
AT	957	0.4%	1.8%	106.3

Figure 5.3

Average annual growth of IPFs for 4IR technologies in leading European countries, 2010-2018



Source: European Patent Office

An analysis of the RTAs of European countries at a detailed technology level can reveal niches in which these countries can build on their relative strengths. For this purpose, Table 5.4 shows the RTA index of the main European innovation centres in all 4IR sectors and fields over the period 2010-2018.

The specialisation profiles of Germany, France and the Netherlands are in line with Europe's profile as a block, with a relatively low performance in core technologies and some specialisation in enabling technologies and application domains. Germany in particular is the only European country with a strong specialisation in enabling technologies, due to its contribution to innovation in data management, geo-positioning and safety. It also stands out for its particularly high specialisation in 4IR applications for vehicles, while making important relative contributions to 4IR applications for industry and agriculture.

France's main areas of specialisation likewise relate to enabling technology fields (safety, data security and 3D systems) and application domains (smart infrastructures, smart vehicles and smart homes), athough the country also shows some degree of specialisation in core software technology. The Netherlands show a strong specialisation in smart health applications and 3D systems, thanks to the leadership of Philips in these fields, as well as in smart agriculture. In contrast with these counries, the 4IR contribution of the United Kingdom appears to be evenly distributed across all sectors, with some specialisation in enabling technologies (artificial intelligence, data security). The United Kingdom's 4IR profile is therefore closer to that of the US.

Smaller European countries such as Sweden and Finland show quite different 4IR specialisation profiles. Both countries stand out in the core field of connectivity, thanks to the major contribution of Ericsson and Nokia respectively in this field. Finland is also highly specialised in a number of enabling technology fields (geo-positioning, power supply, data security), while having a limited footprint in application domains. Sweden's innovative activities are likewise focused on geo-positioning and power supply, as well as 4IR applications in agriculture.

Table 5.4

Specialisation of European innovation centres by 4IR technology fields, 2010-2018

Core technologies	DE	UK	FR	SE	NL	FI
Number of IPFs 2010-2018	4 216	2 838	2 231	2 940	1 089	1 747
			Revealed technology advantage:			
All core technologies	0.7	1.0	0.9	1.3	0.7	1.3
IT hardware	0.6	1.0	0.8	0.5	0.7	1.0
Software	0.7	1.1	1.1	0.8	0.4	1.1
Connectivity	0.8	1.1	0.9	1.9	0.8	1.5

Enabling technologies	DE	UK	FR	SE	NL	FI
Number of IPFs 2010-2018	7 166	2 872	2 674	1 842	1 447	1 271
			Revealed technology advantage:			
All enabling technologies	1.3	1.0	1.1	0.8	1.0	0.9
Data management	1.5	1.0	1.0	0.7	1.0	0.5
User interfaces	0.9	1.1	1.1	0.5	0.6	1.0
Artificial intelligence	0.4	1.2	0.8	0.4	0.5	0.4
Geo-positioning	1.6	1.1	1.1	1.2	1.2	1.6
Power supply	0.6	1.0	0.5	2.1	0.6	1.6
Data security	1.0	1.4	1.6	1.0	0.9	1.5
Safety	1.7	1.1	1.7	0.8	0.7	0.6
3D systems	1.1	1.0	1.3	0.4	3.9	0.7

Application domains	DE	UK	FR	SE	NL	FI
Number of IPFs 2010-2018	8 189	3 351	3 246	2 031	2 283	1 344
			Revealed technology advantage:			
All application domains	1.1	1.0	1.0	0.7	1.2	0.8
Consumer goods	0.7	0.9	0.9	0.8	0.9	1.1
Home	1.0	1.0	1.3	0.6	1.1	0.8
Vehicles	2.0	0.9	1.4	0.9	1.0	0.5
Services	0.7	0.9	0.9	0.6	0.6	0.7
Industrial	1.5	1.0	1.0	0.5	0.7	0.4
Infrastructure	1.2	0.9	1.5	0.5	0.5	0.5
Healthcare	0.9	0.9	0.9	0.3	3.9	0.8
Agriculture	1.5	0.7	0.7	2.4	1.7	0.6

The revealed technology advantages in each 4IR sector or field are calculated as the share of an innovation centre's IPFs in that sector or field, divided by the share of the same innovation centre's IPFs in all 4IR technologies.

Case study: Video compression

Case study: Video compression
Company: Qualcomm Technologies
Sector: Data compression
Invention: Advanced video coding
Country: United States

Video streaming is data intensive, requiring large amounts of bandwidth and storage space. In 2020, the coronavirus pandemic caused a spike in videoconferencing as people worldwide were forced to work from home. Despite these challenges, high-quality video can easily be streamed, even on mobile devices, and online conferences have become common. Data compression is the key that has enabled the easy transfer of large amounts of video.

Polish inventor Marta Karczewicz, who was nominated for the European Inventor Award in 2019, has spent much of her career developing video compression methods. She is currently the Vice President of Technology at Qualcomm Technologies and is named as inventor on over 190 granted European patents. Her inventions have enabled the growth of streaming services such as Netflix and facilitated a global shift to remote working, and will play a role in 4IR-related fields ranging from virtual reality to telemedicine.

Eyes on the future

By 2022, over 28 billion devices will be online and video will account for 82% of all traffic. While entertainment, gaming and social media will generate a large proportion of video content, businesses will increasingly explore technologies such as virtual reality (VR) and augmented reality (AR). VR and AR can be used in training, for example by replicating high-risk scenarios or medical emergencies. Via a headset, engineers or technicians in the field can be fed critical information that helps them analyse a problem and conduct maintenance procedures. Product design teams can develop and test new concepts in a VR or AR environment, shortening the time needed to get a new product to market.

Traditionally, telemedicine has allowed healthcare professionals to diagnose and treat patients in remote communities with limited access to healthcare. More recently, it has benefitted patients in urban areas. Throughout the coronavirus pandemic, many doctors have offered virtual consultations, enabling patients to remain isolated at home and reduce infection risks. With connected devices and sensors becoming more widely adopted, healthcare providers will be able to collect and analyse large amounts of patient data outside of medical centres.

Setting new standards

Video coding algorithms, or codecs, have advanced over the past twenty years and made it possible to compress video files without losing perceivable image quality. Essentially, they compress the video data that needs to be stored or sent, and decompress it when it is played.

For two decades, Marta Karczewicz has worked on a series of codecs. She helped develop the Advanced Video Coding (AVC) standard between 1999 and 2003, Scalable Video Coding (SVC) standards from 2003-2007, and thereafter the High Efficiency Video Coding (HEVC) standard. In July 2020, Qualcomm Technologies announced the completion of the latest standard: Versatile Video Coding (VVC).

Several companies and organisations worked on the development of VVC, including Qualcomm, Fraunhofer Heinrich Hertz Institute, Ericsson, Intel, Huawei and Microsoft. It is due to be deployed commercially in 2021 and offers a 40% reduction in file size compared with its predecessor, High Efficiency Video Coding (HEVC). Once available and supported by chipsets, VVC will support multiple sectors due to the cost-saving effect of bandwidth reduction.

Standardisation of technology is critical to market success: it ensures interoperability and economies of scale while allowing individual firms to make products that are different from their competitors'. Consumers benefit through a diverse product offering and lower prices due to competition. In order to ensure widespread adoption of the standards, companies and organisations that participate in their development are typically required to offer to license patents that are related to the standard (so-called "essential patents") on a FRAND ("fair, reasonable and non-discriminatory") basis.

Ultimately, this balance of co-operation and competition drives innovation, with intellectual property rights playing an important role.

6. Top 4IR innovation clusters

6. Top 4IR innovation clusters

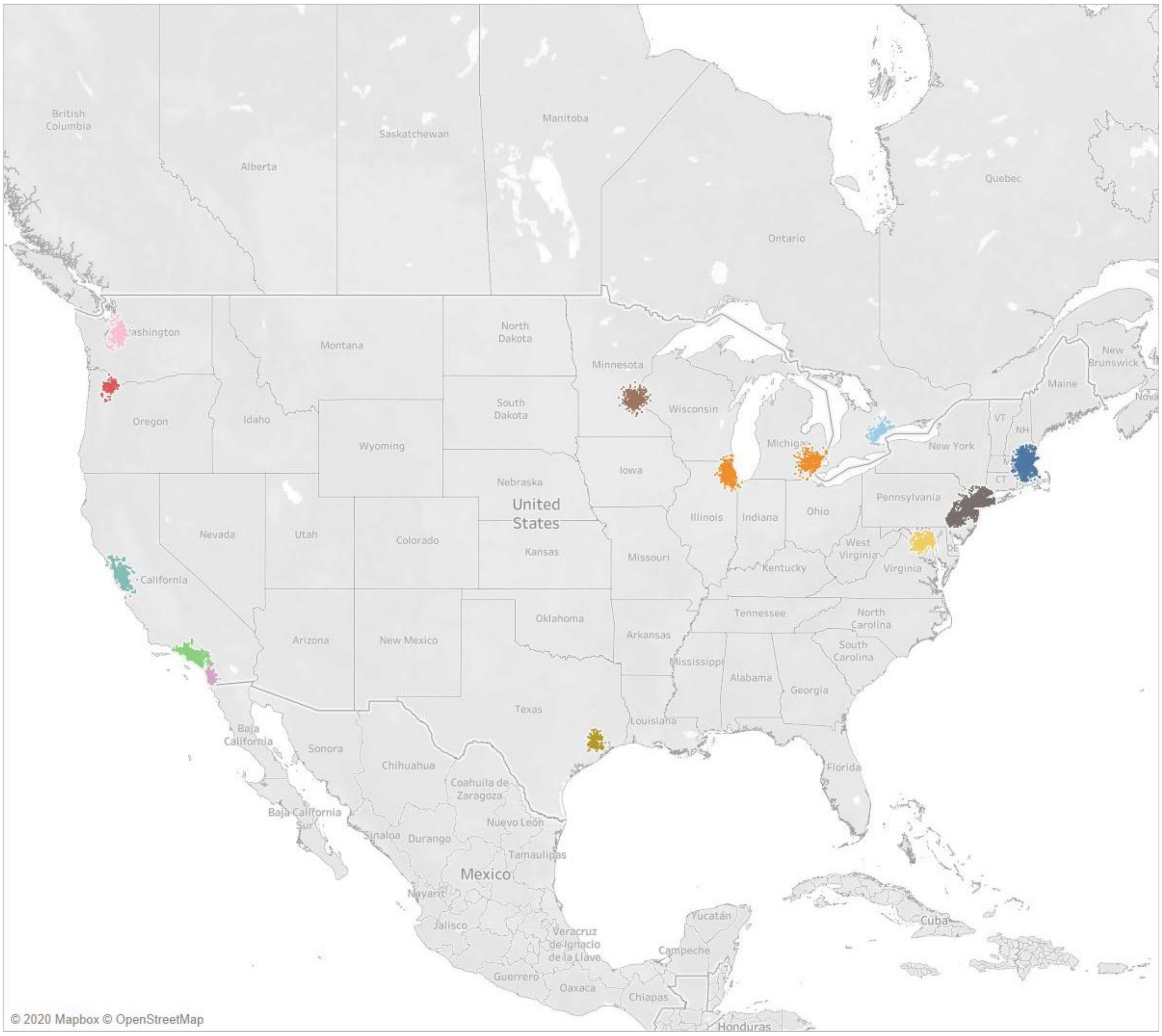
Innovative activities are often highly concentrated, typically in large urban agglomerations with an ecosystem of R&D-performing institutions and companies. This chapter reports on the most important of these clusters in relation to 4IR technologies. The top 30 4IR clusters have been identified for this purpose, based on the location of inventors named on IPFs. Together, they are responsible for nearly two thirds (62.4%) of all international patent families (IPFs) for 4IR technologies in the period 2010-2018. They include thirteen clusters located in North America, eight in South and East Asia, and nine in Europe and the Middle East; they are the main engines of their respective countries' performance in 4IR innovation.

6.1. Top 4IR clusters in North America

The large number of top 4IR clusters located in North America is clear confirmation of the current leadership of the US in 4IR technologies. Twelve of these thirteen clusters are located on US territory, and the locations of the remaining one spans the borders between the US and Canada (Figure 6.1).

Figure 6.1

Top global 4IR clusters in North America, 2010-2018



Unsurprisingly, the top 4IR cluster in North America is the so-called "Silicon Valley" around San José, at the southern end of the San Francisco Bay (Table 6.1). With nearly 7% of worldwide 4IR patenting activity since 2010 and Alphabet, Apple and Intel as top applicants, it shows a strong RTA in software and core AI technologies. However, this cluster is only ranked third globally in this period of time, after those of Seoul and Tokyo (see next section).

Another four of the thirteen regional clusters are also located on the Pacific coast or in close proximity to it. They include three of the fastest-developing 4IR clusters in North America, with average growth rates exceeding 20% since 2010: San Diego (headquarters of Qualcomm, with a specialisation in connectivity and power supply), Seattle (headquarters of Amazon and Microsoft) and Portland (a major R&D centre for Intel). The University of California is the top research institution in three of these West Coast clusters (San José, San Diego and Los Angeles), and has in particular a strong impact on the 4IR cluster of Los Angeles (with 7.5% of the IPFs generated by this cluster).

Most of the other 4IR clusters are located on North America's East Coast (New York, Boston, Washington) and around the Great Lakes (Detroit, Chicago, Toronto, Minneapolis), the only exception being a cluster located in Houston, Texas. The clusters of Boston, Toronto, Washington and Minneapolis stand out in smart healthcare and 3D systems with, for the first three of these, an important contribution from local academic research institutions (15.5%, 15.9% and 6.3% respectively). The cluster of Detroit shows a specialisation in 4IR technologies for automotive industries, with Ford and General Motors as top local applicants.[10]

10 The US more generally appears as a major partner of Canada in 4IR innovation. Since 2010, up to 34% of the IPFs originating from Canada were co-invented with partner countries, and in particular (in nearly 75% of cases) with the US.

Table 6.1

Top 4IR clusters in North America, 2010-2018

Cluster (country)	Global ranking	Share 4IR (avg. growth rate)	RTA* > 1.5	Top applicants** (share of IPFs)	Share UNI/PRO	Top research institution
San José/Silicon Valley (US)	3	6.8% (21.1%)	Software, core AI	Alphabet (14%), Apple (7%), Intel (5%)	1.4%	University of California
San Diego (US)	6	2.9% (20.2%)	Connectivity, power supply	Qualcomm (71%)	1.5%	University of California
Seattle (US)	7	2.4% (21.5%)	IT hardware, software, user interfaces, core AI, data security	Amazon (62%), Microsoft (7%)	1.2%	University of Washington
New York (US)	9	2.0% (13.8%)	Core AI, 3D systems	Honeywell (15%)	6.0%	Columbia University
Detroit (US)	10	1.5% (25.8%)	Data management, geo-positioning, vehicles, safety, industrial	Ford (47%), General Motors (28%)	3.2%	University of Michigan
Boston (US)	12	1.4% (12.2%)	3D systems, healthcare	Harvard University (6%)	15.5%	Harvard University
Los Angeles (US)	13	1.3% (13.7%)	Core AI, 3D systems, healthcare	–	7.5%	University of California
Chicago (US)	21	0.9% (11.9%)	Geo-positioning, safety	Boeing (11%), Alphabet (11%), There Holding BV (7%)	3.1	Northwestern University
Portland (US)	22	0.8% (21.6%)	Core AI, power supply, data security, 3D systems	Intel (69%)	1.4%	Oregon Health And Science University
Minneapolis (US)	24	0.6% (6.6%)	3D systems, healthcare	Medtronic (28%), Cardiac Science (10%), 3M (8%)	2.1%	University of Minnesota
Houston (US)	27	0.5% (19.2%)	Enabling technologies, data management, 3D systems, industrial	Halliburton (28%), Schlumberger (11%), Landmark Graphics (8%)	4.3%	Rice University
Washington (US)	28	0.5% (14.8%)	Core AI, data security, 3D systems, infrastructure, healthcare, agriculture	Johns Hopkins University (7%)	15.9%	Johns Hopkins University
Toronto (CA/US)	30	0.5% (20.7%)	Core AI, 3D systems, healthcare	Blackberry (8%), Synaptive Medical (5%), General Motors (5%)	6.3%	University Health Network

* The (RTAs) in each 4IR sector and field are calculated as the share of an innovation centre's IPFs in that sector or field, divided by the share of the same innovation centre's IPFs in all 4IR technologies.

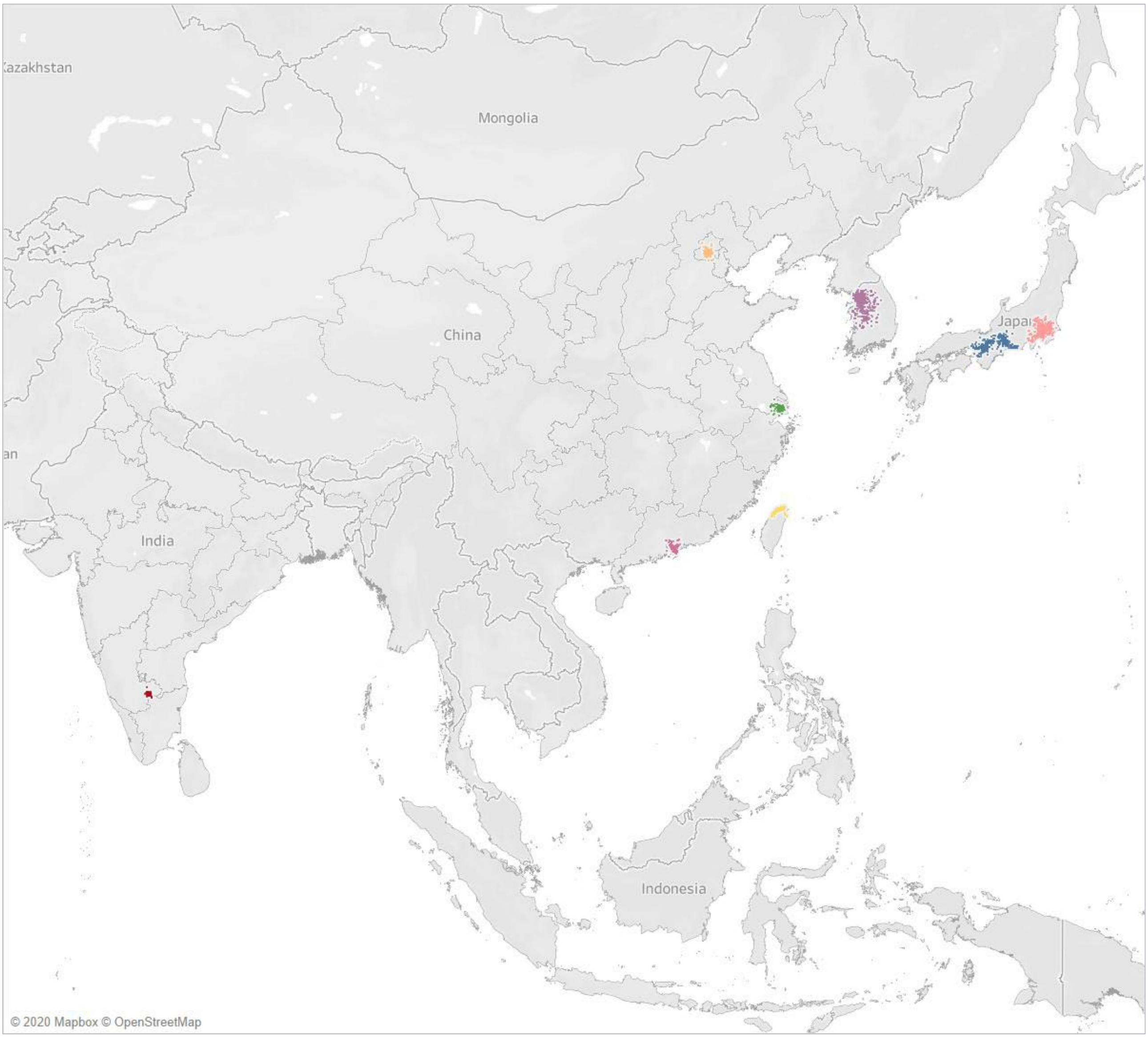
** The top three corporate applicants in each cluster are reported in this column, provided that they contributed more than 5% of the cluster's 4IR IPFs. Their respective shares of IPFs in the cluster are also reported.

6.2. Top 4IR clusters in South and East Asia

Eight of the top 30 4IR clusters are located in South and East Asia, including the two largest ones, namely the regions of Seoul in Korea and Tokyo in Japan. While Seoul is the only Korean cluster on the list, Japan has another one – Osaka – at 4th place in the global ranking and 3rd place in Asia. China is the best represented country in the Asian section of the ranking, with a total of three (very) fast-growing clusters out of eight. The remaining two clusters in the list are Taipei City in Chinese Tapei and Bengaluru (Bengalore) in India.

Figure 6.2

Top global 4IR clusters in South and East Asia, 2010-2018



The regions of Seoul and Tokyo generated nearly 10% each of IPFs related to 4IR technology since 2010, which places them ahead of the US clusters of San José (6.8%) as the top two global 4IR clusters during the last decade. However, only the cluster of Seoul developed as fast as that of San José in the past decade: it shows an average growth rate of more than 20% over this period, whereas the average annual growth of IPFs was closer to 10% in the Tokyo area during the same period.

Both clusters are dominated by national industry champions, namely Samsung and LG in the case of Seoul, and Sony, Fujitsu and Canon in the case of Tokyo. The footprint of these top applicants is much larger in the case of Seoul, which represents 86% of all 4IR patenting activities in Korea. Samsung and LG have a combined share of two thirds of the cluster's IPFs, while another 15% are contributed by ETRI, a public research organisation. In comparison, the combined share of the top three applicants in Tokyo is lower (26%). Together with a relatively low share of IPFs from reseach institutions and the lack of a clear specialisation pattern, this suggests that the cluster of Tokyo is the home of a more diverse industrial ecosystem. Osaka, the other Japanese cluster, has a profile comparable with Panasonic, Denso and Sharp as lead applicants, but a more specific specialisation profile (in safety and 4IR applications for automotive and manufacturing industries).

The three 4IR clusters located in China are Shenzhen (the 5th largest 4IR cluster in the global ranking), Beijing (ranked 8th) and Shanghai (ranked 23rd). They have been growing extremely fast since 2010, with an average annual growth rate above 20% for Shenzhen, and in excess of 30% for Beijing and Shanghai. The cluster of Shenzhen is organised around domestic champions Huawei and ZTE, which together contributed 62% of the IPFs produced by the cluster between 2010 and 2018. Like these two companies, the cluster shows a strong specialisation in connectivity. The cluster of Beijing is likewise led by Chinese applicants (Xiaomi and BOE Technology Group). It has a relatively high share (7.1%) of IPFs originating from local research institutions, and an RTA in core AI technology. By contrast, the cluster of Shanghai seems to be an important R&D hub for non-Chinese companies such as Intel and Nokia.

The cluster of Taipei City in Chinese Taipei does not show any noticeable specialisation in specific 4IR fields and can therefore be considered a generalist cluster. It is dominated by three domestic applicants (HTC, Hon Hai and Mediatek), which together produced 27% of the cluster's IPFs in 4IR technology. With 16% of the cluster's IPFs, research institutions such as the Industrial Technology Research Institute of Taiwan (ITRI) are major contributors to the local 4IR innovation ecosystem. The last cluster in the Asian section of the ranking is Bengaluru (Bangalore) in India, with an RTA in software, data security and power supply. The cluster's top applicants are two foreign companies (Samsung and Intel), which illustrates its role as a major offshore R&D centre in digital technologies (see also Box 5.1). Its third top applicant, Wipro, is a multinational IT company headquartered in Bengaluru (Bangalore).

Table 6.2

Top 4IR clusters in South and East Asia, 2010-2018

Cluster (country)	Global ranking	Share 4IR (avg. growth rate)	RTA* > 1.5	Top applicants** (share of IPFs)	Share UNI/PRO	Top research institution
Seoul (KR)	1	9.9% (22.7%)	IT hardware, power supply	Samsung Electronics (41%), LG (25%), ETRI (5%)	10.5%	ETRI (Electronics and Telecommunications Research Institute)
Tokyo (JP)	2	9.8% (10.3%)	–	Sony (14%), Fujitsu (6%), Canon (6%)	1.4%	University of Tokyo
Osaka (JP)	4	4.0% (9.1%)	Safety, vehicles, industrial	Panasonic (17%), Denso (14%), Sharp (9%)	1.8%	Osaka University
Shenzhen (CN)	5	3.1% (20.6%)	Connectivity, data security	Huaewi (39%), ZTE (23%), Tencent (5%)	1.4%	Peking University Shenzhen
Beijing (CN)	8	2.3% (30.5%)	Core AI	Xiaomi (11%), BOE Technology Group (11%)	7.1%	Research Institute of Telecommunication Science & Technology
Taipei City (TW)	11	1.4% (16.5%)	–	HTC Corp. (9%), Hon Hai Precision Industry (8%), Mediatek (7%)	16.0%	ITRI (Industrial Technology Research Institute)
Shanghai (CN)	23	0.6% (30.6%)	Software, agriculture	Intel (11%), Nokia (8%), Shanghai United Imaging Healthcare (6%)	1.9%	Shanghai Research Center for Wireless Communications
Bengaluru (IN)	29	0.5% (29.5%)	Software, power supply, data security	Samsung Electronics (19%), Intel (9%), Wipro (6%)	0.9%	Indian Institute of Technology

* The RTAs in each 4IR sector and field are calculated as the share of an innovation centre's IPFs in that sector or field, divided by the share of the same innovation centre's IPFs in all 4IR technologies.

** The top three corporate applicants in each cluster are reported in this column, provided that they contributed more than 5% of the cluster's 4IR IPFs. Their respective shares of IPFs in the cluster are also reported.

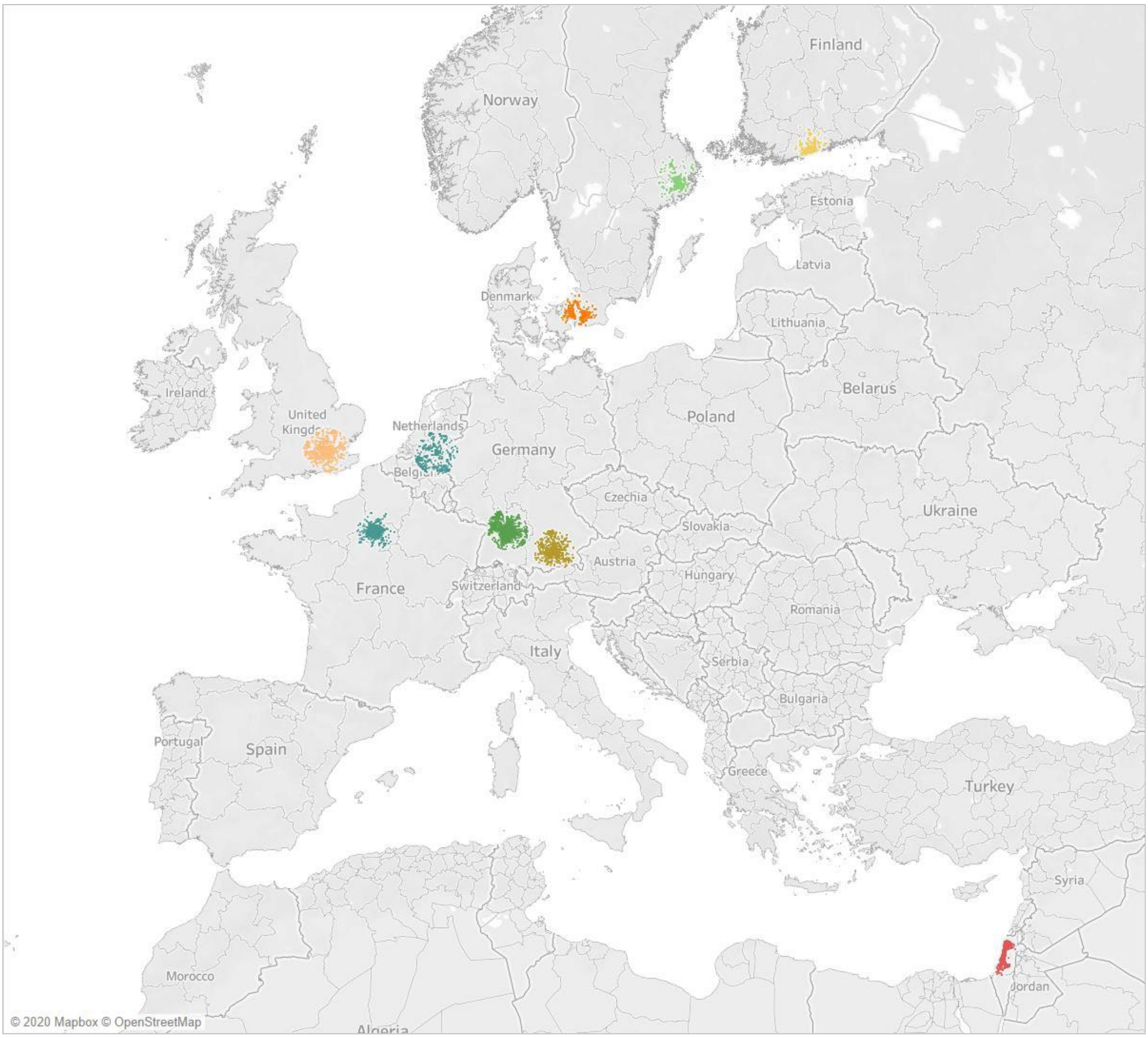
6.3. Top 4IR clusters in Europe and the Middle East

Europe and Israel host eight of the top 30 global 4IR clusters. Apart from the Israeli region of Tel Aviv (ranked 14th globally), all these clusters belong to the lower half of the ranking and have experienced a moderate growth in the past decade compared with some of their counterparts in North America and Asia.

Germany is the European country that is best represented in this ranking, with two purely German clusters (the regions of Munich and Stuttgart) and one cross-border cluster shared with Belgium and the Netherlands (around the Dutch city of Eindhoven). Sweden contributes two other clusters, one of which is the capital city (Stockholm) while the other one, Malmö, is shared with Denmark. The last three clusters are located in the capital cities of the United Kingdom (London), Finland (Helsinki) and France (Paris).

Figure 6.3

Top global 4IR clusters in Europe and the Middle East, 2010-2018



Tel Aviv is the main 4IR cluster in Israel (with more than 80% of the IPFs produced by the country) and the 14th 4IR cluster in the global ranking, with an RTA in core AI, 3D systems, healthcare and agriculture. The fact that the cluster's main applicant is US company Intel (with 14% of its IPFs) denotes strong ties developed between Israel and the US in the domain of 4IR technologies. About 15% of the IPFs originating from Israel between 2010 and 2018 were indeed co-invented with a partner based in the US (see Box 5.1).

The first European cluster in the ranking is the broader region of Eindhoven, spanning the Netherlands, Belgium and Germany. This cluster is organised around Philips and Signify (formerly Philips Lighting), which together have generated up to 72% of its IPFs since 2010. Like Philips, the cluster shows a strong specialisation in 3D systems and smart healthcare.

The German clusters of Stuttgart and Munich have diversified profiles. The region of Munich stands out in the fields of geo-positioning, data security, 3D systems and vehicles. It is led by German industry champions Siemens, BMW (both headquartered in Munich) and the Volkswagen group (its Audi subsidiary being headquartered in Ingolstadt, Bavaria), which together generate 40% of the cluster's IPFs. The region of Stuttgart shows a specialisation in data management, geo-positioning and 4IR applications for automotive and manufacturing industries. It is structured around the German company Robert Bosch, which has contributed 39% of the cluster's IPFs since 2010, as well as Finnish telecom equipment company Nokia (7%) and German software company SAP (5%).

The clusters of Stockhom and Helsinki have similar profiles, with a specialisation in connectivity and power supply and a strong influence on the part of global industry champions in the sector of telecom equipment. Swedish company Ericsson is active in both regions and is responsible for 64% and 13% respectively of the IPFs produced by the clusters of Stockholm and Helsinki since 2010. Finnish company Nokia likewise produced 45% of Helsinki's IPFs in the same period. Although more diversified, the cluster of Malmö has likewise benefitted from the R&D carried out locally by Ericsson, its second main applicant after Japanese company Sony.

The clusters of London and Paris have the largest share of IPFs contributed by universities (4.2% and 7% respectively) thanks to their rich ecosystems of universities and PROs. Unlike most other European clusters, they do not appear to be structured around a small number of national industry champions, and count foreign entities, such as Japanese company Sony in London and Finnish Nokia in Paris, among their top 4IR applicants. While the region of London stands out in core AI technology, Paris shows RTAs in data security, safety, vehicles and infrastructure.

Table 6.3

Top 4IR clusters in Europe and the Middle-East, 2010-2018

Cluster (country)	Global ranking	Share 4IR (avg. growth rate)	RTA* > 1.5	Top applicants** (share of IPFs)	Share UNI/PRO	Top research institution
Tel Aviv (IL)	14	1.2% (15.4%)	Core AI, 3D systems, healthcare, agriculture	Intel (14%)	3.8%	Tel Aviv University
Eindhoven (NL/BE/DE)	15	1.2% (8.9%)	3D systems, healthcare	Philips (65%), Signify (7%)	2.6%	Eindhoven University of Technology
London (UK)	16	1.1% (12.9%)	Core AI	Sony (15%)	4.2%	University of London
Munich (DE)	17	1.1% (16.1%)	Position determination, data security, 3D systems, vehicles	Siemens (15%), Volkswagen (13%), BMW (12%)	2.8%	Fraunhofer
Stockholm (SE)	18	1.0% (15.2%)	Connectivity, power supply, agriculture	Ericsson (64%), Volkswagen (9%)	0.3%***	Fraunhofer
Paris (FR)	19	1.0% (8.5%)	Data security, safety, vehicles, infrastructure	Nokia (7%), Valeo (6%)	7.0%	CEA (Commissariat à l'Energie Atomique et aux Energies Alternatives)
Stuttgart (DE)	20	0.9% (11.4%)	Data management, geo-positioning, vehicles, industrial	Robert Bosch (39%), Nokia (7%), SAP (5%)	1.8%	Karlsruhe Institute of Technology
Helsinki (FI)	25	0.6% (9.6%)	Connectivity power supply, data security	Nokia (45%), Ericsson (13%)	2.2%	Valtion Teknillinen Tutkimuskeskus
Malmö (DK/SE)	26	0.6% (17.8%)	Power supply	Sony (26%), Ericsson (21%)	1.4%****	Danmarks Tekniske Universitet

* The RTAs in each 4IR sector and field are calculated as the share of an innovation centre's IPFs in that sector or field, divided by the share of the same innovation centre's IPFs in all 4IR technologies.

** The top three corporate applicants in each cluster are reported in this column, provided that they contributed more than 5% of the cluster's 4IR IPFs. Their respective shares of IPFs in the cluster are also reported.

*** Due to the system of *professors' privilege* in Sweden, most of the IPFs originating from academic inventors are attributed to these individual inventors and not to the research institutions that employ them. Such IPFs are not included in the share of IPFs originating from universities and PROs.

Annex 1 Impact of application domains on enabling and core technologies

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While Table 3.2 shows the proportion of IPFs in each application domain that are also classified in core and enabling technology fields, Table A.1 below takes the opposite perspective. It indicates the proportion of IPFs in each core or enabling technology field that is also related to each application domain. As such, it provides an indicator of the influence of developments in application domains on innovation in related core or enabling technologies. For instance, more than 61% of IPFs related to geo-positioning are also connected to applications for vehicles, which suggests that 4IR innovation in the transport industry is a major driver of technical progress in geo-positioning.

Table A.1

Importance of application domains for different enabling and core technologies, 2000-2018

Importance of application field	Consumer goods	Home	Vehicles	Services	Industrial	Infra-structure	Healthcare	Agriculture
IT hardware	41.8%	6.3%	10.8%	32.5%	4.0%	2.3%	3.8%	0.2%
Software	33.8%	7.8%	5.5%	14.6%	3.9%	2.8%	1.7%	0.1%
Connectivity	30.5%	15.6%	6.2%	17.8%	3.3%	4.7%	5.1%	0.1%
Data management	18.3%	11.2%	36.3%	11.6%	34.6%	10.3%	13.1%	0.6%
User interfaces	32.4%	5.0%	15.0%	12.2%	3.6%	1.9%	5.8%	0.1%
Core AI	20.4%	5.1%	10.2%	19.6%	7.2%	4.4%	6.9%	0.5%
Geo-positioning	54.2%	4.3%	61.6%	6.6%	2.4%	3.3%	2.3%	0.7%
Power supply	26.1%	3.0%	2.0%	5.6%	2.0%	1.6%	9.1%	0.0%
Data security	27.3%	5.0%	3.2%	12.6%	2.3%	2.0%	1.7%	0.0%
Safety	8.5%	55.6%	48.2%	15.8%	48.2%	6.1%	3.0%	0.1%
3D systems	36.4%	1.7%	2.3%	6.7%	13.2%	1.5%	57.3%	0.2%

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