Measuring the Internet of Things

OECD

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Foreword

The OECD 2016 Ministerial Declaration mandates the OECD to develop metrics to measure the effects of the adoption of Internet of Things (IoT) solutions in different policy areas, such as economic growth, employment and education needs.

Measuring the Internet of Things provides new evidence on how the IoT – the inter-networking of the physical devices and objects whose state can be altered via the Internet – is diffusing in OECD countries. It also analyses the effects of the IoT on productivity based on two case studies on manufacturing firms in Brazil and Germany.

The report was prepared by Pierre Montagnier, Lucia Russo and Vincenzo Spiezia, under the supervision of Audrey Plonk, Head of the Digital Economy Policy Division in the OECD Directorate for Science, Technology and Innovation.

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Abbreviations and acronyms

AI	Artificial intelligence
BDA	Big data analytics
CBM	Condition-based maintenance
CC	Cloud computing
CNC	Computer numerical control
COVID-19	Coronavirus disease 2019
ECG	Electrocardiogram
GP	General practitioner
IC	Integrated circuit
ICT	Information and communication technology
IIoT	Industrial Internet of Things
IoT	Internet of Things
IP	Internet protocol
IT	Information technology
LAN	Local area network
ML	Machine learning
NRRP	National recovery and resilience plan
OECD	Organisation for Economic Co-operation and Development
RFID	Radio frequency identification
RPM	Remote patient monitoring
SMEs	Small and medium-sized enterprises
UNCTAD	United Nations Conference on Trade and Development
USD	United States dollar
UWB	Ultra-wideband
VC	Venture capital
VPN	Virtual private network
WEF	World Economic Forum
WLAN	Wireless local-area network
WSTS	World Semiconductor Trade Statistics

Executive summary

This report provides new evidence on how the Internet of Things (IoT) – *the inter-networking of physical devices and objects whose state can be altered via the Internet* – is diffusing in OECD countries. Connected industrial equipment, smart home devices and connected cars are all examples of IoT applications.

According to some estimates, the number of IoT connections surpassed that of non-IoT in 2020. Semiconductor components of IoT devices have been growing constantly in recent years and are estimated to account for between 5 and 7% of the worldwide semiconductor market. IoT-related patent applications grew by close to 20% a year in 2010-18 and accounted for over 11% of all patenting activity worldwide at the end of the period. Venture capital investment in IoT firms also increased dramatically in the last decade, reaching USD 8 billion in 2020. Despite this buoyant environment, the IoT is diffusing unevenly among firms, industries and countries.

In 2021, 29% of European firms used the IoT, an increase of almost 8 percentage points from the previous year. This share was lower in Canada (23%) and Korea (14%) in 2020, although differences in the survey design limit comparability across countries. Overall, utilities, energy and transport are leading in uptake. The figures also point to a divide between large and small firms: on average, the gap in IoT adoption in OECD countries was as big as 20 percentage points in 2020.

Case studies on manufacturing firms in Germany and Brazil show that the use of IoT increases their competitiveness by reducing costs and improving processes. For instance, one large firm reports that IoT data, in combination with machine learning, has reduced the cost associated with poor product quality by nearly 70%. Concerns about digital security and data protection are among the major barriers to IoT uptake in the sector, with a lack of interoperability and limited scalability also playing an important role.

People enjoy smart TVs and smart speakers in their living rooms but seem less keen on smart fridges in their kitchens. In European countries, on average, 56% of individuals had some smart entertainment device at home in 2020 but only 27% had home automation devices. Smartwatches and wristbands are becoming popular for tracking calories but fewer individuals use smart devices to monitor their health conditions. Only 6% of individuals in the United States and European countries owned health-related IoT devices in 2020, whereas many more had a smartwatch (12%) or a wristband (23%). These statistics suggest an untapped potential for IoT in healthcare.

Remote patient monitoring (RPM) has the potential to reduce hospital length of stay and hospitalisation costs, as found in some pilot projects. However, a few hospitals and general practitioners in OECD countries use smart devices for RPM. The lack of specific reimbursement mechanisms, limited digital skills, and the low degree of digitalisation of the healthcare sector are some of the most cited barriers to higher adoption of RPM.

While these metrics provide useful insights, measurement of the IoT is still in its infancy and statistical efforts need to continue in this rapidly evolving field. In addition, future work should further inquire into the drivers and obstacles to IoT adoption to help policy makers formulate effective policies.

1 Setting the scene

This chapter provides an overview of the Internet of Things (IoT), which refers to the interconnection of physical devices via the Internet. It discusses how IoT devices collect and share data to improve various processes, and can be used in several applications and sectors, including agriculture, energy, and healthcare. It also discusses the growth and adoption of IoT devices worldwide, along with associated challenges such as cybersecurity threats. Additionally, the text explores the convergence of IoT with other technologies like big data analytics and artificial intelligence. Finally, it outlines the structure of the book, which includes chapters on measuring IoT diffusion and case studies in the manufacturing and healthcare sectors.

The Internet of Things: What it is and what it is for

The Internet of Things (IoT) refers to "the inter-networking of physical devices and objects whose state can be altered via the Internet, with or without the active involvement of individuals" (OECD, 2015[1]). The IoT is an aggregation of uniquely identifiable "endpoints" that communicate bi-directionally over a network in a seamless way. The main driver of value of the IoT is the capacity to collect, store and share data about the environments and assets it monitors, thereby helping improve different processes as these become measurable and quantifiable. Depending on the IoT device, the processing of IoT data can be performed either locally by the object itself or in some other network location, e.g. another IoT device, a mobile device, the cloud or a data centre.

There are many type of IoT devices that serve varied functions, spanning from sensors for agriculture to smart meters for energy efficiency and wearables to monitor health conditions, just to name a few. IoT domains of application are also heterogeneous: they range from consumer applications to industrial ones, carrying the promise to deliver efficiency gains, such as cost reduction, energy savings, improved healthcare, decreased pollution or reduction in road congestion. The IoT is changing agriculture, energy, healthcare, manufacturing, transportation and cities, and has the potential to profoundly transform these sectors, contributing to economic growth and well-being.

The diffusion of IoT devices is driven by the declining cost of sensors, high mobile adoption and expanded Internet connectivity. IoT Analytics (2020[2]), a private company that mapped 1 414 IoT projects from 620 IoT platforms in the public domain, estimates that, in 2020, for the first time, there were more IoT connections (e.g. 11.7 billion connected cars, smart home devices, connected industrial equipment) than non-IoT connections (10 billion smartphones, laptops and computers). Other estimates suggest that by 2023, there will be 29.3 billion networked devices worldwide and 14.7 billion – half of the total – will be machine-to-machine (M2M) connections (Cisco, 2020[3]). The United Nations Conference on Trade and Development (UNCTAD, 2021[4]) estimates the market size of IoT technologies – as measured by revenues – at USD 130 billion in 2018, with expected growth of up to USD 1.5 trillion in 2025. In its estimates, the IoT accounts for the highest share of the market size of 11 "frontier technologies",[1] at 37% in 2018 and 47% in 2025 (UNCTAD, 2021[4]). However, the diffusion of IoT devices has also increased cybersecurity threats, and security risks and privacy concerns appear among the main barriers to adoption.

The IoT both enhances and is enhanced by other technologies such as big data analytics, cloud computing, artificial intelligence (AI) and machine learning (ML), which make it possible to process and capitalise on the large volumes of IoT data. As the value of the IoT gets unlocked with AI and ML algorithms applied to IoT data, the term artificial intelligence of things has also emerged recently. Edge computing – a decentralised and distributed form of computing – contributes to the convergence of these technologies (AIOTI, 2020[5]). Blockchain, augmented reality and virtual reality are other technologies that complement or enhance the IoT.

Although there is no agreed classification of the IoT, a frequent classification divides IoT application domains into commercial, consumer, enterprise and industrial IoT. Commercial IoT concerns applications developed to provide a better experience to guests in places like hotels and restaurants, through connected lighting or building access in smart buildings and smart offices for example. Consumer IoT hosts a great variety of IoT-connected devices, such as health monitors, smart home applications and connected automobiles. Enterprise IoT connects diverse technologies to enable new business applications that connect with physical objects and enterprise systems (e.g. enterprise resource planning, customer relationship management). Enterprise IoT applications can be implemented across multiple sectors, including agriculture and healthcare, as well as government and cities. The Industrial Internet of Things (IIoT) focuses on the specialised requirements of industrial applications, such as manufacturing, oil and gas, and utilities.

The surveys on information and communication technology (ICT) Usage by Businesses show that energy, transportation/storage and information and communication are the leading sectors for IoT adoption in Europe, while in Canada, utilities, information and cultural industries, mining, and oil and gas extraction rank at the top. IoT Analytics (2020[2]) found that most IoT projects are in the manufacturing/industrial sector, with transportation/mobility, energy, retail and healthcare having also increased their relative share in comparison to past analyses. The Economist Intelligence Unit (EIU, 2020[6]) also reports manufacturing, transportation and logistics, as well as utilities as the main sectors for the IoT, followed by the healthcare sector. In Italy, the Osservatorio Internet of Things estimates that the highest share of the market in the country is represented by utilities, followed by transportation and smart buildings (Osservatorio Internet of Things, 2021[7]).

Measuring the IoT: Some considerations

Several government authorities, organisations and market players (telecommunication providers) collect metrics on the diffusion of connected devices (OECD, 2018[8]). The OECD has collected data from regulatory authorities since 2012 on the number of M2M-embedded subscriber identity modules (SIMs). As of June 2021, there were about 385 million M2M SIM card subscriptions in the OECD area, compared to 132 million in 2015 (OECD, 2022[9]). However, while being an important component of the IoT – this category comprises only a small subset of all devices that are currently connected or will be so in the future. The fifth-generation technology standard for broadband cellular networks (5G) promises to become central to the IoT due to its low latency and capacity to support massive M2M communication. OECD countries have made significant progress in 5G commercial deployments: by June 2022, 5G commercial services were available in 36 out of the 38 OECD countries (OECD, 2022[10]). However, most commercial 5G services currently rely on presently deployed fourth generation of broadband cellular network technology (4G) core networks aimed at enhanced mobile broadband. The second phase of the deployment of 5G networks is more oriented to the IoT. 5G private networks are also being deployed in smart factories around the world, e.g. Factory 56 in Sindelfingen (Germany) or Factory Zero in Detroit (Unites States) (OECD, 2022[10]).

Mobile connectivity, however, is just one type of connectivity used for IoT devices and networks. Different IoT applications make use of different connectivity technologies as they have specific requirements. These requirements have driven the emergence of a new wireless communication technology: low-power wide-area network (LPWAN). Cisco (2020[3]) estimates that in 2018 there were 223 million LPWA connections (all M2M), representing 2.5% of total device connections. The company forecasts an increase up to 1.9 billion LPWA connections by 2023, or 14% of total device connections. Cisco adopts a different definition of the IoT than the OECD; they estimate that mobile M2M connections were 1.2 billion in 2018, expected to grow to 4.4 billion by 2023.

In recent years, national statistical offices in OECD member countries have introduced questions in their ICT usage surveys to estimate the use of the IoT by businesses, households and individuals. These data start offering a more complete overview of IoT adoption by sectors and of usage by individuals. However, measures of other dimensions, such as social and economic impacts, are at present scattered.

Several management consultancies have produced estimates on the diffusion of IoT devices and the potential economic impact of the IoT, though academic research is quite limited on the topic, mostly due to the relative recentness of the technology and the difficulties in defining it for analytical purposes. Edquist, Goodridge and Haskel (2019[11]) suggest a potential global annual average contribution to growth of 0.99% per year in 2018-30, approximately USD 849 billion per year of world gross domestic product in 2018 prices. Espinoza et al. (2020[12]) used a growth accounting framework to evaluate the likely impact of the IoT on productivity. They found a positive impact of the IoT on labour productivity growth, though relatively small (0.01 percentage points in the United States and 0.006 in ten European Union countries).[2] Cathles, Nayyar and Rückert (2020[13]), based on data from the European Investment Bank Investment Survey 2019

(EIBIS 2019), found IoT adoption in firms to be positively associated with productivity. They also found complementarities among advanced digital technologies, i.e. three-dimensional (3D) printing, advanced robotics, the IoT and cognitive technologies such as AI and big data.

The IoT is multidimensional and manifold: in the IoT ecosystem, not only are the "things" connected to the Internet rapidly growing in quantity and variety but the domains in which they are flourishing are also heterogeneous. The IoT does not only refer to the connected devices but to the entire ecosystem in which the "things" sense and communicate, which is composed of various layers: the enabling infrastructure, which includes telecommunication, cloud and data services, the devices embedded in "things", which contain software and application programming interfaces to connect to objects, the operating platform (i.e. the integral support software that connects everything in an IoT system) and the application ("user") layer (OECD, 2018[8]). Several economic actors are involved in each of these key-enabling layers (see Table 1.1 for examples of major market players), such as the designers and producers of connected devices sold to consumers, the IoT module providers (i.e. chips, processors, software and application programming interfaces), network integrators or service providers, and data aggregators. All of the above elements can be measured; therefore, possible IoT metrics can measure a variety of dimensions, following different approaches.

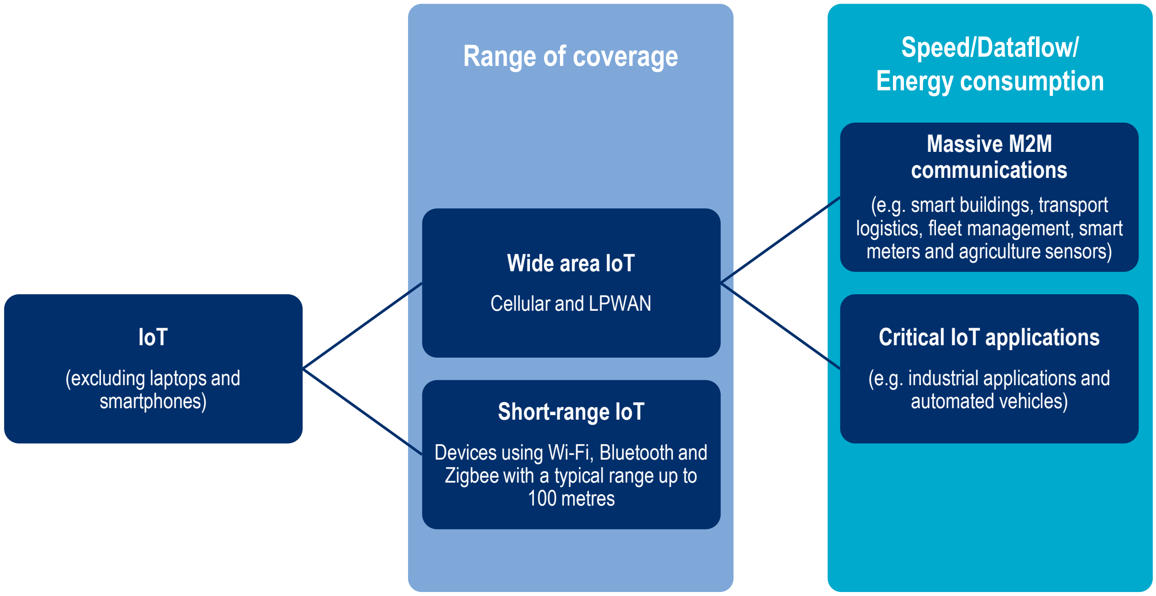
Table 1.1. Major players in the IoT value chain

	Technology leaders	New entrants
Application layer	Amazon, Apple, Cisco, GE, Google, IBM, Microsoft	Alibaba, Huawei, Samsung, Schneider, Siemens, Tencent
Data layer	AWS, Google Cloud Services, Infosys, Fortinet, IBM, Microsoft, Oracle, SAS, Tableau	Alteryx, Cloudera, Dataiku, Hortonworks, RapidMiner
Connectivity layer	Arista Networks, AT&T, Cisco, Dell, NTT, Ericsson, Nokia, Orange	Bharti Airtel, China Telecom, Citrix, Coriant, Equinix, Tata Comms
Device layer	AMD, Apple, Fitbit, Honeywell, Intel, Nvidia, Sony	AAC Tech, Ambarella, Garmin, Goertek, HTC, GoPro, LinkLabs

Note: This list is not exhaustive and is for illustrative purposes only.
Source: IRENA (2019[14]), *Innovation Landscape Brief: Internet of Things*, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Sep/IRENA_Internet_of_Things_2019.pdf?rev=4a5a17b14dbb4bd7be9e8a33c593e458.

Given the variety of different IoT use cases and their different levels of development across sectors, it is necessary to narrow the scope to specific use cases for measurement purposes. In this light, previous OECD work (2018[8]) proposes prioritisation criteria and suggests measuring specific IoT applications instead of attempting to measure the IoT in general. To this end, it developed a taxonomy identifying sub-categories of the IoT, classified according to their connectivity requirements. In addition, the proposed taxonomy of the IoT for measurement purposes (Figure 1.1) provides an approach according to dimensions, mainly based on implicit underlying technical criteria: the range of coverage and the specific functionalities of the IoT. These are considered from the combined angle of: i) the future market developments (main usage scenarios); ii) the IoT ecosystem approach; and iii) the way stakeholders from the private sector developing the IoT business cases (e.g. Cisco and Ericsson) are measuring the IoT.

Figure 1.1. Underlying criteria of the OECD taxonomy of the IoT for measurement purposes



Source: Updated from OECD (2018[8]), "IoT measurement and applications", https://doi.org/10.1787/35209dbf-en.

Outline of this book

In this book, Chapter 2 focuses on the initiatives undertaken by national official statistical agencies and Eurostat to measure IoT diffusion, focusing on ICT usage surveys. It provides an overview and discussion of the definitions adopted and presents results for businesses, households and individuals. Chapter 3 provides further metrics on IoT diffusion, including trends in IoT-related semiconductors, patents, venture capital investments and firms. Chapters 4 and 5 present the results of two case studies on the manufacturing and healthcare sectors respectively.

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Notes

[1] Artificial intelligence, IoT, big data, blockchain, 5th generation mobile network (5G), three-dimensional (3D) printing, robotics, drones, gene editing, nanotechnology and solar photovoltaic.

[2] Austria, Belgium, Finland, France, Germany, Italy, the Netherlands, Spain, Sweden and the United Kingdom.

2 Information and communication technology usage surveys in OECD countries

This chapter discusses the definitions of the Internet of Things (IoT) in statistical surveys across countries, compares results on IoT uptake by businesses, households and individuals, and provides guidance for countries wishing to refine or introduce questions on the IoT in their surveys.

This chapter reports on the initiatives by national statistical offices in different OECD countries and Eurostat to measure Internet of Things (IoT) adoption by firms, households and individuals. Since there is no official internationally agreed definition of the IoT, the chapter discusses and compares the definitions and approaches used in the surveys across countries. The objective is to provide information on the comparability of the results as well as guidance for countries wishing to refine or introduce questions on the IoT in their surveys. In surveys on information and communication (ICT) Usage by Businesses, differences concern how the devices are defined, the examples provided and the questions about functions. As for the surveys on ICT Usage by Households and Individuals, differences concern the categories and examples provided. Results from these surveys are then discussed in detail for businesses, households and individuals.

IoT use by businesses: A comparative analysis of the statistical surveys

National statistical offices have recently introduced measures of IoT uptake by firms in official statistics, mostly in ICT usage surveys but also in innovation surveys and general business surveys, among others. This book focuses on surveys on ICT Usage by Businesses.[1]

The IoT statistical definitions (see Annex 2.A for the full definitions and Annex Table 2.A.1 for a summary) show some commonalities and differences in relation to some key aspects, as discussed in Box 2.1. Overall, definitions refer to devices that can be interconnected via the Internet and collect and exchange data. They do not specify the underlying criteria of the technical dimension of the network, i.e. the range of coverage (wide versus short range), the speed, the data flow and the energy consumption. Key differences in definitions concern how the types of devices are defined and their functions, as well as in the examples provided to respondents.

Box 2.1. How is the IoT defined in ICT usage surveys? An analysis of key aspects

1. **Network and connection**: All definitions include the ability to be interconnected via the Internet, with Japan additionally including local area networks (LANs) and other networks. Canada and Korea also specify that devices can connect to each other. All other countries point to the fact that devices can exchange or transfer data or information.
2. **Type of devices**: Definitions refer to devices, possibly associated with objects or systems, except for Japan and Korea. Those two countries specifically refer to the IoT as “a technology”. Korea additionally includes the concept of “service” (also included in the filter question on IoT usage). The types of devices range from a very broad approach (“various things” in Japan and Korea, “All devices and objects whose state can be altered via the Internet with or without the active involvement of individuals” for the OECD) to a more detailed description (“Computing devices embedded in everyday objects, electronic devices that can connect to each other and the Internet through a network” in Canada). Two definitions include the qualification of “smart” (Eurostat, Canada) and three definitions include “systems” (Australia, Eurostat and Korea). Australia includes not only computing devices but also “mechanical and digital machines, objects, animals or people that are provided with unique identifiers”.
3. **Function(s)**: All definitions refer to function(s) associated with the devices. Those functions include data collection and exchange, the ability to be monitored and remotely controlled, or “digitalisation of their data for collection and accumulation” (Japan). Korea provides a more developed function with “dynamic communication of information between people and things, things and other things, things and systems” and “activity of recognition, monitoring, etc. through the physical sensing equipment […] and the accumulated data would be provided through the

wire/wireless communication to be used in various fields". Israel and the OECD specifically add "with or without the active involvement of individuals" and Australia "without requiring human-to-human or human-to-computer interaction".

4. **Example(s)**: With the only exception of Israel, all definitions include examples. Items range from computing end-user devices (e.g. laptops, tablets and smartphones) or infrastructure components (e.g. routers, servers, radio frequency identification [RFID] or Internet Protocol [IP] tags, sensors) to specific-purpose devices (wireless technology Wi-Fi-enabled security cameras, automatic car tracking adapters) or smart devices (smart thermostats, smart lamps or smart meters, smart televisions, smart speakers, home voice controllers) and finally expand to much broader and complex items or categories (e.g. office equipment, electrical appliances, industrial machines, cars, smart security systems, smart or connective factories). The diversity of examples mirrors the width of possible IoT usages and their continuous evolution, which also requires modifications over time in the definitions (Eurostat, OECD).

Source: Based on definitions in surveys (see Annex 2.A and Annex Table 2.A.1).

ICT usage surveys focus on various aspects of IoT adoption following different approaches, as shown in Table 2.1. Overall, IoT usage by firms is generally surveyed with a standard simple "yes/no" question but when it comes to devices and functions, the situation is much more heterogeneous across countries. In addition, issues related to reasons for using the IoT, perceived effects and impacts, and reasons for not using the IoT are raised in only three countries (Table 2.1).

Table 2.1. Overview of measurement of the IoT in ICT Usage Surveys by Businesses

	Australia (2017-18; 2019-20)	Canada (2019)	Eurostat (2020)	Eurostat (2021)	Israel (2019)	Japan (2017)	Japan (2018) (both IoT and AI)	Korea (2017-21)
Extent of IoT importance (as digital technology)	✓ (2017-18)							
Use of the IoT (Y/N)	✓ (2019-20)	✓	✓	✓	✓1	✓	✓2	✓3
IoT devices		✓	✓	✓		✓	✓2	
Detailed devices mixing end-use (e.g. security devices, healthcare equipment, industrial robots, cellular modules from automobiles) and technical (e.g. smart meters, non-contact integrated circuit cards, sensors, RFID tags, monitoring cameras, etc.) characteristics						✓	✓2	
Family of devices by technical type (e.g. smart meters, sensors, RFID or IP tags, etc.) associated with end-use functions (e.g. optimise energy consumption, improve customer service, track the movement of vehicles or products, etc.)			✓					

	Australia (2017-18; 2019-20)	Canada (2019)	Eurostat (2020)	Eurostat (2021)	Israel (2019)	Japan (2017)	Japan (2018) (both IoT and AI)	Korea (2017-21)
IoT by function				✓	✓			
IoT by end-use function (e.g. production process, management of enterprises, logistics, ICT security, human resources management) associated with devices				✓				
Mix of output (merchandise or services the enterprises produce and business process functions, e.g. production stages, transportation and distribution of merchandise, or end-use functions, e.g. oversight and tracking purposes)					✓			
IoT by activities or end-user market/segments		✓						
IoT (Internet-connected smart devices) by the end-use function associated with segments/markets (e.g. small, consumer market/industrial equipment/digital infrastructure)		✓						
Reasons/purposes for using the IoT		✓				✓	✓2	✓
Reasons for not using the IoT		✓				✓	✓2	✓
Perceived level of efficiency/effectiveness of the IoT systems in the business							✓2	✓

Notes: For details by country, see Annex Table 2.A.2.
1. Restricted to the following area: "for the products (goods or services), production of products and/or transportation of products".
2. AI (artificial intelligence) and the IoT are considered together and not separately.
3. The question includes IoT "device and service". In 2020 and 2021, the survey included only the question on the use of the IoT.
Source: Compiled from various official survey questionnaires.

- **IoT usage**: IoT usage is mainly surveyed using the simple "Yes/No" question as an initial filter. Without covering IoT usage, Australia nevertheless inserted in 2018 a question on the importance of digital technologies for businesses, including the IoT. In its section related to the use of information technology (IT), the 2019-20 Business Characteristics Survey (BCS) (Australian Bureau of Statistics, 2021[1])includes a question on the various ICT used by businesses and the IoT is one of them. Introducing an initial filter question on IoT usage or asking direct questions on IoT devices or functions may produce different survey results. This may limit the comparability of results between countries (for the same year) or the same country (across years) if the option of using a filter question changes over time.

- **Devices and functions**: Statistical offices do not provide lists of IoT devices but rather associate IoT devices with functions or domains of application. For instance, Canada refers to small devices in the consumer market, industrial equipment and digital infrastructures, whereas Japan refers to a mix of more detailed types of devices associated with technical characteristics. On the other hand, Israel focuses on business process functions such as production stages, transport and distribution or tracking purposes. Eurostat refers both to the type of device and its function. In the 2020 survey, the question focused on the type of device first (e.g. smart meters, sensors, RFID or IP tags) followed by the associated function (e.g. optimise energy, improve customer service, etc.). In contrast, the 2021 survey asked the above in reverse order.
- **Activities**: IoT devices can also be qualified by mixing end-of-use functions and specific market segments, such as the consumer market, industrial equipment or digital infrastructures (Canada).
- **Reasons/purposes of use***:* Some countries are also asking respondents about the expected impacts of adoption. These include expected cost savings, productivity gains, improvements in decision making (Canada, Korea), improvements in business efficiency or in customer services (Japan), new business projects/management practices and expansion to new sources of profits through the creation of new products/services (Japan, Korea). Japan and Korea ask respondents to assess effects/impacts based on a scale of effectiveness.
- **Reasons for not using the IoT**: Canada, Japan and Korea also ask respondents about reasons for not using the IoT, providing options such as no business needs, lack of knowledge, employees' lack of skills, costs (of service, equipment or implementation), security or privacy concerns, or legal barriers or concerns. Questions also specifically address issues such as the insufficient communication infrastructure required for the introduction of the IoT (Japan), the incompatibility with existing equipment and software (Canada) or the lack of clarity of business models following IoT adoption (Korea).

IoT use by businesses: Survey results

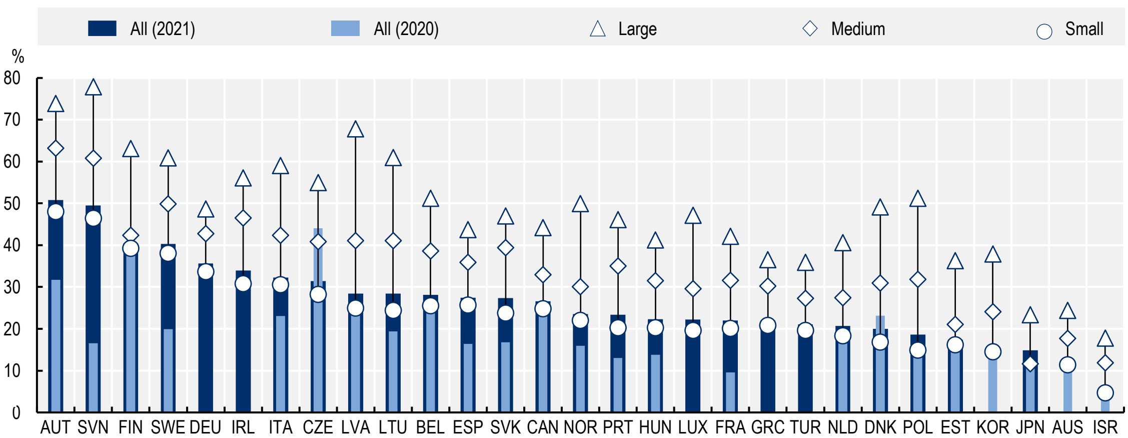
IoT uptake by business

Uptake of the IoT by firms increased significantly between 2020 and 2021 (Figure 2.1), although with large differences among countries, the share of IoT-using firms ranging from 12% in Australia to 51% in Austria. The share of firms using the IoT reached 29% on average in European countries in 2021, an increase of close to 8 percentage points from the previous year. The observed differences in IoT uptake between European and non-European countries may reflect, to some extent, differences in the statistical methodology. Similarly, the decrease registered in two European countries, the Czech Republic and Denmark, might be due to a change in the survey – specifically the inclusion or deletion of a filter question – and to large uncertainty margins.

Large firms are more likely to adopt the IoT than small and medium-sized firms (Figure 2.1). The gap is above 20 percentage points in 20 OECD countries out of 29 and above 30 percentage points in Latvia, Lithuania, Poland and Slovenia. Data for Canada, Israel and Korea also confirm that the IoT adoption rate is much higher among large firms in all industries than in small and medium-sized ones. In those countries, large firms are on average more than twice as equipped with IoT devices compared to small firms. The IoT tends to be associated with complementary advanced technologies such as cloud computing (CC), big data analytics (BDA) or AI, the combination of which is more easily accessible to large firms (see below the section on the complementarity between the IoT and other digital technologies).

Figure 2.1. Enterprises using the IoT in selected OECD countries by firm size, 2021 or latest available year

As a percentage of enterprises in each employment size class

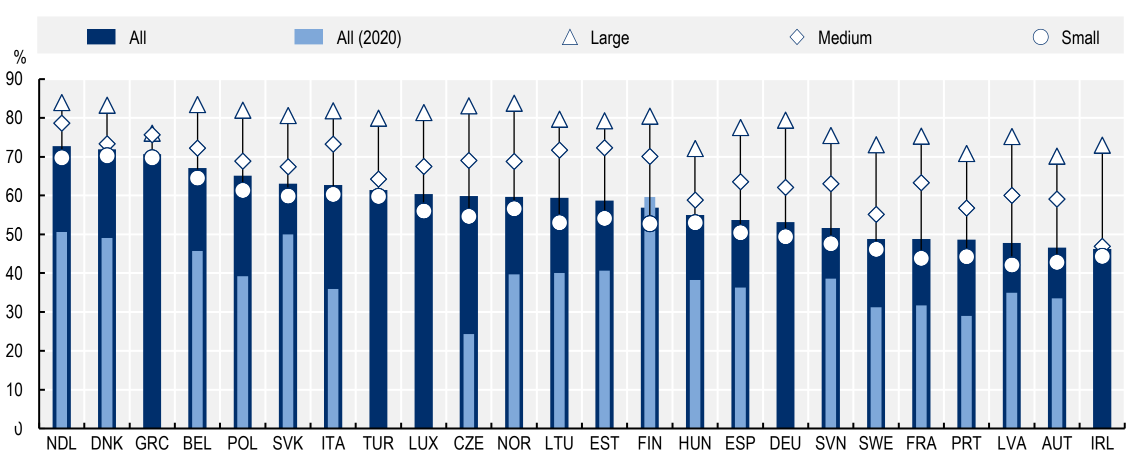


Note: Data for Canada refer to 2019. Data for Australia refer to the 2019-20 reference period ending on 30 June 2020. Data for Israel and Korea refer to 2020. Data for Japan refer to businesses using both the IoT and AI and to businesses with 100 and more employees and are available for medium (100 to 299 employees) and large (300 and more employees) firms only. Data refer to businesses with ten or more employees for all remaining countries. Small: 10 to 49 employees. Medium: 50 to 249 employees. Large: 250 and more employees.
Sources: Based on Eurostat (2022[2]), *Comprehensive Database*, https://ec.europa.eu/eurostat/web/digital-economy-and-society/data/comprehensive-database (accessed on 1 February 2022); and national official sources.

Among large firms, IoT usage is mostly multi-dimensional: in all countries, more than seven large firms out of ten are equipped with two or more different types of IoT functions/devices (Figure 2.2).

Figure 2.2. Businesses using two or more IoT devices or systems in selected OECD countries by firm size, 2021

As a percentage of firms using the IoT in each employment size class

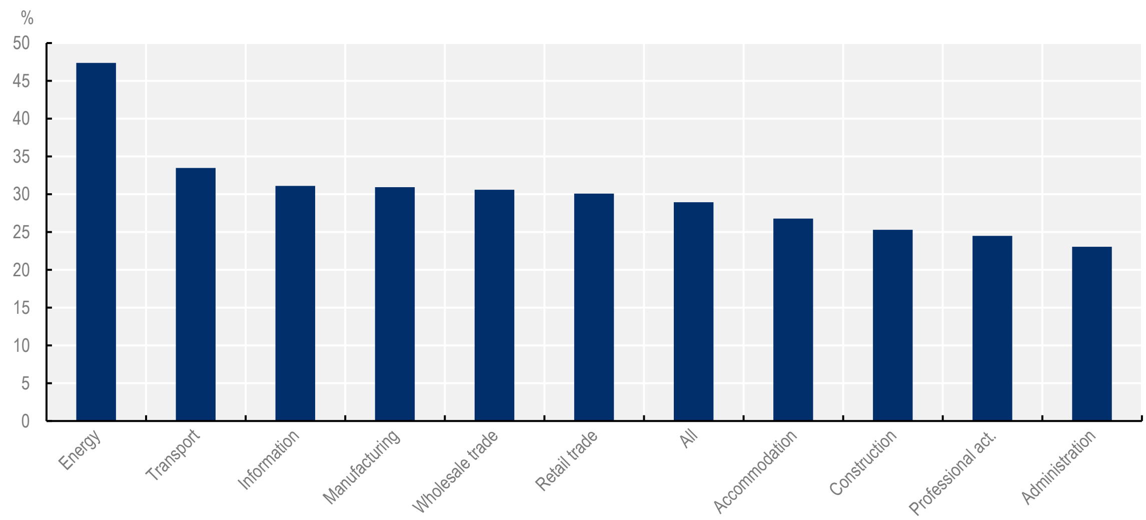


Source: Based on Eurostat (2022[2]), *Comprehensive Database*, https://ec.europa.eu/eurostat/web/digital-economy-and-society/data/comprehensive-database (accessed on 1 February 2022).

While the adoption gap by firm size is common across countries, detailed data by industries show different patterns of adoption by industry among countries. In 2021, the share of firms using the IoT in European countries ranged, on average, from 23% in administration to 33% in the transport and 47% in the energy industries. Close to one firm in three adopted the IoT in the manufacturing industry (Figure 2.3).

Figure 2.3. Enterprises using the IoT in selected European countries by industry, 2021

As a percentage of enterprises



Note: Simple average of 23 European countries for which data are available, as shown in Figure 2.1.
Industries covered are the following: Energy = Electricity, gas, steam, air conditioning and water supply; Transport= Transportation and storage; Information = Information and communication; Manufacturing= Manufacturing; All = All industries (without financial sector); Wholesale trade = Wholesale and retail trade; repair motor vehicles and motorcycles; Construction = Construction; Retail trade = Retail trade, except motor vehicles and motorcycles; Administration = Administrative and support service activities; Accommodation = Accommodation and food and beverage service activities; and Professional act. = Professional, scientific and technical activities.
Source: Based on Eurostat (2022[2]), *Comprehensive Database*, https://ec.europa.eu/eurostat/web/digital-economy-and-society/data/comprehensive-database (accessed on 1 February 2022).

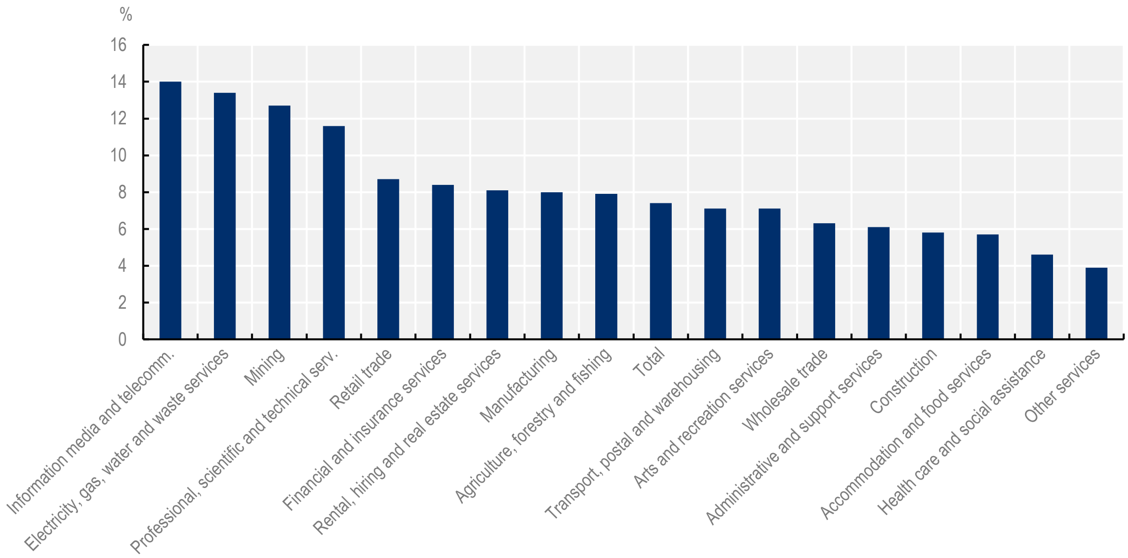
In Australia, IoT adoption by all firms – including those with fewer than 10 persons employed – is the highest in information media and telecommunication (14% in 2020) and energy industries (13.4%), while it is the lowest in healthcare, social assistance and other services (around 4%) (Figure 2.4).

In Israel, 6.2% of firms used the IoT in 2020 (Figure 2.5). Energy industries show the highest rate of adoption (18.3%), followed by the manufacturing sector, although with about 7 percentage points' difference. Construction, retail trade and administrative and support services are the sectors using the IoT the least (below 4%).

In Canada, IoT adoption is the highest – above 30% in 2019 – in the energy (utilities), information and culture, mining and real estate industries (Figure 2.6). In those industries, the share of firms using the IoT is around one-third among small firms (from 5 to 49 employees) and between 50% and 75% among large firms. Large firms are particularly keen to adopt the IoT in the management (approximately 70% and above), mining, transport and construction (approximately 60% and above) industries. On the other hand, IoT adoption rates are the lowest in the construction, healthcare, finance and insurance sectors.

Figure 2.4. Enterprises using the IoT in Australia, by industry, 2020

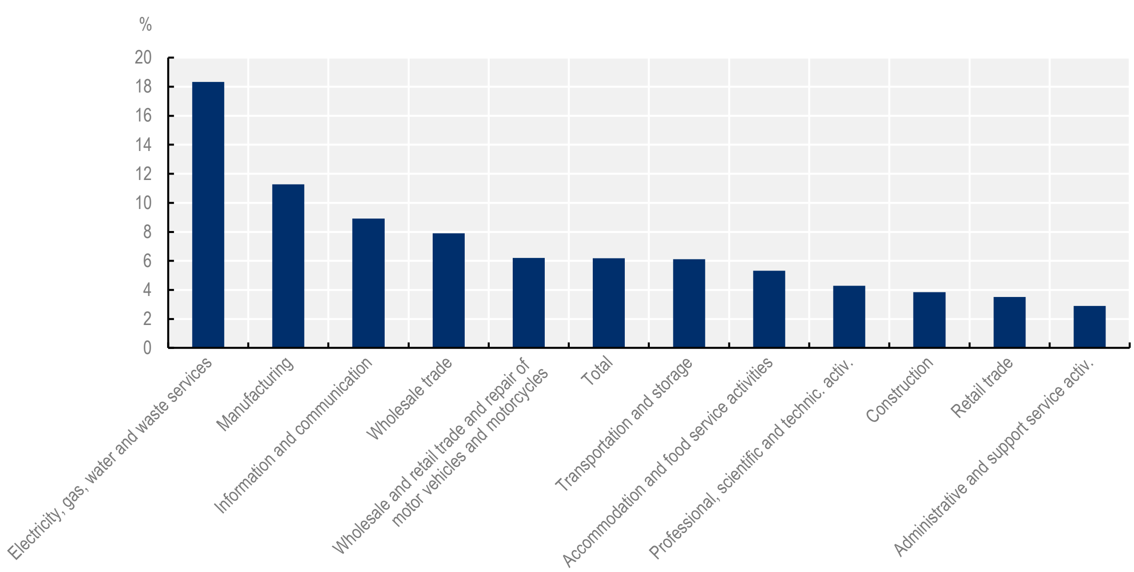
As a percentage of enterprises



Note: Data by industries and for the total include all enterprise sizes. Data refer to the 2019-20 reference period ending on 30 June 2020.
Source: Australian Bureau of Statistics (2021[1]), *Characteristics of Australian Business*, https://www.abs.gov.au/statistics/industry/technology-and-innovation/characteristics-australian-business/latest-release#use-of-information-and-communication-technologies-icts-.

Figure 2.5. Enterprises using the IoT in Israel, by industry, 2020

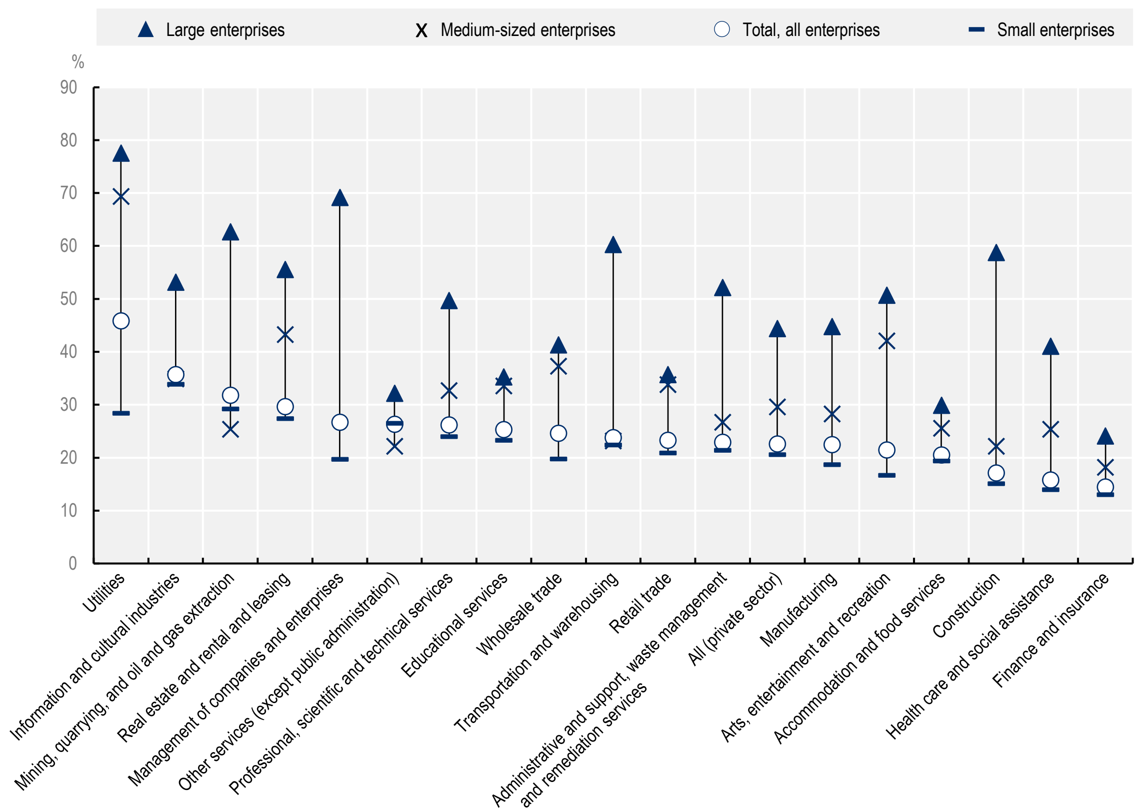
As a percentage of enterprises with ten or more employees



Source: Israel Central Bureau of Statistics, 2022.

Figure 2.6. Enterprises using the IoT in Canada, by industry and size, 2019

As a percentage of enterprises with five or more employees



Note: Large businesses have 100 or more employees except for Manufacturing (NAICS 31-33); medium-sized businesses have 20 to 99 employees except for Manufacturing (NAICS 31-33) and small businesses have 5 and 49 full-time employees. Utilities refer to industries providing electric power, natural gas, steam supply, water supply and sewage removal.
Sources: Based on Statistics Canada (2020[3]), *Survey of Digital Technology and Internet Use: Data Tables 2019*, https://www150.statcan.gc.ca/n1/daily-quotidien/210106/dq210106e-cansim-eng.htm; ad-hoc tabulations.

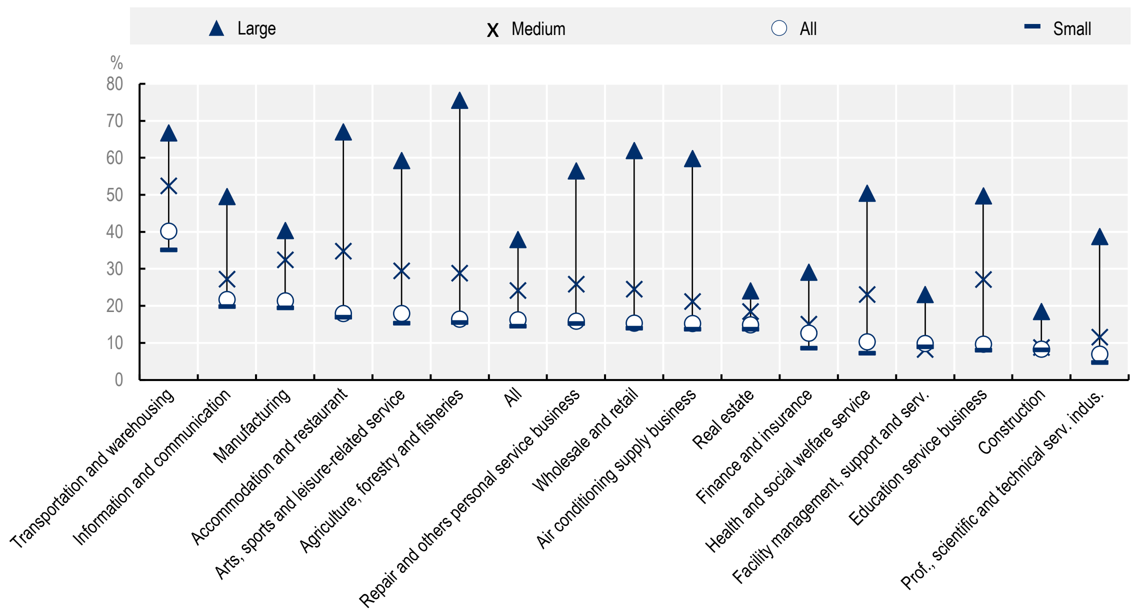
In Korea, the transport industry is by far the highest adopter of the IoT (40%) (Figure 2.7), while health facility management and construction industries display an average very low IoT adoption rate. Such figures, however, conceal differences among enterprises of different sizes. Overall, large firms have a much higher propensity to adopt the IoT than small and medium-sized firms. More than two large firms out of three use the IoT in the transport industry and in accommodation and restaurants, and more than three large firms out of four in agriculture.

Types of IoT devices used by Canadian firms

In Canada, small consumer market smart devices are by far the most used type of IoT device in all industries. In most industries, those devices are used by 16% to 20% of firms. In a few industries (energy, information and culture, mining and quarrying, and real estate), they are used by more than one firm out of four. More than 15% of utilities, mining and quarrying firms have industrial equipment with integrated Internet-connected smart devices and more than 10% of firms in the transport sector. Manufacturing firms show a relatively lower adoption at 7% (Figure 2.8).

Figure 2.7. Enterprises using the IoT in Korea, by industry and size, 2020

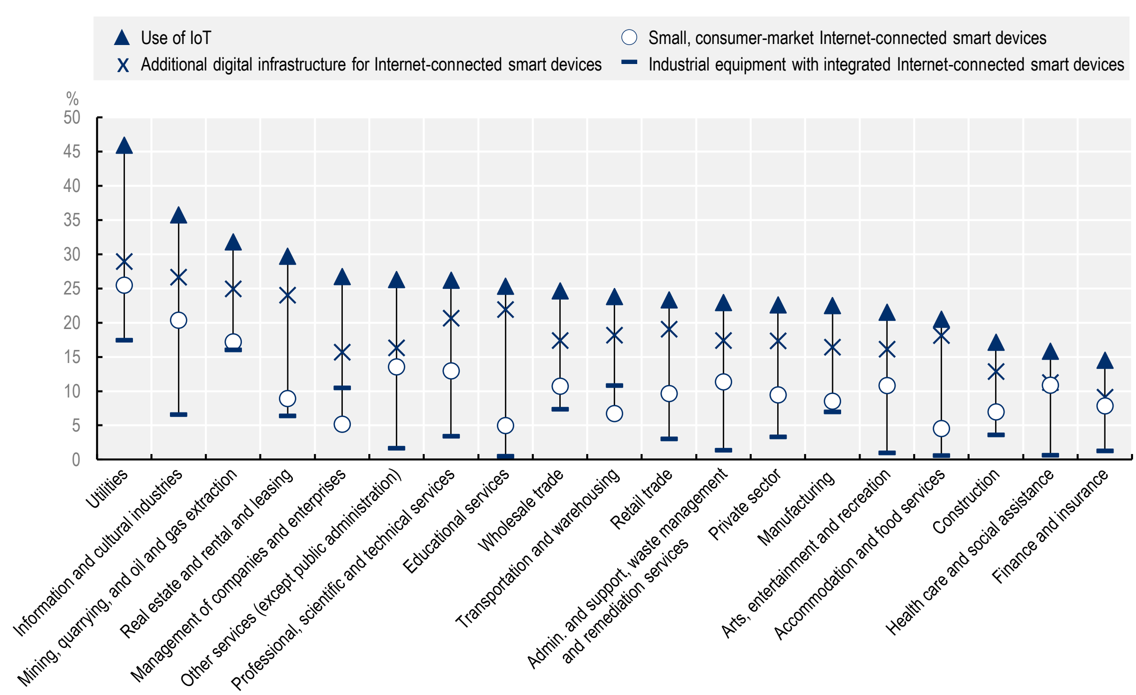
As a percentage of enterprises with ten or more employees



Source: NIA/Ministry of Science/ICT Korea (2022[4]), *2021 Yearbook of Information Society Statistics (in Korean)*, https://www.nia.or.kr/site/nia_kor/ex/bbs/View.do?cbIdx=62156&bcIdx=24143&parentSeq=24143.

Figure 2.8. Use of the IoT in Canada by industry and type of device, 2019

As a percentage of enterprises with five or more employees



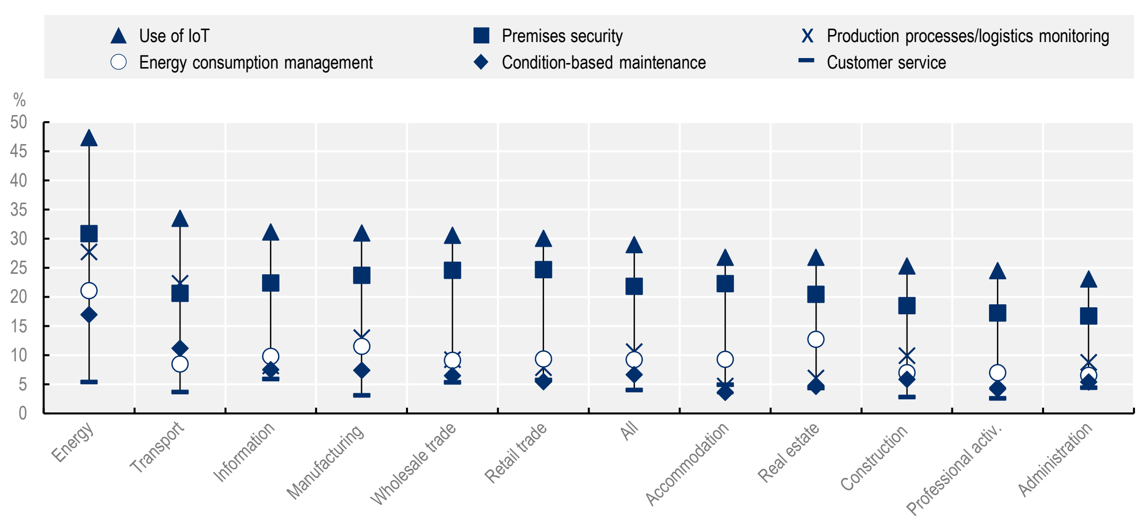
Sources: Based on Statistics Canada (2020[3]), *Survey of Digital Technology and Internet Use: Data Tables 2019*, https://www150.statcan.gc.ca/n1/daily-quotidien/210106/dq210106e-cansim-eng.htm; ad-hoc tabulations.

Types of IoT devices used by European countries

On average, European firms use the IoT mostly for premises security (21.8%) (Figure 2.9), monitoring production processes and logistics (10.6%), energy optimisation (9.2%) and, to a lesser extent, for condition-based maintenance (CBM, 7%) and to improve customer services (4%). CBM is a maintenance strategy that monitors the actual condition of an asset with sensors to decide what maintenance needs to be done, for example. CBM aims to monitor and spot upcoming equipment failure so that maintenance can be proactively scheduled when needed – and not before.[2] European firms in the energy industry use all types of IoT devices more frequently than those in other industries. Firms in the transport sector use more sensors for managing logistics, e.g. for tracking products and vehicles or for the maintenance of machines or vehicles, while energy and real estate firms use more smart devices, e.g. meters, lamps and thermostats, to optimise energy distribution and consumption.

Figure 2.9. Use of the IoT in selected European countries by industry and type of device, 2021

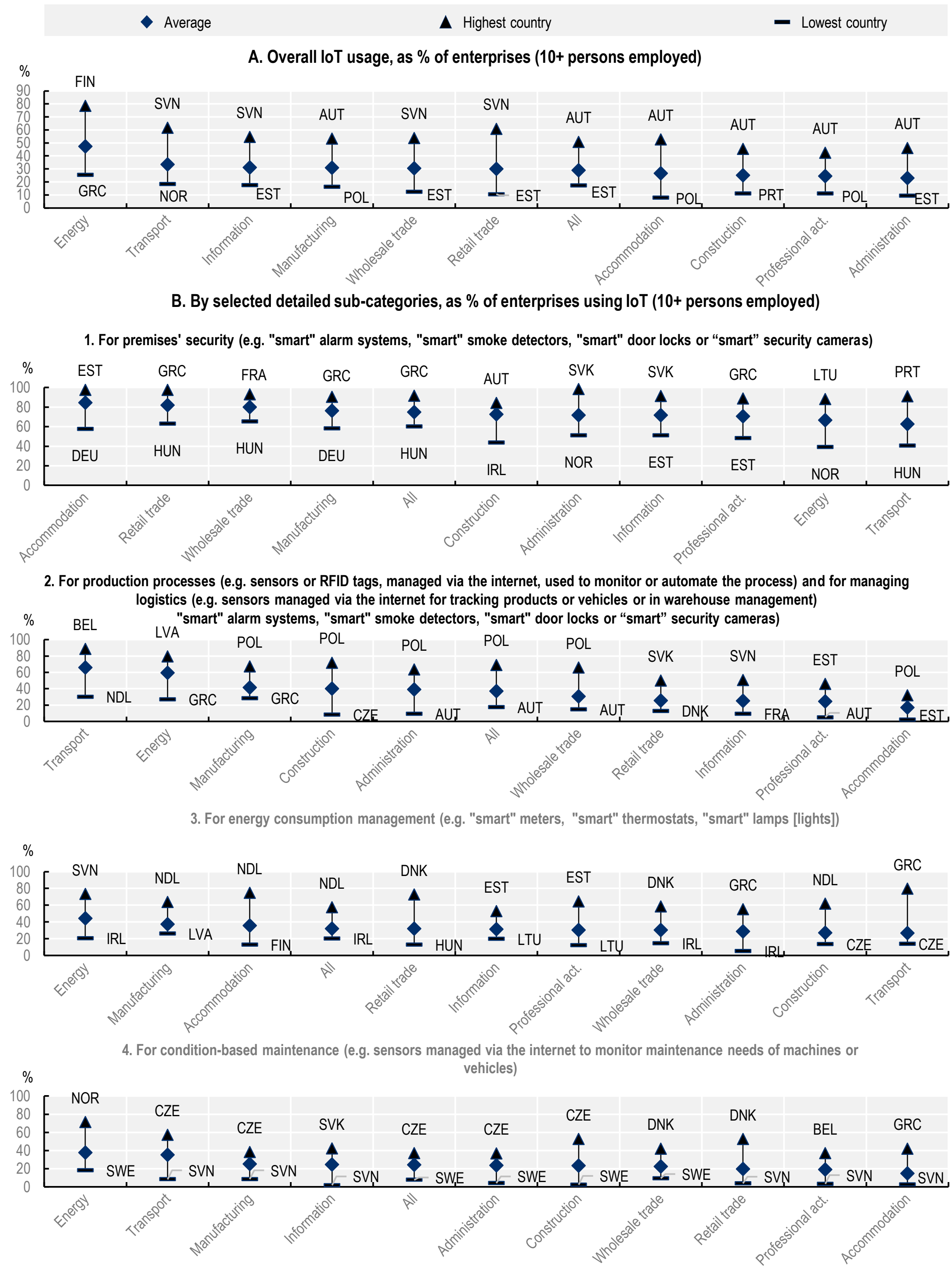
As a percentage of all enterprises with ten or more employees



Notes: Simple average of 23 European countries for which data are available, as shown in Figure 2.1.
Industries covered are the following: Energy = Electricity, gas, steam, air conditioning and water supply; Transport= Transportation and storage; Information = Information and communication; Manufacturing= Manufacturing; All = All industries (without financial sector); Wholesale Trade = Wholesale and retail trade; repair motor vehicles and motorcycles; Real estate = Real estate activities; Construction = Construction; Retail trade = Retail trade, except motor vehicles and motorcycles; Administration = Administrative and support service activities; Accommodation = Accommodation and food and beverage service activities; and Professional act. = Professional, scientific and technical activities.
Functions are described with the following examples of associated IoT devices: energy consumption management (e.g. smart meters, smart thermostats, smart lamps or lights); premises security (e.g. smart alarm systems, smart smoke detectors, smart door locks or smart security cameras); production processes (e.g. sensors or RFID tags, managed via the Internet, used to monitor or automate the process); managing logistics (e.g. sensors managed via the Internet for tracking products or vehicles or in warehouse management); and CBM (e.g. sensors managed via the Internet to monitor maintenance needs of machines or vehicles).
Source: Based on data from Eurostat (2022[2]), *Comprehensive Database*, https://ec.europa.eu/eurostat/web/digital-economy-and-society/data/comprehensive-database (accessed on 1 February 2022).

The following observations are based on more detailed data for each type of IoT device and associated functions in selected European countries (Figure 2.10).

Figure 2.10. Use of the IoT in selected European countries by industry and type of IoT device, 2021



Note: See note to Figure 2.9.
Source: Based on Eurostat (2022[2]), *Comprehensive Database*, https://ec.europa.eu/eurostat/web/digital-economy-and-society/data/comprehensive-database (accessed on 1 February 2022).

IoT devices for premises security

The share of European firms using smart devices for premises security, e.g. alarm systems, smoke detectors, door locks or security cameras, ranges from 63% in transport to 85% in accommodation, with an average of 75% for all industries. This share is particularly high for firms in manufacturing in the Czech Republic, France, Greece, Lithuania and the Slovak Republic (above 85%), in accommodation and food in Estonia, Luxembourg and Portugal, in retail in the Czech Republic, France and Greece and in transport in Portugal (all above 90%).

IoT devices to monitor or automate production processes or manage logistics

The share of European firms using IoT devices to monitor or automate production processes or for logistics, e.g. tracking products or vehicles or in warehouse management, ranges from 17% in accommodation and food to 66% in transport, with an average of 37% for all activities. Such devices are also frequently used by firms in the energy industry, with an average share of 60%. In some countries, the share is also particularly high in specific sectors: in Hungary and Poland for administrative and support services (63%), in Belgium, Denmark, Poland and Slovenia for transport (above 85%), in Hungary, Latvia, Lithuania, Poland and Sweden for energy (above 72%), in Poland for manufacturing (67%), construction (72%) or wholesale and retail (66%) and in Sweden for construction (60%).

IoT devices to optimise energy

The share of European firms using smart devices to optimise energy distribution and consumption (e.g. meters, lamps, thermostats) ranges from 27% in transport to 44% in energy, with an average of 32% for all industries. This share is particularly high in transport in Greece (80%), accommodation and food in the Netherlands (75%) and retail in Denmark (73%).

IoT devices to track movement or offer CBM

In 2021, nearly 24% of European firms used sensors to monitor the maintenance needs of machines or vehicles. This share ranges from 15% in accommodation and food to 38% in energy. The share is particularly high in energy in Estonia (66%) and transport in the Czech Republic (57%).

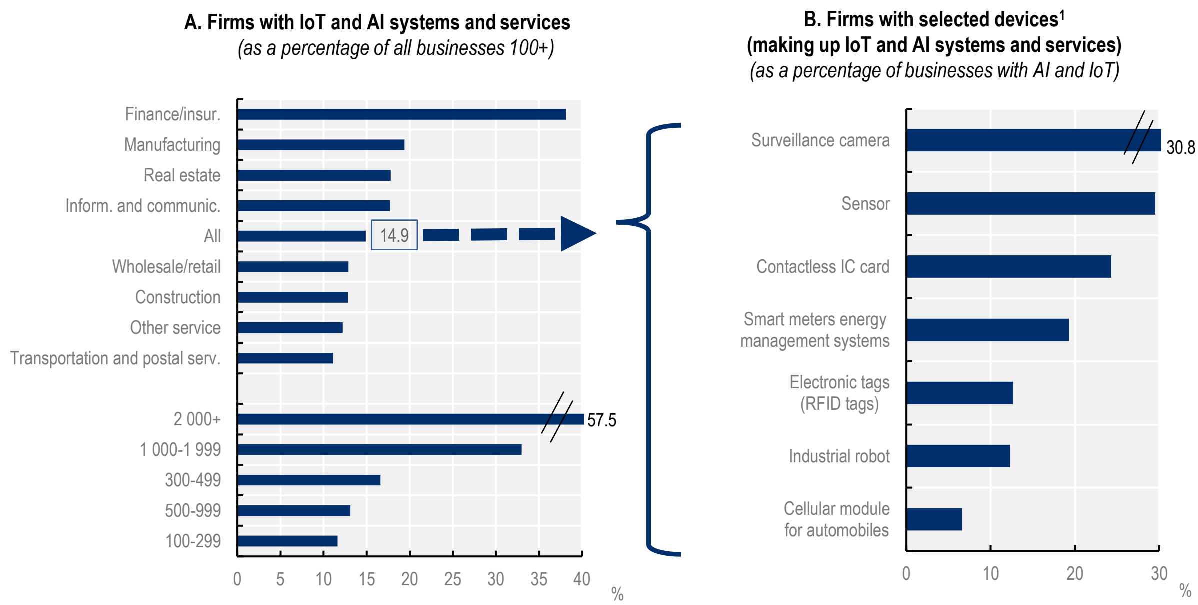
Why are businesses using IoT devices? Insights from the Canadian survey

In Canada, firms are using IoT devices for various reasons: improvement of the work environment, productivity gains, cost savings, decision making, cybersecurity, etc. Overall, improvement of the work environment is the reason most frequently mentioned, followed by productivity gains and cost savings. Industries such as utilities or mining also mention improvement of the work environment and productivity gains as the main reasons for adoption. The reasons for using IoT devices not only depend on the industry but also on the size of companies. Among large firms, productivity gains and improvement of the work environment are the reasons most frequently mentioned, whereas small firms rank improvement of the work environment first, at a much higher level before productivity gains (Annex Table 2.A.3).

Adoption of the IoT by firms in Japan

In Japan, the introduction of IoT and AI systems and services within businesses are not measured separately from each other. In 2021, around 15% of businesses had adopted IoT and AI systems, primarily very large firms (over 1 000 employees) and firms with activities in the finance and insurance industries, as well as in the manufacturing, real estate, and the information and communication industries. Among businesses adopting AI and the IoT, the diffusion rate of devices ranges from more than 30% for surveillance cameras to less than 7% for cellular modules for automobiles. Moreover, they are not evenly spread across industries (Figure 2.11). Surveillance cameras, for example, are used mainly in the construction and real estate industries. Sensors and industrial robots are used mainly in the manufacturing industries. Contactless integrated circuit (IC) cards are used mainly in the information and communication and real estate industries. Smart meters are used primarily in the wholesale and manufacturing industries but also in the construction industries, while cellular modules for automobiles are heavily concentrated in the transport industry.

Figure 2.11. AI and IoT diffusion and selected associated devices in businesses in Japan, 2021



1. Physical security equipment and optical character recognition are not reported in the figure.
Source: Compiled from Japanese Ministry of Internal Affairs and Communications (2022[5]), *Communication Usage Trend Survey 2021*, https://www.soumu.go.jp/johotsusintokei/statistics/statistics05.html.

Complementarity between the IoT and other digital technologies

IoT devices are now diffused in all parts of the economy but their diffusion varies according to a few key factors: the size of the firm, the industry, the type of business functions in which the devices are integrated and the diffusion of other advanced technologies in the firm. IoT usage is generally integrated within business functions but can also be coupled more broadly with complementary technologies, whose combination significantly increases the strategic interest of the firm.

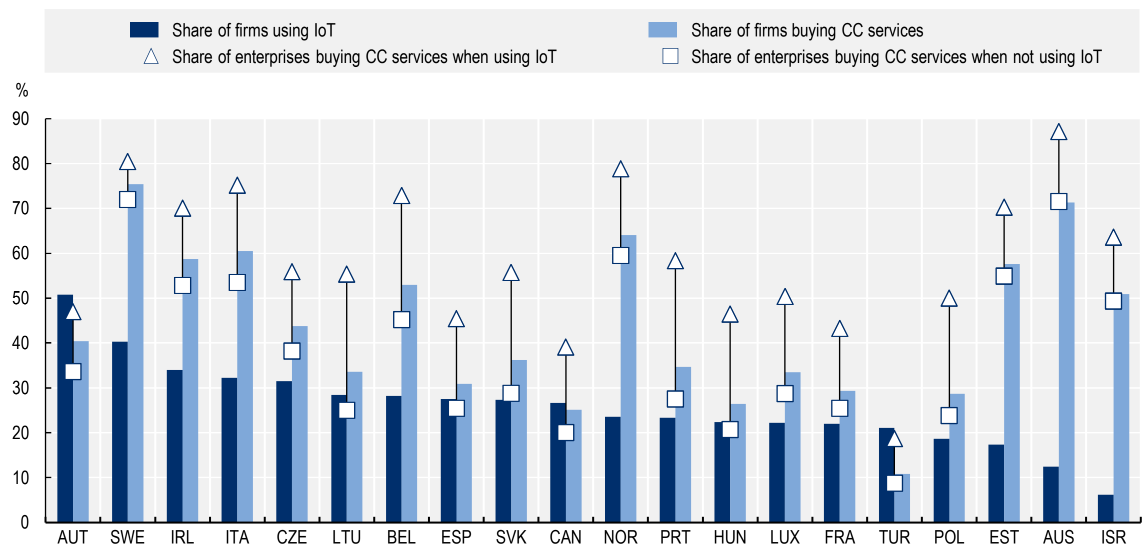
This section looks at the extent to which the IoT is complementary to technologies such as CC or BDA. The diffusion of IoT devices within firms generates an increasing amount of data, which needs to be treated through analytical tools (BDA); CC, with the associated infrastructures and storage solutions, also provides a useful complementary asset.

IoT and CC services

Considering the adoption of IoT and CC services separately, data show that, in 2021, enterprises have a significantly higher propensity to buy CC services than to adopt the IoT in all countries but Austria, Canada and the Republic of Türkiye (hereafter Türkiye) (Figure 2.12). However, without exception, firms using the IoT have a much higher propensity to buy CC services compared to firms not adopting the IoT. The average gap between the former and the latter is at least 8 percentage points in Sweden and above 10 percentage points in all countries. In 6 countries, the gap is above 25 percentage points and, in Lithuania and Portugal, above 30 percentage points. Enterprises buy CC services more than twice as often when using IoT devices in Hungary, Lithuania, Poland, Portugal and Türkiye. Overall, IoT and CC services display a significant complementarity.

Figure 2.12. Joint use of the IoT and CC by firms, selected OECD countries, 2021

As a percentage of all enterprises with ten or more employees



Note: Countries are ranked by decreasing order of the share of enterprises using the IoT. For Canada, data relate to 2019 and for Israel to 2020. For Australia, data relate to the 2019/20 fiscal year.
Source: Based on ad-hoc tabulations provided by Statistics Austria, Statistics Canada, Israel Central Bureau of Statistics and Eurostat (2022).

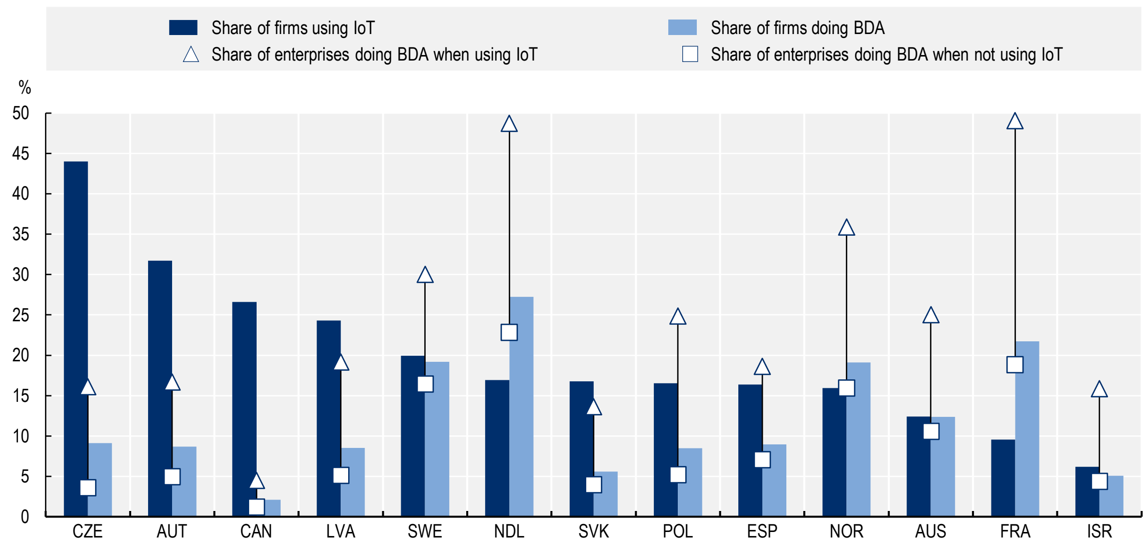
IoT and BDA

The share of enterprises performing BDA is significantly lower than those using IoT devices in most countries, whereas in Australia and Sweden, the adoption rates of these two technologies are very similar (Figure 2.13). By contrast, in France, the Netherlands and Norway, more enterprises perform BDA than use the IoT. As observed for CC services, those enterprises using the IoT have a higher propensity to perform BDA compared to firms which do not use the IoT. The average gap between the former and the latter varies across countries. In Canada, the gap is very small; in this country, performing BDA among small or medium-sized enterprises is rare (1% and 4.5% respectively). However, the gap is significant among large Canadian firms: 30% of those using the IoT perform BDA, while only 12% of those not using the IoT do so (not shown in the figure). In a majority of countries, the gap ranges between 10 and 15 percentage points. In 4 countries, the gap is even larger, reaching 20 percentage points in Norway and Poland, 26 in the Netherlands and more than 30 in France. The gap generally increases with the firm's size.

IoT adoption is associated with a higher propensity to perform BDA in all industries, although this effect varies greatly across countries and industries. It is very large in most industries in France, where more than 1 enterprise out of 5 performs BDA, but relatively small in Canada, where on average, only 2% of the firms perform BDA. The effect in the 13 countries observed is comparatively more significant in industries such as information and communication, energy, manufacturing, transport or retail. Overall, for a given industry, the higher the share of firms performing BDA, the higher the frequency of association BDA-IoT, and the lower the share of firms performing the IoT without BDA (Annex Figure 2.A.1).

Figure 2.13. Joint use of the IoT and BDA by firms, selected OECD countries, 2021

As a percentage of all enterprises with ten or more employees



Note: Countries are ranked by decreasing order of the share of enterprises using the IoT. For Canada, data relate to 2019 and for Israel to 2020. For Australia, data relate to the 2019/20 fiscal year.
Source: Based on ad-hoc tabulations provided by Statistics Austria, Statistics Canada, Statistics Sweden, and INSEE (France).

IoT use in households and by individuals: The measurement framework

Official household and individual survey questionnaires ask about IoT uptake using different approaches, as summarised in Table 2.2. They generally do not use the expression Internet of Things (see Annex 2.A for details on the approach by country) but rather include an introductory sentence describing the devices. The questionnaires inquire about IoT use in the following broad domains: household equipment or appliances, wearables, cars and health.

Table 2.2. Measurement of IoT use by households and individuals, an overview

	Canada	Eurostat	Korea	United States
Interaction with household equipment/appliances		2019		2015, 2017, 2019, 2021
Use of smart home appliances/devices				
Group of items (e.g. robot vacuums, fridges, ovens)	2018, 2020	2020, 2022	2019-20	
Group of items by function (e.g. energy management, security, safety)		2020, 2022		
Detailed items	2018, 2020			
Use of smart TV/Internet-connected TV	2018, 2020	2020, 2022	2016-20	2015, 2017, 2019, 2021[1]
Use of speakers	2018, 2020			
Smart speakers	2018, 2020			
AI speakers			2018-20	
Internet-connected home audio systems, smart speakers		2020, 2022		
Use of wearable devices				
Group of items (e.g. watches, glasses)	2020	2020, 2022	2016-20	2015, 2017, 2019, 2021

	Canada	Eurostat	Korea	United States
Detailed list of items			2016-18	
Functions used			2016-20	
Use of car-related IoT			2016-20	
A car with a built-in wireless Internet connection		2020, 2022		
Connected vehicle devices	2020			
Use of health-related IoT	2020[2]	2020, 2022	2016-20[3]	2015, 2017 (H), 2019 (H), 2021 (H)
Use of AI				
A virtual assistant in the form of a smart speaker or of an application (app), such as Amazon Alexa/Echo/Computer, Bixby, Cortana, Google Assistant, Google Home, Siri		2020, 2022		
AI voice recognition services			2019-20	
Use of other devices[4]		2020, 2022		
Reasons for not using:				
Smart home devices	2020			
Interconnected devices or systems		2020, 2022		
Problems encountered when using Internet-connected devices or systems		2022		
Security and/or privacy concerns	2020	2022		
With smart speakers	2020			
With Internet-connected wearable smart devices	2020			

Notes: For IoT devices details by country, see Annex Table 2.A.4. Questions asked at the household level are flagged with (H).
1. Included with games, video systems or other devices that connect to the Internet and play through a TV.
2. Included with wearables (and listed in the examples).
3. Question included within the functions used (see previous line).
4. Includes toys, game consoles, home audio and smart speakers.
Source: Compiled from various official survey questionnaires.

Household equipment or appliances can be split according to several possible dimensions. They are measured:

1. As a group of items without further specification (e.g. fridges, coffee machines, ovens, robot vacuums) in Canada, Korea and European countries.
2. As a group of items according to specific functions in the house, e.g. energy or security management in European countries or the United States.
3. As a group of detailed items (e.g. cameras, smart doors or window locks, smart plugs and lights, smart thermostats) in Canada.
4. With separate entries for smart TV and smart speakers. The latter can be associated with AI (in Korea). AI is also measured separately in questions related to virtual assistants (in European countries) or voice recognition services (in Korea).

Household equipment or appliances are also measured through indicators aggregating various groups of IoT devices. Eurostat provides aggregates for two distinct groups: i) a group of devices or systems for energy management, security/safety management, Internet-connected appliances and virtual assistants, which relates, therefore, to **home automation**; ii) a group including Internet-connected TV, game consoles, home audio systems and smart speakers, which therefore relates to **home entertainment** items. Canada, in contrast, aggregates under one only group ("Smart home devices used in primary residence") a mix of IoT devices that could belong either to the domain of home automation (e.g. video cameras connected to the Internet, smart doors or window locks, smart thermostats, smart switches or lights, smart large appliances) or to home entertainment (e.g. smart speakers, smart TVs). The diversity of measurement approaches described reflects the several dimensions of IoT uses in everyday life at home, as they cover several entertainment and automation areas and perform different functions and processes.

Wearables form a distinct, fairly well-defined cluster and are measured as a group (in Canada, European countries or the United States), with several examples of applications or detailed items (in Korea). The Korean questionnaire surveys these devices in detail, with focused questions on selected wearables (e.g. watch type, band type, safety tracker for children, glasses) and the functions for which they are used (e.g. making/receiving text messages or phone calls via smartphone connection, managing health such as heart rate and calorie tracking, tracking trips and distances, enjoying virtual and augmented reality).

The wearables category partially overlaps with the one on **health**, a domain where IoT devices are also diffusing. Canada and Korea include questions on health monitoring within the item on wearables, whereas Eurostat's survey has a specific question on health-related Internet-connected devices, and so does the United States (in this country, the question concerns use within the household, not by the individual).

The IoT in **cars** is measured through questions related to connected vehicle devices (Canada) or cars with built-in wireless Internet connections (European countries).

Finally, Canada and European countries also ask questions about security and/or privacy concerns and problems encountered when using the devices. Both countries also enquire about the reasons for not using Internet-connected devices or systems (Eurostat) or smart home devices (Canada).

IoT use in households and by individuals: Results

Introduction

An increasing number of "things" embed Internet connectivity and are able to perform functions which touch upon multiple and varied aspects of individuals' everyday lives. This section offers a review of results from these surveys using two approaches. The first part is organised around the domains of use, providing a comparative overview across countries of adoption of selected devices. Two levels are considered: first, the two large categories of home automation and home entertainment IoT devices; and second, a focus on home appliances, smart TVs, wearables and health-related IoT devices. It is important to remember that, except for smart TVs, questions do not include identical lists of goods in the different surveys. For example, home appliances relate to slightly different goods (and/or associated illustrating examples) in the Canada, Eurostat and United States surveys. The second part provides detailed results for selected OECD countries. Finally, the last section discusses the demand-side factors hindering IoT use by individuals in their everyday life, based on available survey results.

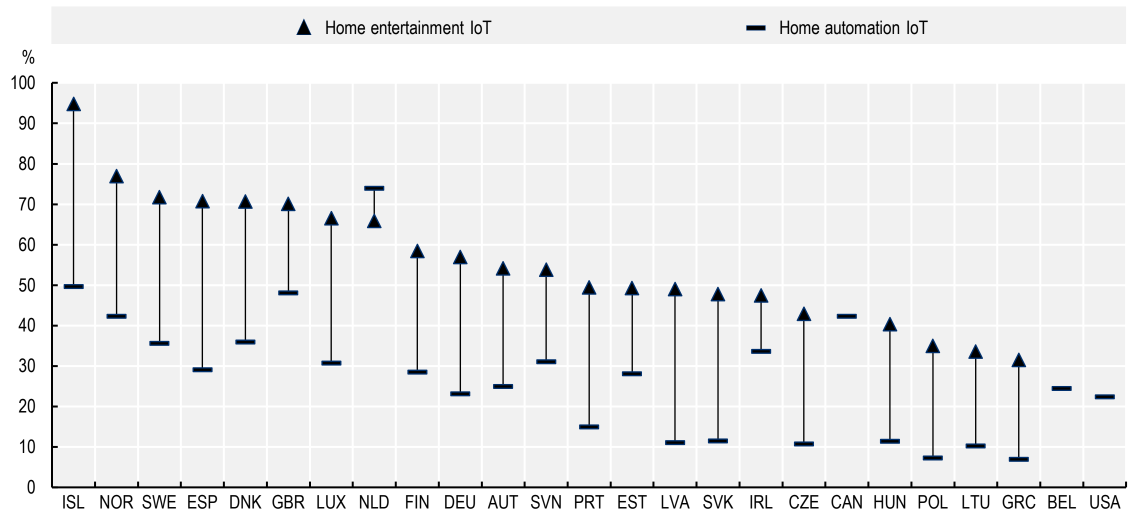
Focus on the devices and their functions

Home automation and home entertainment IoT devices

Eurostat divides IoT devices into two main groups: devices or systems for energy management, security/safety management, Internet-connected appliances and virtual assistants, namely home automation IoT devices; and Internet-connected TVs, game consoles, home audio systems and smart speakers, namely home entertainment IoT devices. Canada and the United States also survey the use of home automation devices. Overall, individuals use home entertainment IoT devices (e.g. smart TVs) much more than home automation IoT devices (Figure 2.14). For both groups, there is a large disparity between countries.

Figure 2.14. Individuals using Internet-connected devices or systems (IoT) for private purposes in selected OECD countries, 2021 or latest available year

As a percentage of all individuals



Note: Data refer to 2021 for the United States and 2020 for the other countries. Individuals aged 3+ in the United States, 15+ in Canada and 16 to 74 in European countries. Home entertainment IoT relates to Internet-connected TVs, game consoles, home audio systems and smart speakers, and data are unavailable for Belgium, Canada and the United States. Home automation IoT relates to the following Internet-connected devices or systems for private purposes: devices or systems for energy management, security/safety management, Internet-connected appliances and virtual assistants. For Canada, home automation IoT relates to smart home devices used in the primary residence and include devices such as smart speakers, video cameras connected to the Internet, smart doors or window locks, smart thermostats, smart switches or lights, smart large appliances, smart TVs, etc. For the United States, home automation IoT relates to household equipment or appliances that are connected to the Internet, such as connected thermostats, light bulbs or security systems.
Sources: Based on Eurostat (2022[2]), *Comprehensive Database*, https://ec.europa.eu/eurostat/web/digital-economy-and-society/data/comprehensive-database (accessed on 1 February 2022); Statistics Canada (2020[3]), *Survey of Digital Technology and Internet Use: Data Tables 2019*, https://www150.statcan.gc.ca/n1/daily-quotidien/210106/dq210106e-cansim-eng.htm; and NTIA (2022[6]), *Digital Nation Data Explorer*, https://www.ntia.gov/data/explorer#sel=internetUser&disp=map (accessed on 20 May 2022).

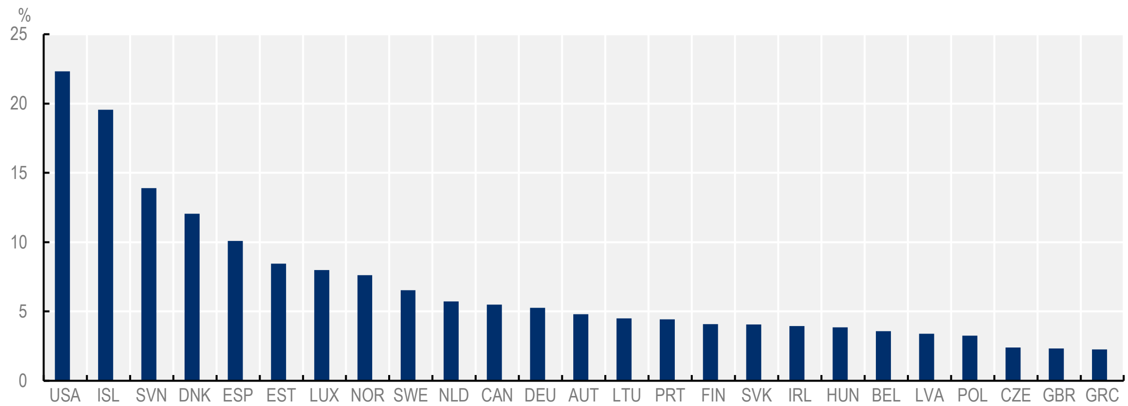
Home appliances

Comparing the use of IoT home appliances across countries is not entirely straightforward, given the differences in surveys of the examples or groups of items given to respondents. In most OECD countries, less than 10% of individuals use Internet-connect home appliances, except in Iceland, Slovenia and the United States. In Korea, data relate to the percentage of households (not individuals) and are therefore not comparable with the above countries. In 2020, 9.9% of households in Korea owned smart home appliances.

Combining the advantages of an Internet connexion with the convenience of a TV set, smart TVs had in 2020 a fairly high level of uptake by individuals. It ranged from 30% in Greece to about 85% in Iceland. It was above 50% in Germany, Luxembourg, the Netherlands, the Nordic countries, Spain and the United Kingdom (Figure 2.16).

Figure 2.15. Diffusion of Internet-connected home appliances in selected OECD countries, 2021 or latest available year

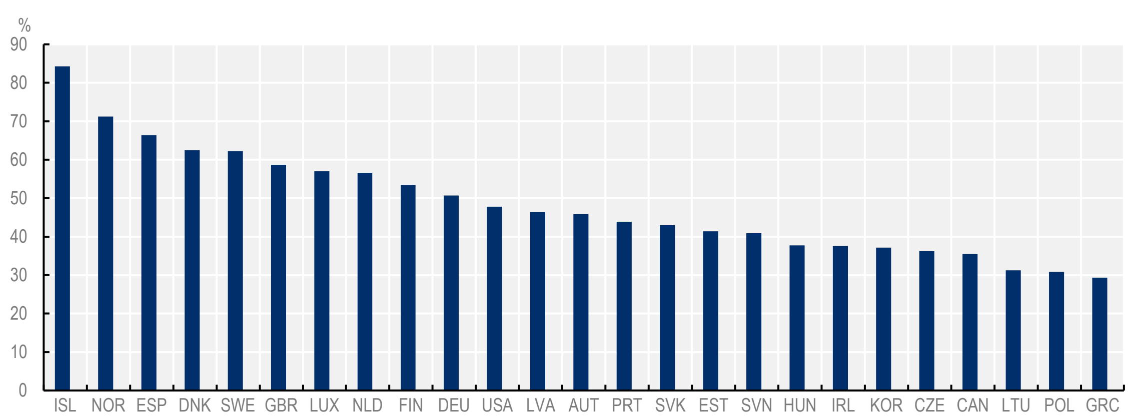
As a percentage of all individuals



Note: Individuals aged 3+ in the United States, 15+ in Canada, and 16 to 74 in European countries. For Canada, data refer to smart appliances (e.g. fridges, stoves, dishwashers, coffee makers and toasters). For the United States, data refer to 2021 and to household equipment or appliances that are connected to the Internet, such as connected thermostats, light bulbs or security systems. For the other countries, data refer to 2020 and to Internet-connected home appliances such as robot vacuums, fridges, ovens and coffee machines.
Sources: Based on Eurostat (2022[2]), *Comprehensive Database*, https://ec.europa.eu/eurostat/web/digital-economy-and-society/data/comprehensive-database (accessed on 1 February 2022); Statistics Canada (2020[3]), *Survey of Digital Technology and Internet Use: Data Tables 2019*, https://www150.statcan.gc.ca/n1/daily-quotidien/210106/dq210106e-cansim-eng.htm; and NTIA (2022[6]), *Digital Nation Data Explorer*, https://www.ntia.gov/data/explorer#sel=internetUser&disp=map (accessed on 20 May 2022).

Figure 2.16. Use of smart TV in selected OECD countries, 2021 or latest available year

As a percentage of all individuals



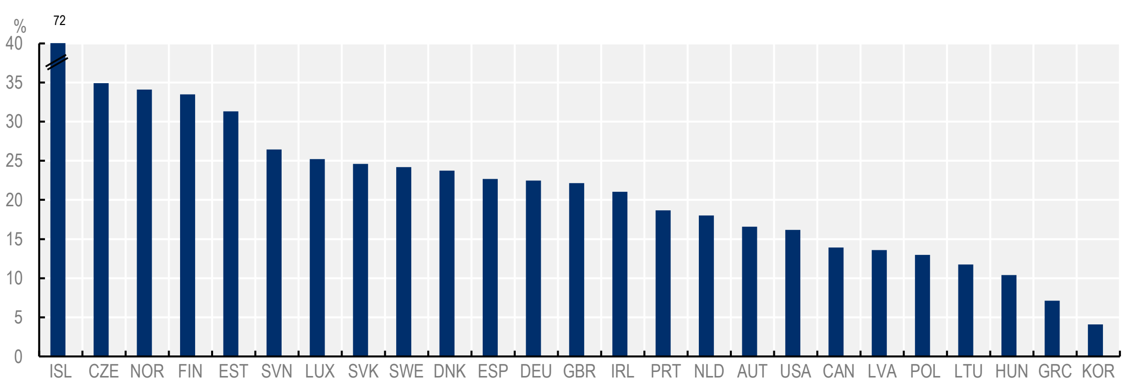
Note: Individuals aged 3+ in the United States, 15+ in Canada, and 16 to 74 in European countries. Data for the United States refer to 2021 and to 2020 for the other countries. For Canada, Korea and the United States, data relate to smart TVs and for the other countries to Internet-connected TVs. For Korea, data are expressed as a percentage of all households having a smart TV to access the Internet.
Sources: Based on Eurostat (2022[2]), *Comprehensive Database*, https://ec.europa.eu/eurostat/web/digital-economy-and-society/data/comprehensive-database (accessed on 1 February 2022); Statistics Canada (2020[3]), *Survey of Digital Technology and Internet Use: Data Tables 2019*, https://www150.statcan.gc.ca/n1/daily-quotidien/210106/dq210106e-cansim-eng.htm; NTIA (2022[6]), *Digital Nation Data Explorer*, https://www.ntia.gov/data/explorer#sel=internetUser&disp=map (accessed on 20 May 2022); and NIA/Ministry of Science/ICT Korea (2022[4]), *2021 Yearbook of Information Society Statistics (in Korean)*, https://www.nia.or.kr/site/nia_kor/ex/bbs/View.do?cbIdx=62156&bcIdx=24143&parentSeq=24143.

Wearables

The adoption rate of wearables is highly variable (Figure 2.17), ranging from less than 4% in Korea to 72% in Iceland, although differences in surveys limit comparability. The rate is the highest (about 25% or above) in the Czech Republic, Estonia, Luxembourg, the Nordic countries, the Slovak Republic and Slovenia. The low rate observed in Korea may be due to the type of question raised, which asks about ownership rather than use (see note to Figure 2.17).

Figure 2.17. Use of wearables devices connected to the Internet by individuals in selected OECD countries, 2021 or latest available year

As a percentage of all individuals



Note: For Canada, the question refers to Internet-connected wearable smart devices and includes examples such as smartwatches, Fitbit or glucose monitoring devices. In the United States, the question refers to a "wearable device that is connected to the Internet, such as a smartwatch or fitness band. Examples include an Apple Watch or Fitbit". For European countries, Norway and the United Kingdom, wearables refer to a group of Internet-connected devices, including "a smart watch, a fitness band, connected goggles or headsets, safety-trackers, Internet-connected accessories, Internet-connected clothes or shoes". For Korea, the question refers to ownership of portable ICT devices, one of the items proposed being "Wearable device (watch/band type, children and elderly device, [virtual reality/augmented reality] VR/AR device)". Individuals aged 3+ in the United States, 6+ in Korea, 15+ in Canada and 16 to 74 in the other countries. Data for the United States refer to 2021. Data for the European countries refer to 2020.

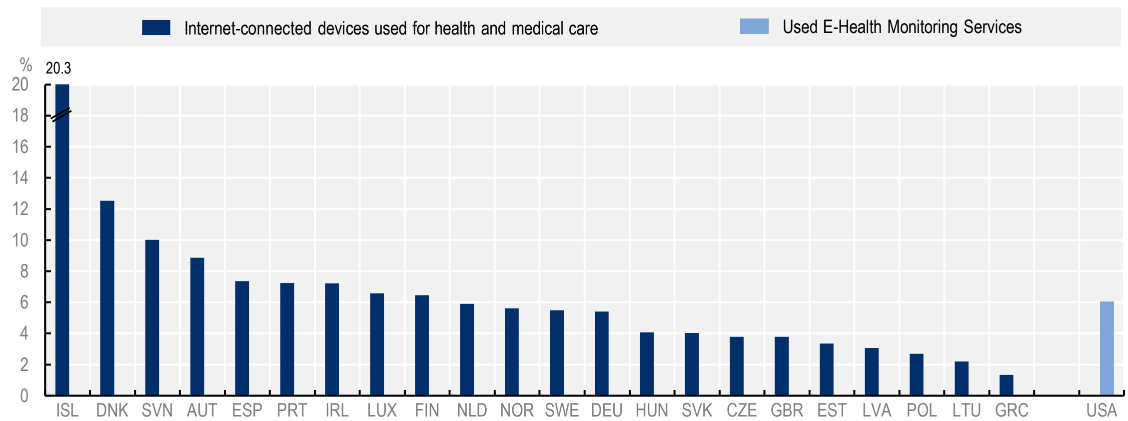
Sources: Based on Eurostat (2022[2]), *Comprehensive Database*, https://ec.europa.eu/eurostat/web/digital-economy-and-society/data/comprehensive-database (accessed on 1 February 2022); Statistics Canada (2020[3]), *Survey of Digital Technology and Internet Use: Data Tables 2019*, https://www150.statcan.gc.ca/n1/daily-quotidien/210106/dq210106e-cansim-eng.htm; NTIA (2022[6]), *Digital Nation Data Explorer*, https://www.ntia.gov/data/explorer#sel=internetUser&disp=map (accessed on 20 May 2022); and NIA/Ministry of Science/ICT Korea (2022[4]), *2021 Yearbook of Information Society Statistics (in Korean)*, https://www.nia.or.kr/site/nia_kor/ex/bbs/View.do?cbIdx=62156&bcIdx=24143&parentSeq=24143.

Health-related IoT devices

The uptake of health-related IoT devices is still relatively low among individuals. In the European Union, several initiatives have been recently taken to foster the development of an IoT ecosystem closely linked to the healthcare sector.[3] The share of Internet-connected devices used for health and medical care by Internet users ranged in 2020 from 1.3% in Greece to 20.3% in Iceland (Figure 2.18). In the United States, 8.7% of Internet-using households used e-health monitoring services in 2021, up from 4.3% in 2017. This share is likely to have been influenced by the growth of telehealth usage during the COVID-19 pandemic.[4] In Korea, around 4.1% of the population owned wearable devices in 2020 and close to 60% of those owners used them frequently for managing health (e.g. heart rate and calorie tracking). Nearly 13% of Korean households are using IoT services at home. In Canada, in 2020, 1 individual out of 4 aged 15 and older had tracked fitness or health on line; this share was 35% among those aged 25-34.

Figure 2.18. Uptake of health-related IoT devices or services in selected OECD countries, 2021 or latest available year

As a percentage of Internet users



Note: Data for the United States relate to 2021 and are expressed as a percentage of Internet-using households. Data for the European countries relate to 2020 and are expressed as a percentage of Internet users aged 16 to 74.
Sources: Based on Eurostat (2022[2]), *Comprehensive Database*, https://ec.europa.eu/eurostat/web/digital-economy-and-society/data/comprehensive-database (accessed on 1 February 2022); NTIA (2022[6]), *Digital Nation Data Explorer*, https://www.ntia.gov/data/explorer#sel=internetUser&disp=map (accessed on 20 May 2022); ad-hoc tabulation.

Focus on diffusion by countries

Eurostat

IoT devices are currently diffusing more rapidly in the living room than in the kitchen. Looking more closely at each component of those groups reveals the following patterns:[5]

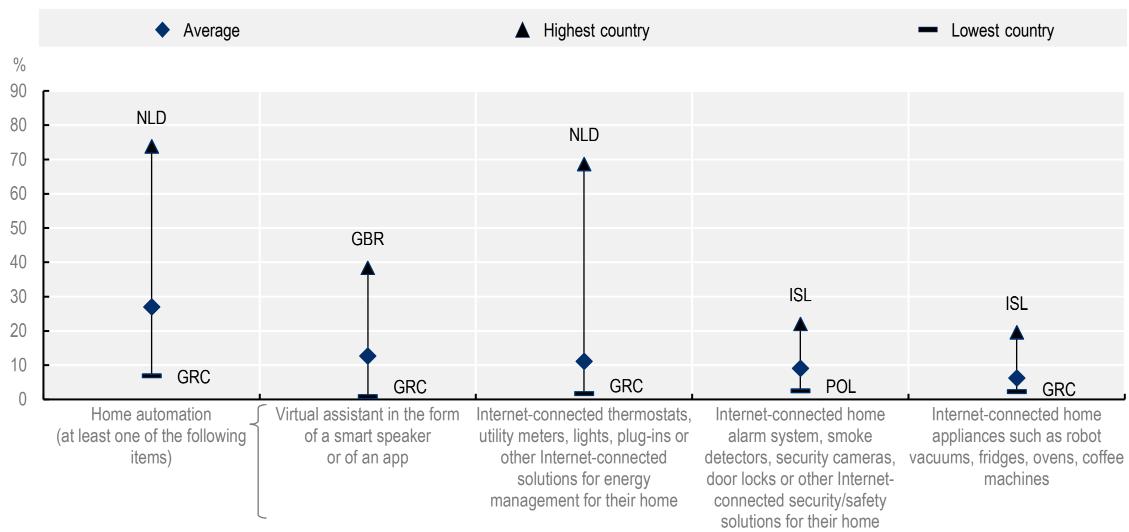
- Virtual assistants are the most used IoT devices within "home automation", followed by IoT devices for energy management or security/safety purposes. Home appliances are much less diffused (Figure 2.19), possibly due to a lower level of perceived utility or the limited supply of attractive solutions on the market.
- Smart TVs are used on average by one individual out of two in European countries, Internet-connected game consoles, home audio systems and smart speakers by one individual out of five (Figure 2.20). The diffusion of each of these devices varies greatly from country to country: they are relatively scarce in Greece but almost universal in Iceland.

Korea

In Korea, close to one household out of two owns a smart TV, while other IoT goods and services are only at an early stage of diffusion (Figure 2.21). Nevertheless, individuals are increasingly using AI voice recognition services. In 2021, 31% of the individuals (aged 6+) were using an AI voice recognition service, up from 25% in 2019. Around four out of ten individuals aged between 20 and 40 were using such a service, and nearly one out of ten among individuals aged 60 or older.

Figure 2.19. Diffusion of home automation IoT in selected European countries, 2020

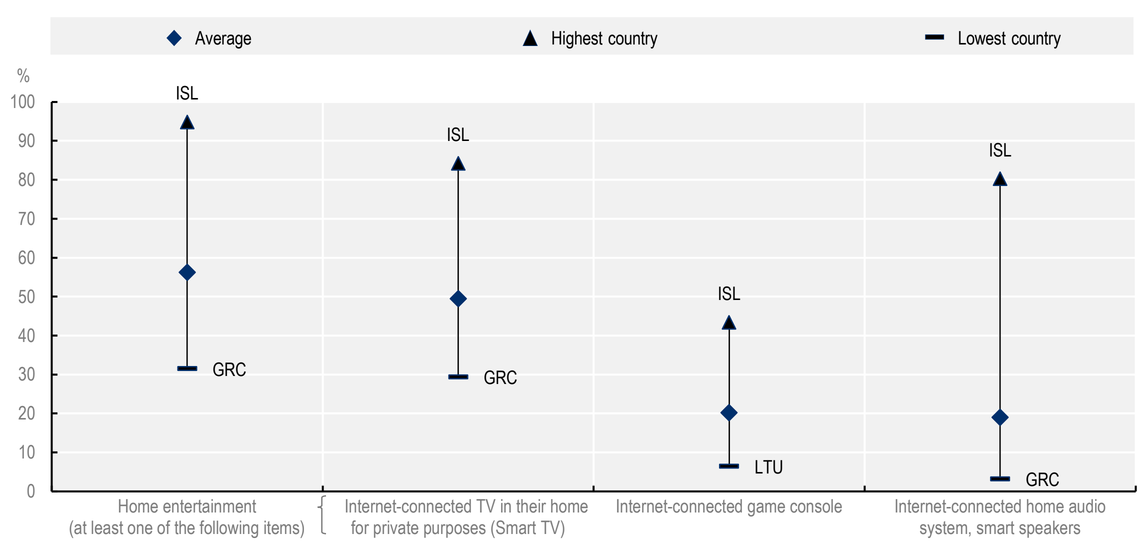
As a percentage of all individuals



Note: Home automation IoT includes the following items: a virtual assistant in the form of a smart speaker or an app; Internet-connected thermostats, utility meters, lights, plug-ins or other Internet-connected solutions for energy management for their home; Internet-connected home alarm system, smoke detectors, security cameras, door locks or other Internet-connected security/safety solutions for the home; and Internet-connected home appliances such as robot vacuums, fridges, ovens, coffee machines. Simple average of the 23 European countries for which data are available, as shown in Figure 2.12.
Source: Eurostat (2022[2]), *Comprehensive Database*, https://ec.europa.eu/eurostat/web/digital-economy-and-society/data/comprehensive-database (accessed on 1 February 2022).

Figure 2.20. Diffusion of home entertainment IoT in selected European countries, 2020

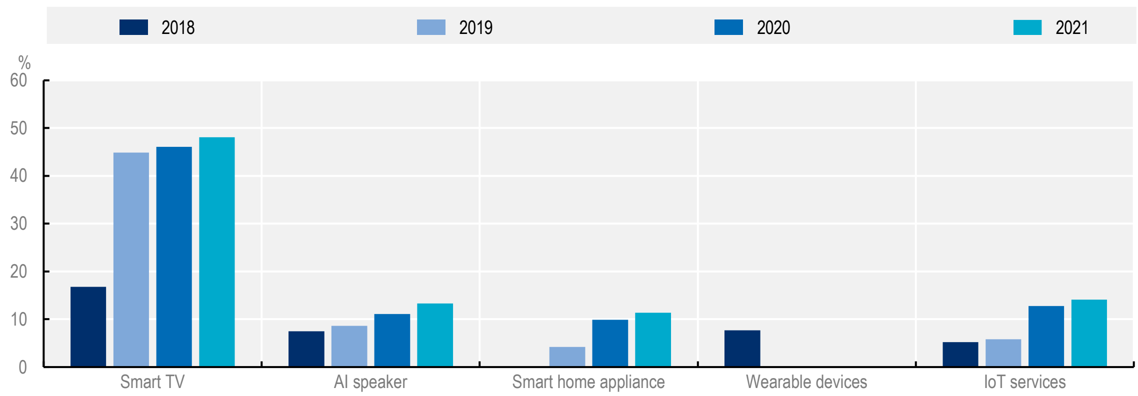
As a percentage of all individuals



Note: Use of the Internet on one of the following home entertainment items: an Internet-connected TV, game console, home audio system and smart speakers. Simple average of the 23 European countries for which data are available, as shown in Figure 2.12.
Source: Eurostat (2022[2]), *Comprehensive Database*, https://ec.europa.eu/eurostat/web/digital-economy-and-society/data/comprehensive-database (accessed on 1 February 2022).

Figure 2.21. Uptake of selected IoT goods and services in Korea

As a percentage of households



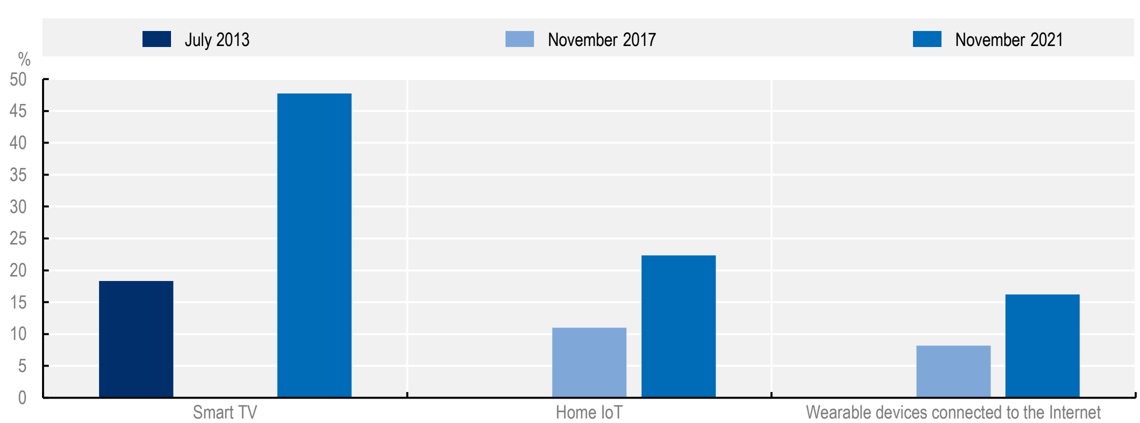
Note: IoT services include the use of remote-control functions for closed-circuit television (CCTV), lighting, gas, cooling and heating, etc., LG IoT@Home, SKT SMART HOME, KT GIGA IoT, etc.
Source: NIA and Ministry of Science and ICT, *Survey on the Internet Usage*, various years.

United States

In the United States, as similarly observed in Korea, smart TVs are increasingly used as an Internet entry point: in 2021, 47% of individuals had smart TVs, up from 18.3% in 2013 (Figure 2.22). The share of individuals interacting with home IoT devices (household equipment or appliances connected to the Internet) is also growing significantly, reaching 22.3% of individuals in 2021. Finally, wearable devices were used by 16.2% of individuals in 2021, up from 8.2% in 2017. More detailed data by socio-economic breakdowns show that IoT device usage is generally much more widespread among younger generations, and increases with income and educational attainment level (Annex Figure 2.A.2).

Figure 2.22. Use of selected IoT goods by individuals in the United States

As a percentage of all individuals



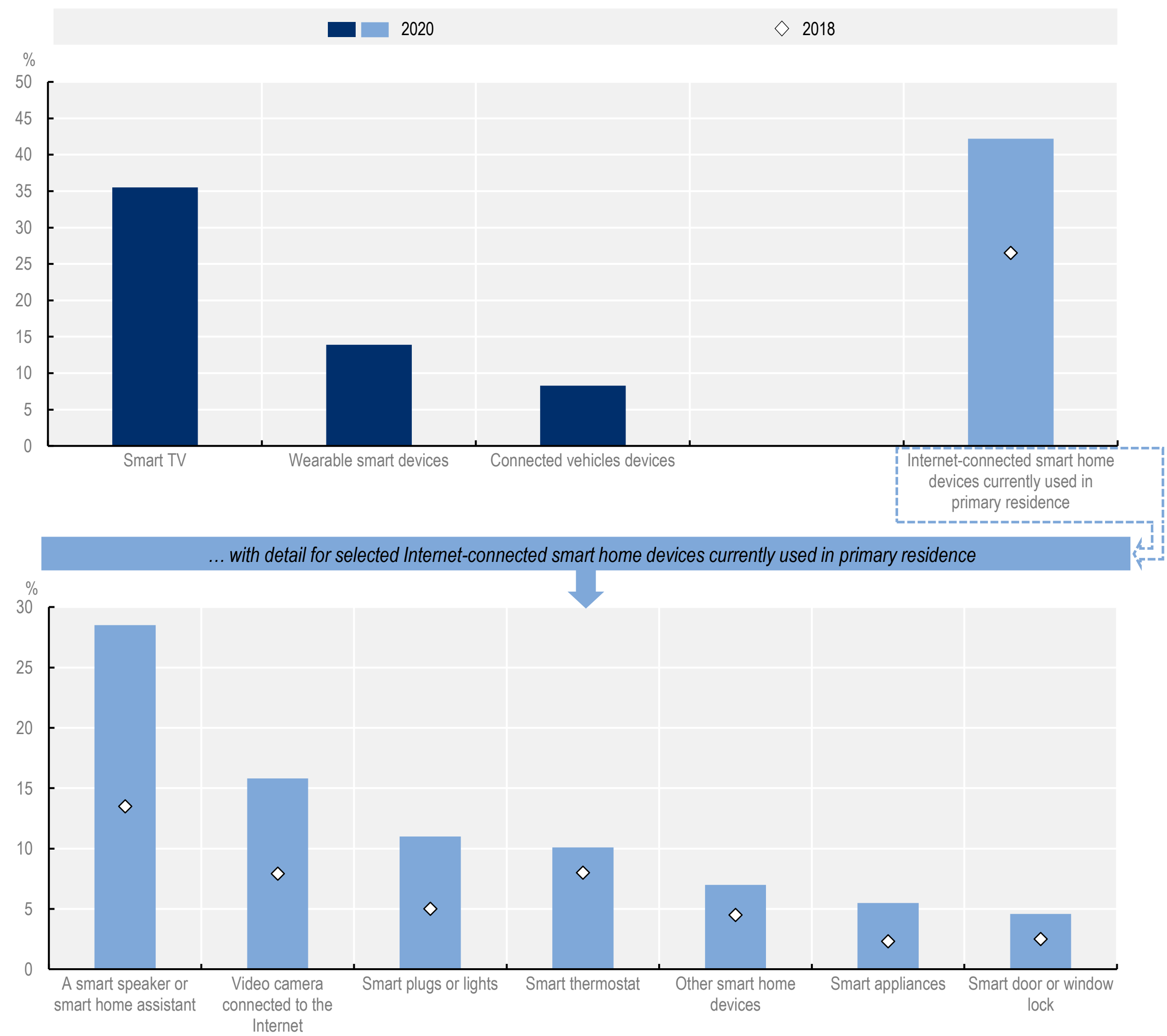
Note: Individuals aged 3+. Smart TVs also includes games or video systems or other devices that connect to the Internet and play through a TV. Home IoT refers to household equipment or appliances that are connected to the Internet, such as connected thermostats, light bulbs or security systems. Wearable devices connected to the Internet refer to devices such as smartwatches or fitness bands (examples include Apple Watch or Fitbit).
Source: Based on data from NTIA (2022[6]), *Digital Nation Data Explorer*, https://www.ntia.gov/data/explorer#sel=internetUser&disp=map (accessed on 20 May 2022).

Canada

In 2020, the share of Canadians using smart TVs (35%) or wearable smart devices (14%) was similar to the United States (Figure 2.23). In addition, over 42% of individuals were using Internet-connected smart devices in their primary residence, reflecting a significant diffusion of IoT devices in everyday life. Overall, the uptake of Internet-connected smart home devices strongly increased between 2018 and 2020, particularly of smart speakers and video cameras connected to the Internet. On the other hand, the diffusion of home automation devices is an early stage. Several factors may explain the low diffusion of home automation devices (see the section on obstacles to the use of the IoT by individuals below).

Figure 2.23. Use of selected IoT devices in Canada

As a percentage of all individuals



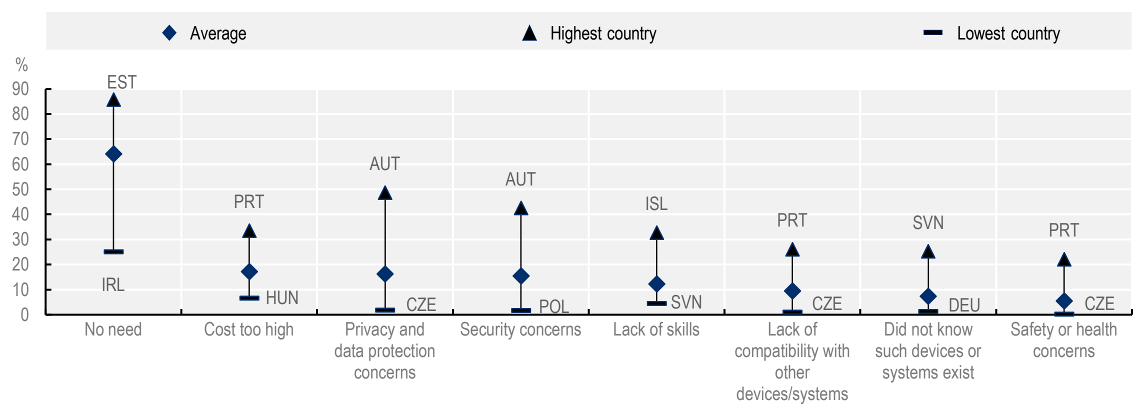
Source: Based on Statistics Canada, custom tabulation, *Canadian Internet Use Survey, 2018 and 2020.*

Obstacles to the use of the IoT by individuals

A number of factors prevent individuals from using IoT devices in everyday life: cost of the devices, perceived lack of skills, concerns around data protection, privacy and security, as well as safety and health (Figure 2.24). While all of these factors negatively impact IoT adoption, results from Canada and Eurostat surveys show that the primary reason for not using any of those devices is simply and above all the lack of perceived need: this is the case for nearly two out of three in European countries[6] and for three individuals out of four in Canada (Figure 2.25). Cost is the second reason provided for not using IoT devices, followed by privacy and data protection and security concerns. Lack of skills or difficulties in using such devices only come in fourth in Canada and fifth in European countries. Compatibility between different systems is also an issue in Europe. In Canada and European countries, safety and health concerns are put forward only by 5% of IoT non-users. In European countries, only a small share (7%) of individuals did not know that IoT devices exist.

Figure 2.24. Reasons for not using the IoT in selected European countries, 2020

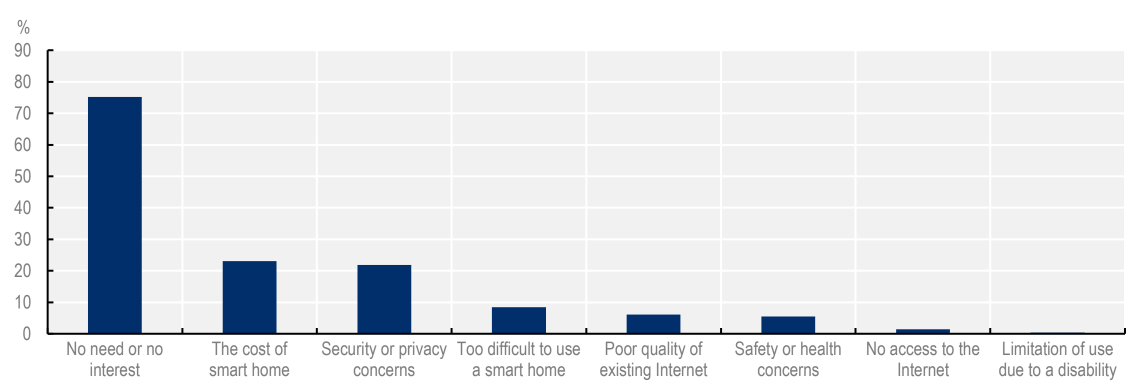
As a percentage of individuals who have not used any Internet-connected devices or systems



Note: Simple average of the 23 European countries for which data are available, as shown in Figure 2.12.
Source: Eurostat (2022[2]), *Comprehensive Database*, https://ec.europa.eu/eurostat/web/digital-economy-and-society/data/comprehensive-database (accessed on 1 February 2022).

Figure 2.25. Reasons for not using the IoT in Canada, 2020

As a percentage of individuals who have not used any Internet-connected devices or systems



Source: Based on Statistics Canada, custom tabulation, *Canadian Internet Use Survey, 2020*.

Conclusions

Surveys undertaken by national statistical offices have started shedding light on the use of the IoT by firms, households and individuals. Although these surveys share common features, they vary in their definitions and scope, thus limiting cross-country comparability. Therefore, further efforts by the international statistical community are needed to develop common definitions and methodologies in order to monitor the adoption of the IoT.

In addition, further measurement of the IoT should be more clearly oriented towards policy objectives, e.g. promoting the IoT in healthcare or energy-saving IoT applications. As the information and communication technology surveys, from which most IoT statistics are drawn, cannot cover all IoT fields of applications that are relevant for policy, it is important to identify the most suitable survey tools among the existing ones (e.g. health surveys, advanced technology surveys) and develop specialised IoT modules within these surveys.

Annex 2.A. IoT statistics in the ICT usage surveys

Businesses

OECD

The OECD revised its previous – broader – IoT definition and proposed the following "overarching IoT definition":

> *"The Internet of Things includes all devices and objects whose state can be altered via the Internet, with or without the active involvement of individuals. While connected objects may require the involvement of devices considered part of the "traditional Internet", this definition excludes laptops, tablets and smartphones already accounted for in current OECD broadband metrics." (OECD, 2018[7])*

Eurostat (ICT Business Survey)

In the 2020 questionnaire, the module starts with the following definition:

> *"The IoT refers to interconnected devices or systems, often called "smart" devices or systems. They collect and exchange data and can be monitored or remotely controlled via the Internet. Examples of usage are:*
> - *Smart thermostats, smart lamps or smart meters;*
> - *Radio Frequency Identification (RFID) or Internet Protocol (IP) tags applied or incorporated into a product or an object in order to track them;*
> - *Sensors for tracking the movement or maintenance needs of vehicles monitored over the Internet." (Eurostat, 2020[8])*

In 2021, the following sentence was added before the examples:

> *"Please exclude plain detection and sensors (e.g. motion, sound, temperature, smoke, etc.) and RFID tags that cannot be monitored or remotely controlled via the internet). Internet of Things may include various types of network connections via WAN, Wi-Fi, LAN, Bluetooth, ZigBee, Virtual Private Networks (VPN), etc."*

Australia (Business Characteristics Survey [BCS], part on Business Use of IT)

The IoT[7] refers to the system of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction. Examples of IoT devices include: universal remote controls, smart power plugs, smart light switches, home voice controllers, e.g. Google home voice controller.

Canada (ICT Business Survey)

The IoT refers to the interconnection via the Internet of computing devices embedded in everyday objects, enabling them to send and receive data. Examples include smart televisions, Wi-Fi-enabled security cameras, automatic car tracking adapters, Canary smart security systems, the Cisco Connective Factory, Phillips Hue smart bulbs and August smart locks. Internet-connected smart devices are electronic devices that can connect to each other and the Internet through a network. These devices are designed to automatically send and receive information from the Internet on a constant basis.

Israel (ICT Business Survey)

The IoT refers to the Internet interconnection of computing devices embedded in machines, devices and everyday objects, enabling them to send and receive data and/or affect their operation, with or without human intervention.

Japan (ICT Business Survey)

The IoT[8] here means a technology that connects various things (including computers, smartphones, tablets and other information and communications equipment, as well as sensors in general, office equipment, electrical appliances, industrial machines, cars, etc.) with the Internet, LAN and other networks to digitalise their data for collection and accumulation.

Korea (ICT Business Survey)

The IoT is the intellectual technology or service that links various things with the Internet to allow dynamic communication of information between people and things, things and other things, things and systems. This implements the activity of recognition, monitoring, etc., through physical sensing equipment such as radio frequency identification/ubiquitous sensor network (RFID/USN), etc., and the accumulated data would be provided through the wire/wireless communication to be used in various fields. E.g. smart factory that can be remotely controlled, smart building that controls indoor temperature, a heartbeat monitoring device for patients with arrhythmia, etc.

Annex Table 2.A.1. Overview and comparison of IoT definitions in official surveys

	Network and connection	Things (type of device)		Characteristics	Functions	Examples
		D, S, O or T	Smart			
OECD (2015)	Can be altered via the Internet	D and O		• Whose state can be altered via the Internet, with or without the active involvement of individuals.		• Includes laptops, routers, servers, tablets and smartphones.
OECD (2018)						• Excludes laptops tablets and smartphones already accounted for in current OECD broadband metrics.
Eurostat (2020)[1]	Interconnected	D or S	✓		• Collect and exchange data and can be monitored or remotely controlled via the Internet.	• Smart thermostats, smart lamps or smart meters. • RFID or IP tags applied or incorporated into a product or an object in order to track them. • Sensors for tracking the movement or maintenance needs of vehicles monitored over the Internet.
Eurostat (2021)						• Exclude plain detection and sensors (e.g. motion, sound, temperature, smoke, etc.) and RFID tags that cannot be monitored or remotely controlled via the Internet). • May include various types of network connections via WAN, Wi-Fi___33, LAN, Bluetooth, ZigBee, VPN, etc.
Australia[2]	Systems of interrelated /…/ devices /…/ with /…/ the ability to transfer data over a network	D or S		• Provided with unique identifiers and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction.		• Universal remote control, smart power plug, smart light switch, home voice controller e.g. Google home voice controller.

	Network and connection	Things (type of device)		Characteristics	Functions	Examples
		D, S, O or T	Smart			
Canada[3]	Internet interconnection	Computing devices		• Embedded in everyday objects.	• Enabling them to send and receive data.	• Include smart televisions, Wi-Fi-enabled security cameras, automatic car tracking adapter, Canary smart security system, Cisco's connective factory, Phillips Hue smart bulbs and August smart locks.
	Internet-connected	D	X	• Electronic devices that can connect to each other and the Internet through a network.	• Designed to automatically send and receive information from the Internet on a constant basis.	
Israel[4]	Internet interconnection	Computing devices		• Embedded in machines, devices and everyday objects.	• Enabling them to send and receive data and/or affect their operation, with or without human intervention.	
Japan[5]	Connects /…/ with the Internet, LAN and other networks	T			• Connects various things with the Internet, LAN and other networks to digitalise their data for collection and accumulation.	• Including computers, smartphones, tablets and other information and communications equipment, as well as sensors in general, office equipment, electrical appliances, industrial machines, cars, etc.
Korea[6]	Links /…/ with the Internet	Intellectual technology or service		• Allow dynamic communication of information between people and things, things and other things, things and systems. • Implement the activity of recognition, monitoring, etc. through the physical sensing equipment /…/ and the accumulated data during such course would be provided through the wire/wireless communication to be used in various fields.		• Through the physical sensing equipment such as RFID/USN, etc. • Smart factory that can be remotely controlled, smart building that controls indoor temperature, a heartbeat monitoring device for patients with arrhythmia, etc.

Note: Device (D); System (S); Object (O); Technology (T). Based on definitions in surveys. For Korea, the definition stays unchanged for the years 2017 to 2020.

Sources: 1. Eurostat (2020[8]), "ICT usage and e-commerce in enterprises, Survey year 2020, version 1.3", https://circabc.europa.eu/faces/jsp/extension/wai/navigation/container.jsp; 2. Australian Bureau of Statistics (2021[1]), *Characteristics of Australian Business*, https://www.abs.gov.au/statistics/industry/technology-and-innovation/characteristics-australian-business/latest-release#use-of-information-and-communication-technologies-icts-; 3. Statistics Canada (2019[9]), *Survey of Digital Technology and Internet Use (SDTIU)*, https://www23.statcan.gc.ca/imdb/p2SV.pl?Function=getSurvey&Id=1250752; 4. CBS (2020[10]), *ICT Usage Survey 2019 in Enterprises*, Statistics Netherlands; 5. MIC (2018[11]), *Communications Usage Trend Survey Form*, https://www.soumu.go.jp/johotsusintokei/tsusin_riyou/data/eng_tsusin_riyou01_2018.pdf; 6. NIA/Ministry of Science/ICT Korea (2019[12]), *2018 Yearbook of Information Society Statistics*, https://eng.nia.or.kr/site/nia_eng/ex/bbs/View.do?cbIdx=31975&bcIdx=20512&parentSeq=20512 and NIA/Ministry of Science/ICT Korea (2022[4]), *2021 Yearbook of Information Society Statistics (in Korean)*, https://www.nia.or.kr/site/nia_kor/ex/bbs/View.do?cbIdx=62156&bcIdx=24143&parentSeq=24143.

Annex Table 2.A.2. IoT-related questions in the ICT Usage Survey questionnaires

	Australia (2017-18)	Canada (2019)	Eurostat (2020)	Eurostat (2021)	Israel (2019)	Japan (2017)	Japan (2018) (both IoT and AI)	Korea (2017-20)
Use of the IoT? (Y/N)		✓	✓	✓	✓[1]	✓	✓[2]	✓
Extent of IoT importance	✓							
Devices			✓			✓	✓[2]	
1. Smart meters, energy management systems						✓	✓	
2. Physical security devices						✓	✓	
3. Image authentication control						✓	..	
4. Systems or services using GPS, mobile phone or any other localisation function						✓	..	
5. Computer management with wearable devices						✓	..	
5. Sensors (temperature, pressure and other sensors)						..	✓	
6. Healthcare equipment (X-ray or supersonic)						✓	..	
7. Electronic tags (RFID tags)						✓	✓	
8. Non-contact IC cards						✓	✓	
9. Equipment with additional network functions (network cameras, sensors, etc.)						✓	..	
10. Smart lighting equipment						✓	..	
11. Industrial robots						✓	✓	
12. Monitoring cameras						✓	✓	
13. Cellular modules for automobiles						✓	✓	
14. Drones						✓	..	
15. Others						✓	✓	
a) Smart meters, smart lamps, smart thermostats to optimise energy consumption in enterprise's premises (warehouses, production sites, distribution sites)			✓					
b) Sensors, RFID or IP tags* or Internet-controlled cameras to improve customer service, monitor customer activities or offer them a personalised shopping experience (targeted and relevant discounts, self-checkout)			✓					
c) Movement or maintenance sensors to track the movement of vehicles or products, to offer CBM of vehicles			✓					

	Australia (2017-18)	Canada (2019)	Eurostat (2020)	Eurostat (2021)	Israel (2019)	Japan (2017)	Japan (2018) (both IoT and AI)	Korea (2017-20)
d) Sensors or RFID tags to monitor or automate production processes, to manage logistics, to track the movement of products			✓					
e) Other IoT devices or systems			✓					
The IoT by function				✓	✓			
a) for energy consumption management (e.g. “smart” meters, “smart” thermostats, “smart” lamps (lights))				✓				
b) for premises’ security (e.g. “smart” alarm systems, “smart” smoke detectors, “smart” door locks or “smart” security cameras)				✓				
c) for production processes (e.g. sensors or RFID tags, managed via the Internet, used to monitor or automate the process)				✓				
d) for managing logistics (e.g. sensors managed via the Internet for tracking products or vehicles or in warehouse management)				✓				
e) for CBM (e.g. sensors managed via the Internet to monitor maintenance needs of machines or vehicles)				✓				
f) for customer service (e.g. “smart” cameras or sensors managed via the Internet to monitor customer activities or offer them a personalised shopping experience)				✓				
g) for other purposes				✓				
15.2.1. In merchandise and/or services the enterprise produces					✓			
15.2.2. In the production stages (e.g. smart assembly lines, production machinery, etc.)					✓			
15.2.3. In transportation and distribution of merchandise and services (e.g. vehicles with Internet connectivity, GPS devices, etc.)					✓			
15.2.4. For oversight and tracking purposes (e.g. with sensors, surveillance cameras, smart locks, etc.)					✓			
15.2.5. Other					✓			

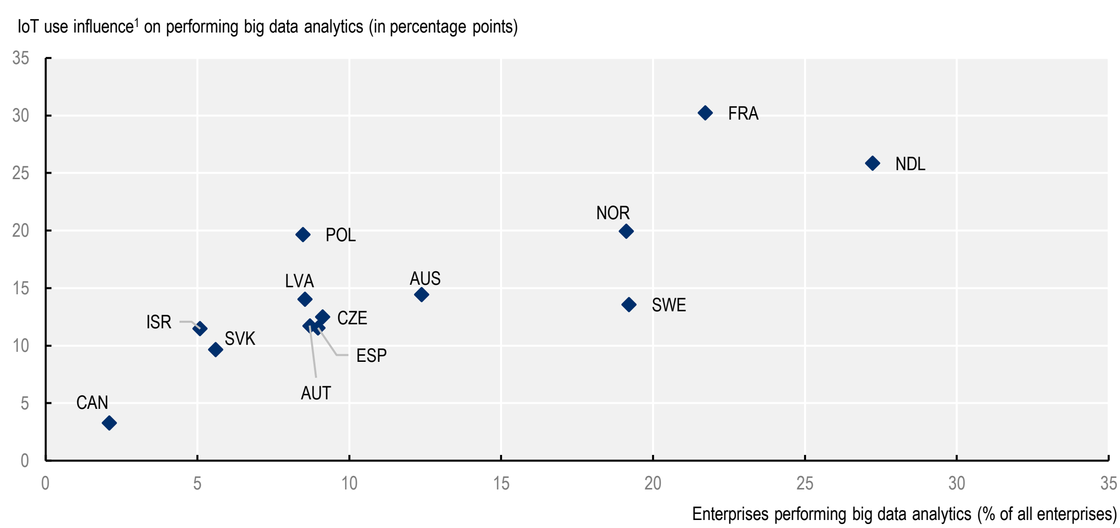
	Australia (2017-18)	Canada (2019)	Eurostat (2020)	Eurostat (2021)	Israel (2019)	Japan (2017)	Japan (2018) (both IoT and AI)	Korea (2017-20)
The IoT by market segment		✓						
1: Small, consumer market Internet-connected smart devices		✓						
2: Industrial equipment with integrated Internet-connected smart devices		✓						
3: Additional digital infrastructure for Internet-connected smart devices		✓						
4: Other		✓						
Reasons/purposes for using the IoT						✓	✓[2]	✓
(Usage purpose of collected and accumulated data)						✓		
Improvement of existing business operations						✓		
Development/deployment of new products/services						✓		
1. Improvement of business efficiency/operations							✓	
2. Business continuity							✓	
3. Overall optimisation of business operations							✓	
4. New business projects/management							✓	
5. Improvement of customer services							✓	
6. Others							✓	
1: Lack of an alternative		✓						
2: Cost savings		✓						
3: Productivity gains		✓						
4: Decision making		✓						
5: Cybersecurity		✓						
6: Improvement to the work environment		✓						
7: Other		✓						
								✓
1. Cost cutting								✓
2. Increase efficiency								✓
3. Increase productivity and information sharing								✓
4. Reinforcement of information security								✓
5. Improvement of the work environment								✓
6. Expansion of new sources of profits and the creation of product (service)								✓
7. Other								✓

	Australia (2017-18)	Canada (2019)	Eurostat (2020)	Eurostat (2021)	Israel (2019)	Japan (2017)	Japan (2018) (both IoT and AI)	Korea (2017-20)
Reasons for NOT using the IoT		✓				✓	✓[2]	2017-19
1: Lack of knowledge of available technologies		✓						
2: No business needs identified		✓						
3: Cost of service or equipment		✓						
4: Employees lack the skills, training or experience		✓						
5: Security or privacy concerns		✓						
6: Incompatibility with existing equipment or software		✓						
7: Other		✓						
1. Insufficient communication infrastructure for the IoT introduction						✓	✓	
2. We do not know laws, regulations or rules for using or introducing the IoT						✓	✓	
3. Business models after the IoT introduction are unclear						✓	✓	
4. IoT introduction and operation costs						✓	✓	
5. No human resources available for using the IoT						✓	✓	
6. We do not know what the IoT is						✓		
6. Systems or services to introduce are not decided						..	✓	
1) Burden of economic expenses								✓
2) Consideration of security								✓
3) Complexity of service (technology)								✓
4) Lack of capability of operation personnel								✓
5) Insufficient compatibility								✓
6) Insufficient basic equipment								✓
7) Immature IoT market								✓
8) Miscellaneous (please specify):								✓
Perceived level of efficiency/effectiveness of the IoT systems in the business							✓[2]	2017-18
Q8 (4) Have systems or services chosen (1) been effective for attaining the purposes of their introduction?							✓	
1. Very effective							✓	
2. Somewhat effective							✓	
3. Unchanged							✓	
4. Negative effect							✓	

	Australia (2017-18)	Canada (2019)	Eurostat (2020)	Eurostat (2021)	Israel (2019)	Japan (2017)	Japan (2018) (both IoT and AI)	Korea (2017-20)
5. No idea about any effect							✓	
How would you score the level of effectiveness through the usage of IoT devices and services in your company?								✓
(absolutely no effect/no effect/normal/some effects/very effective)								
Cost cutting								✓
Increase of efficiency								✓
Increase in productivity and information sharing								✓
Reinforcement of information security								✓
Improvement of the work environment								✓
Expansion of new sources of profits and the creation of products (services)								✓
Other								✓

1. Restricted to the following area: “for the products (goods or services), production of products and/or transportation of products”.
2. AI and the IoT are considered together and not separately.
.. : Data not available.
Source: Compiled from Eurostat and national sources.

Annex Figure 2.A.1. Influence of the use of the IoT on performing big data analytics in selected countries, 2021



Notes: For Canada, data relate to 2019 and for Israel, to 2020. For Australia, data relate to the 2019-2020 fiscal year.
1. Measured as the difference, in percentage points, between firms using the IoT and performing BDA, and firms not using the IoT and performing BDA.
Source: Based on ad-hoc tabulations provided by Statistics Austria, Statistics Canada, Israel Central Bureau of Statistics and Eurostat (2022).

Annex Table 2.A.3. Reasons for using the IoT devices in Canada, by firm size and industry, 2019

As percentage of firms using the IoT

	NAICS	Cost savings	Productivity gains	Decision making	Cybersecurity	Improvement to work environment
All businesses						
Private sector		24.2	36.6	15.4	19.7	49.3
Mining, quarrying, and oil and gas extraction	21	44.0	46.9	36.7	12.9	48.2
Utilities	22	29.7	44.5	35.4	20.8	45.1
Construction	23	33.3	51.0	23.5	21.8	61.5
Manufacturing	31-33	30.3	48.0	21.5	14.1	55.6
Wholesale trade	41	26.9	43.8	24.6	13.6	46.9
Retail trade	44-45	26.7	31.8	11.0	12.1	51.7
Transportation and warehousing	48-49	23.1	40.3	28.2	8.6	34.1
Information and cultural industries	51	32.4	55.0	21.3	31.4	59.6
Finance and insurance	52	19.1	55.0	17.7	31.3	58.7
Real estate and rental and leasing	53	15.6	27 3	17.2	8.8	46.3
Professional, scientific and technical services	54	23.9	48.6	15.7	23.1	58.0
Management of companies and enterprises	55	28.5	63.2	37.4	11.2	42.2
Administrative and support waste management and remediation services	56	35.3	45.4	16.3	17.6	73.4
Educational services	61	31.5	33.7	1.1	5.2	67.7
Health care and social assistance	62	13.1	40.4	8.0	34.1	46.6
Arts, entertainment and recreation	71	24.6	25.2	9.6	17.5	47.7
Accommodation and food services	72	17.3	18.9	8.7	43.1	36.6
Small businesses						
Private sector		22.5	32.7	13.0	20.0	46.8
Mining, quarrying, and oil and gas extraction	21	41.0	37 3	42.7	6.7	32.3
Utilities	22	20.2	29.5	30.8	10.1	46.7
Construction	23	30.0	47.7	15.0	21.8	60.1
Manufacturing	31-33	32.7	36.4	18.0	13.7	53.2
Wholesale trade	41	24.6	45.4	21.2	13.2	43.7
Retail trade	44-45	23.1	24.7	9.3	8.3	51.1
Transportation and warehousing	48-49	20.2	33.5	29.1	6.8	25.8
Information and cultural industries	51	32.8	57 0	18.1	32.7	55.8
Finance and insurance	52	7.0	55.8	13.6	37.3	56.0
Real estate and rental and leasing	53	15.5	23.4	14.9	8.7	43.1
Professional, scientific and technical services	54	21.9	43.9	14.1	21.4	53.2
Management of companies and enterprises	55	20.1	46.5	39.9	12.9	63.0
Administrative and support waste management and remediation services	56	37.6	41.7	14.4	14.2	75.2
Educational services	61	31.9	35.5	1.2	0.0	70.7
Health care and social assistance	62	10.0	41.0	6.8	38.4	40.1
Arts, entertainment and recreation	71	29.2	23.4	5.6	16.4	47.0
Accommodation and food services	72	17.3	20.3	5.4	52.3	37.5

	NAICS	Cost savings	Productivity gains	Decision making	Cybersecurity	Improvement to work environment
Large businesses						
Private sector		29.0	60.1	27.7	23.3	59.5
Mining, quarrying, and oil and gas extraction	21	52.9	73.8	29.8	28.8	67.3
Utilities	22	28.0	70.9	48.3	29.8	42.7
Construction	23	33.0	68.1	45.2	37.0	64.6
Manufacturing	31-33	41.8	76.8	38.8	22.5	57.2
Wholesale trade	41	24.7	55.9	29.5	20.3	54.1
Retail trade	44-45	23.2	47 8	38.4	21.6	60.8
Transportation and warehousing	48-49	37.1	60.9	31.7	24.3	54.6
Information and cultural industries	51	32.3	68.0	25.6	26.0	53.5
Finance and insurance	52	19.9	67 3	19.0	19.2	59.4
Real estate and rental and leasing	53	23.1	61.6	26.6	22.9	74.9
Professional, scientific and technical services	54	25.5	57.7	24.4	28.2	64.8
Management of companies and enterprises	55	12.3	63.5	12.3	0.0	36.5
Administrative and support waste management and remediation services	56	10.8	63.2	13.3	26.8	67.9
Educational services	61	24.2	54.1	7.8	16.3	43.5
Health care and social assistance	62	42.5	52.4	16.3	18.2	54.9
Arts, entertainment and recreation	71	24.7	36.6	28.0	7.1	42.6
Accommodation and food services	72	21.1	43.4	18.4	12.4	49.2

Note: Data for "All businesses" relate to businesses with five and more employees. Small size businesses have 0 to 49 full-time employees. Large-size businesses have 100 or more employees, except for Manufacturing (NAICS 31-33). For Manufacturing (NAICS 31-33), large-size businesses have 500 or more full-time employees. The following reasons are not reported in this table: "Lack of alternative"; "Other".
Sources: Based on Statistics Canada (2020[3]), *Survey of Digital Technology and Internet Use: Data Tables 2019*, https://www150.statcan.gc.ca/n1/daily-quotidien/210106/dq210106e-cansim-eng.htm; ad-hoc tabulations.

Households and individuals

Canada: The 2018 and 2020 questionnaires do not use the expression "Internet of Things" as such but refer to "Internet-connected smart home devices". These are defined as devices having "the ability to be controlled or monitored remotely through an app or a website" (Statistics Canada, 2018[13]; 2020[3]). A list of devices (with examples) is then provided.

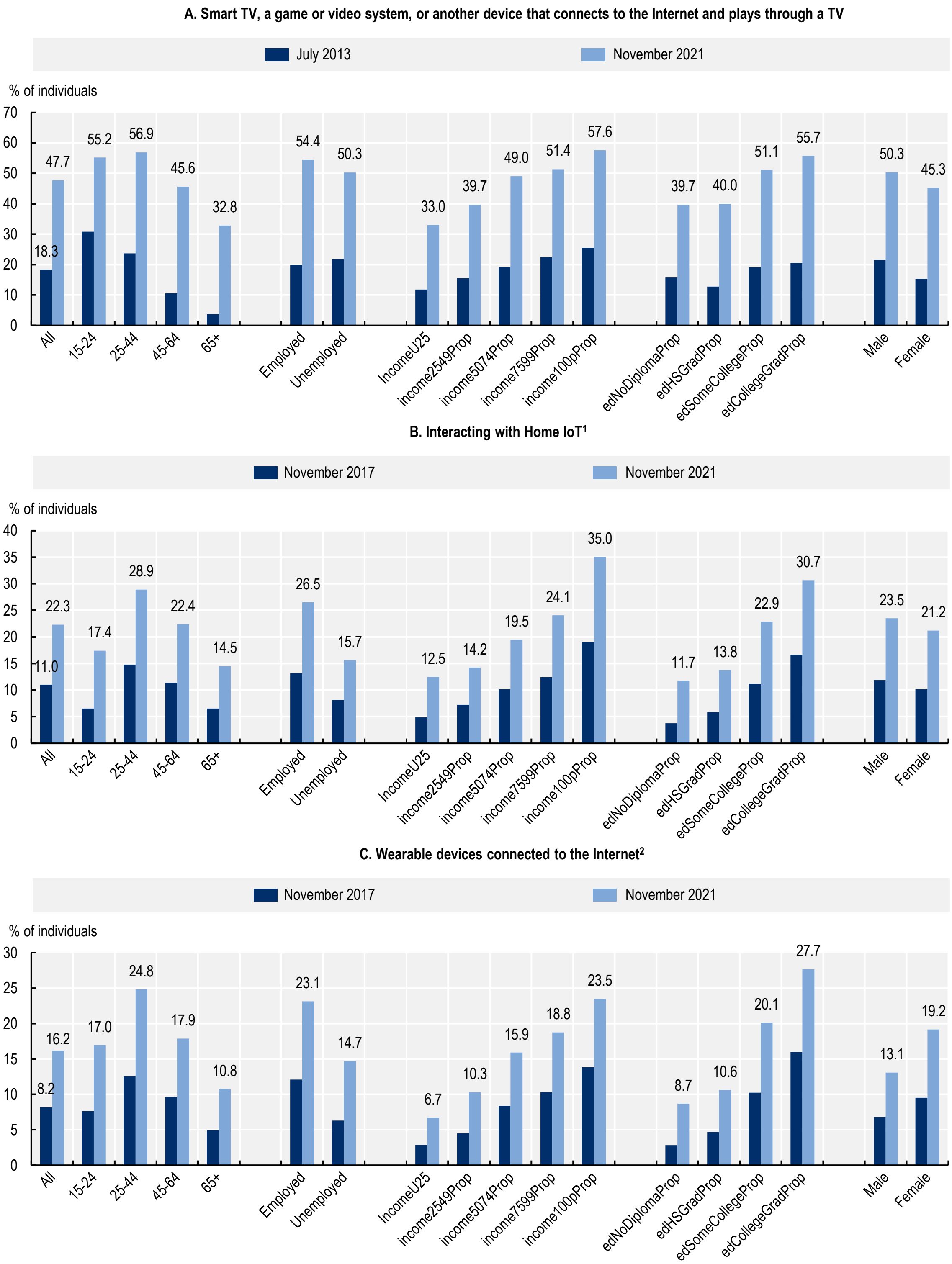
- Smart speaker: A wireless, audio playback device that uses several types of connectivity (often Wi-Fi and Bluetooth) for additional functions. Smart speakers have special features to enhance ease of use, connect to multiple types of audio sources and provide additional functionality. Some smart speakers feature digital assistants and can operate as home automation hubs. These devices are often part of a company's existing product stack. Examples include Google Home and Amazon Echo. Alexa Voice Services (AVS), the suite of services built around Amazon's voice-controlled AI assistant, was introduced with Echo. AVS enables voice interaction online and with various systems in the environment and online. Typically, smart speakers include Wi-Fi and Bluetooth connectivity. Simpler products range from Wi-Fi-enabled boom boxes to adjustable RGB LED smart speakers that can be spread through a home for distributed or localised stereo sound.
- Smart switch: A small device that plugs into any outlet and allows users to control connected appliances wirelessly via an app.
- Smart TV: A television set with integrated Internet capabilities or a set-top box for television that offers computing ability and Internet connectivity.

Eurostat (2020, 2022): The following paragraph introduces the module on the IoT in the 2020 and 2022 surveys: "The following questions concern the use of Internet-connected devices or systems for private purposes that can also be connected to each other to enable advanced services; e.g. remotely controlling the device, adjusting settings, giving instructions for tasks to be performed, receiving feedback from the device etc.". The Eurostat Methodological Manual 2020 provides further details: "In its scope, the module is limited to the individual's use of IoT solutions in the private life context. It concerns mainly the uptake of home automation solutions (domotics), but also the use of wearable devices, e-health solutions or cars with built-in wireless connection. IoT solutions can be connected with e.g. other devices or systems via the Internet (via mobile Internet connections, Wi-Fi) or via Bluetooth. It needs to be highlighted that the use of smartphones, tablets, laptops or desktops is not the objective of the measurement performed in this module when those devices serve to access the Internet only and not to control an IoT device".

Korea: The Internet Usage Survey does not include a definition of the Internet of Things but questions related to selected IoT devices or IoT services, with illustrative examples pointing to devices or services currently in use. In the case of wearable devices, for which a few questions are asked, the following definition is provided: (Wearable device is) "Worn on the body in the form of a watch, glasses, apparel, etc., device that collects information of the surrounding environment and changes in the body, and shares/utilises it via Internet (Ex. Smart band, smart watch, GPS necklace for children, etc.)". Korea is also the only country to include an item called "IoT services" in 2020 (or "ICT services" in the three previous years), relating to smart home services provided in addition to – or bundled with – IoT devices (NIA/Ministry of Science/ICT Korea, 2022[4]).

United States: The expression "Internet of Things" is not used as such in the questionnaires. Questions are provided with illustrative examples, e.g. "household equipment or appliances that are connected to the Internet, such as a connected thermostat, light bulb or security system" (USCB, 2017[14]; 2019[15]).

Annex Figure 2.A.2. Use of selected IoT goods by individuals in the United States, detailed socio-economic breakdowns, 2013 to 2021



Notes: Individuals aged 3 and over. The detail for the 3 to 14 age category is not provided.

1. Home IoT refer to household equipment or appliances that are connected to the Internet, such as a connected thermostat, light bulb or security system. 2. Wearable devices connected to the Internet refer to devices such as a smartwatch or fitness band (Examples include an Apple Watch or Fitbit).

Source: Based on NTIA (2022[6]), *Digital Nation Data Explorer*, https://www.ntia.gov/data/explorer#sel=internetUser&disp=map.

Annex Table 2.A.4. IoT devices used by individuals: details from selected official surveys

	Canada (2018, 2020)	Eurostat (2020, 2022)	Korea (2016-20)	United States (2017, 2019, 2021)
Denomination of the IoT devices	*Internet-connected smart home devices*	*Internet-connected devices or systems used for private purposes*		*Household equipment or appliances that are connected to the Internet*
A smart speaker or smart home assistant e.g. Google Home, Amazon Echo	✓			
Video camera connected to the Internet e.g. security camera, Nest Cam, baby monitor	✓			
Smart door or window lock	✓			
Smart thermostat e.g. Ecobee, Nest, Sensi	✓			
Smart plugs or lights e.g. Samsung Smart Switch, Phillips Hue Light	✓			
Smart appliances e.g. fridge, stove, dishwasher, coffee maker, toaster	✓			
Smart TV	✓			
Other smart home devices e.g. garage door opener, vacuum	✓			
Examples embedded in the question such as:				✓
connected thermostat				
light bulb				
security system				
Smart TV, a game or video system, or another device that connects to the Internet and plays through a TV				✓
Internet-connected thermostat, utility meter, lights, plug-ins or other Internet-connected solutions for energy management for your home		✓		
Internet-connected home alarm system, smoke detector, security cameras, door locks or other Internet-connected security/safety solutions for your home		✓		
Internet-connected home appliances such as robot vacuums, fridges, ovens, coffee machines		✓		
A virtual assistant in the form of a smart speaker or of an app, such as Google Home, Amazon Alexa/Echo/Computer, Google Assistant, Siri, Cortana, Bixby		✓		
An Internet-connected TV		✓		
An Internet-connected game console		✓		
An Internet-connected home audio system, smart speakers		✓		
Smart home appliance (Refrigerator, AC, lamp, etc.)			2019-20	

	Canada (2018, 2020)	Eurostat (2020, 2022)	Korea (2016-20)	United States (2017, 2019, 2021)
Wearable devices			*Worn on the body in the form of a watch, glasses, apparel, etc., device that collects information of the surrounding environment and changes in the body, and shares/utilises it via the Internet Ex.) Smart band, smartwatch, GPS necklace for children, etc.*	*Wearable device that is connected to the Internet*
Examples embedded in the question, such as:				✓
smartwatch				
fitness band				
Devices used to access the Internet during the past three months: Internet-connected wearable smart devices (e.g. smartwatch, Fit Bit, glucose monitoring device)	2020			
A smartwatch, a fitness band, connected goggles or headsets, safety-trackers, Internet-connected accessories, Internet-connected clothes or shoes		✓		
Band type (e.g. MiBand, Samsung Gearfit, Sony SmartBand, Fitbit, etc.)			2016-18	
Watch type (e.g. Samsung Gear S, Apple Watch, LG Watch Urbane, etc.)			2016-18	
Baby-child and Elderly Protecting/Tracking type (LG kizON, T JOON, Olleh ttok-ttok, Juniver Toki, LINE kids phone, Lineable, GPS tracker, etc.)			2016-18	
Clothes type (e.g. Smart clothing, underwear or shoes etc.)			2016-18	
Accessory type (e.g. Swarovski smart bracelet, Logbar ring etc.)			2016-17	
Glasses type (e.g. Google Glass, Intel Recon Jet, Epson BT200 etc.)			2016-17	
IoT devices functions used				
Making/receiving a phone call or sending/ receiving messages by connecting with smartphone			2016-20	
Searching for information using the Internet			2016-20	
Health management by measuring metrics such as heart rate and calories burn			2016-20	
Recording travel distance and path			2016-20	
Guidance of direction			2016-20	
Experience of virtual reality and augmented reality			2016-20	
Location tracking and protection of young children& elderly			2016-20	

	Canada (2018, 2020)	Eurostat (2020, 2022)	Korea (2016-20)	United States (2017, 2019, 2021)
Health				
Included in Wearable devices	✓			
Internet-connected devices for monitoring blood pressure, sugar level, body weight (e.g. smart scales) or other Internet-connected devices for health and medical care		✓		
Use an electronic health monitoring service that collects and sends data to your doctor or healthcare provider through the Internet. Examples include connected devices that monitor vital statistics, blood glucose levels or blood pressure				2017, 2019
(see IoT devices' functions used)			✓	
Toys				
Toys connected to the Internet, such as robot toys (including educational) or dolls		✓		
Cars				
A car with built-in wireless Internet connection		✓		
Connected vehicle devices, e.g. alarm systems, car tracking or diagnostics adapter	2020			

Source: Based on official sources.

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Notes

[1] For example, the following surveys are not covered in this paper: i) in Canada, the Survey of Innovation and Business Strategy, which included a question on the IoT in 2017 and 2019 (Statistics Canada, 2019 and 2021); ii) in Japan, the 2020 Innovation Survey, which included a question on the IoT within a module on digitalisation; and iii) in the United States, the 2020 Annual Business Survey, which included questions on Internet-connected devices as part of a module on the use of digital technologies for innovation activities. The results of the latter survey were not available at the time of publication.

[2] See Eurostat, *Methodological Manual 2021, Part 1 Enterprise Survey*, https://ec.europa.eu/eurostat/web/digital-economy-and-society/methodology.

[3] See European Commission, *The Internet of Things in European Healthcare*, https://digital-strategy.ec.europa.eu/en/policies/internet-things-european-healthcare.

[4] The US telehealth claims volumes have been multiplied by a factor of 38 between 2020 and 2021. See McKinsey (2021), "Telehealth: A quarter-trillion-dollar post-COVID-19 reality?", https://www.mckinsey.com/industries/healthcare/our-insights/telehealth-a-quarter-trillion-dollar-post-covid-19-reality?cid=podcast-eml-alt-mip-mck&hdpid=b8c90668-0686-4f26-9fb8-3176eb2796ba&hctky=9240578&hlkid=a96f0678b0f848d8a2cbf6b8197f871e.

[5] Results include the European Union, Norway and the United Kingdom.

[6] The survey also covers Norway and the United Kingdom.

[7] Australia includes questions related to businesses ICT usage in a section of the Business Characteristics Survey (BCS).

[8] Japan also conducts a National Innovation Survey. In its 2020 issue, there are specific questions on the IoT, accompanied by a definition. The survey's results were not available at the time of writing.

3 Additional metrics and sources to measure the Internet of Things

This chapter reports on additional metrics and sources to monitor the growth and diffusion of the Internet of Things (IoT): patenting activity in IoT-related technologies, venture capital, mergers and acquisitions of IoT firms as well market developments in specific segments in the IoT value chain. These metrics help capture innovation opportunities and emerging commercial applications in the IoT field.

This chapter reports on additional metrics and sources to monitor the growth and diffusion of the Internet of Things (IoT). Patenting activity in IoT-related technologies provides a measure of innovation in the field. The dynamic of firm creation and venture capital (VC) investment helps capture emerging commercial IoT applications. Trends in specific segments in the IoT value chain, e.g. sensors and actuators, bring further insights into the evolution of IoT. Finally, mergers and acquisitions (M&A) of companies active in the IoT domain signal the expectations of key players regarding market potential.

IoT-related patents

Progress in the IoT can be measured by looking at global patenting activity in related technologies. Unfortunately, the International Patent Classification, which is used to allocate patents to specific technology fields, introduced a patent sub-class of the IoT only recently (WIPO, 2021[1]) and IoT patent data will only become available in forthcoming years. Therefore, evidence on IoT-related patents has so far been based on the occurrence of some set of IoT-related keywords in the abstract, i.e. the description of the patent applications.

Early work by the United Kingdom Intellectual Property Office (IPO, 2014[2]) estimated that there were almost 22 000 patent applications related to the IoT worldwide over the period 2004-13, with the annual increase in patenting activity in this field being up to 8 times higher than for patents in all other technologies.

Based on a simple search of the expressions “IoT” and “Internet of Things” in the patent abstracts, the United Nations Conference on Trade and Development (UNCTAD, 2021[3]) estimated that there were 22 180 IoT-related patent applications over the period 1996-2018. The leading countries, based on the location of the assignees, i.e. the patent owners, were the People's Republic of China (hereafter "China") (9 515), Korea (5 106) and the United States (4 275). The 3 leading companies for the number of IoT applications were the Samsung Group (2 508), Qualcomm (1 213) and Intel (667). However, these figures may underestimate the actual number of IoT-related patents. For instance, a recent report (IoTsens, 2021[4]) estimated that 129 710 IoT-related patent applications were filed over the period 2011-21, although the methodology used for such estimation is not explained. Contrary to UNCTAD (2021[3]) findings reported above, LG and Huawei are respectively fourth and fifth worldwide for the number of IoT patent applications, just above Intel.

According to the European Patent Office (EPO, 2020[5]), patent applications related to smart connected objects accounted for over 11% of all patenting activity worldwide in 2018. The report also points to the acceleration during the period 2000-18, with an average annual growth rate in patenting related to smart connected objects close to 20%, compared to 12.8% from 2000 to 2009. The annual increase in patent filings for Industry 4.0 technologies (4.2%) has been nearly five times greater than the growth of patenting in all fields since 2010.

IoT firm creation and VC investment

The creation of firms engaged in the production of IoT goods and services (labelled as “IoT firms” hereafter) provides a complementary measure of the diffusion of IoT technologies and their commercial applications. IoT diffusion is also reflected in the amount of VC investment accruing to these firms.

VC is a form of private equity financing, i.e. equity capital provided to enterprises not quoted on a stock market, particularly relevant for young companies with innovation and growth potential but untested business models and no track record.

Typically, VC investment is made to support a business's pre-launch, launch and early-stage development phases. VC firms or funds invest in these early-stage companies in exchange for equity or an ownership stake. Venture capitalists take on the risk of financing new or growing businesses with perceived long-term growth potential with the expectation that some of the firms they support will become successful.

Data on IoT firms and VC are drawn from Crunchbase (https://www.crunchbase.com/), a commercial database on innovative companies started in 2007 and that has become an international reference in the field (Dalle, den Besten and Menon, 2017[6]).

Crunchbase data are sourced through two main channels: a large investor network and community contributors. Data are then processed via artificial intelligence (AI) and machine learning (ML) algorithms in order to ensure accuracy. In addition, algorithms search the web for further information about the companies' profiles. As potential investors increasingly use Crunchbase, there seems to be an incentive for entrepreneurs to register with the website and to keep their information up-to-date.

As of May 2021, there were 10 384 IoT firms in the database, based on the Crunchbase classification of activities. Further IoT firms have been identified by searching the description of their activities based on a list of keywords (see Annex 3.A for details). This search identified 2 913 additional IoT firms, bringing their total number to 13 296.

Among the information about firms, Crunchbase reports the year of creation, the amount of VC received and the investment stage (Box 3.1). Newly established firms are usually included in Crunchbase with a three- to four-year lag. By contrast, once the firm is in the database, VC investment is documented in a timelier manner.

Box 3.1. VC investment stages

Crunchbase classifies VC investments according to three stages:

- **Early stage**: This stage encompasses all investments from the birth to the market launch of the firm. It ends when the firm starts generating revenues.
- **Expansion stage**: In this stage, the firm is seeing fast growth and seeks additional investment to keep up with demand. VC investment is mainly used to finance market expansion and product diversification.
- **Bridge stage**: In this stage, the firm has reached maturity. VC investments are typically made to support activities like M&A or raise equity capital.

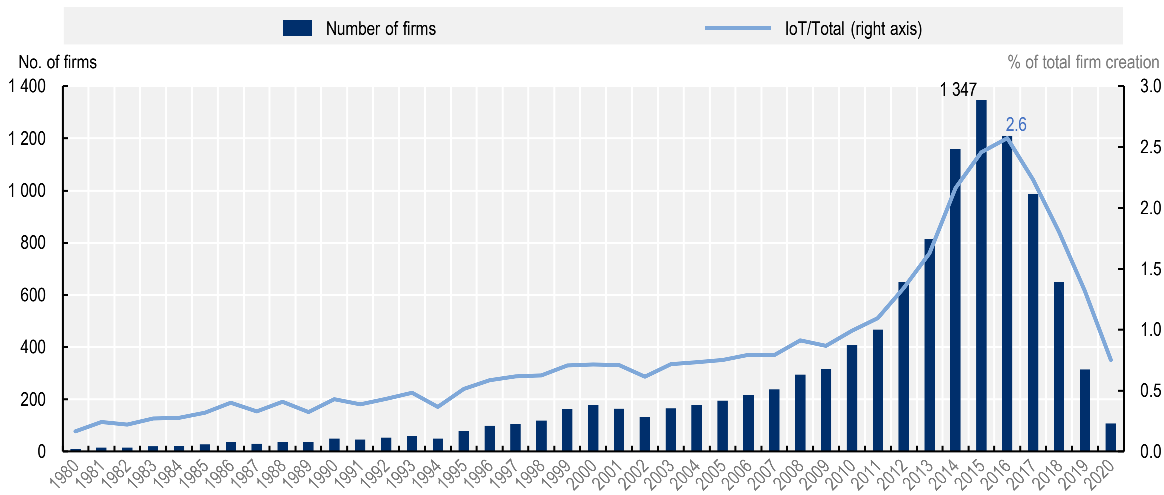
Source: Based on Crunchbase data.

Trends in IoT firm creation

The creation of IoT firms increased slowly between 1980 and 2009, from less than 100 to about 400 a year. It then accelerated in 2009, reaching a peak at 1 347 new firms in 2015 and then dropping to less than 200 new firms a year in 2020. IoT firm creation relative to total firm creation followed a similar trend, reaching a peak of 2.6% in 2016 (Figure 3.1).

The surprising decrease in IoT firm creation after 2015 may have several concurrent explanations. On the one hand, it may follow from the time lag with which Crunchbase registers newly created firms, although this would not explain the observed decrease in new IoT firms relative to all new firms. On the other, it may reflect a consolidation of the IoT market via M&A, as confirmed by the continued increase in VC investment in the IoT (see next section). The growing importance of security issues arising from IoT use, as well as the lack of interoperability between platforms and ecosystems (Nativi et al., 2020[7]), may also have contributed to slowing down firm creation in this field.

Figure 3.1. IoT firm creation, 1980-2020

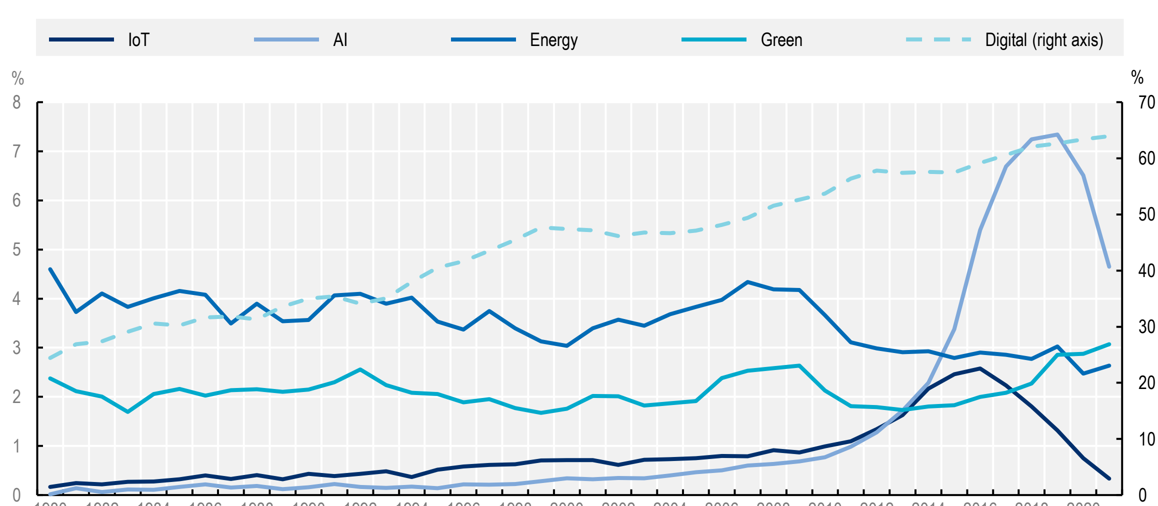


Source: Based on Crunchbase data.

Figure 3.2 shows trends in firm creation in selected activities related to the IoT: AI, energy and green. Firm creation in the IoT and AI followed a similar trend from 1980 to 2014 when the AI share started to grow exponentially from about 2% to above 7% in 2018. The share of newly created firms in energy was higher than in the IoT over the whole period considered. The same holds for newly created firms in green activities, except for 2013-17.

Figure 3.2. Firm creation in selected activities

As a percentage of total firm creation

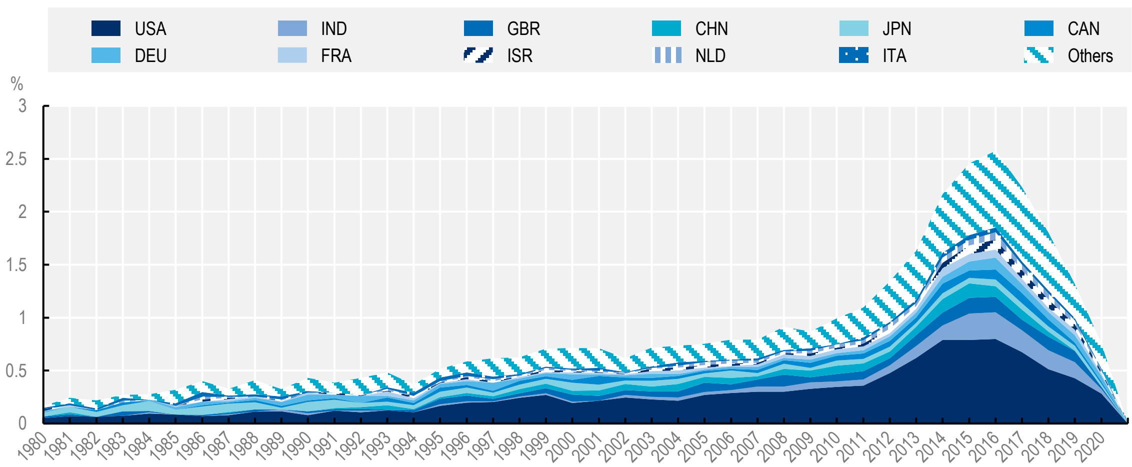


Note: For the definition of IoT firms, see Annex 3.A. The AI activity is defined by Crunchbase. Energy, Green and Digital activities have been developed by the International Energy Agency, building on the Crunchbase classification. Firms may belong to more than one activity.
Source: Based on Crunchbase data.

Over 1980-2020, about 75% of IoT firm creation worldwide occurred in 10 countries, 56% in Group of Seven (G7) countries, and one-third in the United States alone. India and China accounted for 7% and 5% of newly created IoT firms worldwide respectively (Figure 3.3).

Figure 3.3. IoT firm creation by country

As a percentage of IoT firm creation worldwide

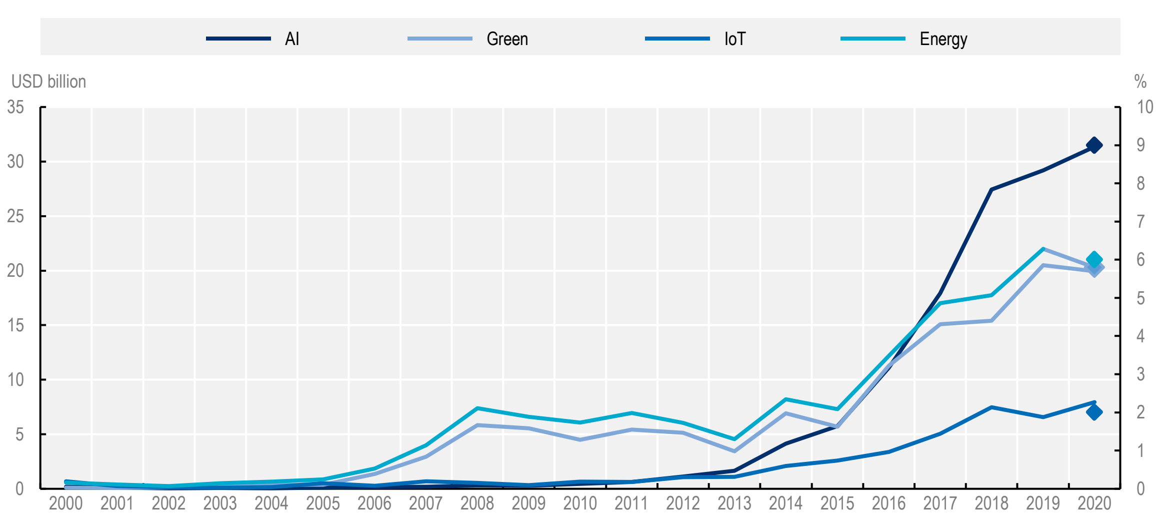


Source: Based on Crunchbase data.

VC investment in IoT firms

VC investment in IoT firms was fairly low until 2011 but increased dramatically afterwards, reaching USD 8 billion in 2020. Yet, VC investment in IoT firms has been much lower than in AI, energy and green firms, with the gap increasing dramatically in most recent years. In 2020, investment in energy and green, on the one hand, and AI, on the other, were respectively 3 and 4.5 times greater than in the IoT (Figure 3.4).

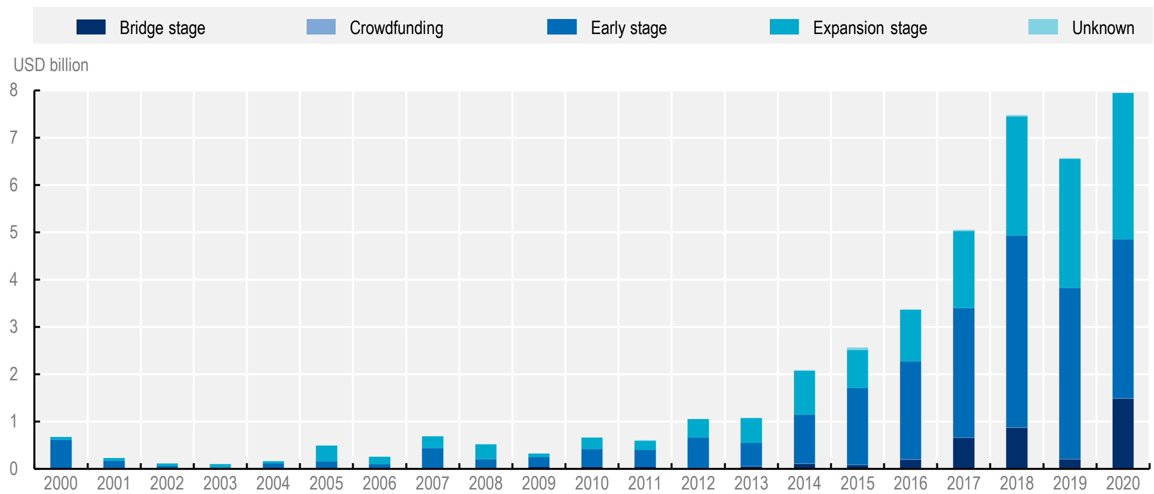
Figure 3.4 VC investment in selected fields of activity



Note: The markers (right axis) represent the 2020 percentage of total funding in start-ups.
Source: Based on Crunchbase data.

Since 2019, VC investment in IoT firms has focused on expansion and bridge stages, which correspond to firms' growth and maturity phases. This shift seems to confirm the hypothesis of consolidation of the IoT sector discussed above (Figure 3.5).

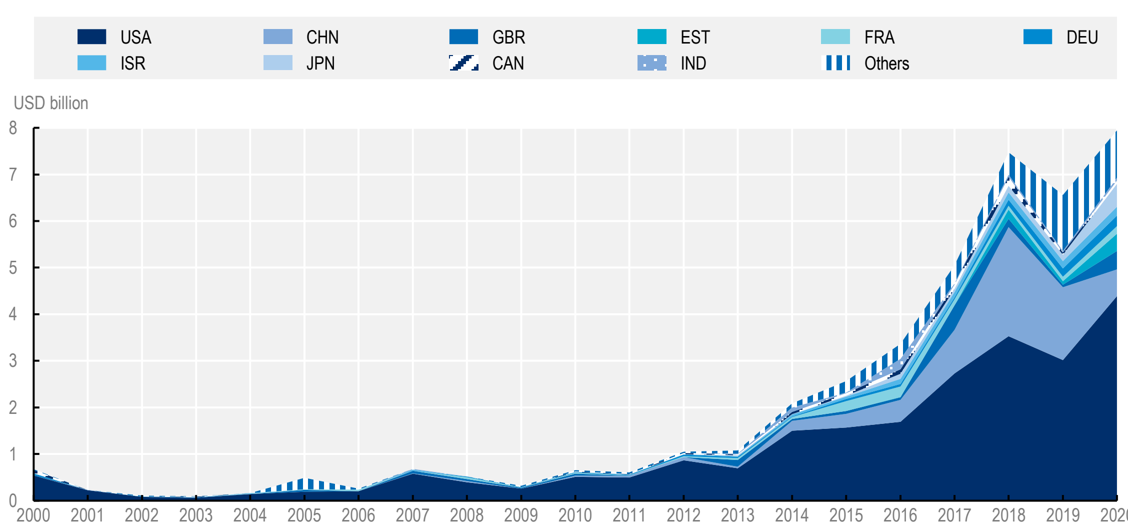
Figure 3.5. VC investment in IoT firms by stage, 2000-20



Note: VC investment stages are defined in Box 3.1.
Source: Based on Crunchbase data.

Over 2000-21, VC investment in IoT firms was concentrated in a few countries, with 10 countries accounting for over 90% of total VC investment worldwide. The main recipients were the United States (60%) and China (15%). In 2020, VC investment in United States IoT firms reached USD 4.5 billion, up from USD 1.6 billion in 2015 (Figure 3.6).

Figure 3.6. VC investment in IoT firms by recipient country, 2000-20



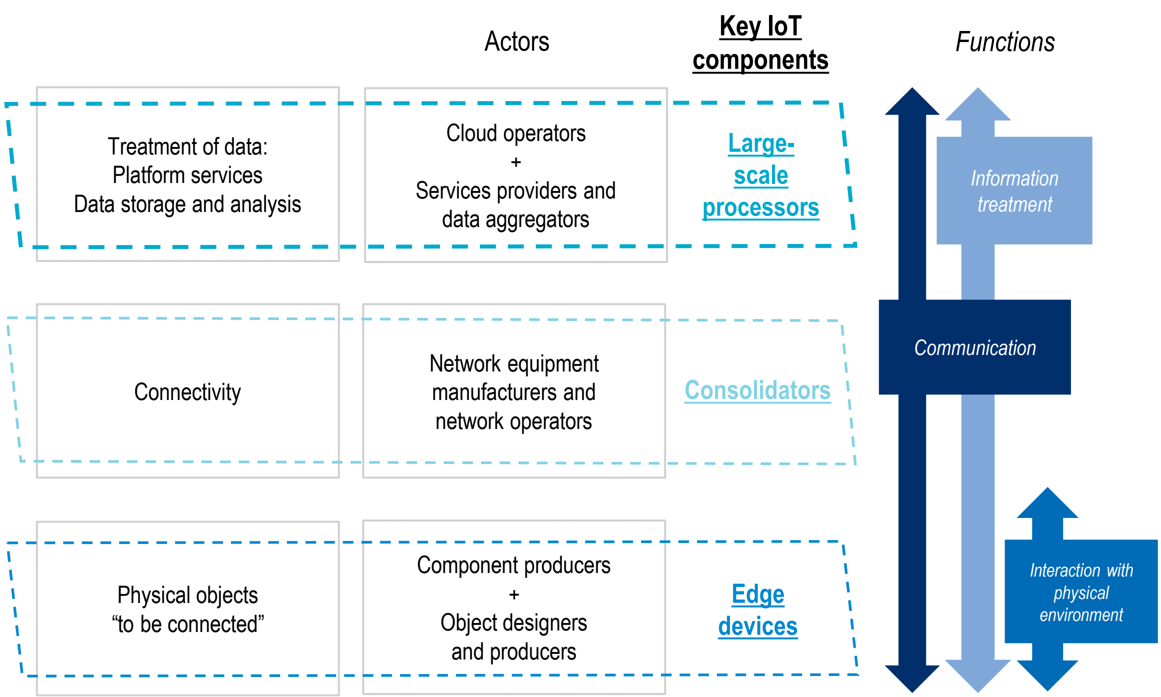
Source: Based on Crunchbase data.

Semiconductor industry trends relevant to the IoT

The importance of semiconductors for the IoT

Semiconductors are one of the key components and foundational layer of the IoT ecosystem, as the three key components of any IoT system – edge devices, consolidators and large-scale processors – rely on them (Figure 3.7). Semiconductors in the IoT are essential to ensure the sensing and actuating functions ("interaction with the physical environment" at the level of the devices), the connectivity function ("communication" across all layers) and the data processing function ("information treatment" at the level of the device and/or at the data centre). The type of semiconductors used varies among IoT components due to the variety of their applications. For example, smart vehicles require more processing power and data collection than sensors in smartwatches or clothing.

Figure 3.7. IoT enabling environment and key IoT components



Note: Functions refer to binding characteristics to be associated with semiconductors. Edge devices, e.g. watches, meters, typically gather, to varying degrees, the following abilities: i) capture some characteristics of the environment and translate them into information or physical action through one or more sensors and actuators; ii) treat and process this information through a processor; iii) transmit this information to a network using various means of communication. Consolidators are hubs or access points. As the means of communication in edge devices are likely to have a limited range, they need to be connected to something that acts as an access point for a wide-area network. Large-scale processors, often hosted in the cloud, make use of the data being generated from the edge devices.
Source: Adapted from OECD (2018[8]), "IoT measurement and applications", https://doi.org/10.1787/35209dbf-en.

The large scope of applications for semiconductors within the same family does not make it possible to identify those that are specific to IoT components. For instance, while virtually all IoT use communication integrated circuits (ICs), semiconductors in this family are used for a much wider set of applications, e.g. home Wi-Fi wireless network protocols, mobile telecommunications. In addition, the product classification currently used by the semiconductor producers is too broad to single out semiconductors that are used predominantly, if not exclusively, in IoT components. IC Insights cited in an OECD paper (2019[9]) estimated the value of semiconductors for Internet connection ("communication") used by the IoT at

USD 21 billion in 2017, or one-third of the total communication ICs in 2017, i.e. 5% of the total market of semiconductors in that year. However, the methodology supporting these estimates is not disclosed and IC Insights discontinued this analysis; therefore, it is impossible to outline the share of the IoT within communication ICs in more recent years.

At the same time, many connectivity functions in IoT devices are now embedded in the system-on-chip IC instead of application-specific ICs. Therefore, unlike the effect discussed above, trends in wired and wireless semiconductors may understate the actual growth in IoT devices.

To deal with the above issues, the approach taken in this section is to narrow the scope for measurement based on semiconductors along two axes. First, the measurement focuses on edge devices only, thus leaving aside the other two key IoT components, i.e. consolidators and large-scale processors. Second, the measurement focuses on semiconductors, which, while not exclusive to the IoT, are embodied in all IoT edge devices. This seems to be the case with sensors and actuators: while information processing and communication functions are widely diffused and not limited to IoT devices, the function provided by sensors and actuators can be considered as more specifically related to IoT devices (Figure 3.7). Although not all devices equipped with sensors and/or actuators are connected to a network, therefore meeting the definition of the IoT, it seems safe to assume that this is the case for a large majority of them.

Figures on sensors and actuators are likely to be lower band estimates, as IoT-relevant items can also be found within communication ICs – although they are probably a minority within this group – and in other semiconductor sub-families, such as processors, where they are also present but in relatively lower shares than other items such as computers. The section also provides some figures on “wireless” and “wired” subproducts intended for “communication” within the product group “application-specific ICs”. Figure 3.9 provides both the overall revenues for these sub-products and the revenues of subset products dedicated to short-range communication. However, as it is not possible to single out IoT applications within these sub-products, these figures are only shown for illustrative purposes.

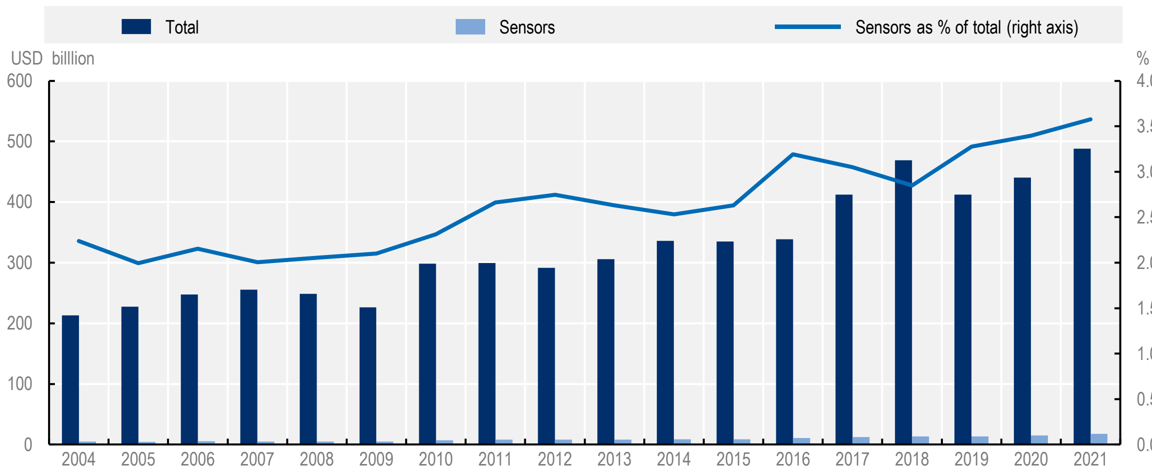
Sensors

In 2021, worldwide semiconductor revenues were estimated to reach USD 488 billion, up from USD 213 billion in 2004 (Figure 3.8). The share of sensors and actuators is expected to reach 3.6% of the market, up from 2.2% in 2004. Growth of this share was marked during the 2010-20 decade, while being relatively stable – at around 2% - between 2004 and 2009. Sensors are important components which benefitted from strong demand during the most recent decade and in many different sectors, such as advanced driver assistance systems in the automotive industry or within the increasing variety of smart home devices.

Communication ICs

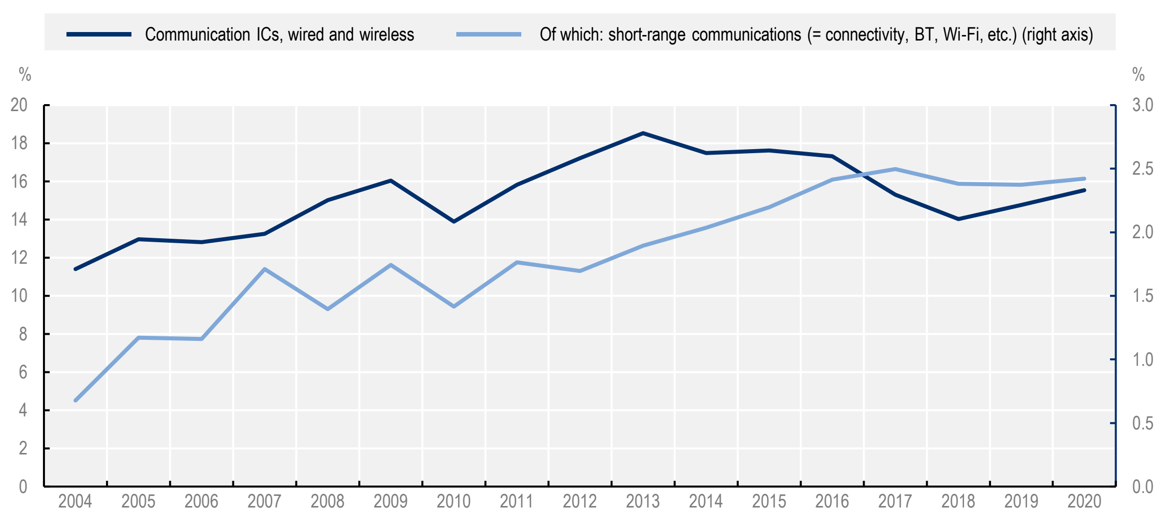
As shown in Figure 3.9, with a market of 68.4 USD billion, the share of communication ICs reached 15.5% of the worldwide semiconductor market in 2020, up from 11.4% in 2004 (USD 24.3 billion). However, this share slightly decreased between 2014 and 2020 (from 17.5% to 15.5%). The short-range communication components, while accounting for a small share of the worldwide market (below 3%), have been regularly growing over the 2004-20 period. This is clearly reflecting the progressive diffusion of portable wireless communications devices using short-range wireless transmission technologies such as Bluetooth, Wireless Local-Area Network, Ultra-Wideband (UWB) and Zigbee. According to World Semiconductor Trade Statistics, the volume of short-range semiconductors shipments multiplied by more than 7 times during the period, reaching 6.6 million units in 2020 worldwide.

Figure 3.8. Worldwide semiconductor and sensors revenues, 2004-21



Note: Sensors include actuators. Estimates for 2021.
Source: WSTS (2021[10]), *Market Statistics (database)*, https://www.wsts.org (accessed on 15 January 2022).

Figure 3.9. Share of communication ICs (wired and wireless) in the worldwide semiconductor market, 2004-20



Note: Short-range communications include "Wireless Communication Short Range" and "Short-Range Wireless", corresponding respectively to the categories JDc and L7c of the WSTS Product Classification 2018.
Source: WSTS (2021[10]), *Market Statistics (database)*, courtesy from WSTS.

Overall, sensors account for 3.6% of the market (as per above, most of them are assumed to be relevant to IoT devices). Communication ICs account for 15.5% of the market: while most of this is not presumably associated with IoT devices, a tiny part probably is. Within those, short-range communication ICs account for nearly 2.5% of the market (a small part of this is associated with IoT devices). Those two groups display a regularly growing trend of their share in the worldwide semiconductor market. Taking into account the above figures and assumptions, it seems to consider that the share of semiconductors components related to the IoT is currently at least between 5% and 7% of the worldwide semiconductor market and certainly encounters a regularly growing trend.[1]

M&A in the semiconductor industry

Over the past two decades, a broad movement of industry consolidation has taken place in the global semiconductor industry, as can be observed in the value of M&A, particularly intense in 2015 (OECD, 2019[9]). One explanation for this trend toward industry consolidation may be found in accelerating increases in the costs of semiconductor R&D and capital equipment in the race to produce leading-edge chips (EC, 2021[11]), which have made it harder for smaller firms to compete (OECD, 2019[9]).

Addressing the technology requirements of a growing IoT market is likely to have contributed to consolidation in the semiconductor industry, as leading semiconductor firms acquire capabilities and talent to improve their offers, signalling where the market potential is expected to be the highest. IoT applications rely on the capability of the semiconductor industry to develop the technology necessary to meet the specific needs of this market: IoT application-specific microcontrollers, AI capabilities at the edge (Box 3.2), efficient power consumption and environmental resistance (IEEE, 2020[12]).

In an attempt to gain IoT market segments, the semiconductor industry is also shifting from the development of chips and hardware to the provision of security and software solutions, moving from component suppliers to solution providers. Particularly relevant in this regard is the specialisation in vertical applications, such as the automotive or smart home sectors (Deloitte, 2018[13]).

Intel and Qualcomm, two leading semiconductor companies, have created specific IoT segments in their businesses, also starting to disclose revenues for these segments separately. Intel IoT Group's net revenues amounted to USD 3.007 billion in 2020 or 4% of the company's total net revenues. In 2018 and 2019, this share was 5%. Qualcomm Ventures LLC, the investment arm of Qualcomm, together with Indicator and the Brazilian Development Bank (BNDES), has also recently announced the launch of the USD 45 million early-stage VC fund Indicator 2 for the IoT. This is the first investment vehicle dedicated exclusively to the IoT and connectivity in Latin America (BNDES, 2021[14]). Another trend pushed by the diffusion of the IoT – as well as by ML, he fifth-generation technology standard for broadband cellular networks (5G) and autonomous cars – is the entry of non-semiconductor technology groups such as Alphabet (Google), Amazon, Apple and Facebook in the semiconductor development market. In recent years, these companies have started developing their own application-specific ICs for use in their businesses, from data centres to smart speakers.

Box 3.2. Edge AI

In edge (as opposed to cloud-based) AI inference functions are embedded locally in the IoT endpoints that reside at the edge of the network. The IoT devices communicate wirelessly with an edge server that is located relatively close. This server decides what data will be sent to the cloud server (typically, data needed for less time-sensitive tasks, such as retraining) and what data get processed on the edge server.

Compared to cloud-based AI, in which data need to move back and forth from the endpoints to the cloud server, edge AI addresses privacy concerns more easily. It also offers the advantages of response speeds and reduced cloud server workloads. Due to the power constraints typically imposed by battery-powered IoT devices, the inference engines in these IoT devices also need to be very energy efficient.

Source: imec (2021[15]), "The future semiconductor landscape: Five trends", https://www.imec-int.com/en/articles/five-trends-will-shape-future-semiconductor-technology-landscape.

The IoT is considered to have fuelled USD 163 billion in M&A investments for 782 IoT-related M&A deals during the period 2014-20 (451 Research, 2021[16]). Looking at the semiconductor industry only, Intel, one of the leading semiconductor companies, concluded a number of deals in recent years, which can be considered as related to the IoT market. In 2015, the company acquired manufacturer of programmable logic devices Altera for USD 16.7 billion, with the objective to merge Altera's field-programmable gate array technology – processors which the customer can configure and customise to adapt the algorithms involved with various workloads – and Intel's processors so as to tailor them for IoT applications in automotive and manufacturing. Relevant for edge AI, Intel acquired Habana Labs, a start-up focusing on chips with training and inference processing, for USD 2 billion in 2019. To strengthen its value proposition to the automotive industry, in 2017, the company acquired Mobileye, an Israeli start-up specialised in computer vision for autonomous driving technology, for USD 15.3 billion in 2017 and Moovit, a mobility-as-a-service solutions company, for approximately USD 900 million in 2020.

Table 3.1 reports, for illustrative purposes, a selection of deals operated by some of the major semiconductor companies in the years 2014-20, based on information in the press.

Table 3.1. Select M&A deals by major semiconductor companies relevant to the IoT market, 2014-21

Company acquiring	Company acquired	Year	Value (USD)	Acquired company's specialisation	Relevant for:				
					Edge AI	Connected and autonomous vehicles	Wearables	Smart home	Manufacturing
Intel	Moovit	2020	900 million	Mobility-as-a-service		✓			
	SigOpt	2020	Not disclosed	AI software models	✓				
	Habana Labs	2019	2 billion	AI training and inference chips	✓				
	Nervana	2018	350 million	Deep learning	✓				
	Vertex AI	2018	Not disclosed	Deep learning	✓				
	Mobileye	2017	15.3 billion	Computer vision for autonomous driving		✓			
	Yogitech	2016	Not disclosed	Functional safety		✓			
	Altera	2015	16.7 billion	Field-programmable gate array processors and technology		✓			✓
	Recon Instruments	2015	175 million	Smart glasses			✓		
	Saffron AI	2015	Not disclosed	Cognitive computing platform					✓
	Lantiq	2015	Not disclosed	Broadband access and home networking technologies				✓	
	Basis	2014	100 million	Health tracker			✓		

Company acquiring	Company acquired	Year	Value (USD)	Acquired company's specialisation	Relevant for:				
					Edge AI	Connected and autonomous vehicles	Wearables	Smart home	Manufacturing
Samsung Electronics	Harman International Industries	2017	8 billion	Audio, visual and connectivity company	✓				
	Dacor	2016		Luxury home appliance				✓	
	Viv	2016	215 million	AI virtual personal assistant				✓	
	SmartThings	2014	200 million	Smart home and IoT applications				✓	
Micron Technology	FWDNXT	2019	Not disclosed	Deep learning	✓				
	Pico Computing	2015	Not disclosed	Deep learning	✓				
Qualcomm	CSR	2015	2.4 billion	End-to-end semiconductor and software solutions		✓			

Annex 3.A. Defining IoT firms in Crunchbase

As of May 2021, Crunchbase classified 10 384 firms as active in the IoT. However, as the IoT is a technology diffused to several sectors, complementary to other technologies and enabling diverse applications and use, the Crunchbase classification may leave out some IoT firms. To address this issue, a text search was carried out on the description of the firms' activities based on a set of keywords and their combinations (labelled IoT expressions) drawn from IoT-related patents.

The search returned 5 032 additional firms, of which 2 913 were retained as IoT firms after validation.

Annex Table 3.A.1. Top-20 IoT expressions used to identify IoT firms

IoT expressions	Number of start-ups
['iot']	1 493
['home automation']	316
['internet of things']	252
['smart city']	112
['smart grid']	99
['m2m']	83
['smart device']	61
['sensor technology']	59
['industry 4.0']	33
['industrial internet']	31
['iot', 'm2m']	30
['smart solution']	29
['iiot', 'iot']	28
['smart metering']	18
['industrial internet', 'industrial internet of things', 'internet of things']	17
['smart technology']	17
['smart lighting']	15
['internet of things', 'iot']	15
['smart home device']	11
Others	194
Total	**2 913**

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Note

[1] Following a different IoT semiconductor classification methodology, IoT Analytics estimates that the penetration of semiconductor components classified as IoT is expected to grow from 7% in 2019 to 25% by 2025 (2021[17]).

4 Case study on Internet of Things in manufacturing

This chapter presents the findings from two case studies on adopting the Internet of Things (IoT) in manufacturing in Brazil and Germany. The studies are intended to complement information from information and communication technology (ICT) usage surveys of the drivers and obstacles to IoT diffusion and the impact of IoT applications. Their findings aim to improve the evidence base for policy making in relation to manufacturing and to gain insights relevant to IoT applications in other domains.

This chapter discusses the main IoT applications in the manufacturing sector, where the current adoption of the IoT and the scope for further use seem among the highest. The drivers for IoT adoption and its effects on productivity are analysed based on two case studies of manufacturing firms in Brazil and Germany. Their findings provide a useful complement to the evidence from ICT usage surveys presented in Chapter 2.

Main uses of the IoT in manufacturing

Through the IoT, manufacturing processes can be improved in several ways. Sensor data from machinery can, for instance, help monitor the status of production equipment in real time and predict machine failure, thus enabling maintenance before the failure occurs (predictive maintenance); location sensors can track incoming supply and outgoing goods, thus enabling more efficient planning (tracking and monitoring); sensors provide manufacturers with a comprehensive view of what is occurring at every point in the production process, thus helping to make real-time adjustments (production optimisation*)* and monitor the inventory stock in real time, thus helping inventory optimisation. Smart meters and IoT sensors can monitor energy consumption and allow organisations to deploy practices for more effective usage of resources (energy/resource optimisation). An emerging use in manufacturing is the creation of digital twins, i.e. the exact reproduction through digital data of a physical object which allows to test processes first on the digital rather than on the real object, thus saving costs and resources.

Predictive maintenance

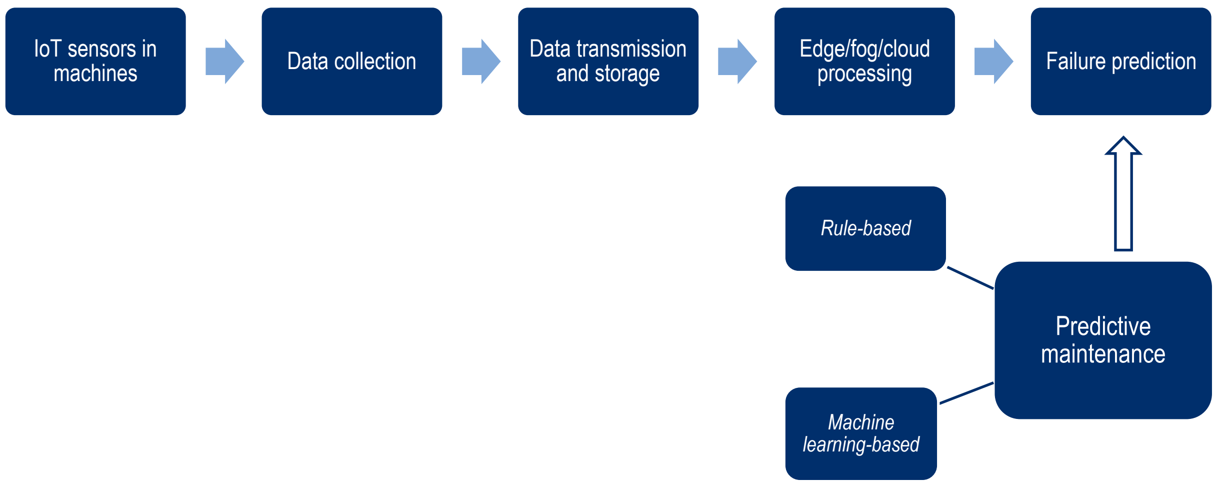
One of the most important use cases of Industry 4.0 is predictive maintenance. Predictive maintenance can identify maintenance issues in real time differently than traditional maintenance methods, which deal with machine failures as they emerge (reactive maintenance) or are based on asset inspections at regular times (preventive maintenance). In predictive maintenance, sensor data from machinery are used to determine failure ahead of time, thus allowing machine owners to reduce maintenance costs and downtime. Predictive maintenance can extend the lifespan of industrial assets, improve their utilisation and thus also production output. It also has the potential to promote sustainable practices in production by maximising the useful lives of production (Lee, Kao and Yang, 2014[1]).

The process of predictive maintenance is illustrated in Figure 4.1. IoT sensors in machinery collect relevant data, which are then transmitted by the IoT hardware to a central cloud system for storage and processing. Data scientists then have two general approaches to predictive maintenance analysis at their disposal: they can manually discover patterns in the data and define explicit databased rules for maintenance (rule-based predictive maintenance) or rely on machine learning (ML)-based predictive maintenance. In this case, the data science team needs to create a labelled dataset containing incidents of past machine failures in combination with other data. The algorithm can then be trained on this dataset and predict future machine failures. The predictions can then be integrated into a human-machine interface and help engineers find the ideal maintenance time.

The possibility of remotely controlling equipment and ensuring its maintenance through the prediction of failures also allows for the creation of new service-oriented business models, i.e. servitisation with remote monitoring and predictive maintenance enabled by the IoT. Equipment manufacturers can offer a payment model based on use, i.e. Hardware as a Service. This model would allow the creation of a data-centred (digitallybased) service value chain beyond the traditional product-centric value chain.

Predictive maintenance is not only used in smart manufacturing: industries relying on predictive maintenance include transportation, oil and gas and process industries. Infrastructure sectors, such as railway, adopt the IoT for real-time monitoring, predictive maintenance and on-demand component replacement to keep trains operating at all times, thus reducing the need for significant number of trains on standby to cover any unforeseen failures and maintenance issues.

Figure 4.1. From IoT sensors to machine failure prediction: IoT-enabled predictive maintenance



Source: Based on Nangia, S., S. Makkar and R. Hassan (2020[2]), "IoT based predictive maintenance in manufacturing sector", https://www.researchgate.net/publication/340443898_IoT_based_Predictive_Maintenance_in_Manufacturing_Sector.

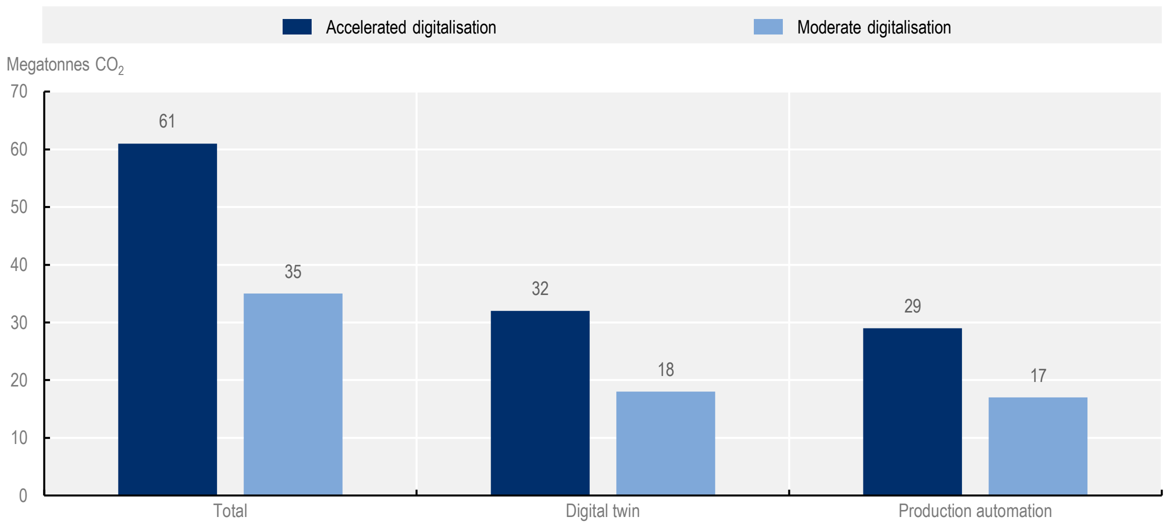
Production optimisation

In a standard quality control process, manufacturers produce an item, their quality control unit tests it and they hope to identify and rectify defects before the product reaches the market. The IoT makes this process proactive, with sensors collecting complete product data through different stages of the product cycle. The products can also be tested at each manufacturing step to check if their attributes are within specifications. In addition, monitoring manufacturing equipment helps quality control personnel check if and where equipment settings diverge from standards. The IoT's support in monitoring both equipment settings and the outcomes of each production step allows manufacturers to detect quality problems at the source so that measures for improvement can be taken early in the process.

More efficient energy use and reduced emissions

IoT sensors and smart meters allow organisations to measure the specific use of water, electricity and other resources and deploy practices for their more efficient use. In their study estimating the contribution of digital technologies to climate protection, Bitkom (2021[3]) – a German business association representing more than 2 700 digital economy companies – reports that the greatest potential for carbon dioxide (CO_2) savings is in the field of industrial production. The study estimates 2 scenarios: in one of accelerated digitalisation in 2030, up to 61 megatons of CO_2 can be saved, while in a scenario with a moderate digitalisation rate, savings go down to 35 megatons, corresponding to 16-10% of the expected emissions for industrial manufacturing processes in 2030 (Figure 4.2). Key technologies contributing to these results are production automation and digital twin; Industrial IoT (IIoT) is one of the main technologies contributing to their deployment.

Figure 4.2. Estimated potential CO_2 savings thanks to digital technologies in Germany



Note: Potential savings refer to industrial production in 2030.
Source: Bitkom (2021[3]), *Klimaeffekte der Digitalisierung – Climate Effects of Digitization*, https://www.bitkom.org/sites/main/files/2021-10/20211010_bitkom_studie_klimaeffekte_der_digitalisierung.pdf.

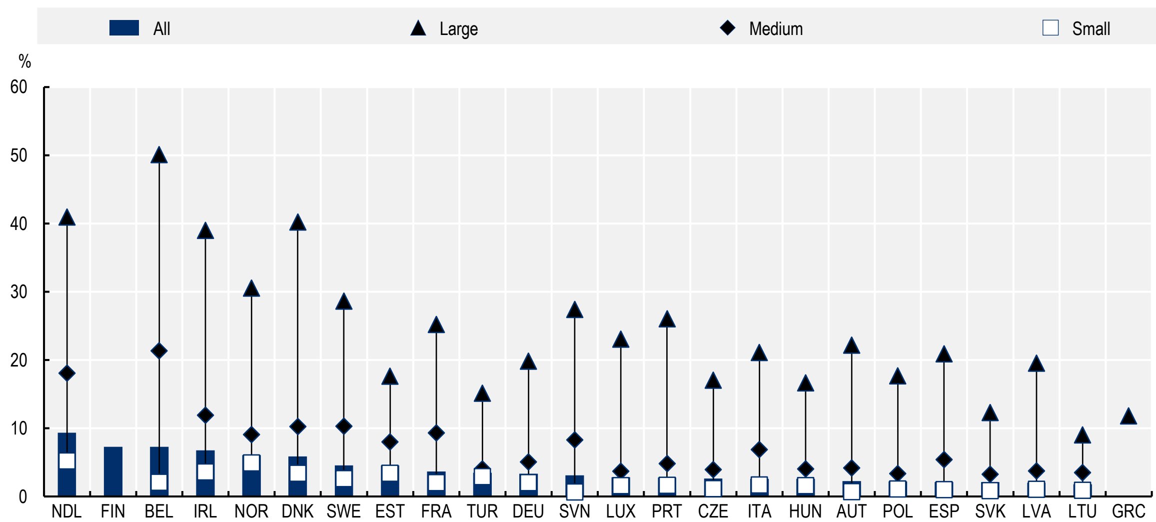
Use of the IoT in manufacturing: Current scenario

Data from the ICT Survey show that, on average, 31% of enterprises in the manufacturing sector in European countries and 22% in Canada have adopted IoT technologies, well below the energy sector, which leads with 47% in European countries (Figure 2.9) and 46% in Canada (Figure 2.6). On average, enterprises using the IoT in the manufacturing sector in European countries adopt this technology mainly to ensure their premises' security (76%), to monitor production processes and logistics (42%) and to optimise energy consumption (37%). Only one-fourth of enterprises using the IoT do so for condition-based maintenance and only about 11% to improve customer service. However, these figures conceal great differences across countries (Figure 2.10). Consistently, the same proportions in usage are reported for Italy by the Osservatorio Internet of Things (2021[4]), which found that in 2019 the most popular IoT applications in manufacturing were related to factory management (smart factories, 66% of cases), especially for real-time control of production and energy consumption. These were followed by applications focusing on the traceability of goods within the warehouse or along the supply chain (smart logistics, 27%), whereas smart lifecycle projects aimed at the optimisation of the development processes of new models and product updates were limited (7%) and still mainly at an early stage of deployment.

Eurostat data also confirm the early-stage integration of data analytics from IoT devices and the use of big data analytics by firms. Data sourced from smart devices and sensors are used only by 3.2% of enterprises in the manufacturing and energy sector, with some countries standing out in their use (about 10% of enterprises in the Netherlands and about 7% in Belgium and Finland). These numbers also conceal high discrepancies between firms of different sizes (Figure 4.3).

Market studies, such as the IoT Business Index 2020 carried out by the Economist Intelligence Unit and sponsored by leading semiconductor company Arm, indicate that scaling up adopted IoT solutions, both to add more connected products and systems or multiple cloud solutions and applications, is a key barrier for deployment (Forbes, 2020[5]). Nearly one-third of projects fail in the proof-of-concept stage (Microsoft, 2020[6]), with security and privacy risks, integration costs and lack of standards and interoperability being reported as the factors that slow down or halt the deployment of the IoT.

Figure 4.3. Share of businesses in the manufacturing and energy sector analysing big data from smart devices or sensors, selected European countries, by size, 2019



Note: Data for big data analysis by firm size are not available for the manufacturing sector only.
Source: Eurostat (2022[7]), *Comprehensive Database*, https://ec.europa.eu/eurostat/web/digital-economy-and-society/data/comprehensive-database (accessed on 1 February 2022).

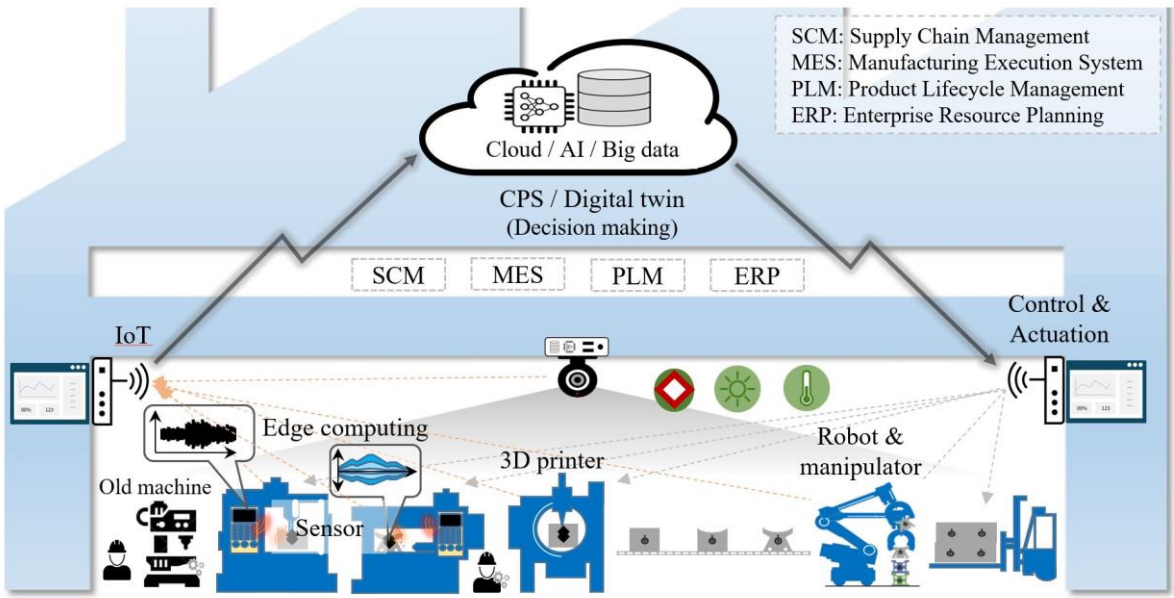
However, manufacturing is expected to lead in IoT adoption, given the high potential impact of IoT solutions in this sector. GSMA Intelligence (2019[8]) estimated that manufacturing businesses benefitted by USD 92 billion in 2018 in productivity gains from the use of the IoT, or 53% of the total estimated productivity benefits from the adoption of the IoT globally. Predictive maintenance applications have shown high potential for reducing costs: for example, Vodafone found that the IoT reduces costs among industrial adopters by 18% on average and increases uptime and productivity (OECD, 2017[9]).

IIoT as an enabling technology of Industry 4.0

The IoT is one of the main drivers of digital transformation in the manufacturing sector and one of the key enabling technologies of Industry 4.0. The latter is often considered a synonym of the IIoT, although Industry 4.0 is a broader concept which relies on the adoption of several technologies, such as cyber-physical systems (CPS), the IoT, big data, artificial intelligence (AI), cloud and edge computing, virtual and augmented realities (Figure 4.4). Smart factories use those technologies to move the production process from traditional automation to a fully connected, flexible and optimised system and design customised products at mass production prices. Industry 4.0 includes horizontal integration of data flow between partners, suppliers and customers, as well as vertical integration within the organisation's borders – from development to final product. The result is a system in which all processes are fully integrated with information in real time and the speed and rate of changes in consumer trends acts as a driver.

The digital transformation of the manufacturing sector is high on the political agenda and several countries have introduced policies to support advancement towards Industry 4.0. Starting with Germany and the launch of Industrie 4.0 in 2011, leading economies such as Japan (Society 5.0), the United States (Industrial Internet Consortium) and the People's Republic of China (Made in China 2025) have adopted initiatives to support the digitalisation of manufacturing. As of 2017, 15 European Union countries had adopted initiatives for digitising industry (EC, 2017[10]). Smart factories are central to the Korean government's plan for the Fourth Industrial Revolution (Box 4.1). Industry 4.0 is also one of the strategic verticals of the Brazilian Internet of Things Plan. Support for investment in Industry 4.0 has received new impetus as part of the national recovery and resilience plans in the European Union. In Italy, for instance, the Transition Plan 4.0 foresees an investment of EUR 24 billion up to 2022.

Figure 4.4. Combination of digital technologies for the smart factory



Source : Jung, W. et al. (2021[11]), "Appropriate smart factory for SMEs: Concept, application and perspective", https://doi.org/10.1007/s12541-020-00445-2.

Since 2016, the World Economic Forum (WEF) and consulting firm McKinsey & Company have tracked the frontrunners in advanced manufacturing: as of March 2021, there were 69 such "lighthouses" in the world (WEF, 2021[12]) operating across industry sectors. These factories employ a range of digital technologies, reporting positive impacts on cost reduction, equipment efficiency, energy savings and productivity gains, among others, to which IIoT also contributes (Table 4.1).

Table 4.1. Selected examples of impacts of IoT use in lighthouse factories

Company	Country/ Economy	Industry	Description	Detail on IoT use	Impact	IoT use function
Micron	Chinese Taipei	Semiconductors	Micron's high-volume advanced semiconductor memory manufacturing facility developed an integrated IoT and analytics platform, ensuring that manufacturing anomalies can be identified in real time while providing automated root cause analysis to accelerate new product ramp-up by 20%, reduce unplanned downtime by 30% and improve labour productivity by 20%.	• IIoT real-time energy data aggregation and reporting dashboard	• 15% reduction in energy consumption	• Energy efficiency • Production optimisation

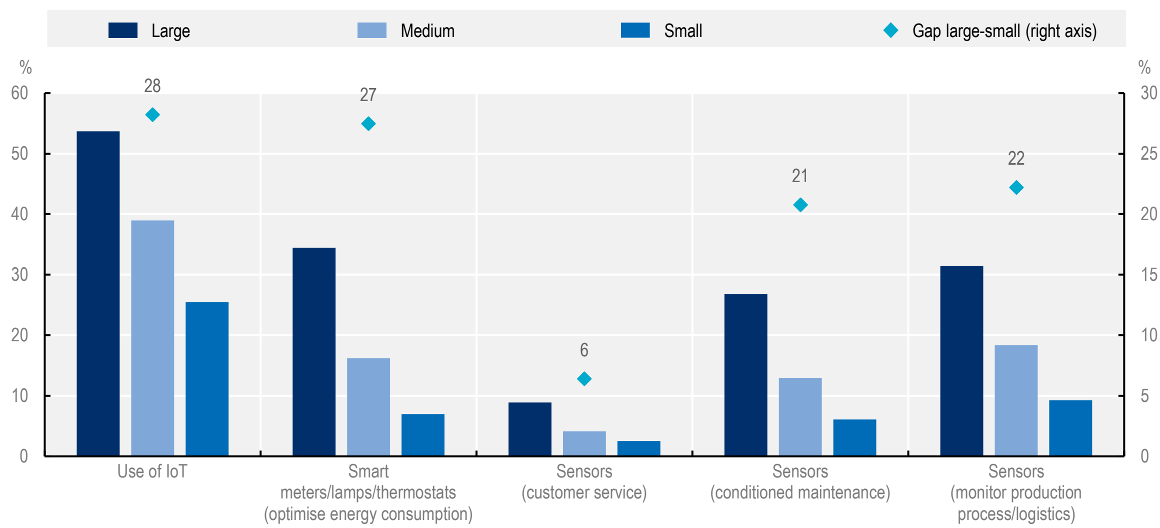
Company	Country/ Economy	Industry	Description	Detail on IoT use	Impact	IoT use function
Novo Nordisk Device Manufacturing & Sourcing	Denmark	Pharmaceuticals	Novo Nordisk has invested in optimisation, automation and advanced analytics, building a robust IIoT operating system to be scaled across their manufacturing footprint, increasing equipment efficiency and productivity by 30%.	• Automated overall equipment effectiveness data collection	• 7% increase in productivity	• Equipment monitoring • Real-time data collection
Saudi Aramco	Saudi Arabia	Gas treatment	The Khurais oil field was built as a fully connected and intelligent field, with over 40 000 sensors covering over 500 oil wells spread over 150 x 40 km. This enabled autonomous process control, remote operation and monitoring of equipment and pipelines, resulting in the maximisation of oil well production, with at least 15% attributed to smart well completion technology alone.	• Advanced IIoT applied to process optimisation • Cost optimisation of heavy operations through sensor analysis	• 5% increase in oil production • 50% increase in workforce productivity	• Process optimisation
Ericsson	United States	Electronics	Ericsson built a US-based, 5th generation mobile network (5G)-enabled digital native factory. Leveraging agile ways of working and a robust IIoT architecture, the team was able to deploy 25 use cases in 12 months and, as a result, increased output per employee by 120% and reduced lead time by 75% and inventory by 50%.	• 5G sensor-based data collection for energy management • Digital twin for remote production optimisation	• 97% reduction in CO_2 emissions • 8% increase in efficiency	• Production optimisation • Energy efficiency
Hitachi	Japan	Industrial equipment	By leveraging a range of IIoT technologies and data analytics in engineering, production and maintenance operations, Hitachi Omika Works has reduced the lead time of core products by 50% without impacting quality.	• Digitally enabled operator performance management and equipment performance management • IoT infrastructure for control systems • Digital twin to simulate customer systems	• 50% reduction in production lead time • 30% increase in capacity • 70% increase in inspection efficiency	• Production optimisation • Monitoring

Note: The solutions described in the table are enabled by a range of digital technologies; results are only reported for specific uses of the IoT, while results from other technologies are not shown.

Sources: Compilation based on WEF (2019[13]), *Global Lighthouse Network: Insights from the Forefront of the Fourth Industrial Revolution*, http://www3.weforum.org/docs/WEF_Global_Lighthouse_Network.pdf; WEF (2020[14]), *Global Lighthouse Network: Four Durable Shifts for a Great Reset in Manufacturing*, https://www.weforum.org/whitepapers/global-lighthouse-network-four-durable-shifts-for-a-great-reset-in-manufacturing (accessed on 29 January 2021); WEF (2021[12]), *Global Lighthouse Network: Reimagining Operations for Growth*, http://www3.weforum.org/docs/WEF_GLN_2021_Reimagining_Operations_for_Growth.pdf.

Figure 4.5. Use of IoT devices in the manufacturing, energy and construction sectors in selected European countries, by firm size, 2021

As a percentage of enterprises with ten or more employees



Note: Weighted average of European countries for which data are available, as shown in Figure 2.1. Sectors included are manufacturing, electricity, gas, steam and air conditioning supply, water supply and construction.
Source: Eurostat (2022[7]), *Comprehensive Database*, https://ec.europa.eu/eurostat/web/digital-economy-and-society/data/comprehensive-database (accessed on 1 February 2022).

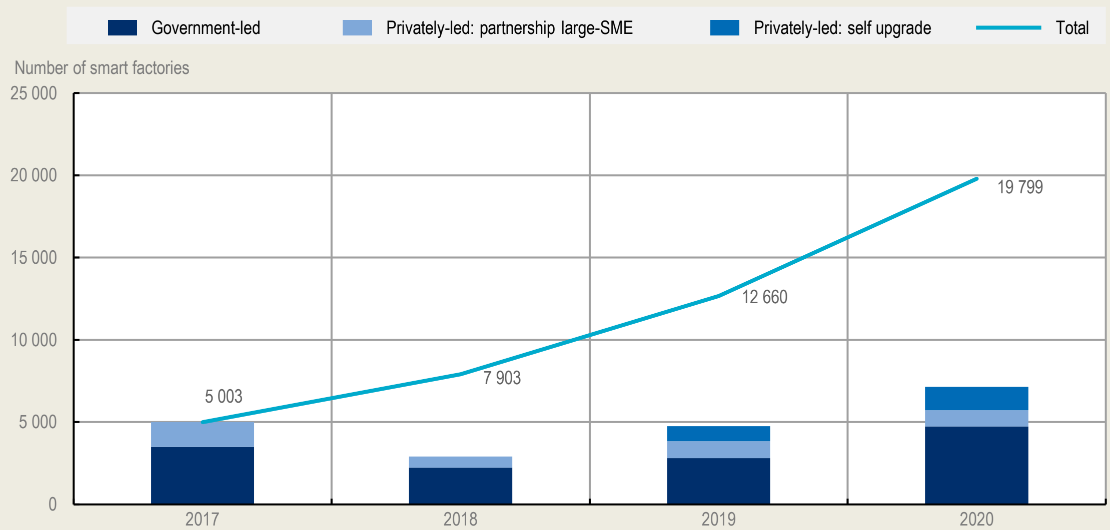
Lighthouses embody the highest advancements in the implementation of Industry 4.0 technologies. However, they are not representative of the degree of diffusion of digital technologies in firms across the spectrum of different sizes. Taking the IoT only, in Canada, there is a gap of about 25 percentage points between small and large firms (Figure 2.6), while in Korea, there are about 23 percentage points (Figure 2.7). The low level of digitalisation of Korean small and medium-sized enterprises (SMEs) has been tackled since 2014 by the government through the Korea Smart Factory Initiative (Box 4.1).

Although data for the manufacturing sector only do not exist for European countries, aggregate data for manufacturing, energy and construction sectors suggest that severe gaps exist between large and smaller companies, as high as 27 percentage points for the overall use of IoT devices (Figure 4.6). Furthermore, while large and medium companies in the manufacturing, energy and construction sectors use IoT devices (for the different surveyed uses) on average at a higher rate than in other sectors, smaller firms lag behind as compared to their counterparts in other sectors.

Box 4.1. The Korea Smart Factory Initiative: Supporting SMEs to adopt digital technologies in manufacturing

In 2014, the Ministry of Trade, Industry and Energy (MOTIE) launched the Korea Smart Factory Initiative as part of the Manufacturing Industry Innovation 3.0 strategy. The initial goal was to build 10 000 smart factory sites for Korean SMEs (firms with more than 10 employees) by 2020, then revising this goal to 30 000 by 2022 (out of total 67 000 SMEs in the country). The Smart Factory Initiative represents the main government instrument to assist Korean SME manufactures with funding, technology development and know-how to adopt digital manufacturing practices. The initiative is implemented through two methods: government support or large corporation voluntary support. At the end of 2020, Korea had 19 799 mostly government-led smart factories (Figure 4.6).

Figure 4.6. Smart factories in Korea by method of support, 2017-20



Source: Ministry of SMEs and Startups of Korea (2021[15]), *Key Achievements of Smart Factories in 2020.*

Korea distinguishes four levels of development towards a smart factory (Table 4.2). In 2020, most SMEs were at the Basic or Intermediate I level (74.5% and 23.7% respectively), only 1.8% were at the Intermediate II level and none of the SMEs had reached the Advanced level.

Table 4.2. Levels of smart factory

Development stage	Korea	Germany	Goal	Main ICT tools
Basic	Level 1 – Identify	Lv 1-Lv2	Construct the information system to identify materials	Barcodes and radio frequency identification (RFID)
	Level 2 – Monitor		Gather and monitor in real time data from the workforce, machines, equipment and materials	Sensors
Intermediate I	Level 3 – Analyse	Lv 2-Lv3	Control, measure and analyse data collected in Level 2	Sensors and analysing tools
Intermediate II	Level 4 – Optimise	Lv 4-Lv5	Gather, analyse and simulate data to optimise the production process (workforce, machines, equipment, materials, operating conditions)	Sensor controller optimisers
Advanced	Level 5 – Customise	Lv5	Customise the production process by optimising the workforce, machines, equipment, operation and environment conditions	AI, augmented reality/virtual reality, CPS

Source: Adapted from Smart Factory Korea (2021[16]), *Introduction to Smart Factory*, https://www.smart-factory.kr/smartFactoryIntro.

The performance of the SMEs supported by the programme is estimated to be good, as their productivity increased, while product defect rate, production cost and delivery time were reduced. It is estimated that private support by large companies performed better than government support (Table 4.3).

Table 4.3. Performance of the Korea Smart Factory Initiative, by support method (%)

	Productivity increase	Decrease in defect rate	Cost reduction	Shortening of delivery time
SMEs supported by large companies	49.5	48.7	26.2	21.4
SMEs supported by the government	28.0	44.8	14.0	16.1

Source: Yu, J. (2018[17]), "Korea Smart Factory Initiative", Colloquium on Digital Industrial Policy Programme, 12 November 2018.

Based on a review of existing surveys of SMEs in a number of countries (mostly European), Rauch, Erwin and Dominik (2021[18]) found that the IIoT is the third technology mostly adopted by SMEs among the technologies of Industry 4.0 (Table 4.4). However, SMEs limit their adoption of the IIoT (and Industry 4.0 concepts) to monitoring industrial processes (Moeuf et al., 2018[19]) without real applications in production planning and without real changes in the business model. SMEs mostly invest in the IIoT by retrofitting legacy equipment with actuators and sensors for data collection and introducing machine and process control systems to monitor the status of manufacturing systems in real time. In most cases, data analytics is based on simple and commercially available data monitoring and analysis tools, while the use of ML or more complex AI technologies is still in its early stages.

Case study: Objective and data collection

While ICT usage surveys provide information on the diffusion of the IoT in manufacturing, statistical evidence on the uses and effects of IoT adoption is still limited. The objective of the two case studies presented here is to gain a richer understanding of the uses of the IoT in the manufacturing sector, the main functions the IoT is used for and the related impacts. Therefore, the nature of these case studies is qualitative as they are not intended to represent all IoT manufacturing firms.

The case studies provide an in-depth analysis of IoT use in a small sample of small, medium and large manufacturing firms in Brazil and Germany, based on available information and complemented by interviews. The criterion for firm selection is the implementation of an IoT solution (devices and system) in order to perform at least one of the following functions:

- tracking and monitoring
- predictive maintenance
- production optimisation
- energy/resource optimisation
- product customisation/feedback from customers.

In order to have different complementary technologies, sectors and enterprise sizes, several examples are included for the same IIoT function.

The case studies provide a technical description of the solution adopted, describe the implementation process and analyse the value for the company. They also provide a description of the company together with background information, e.g. size, location and industry.

During the interviews, the following questions were asked:

- Was the investment in the IIoT (or the implementation of the IIoT technology) triggered by a specific need, e.g. client request/production or process improvement?
    - If yes, which one?
- Was the IIoT the specific focus of the digital investment, or was it just a component of a larger digitalisation toolkit (e.g. with AI, cloud computing, big data analysis)?
    - If yes, why?
    - If not, why does the IIoT represent strategic importance?
- What other digital technologies are used to complement the IIoT solution? (e.g. three-dimensional [3D] printing, AI …)?
- How was the technology upgrade implemented: retrofitting or investment in new machinery?
- What were the types of effort needed, e.g. in terms of skills?
- Did the company rely on any public support for the implementation (advisory or financial)?
- What was the cost of the solution (also expressed in magnitude)?
- Does the firm track the benefits of the IIoT solution implemented (specifically)?
- What are the benefits of the IIoT (if possible quantitative, otherwise based on a qualitative assessment)?
- What connectivity solution was adopted and why?
- What are the positive lessons learned from the implementation (e.g. benefits)?
- What are the negative lessons learned from the implementation (e.g. obstacles)?

Results from the case study in Germany

Background on the IIoT in Germany

Manufacturing industries play a key role in the German economy, as some 15 million jobs depend directly and indirectly on this sector. In the overall economy, SMEs account for more than 99% of companies and 60% of jobs (BMWK, 2019[20]). Some of these SMEs are global market leaders in their product segments and are essential drivers for innovation and technology diffusion. Unlike other large European economies such as France and the United Kingdom, corporations play a less important role in the German industry: among the largest 10 000 industrial firms in Germany, 39% are family-owned (Die Deutsche Wirtschaft, 2021[21]). These firms – SMEs and, to some extent, larger family-owned enterprises – constitute the so-called German Mittelstand (German middle class).

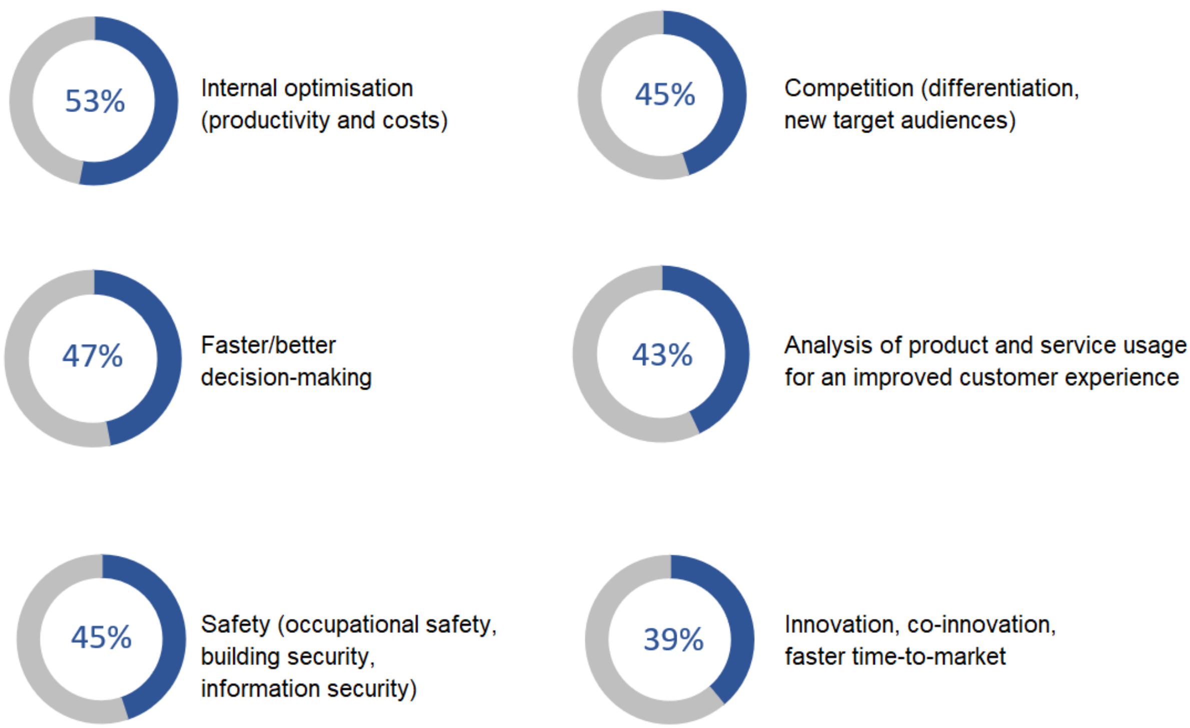
German industry, however, is less advanced in digital transformation than other sectors such as ICT, finance and services (DIHK, 2021[22]). Given the strong economic role of the Mittelstand, public support is provided to enhance their digital transformation, e.g. Mittelstand Digital and Mittelstand 4.0 competency centres.

Industry 4.0 is the focus of the federal government's digital agenda. It involves using ICT in the production process to enable autonomous components' communication with the production equipment, orders of new material or maintenance services. This means that humans, machines and industrial processes are intelligently connected (BMWK, 2020[23]). Therefore, the IIoT and Industry 4.0 are often used interchangeably.

Public support for IIoT uptake includes showcases about the IoT potential for SME users as well as smart factory labs where firms can experiment with new production processes enabled by the IoT. Experts from Mittelstand 4.0 agencies act as multipliers and transfer IoT-related know-how through various channels, e.g. workshops, training and networking events. In addition, several programmes provide funds for research and innovation in the IIoT, in particular the Automatics for Industry 4.0 and the Smart Services World with a fund of about EUR 100 million each (BMWK, 2020[23]). Various public funds support the financing of innovative start-ups at the federal and state levels (BMWK, 2020[24]).

A recent study (IDC, 2020[25]) provides insights into IIoT uptake by German firms with 100 employees and more. It shows that IIoT implementation is strategically motivated by its potential to optimise productivity and costs, speed up and improve decision-making processes and differentiate from competitors (Figure 4.7).

Figure 4.7. Key objectives of IIoT projects in German firms

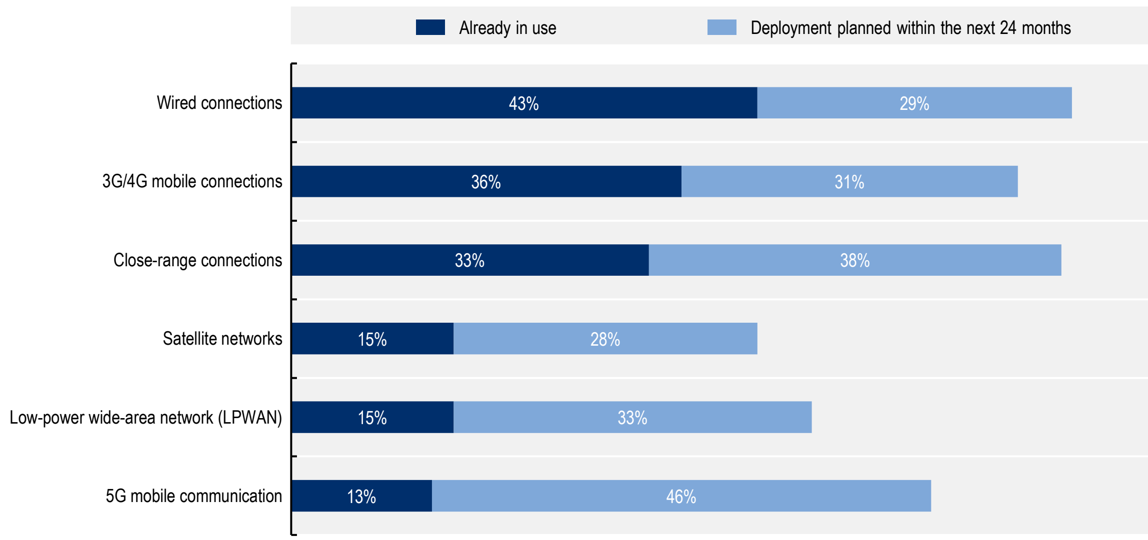


Note: N = 254; multiple answers possible; abbreviated.
Source: IDC (2020[25]), *Industrielles IoT in Deutschland 2021 – Innovative Technologien und Trends für IIOT [Industry IoT in Germany 2021 - Innovative technologies and trends for the IIoT]*, IDC Central Europe GmbH.

With regard to connectivity, those IIoT projects deploy a mix of different technologies. Fixed connections play a major role at present but wireless connections are increasingly important, with 59% of IIoT projects using or planning to use 5G (Figure 4.8).

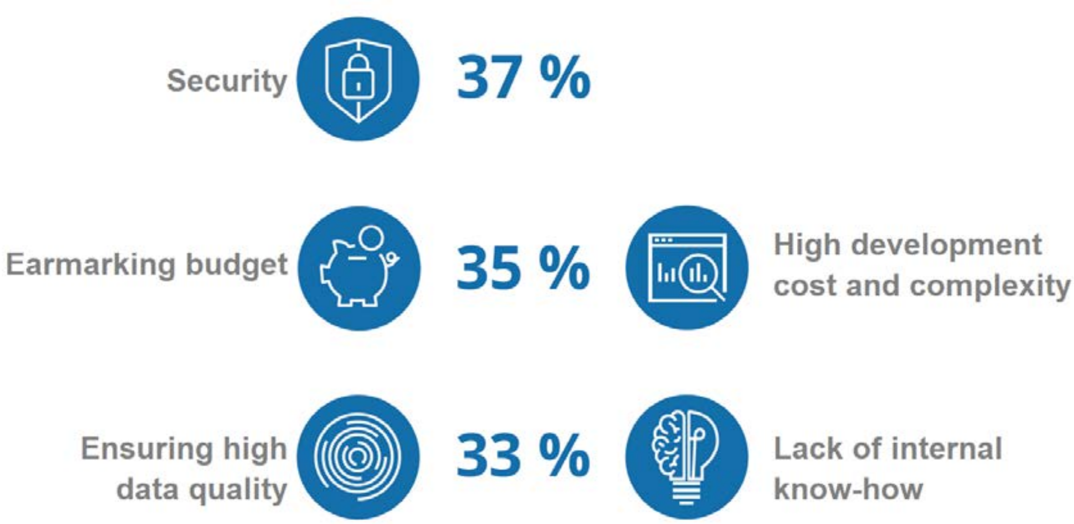
More than one-third of companies see major challenges in implementing the IIoT in the fields of security, financing, data quality and complexity of the projects (Figure 4.9). Moreover, they point to a lack of internal know-how.

Figure 4.8. Connection types used in IIoT projects in German firms



Note: N = 254; multiple answers possible; abbreviated.
Source: IDC (2020[25]), *Industrielles IoT in Deutschland 2021 – Innovative Technologien und Trends für IIOT [Industry IoT in Germany 2021 - Innovative technologies and trends for the IIoT]*, IDC Central Europe GmbH.

Figure 4.9. Top five obstacles to IIoT uptake in German firms



Note: N = 254; without "Don't not"; abbreviated.
Source: IDC (2020[25]), *Industrielles IoT in Deutschland 2021 – Innovative Technologien und Trends für IIOT [Industry IoT in Germany 2021 - Innovative technologies and trends for the IIoT]*, IDC Central Europe GmbH.

Industrial IoT in Germany: Case studies and lessons learned

Overview

The next sections present the findings from the analysis of a set of IIoT providers and IIoT-using firms. The analysis aims to provide insights into the potential, challenges and benefits of the IIoT. Firms were selected so as to cover different characteristics, as detailed in Box 4.2, and based on desk research and experts' views. While covering different firms' characteristics, the set of firms selected should not be regarded as representative of the whole German industry.

Box 4.2. Firms' characteristics considered in the selection process

1. Role in the IIoT
   - industrial enterprise/user
   - enabler/solutions provider
2. Technological focus/industry
3. Geographical market (sales market)
   - national
   - international
4. Company size
   - small (less than 49 employees)
   - medium (49-250 employees)
   - large (more than 250 employees)
5. Experience in the IoT
   - early adopter (5-10 years)
   - IoT pioneer (more than 10 years)
6. Strategic objectives of IoT implementation (referring to the user)
   - enhance customer service
   - optimise internal processes
   - develop new business models.

Based on the above-mentioned criteria, a long list of 60 companies was established and a total of 35 candidates approached. Finally, a set of nine firms were selected, consisting of five IIoT providers and four IIoT-using firms, based on the above-mentioned search criteria and their availability for an interview.

The set of IIoT providers includes two large companies (LAP and q.beyond), a medium-sized company (TELOGS) and two small companies, one with a long-standing experience in the IIoT (Schildknecht) and one start-up (PANDA). These firms cover a range of different technologies, e.g. retrofit, AI, laser.

In the selection process of IIoT-using firms, SMEs were found either without sufficient maturity for IIoT solutions or for tackling more urgent issues such as supply chain interruptions or excess demand following the COVID-19 pandemic. Therefore, the analysis has focused on firms with 250 employees and above. The largest company included in the set is TRUMPF GmbH & Co. KG, one of the top 100 industrial enterprises and the leading firm in machinery and plant engineering in Germany (Die Deutsche Wirtschaft, 2021[21]). The other two firms in the selection, Siegwerk and Wanzl, belong to the largest family-owned industrial enterprises. The fourth company, Kreyenberg, is a family-owned industrial enterprise that moved into industry from the craft business.

In-depth interviews (about 60 minutes) were carried out with all 9 companies about their company background, the strategic role of the IoT for their businesses and their experiences with regard to the potential and challenges of the IoT, costs and benefits, as well as success factors for IoT uptake.

Table 4.4. Main characteristics of the German firms selected for the case study in manufacturing

Company	Role in the industrial IoT	Technological focus/industry	Geographical market	Company size	Experience in the IoT	Strategic objectives of IoT implementation
Kreyenberg GmbH	Industrial enterprise/ user	Machining/ Supplier	National	Medium	Early adopter	• Enhance customer service • Optimise internal processes • Develop new business
Siegwerk Druckfarben AG & Co. KGaA	Industrial enterprise/ user	Manufacturing of print=s, inks and coatings for packaging	International	Big	Early adopter	• Enhance customer service • Optimise internal processes • Develop new business
TRUMPF SE & Co. KG	Industrial enterprise/ user	Manufacturing of machine tools, laser technology and electronics for industrial applications	International	Big	IoT pioneer	• Enhance customer service • Optimise internal processes • Develop new business
Wanzl GmbH & Co. KgaA	Industrial enterprise/ user	Manufacturing of shopping and luggage transport trolleys	International	Big	Early adopter	• Enhance customer service • Optimise internal processes • Develop new business
LAP GmbH Laser Applikationen	Enabler/ solutions provider	Laser projection for worker guidance in manufacturing industries	International	Big	Early adopter	• Optimise customer processes
PANDA GmbH	Enabler/ solutions provider	AI-based IoT solutions for production processes	National	Small	Early adopter	• Optimise customer processes
q.beyond AG	Enabler/ solutions provider	IoT edge solutions	National	Big	IoT pioneer	• Optimise customer processes • Develop new business models
Schildknecht AG	Enabler/ solutions provider	Wireless IoT solutions	International (Europe)	Small	IoT pioneer	• Optimise customer processes
TELOGS GmbH	Enabler/ solutions provider	Intralogistics	International	Medium	Early adopter	• Optimise customer processes

Main findings

The interview findings provide useful insights into the drivers, obstacles and benefits of IoT uptake by manufacturing firms in Germany. Further information about case study findings is provided in Annex 4.A.

The **strategic objective** for IIoT uptake most frequently reported is to optimise production processes and/or strengthen customer relationships:

- In large firms, IoT uptake is part of a broader digital transformation strategy and aims to achieve both objectives. Smaller firms tend to implement narrower projects with a more operational focus.
- Many firms also regard the IoT as having the potential to enable new business models.
- The motivation and opportunities to adopt the IoT are strongly firm-specific. In particular, uptake is higher among firms facing challenges for which a ready-made IoT solution is available.

IIoT uptake depends on firms' size, sector and business model:

- Small companies have limited resources to start and undertake IoT projects. They do not have the skilled staff or even a dedicated department for digitalisation: a digitalisation expert is typically employed in companies with at least 250 employees. Therefore, they often lack sufficient inhouse expertise to assess the potential of the IoT and manage its implementation.
- The type of IoT devices and applications adopted are strongly influenced by the sector in which firms operate, e.g. hazard detection in the chemistry sector, radio interference in metal companies. In addition, sector-specific standards and processes affect IoT adoption in firms.
- Industrial production processes and machine parks, which are at the core of IIoT solutions, differ significantly from company to company with regard to the level of automation, supported applications, level of standardisation and age of the machines in place.
- Data represent both a driver and a precondition for many IIoT solutions: the more data are available to the using firm and the better their quality, the higher the potential benefits from many IoT solutions.

Costs are a significant hurdle, especially in smaller companies with their limited budgets:

- Firms' interest in the IIoT competes with other important projects and day-to-day business activities in terms of time and resources.
- IIoT providers with a specific focus on SMEs offer solutions to meet their needs, e.g. simple and fast IoT solutions at a fixed price that can be expanded at a later stage.
- Public funds for training, trials and financial support are essential to lower barriers for SMEs to define and implement IoT projects.

As a positive cost-benefit balance is key to driving IIoT uptake, **benefits need to be identified**:

- For some specific IoT solutions, positive effects are easy to trace, e.g. remote monitoring can reduce travelling up to 100% and results in measurable cost reductions.
- However, a cost-benefit analysis is hardly feasible for most IIoT solutions, e.g. AI-based IoT for predictive maintenance, which are implemented within complex and constantly changing systems.
- Early adopters are typically convinced about the positive effects of the IIoT on efficiency and competitiveness. They have learned to assess the "broader picture" of IIoT adoption rather than the effect of single IoT solutions. They also report a positive contribution of the IIoT to address pressing challenges, e.g. maintaining production running despite a shortage of skilled workers. The positive feedback from these companies typically serves as an incentive for new IIoT adopters.

Technical and operational aspects can be a challenge for IIoT implementation:

- Digital security and data protection concerns are among the major barriers to IIoT uptake. These concerns are even stronger for the IoT than for other ICT tools due to the much larger number of connected devices. While digital security and data protection issues tend to be neglected by firms at the early stage of IoT adoption, they become an obstacle to further deployment.
- Interoperability and scalability also play an important role. Many firms prefer flexible, scalable and versatile solutions which can be easily integrated into the user's technical systems. Technology-neutral solutions are preferred by many enterprises that use different technical standards and interfaces.

- Some firms employ machinery whose design and installation are highly customised, thus making their replacement costly. Instead of replacing old machinery with new ones equipped with the IoT devices, firms, especially SMEs, tend to rely on retrofit solutions, with the old machinery remaining in operation while IoT solutions are plugged in.

Finally, **soft factors play an important role** in IoT uptake:

- Decision makers' positive attitude towards innovative technologies is essential. It sets the precondition to drive IoT adoption.
- An open-minded corporate culture also facilitates the implementation of the IoT.
- The involvement of employees increases the probability of success of the IoT. Workers' concerns about the IoT should be addressed from the beginning. Also, it is important to show the potential benefits of IoT solutions and provide training for all employees involved in the process.

Results from the case study in Brazil

Background on IIoT in Brazil

This section[1] presents an overview of the manufacturing industry[2] in Brazil. It also includes evidence on the use of ICT in Brazilian companies, so as to assess the technological readiness of the Brazilian economy in general and that of manufacturing companies.

Since the 1990s, the economic weight of the manufacturing sector has been declining in Brazil. In 1985, the sector accounted for 36% of gross domestic product, whereas it only represented 11.3% in 2021.

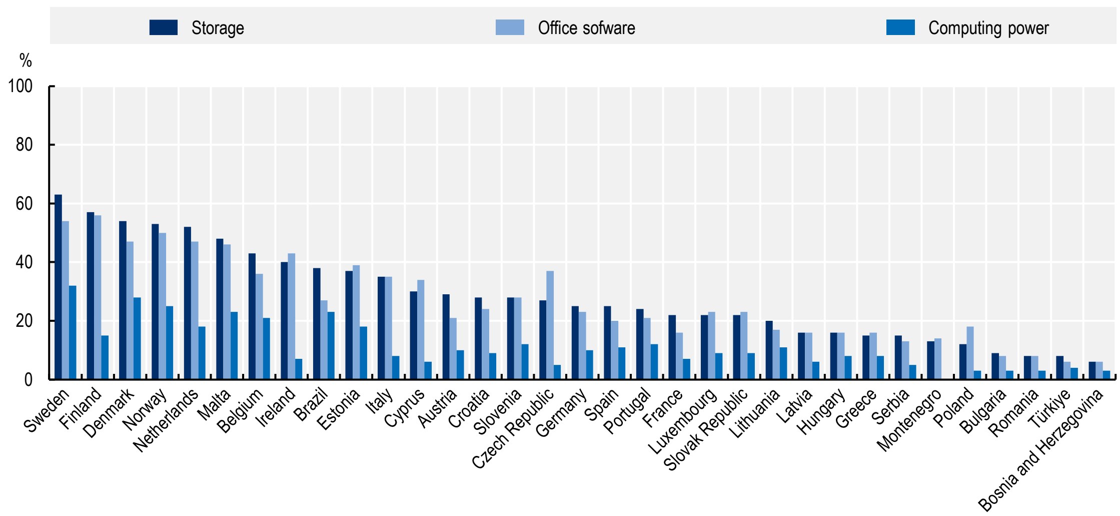
The manufacturing industry is labour-intensive in Brazil. In 2020, the sector had 6.9 million formal employment contracts, corresponding to 14.8% of the total number of contracts. Industrial activities in Brazil have been traditionally concentrated geographically along the South-Southeast axis, in particular in the state of São Paulo, although concentration has decreased over the last decade. In terms of socio-economic and demographic indicators, the South and Southeast regions present a higher level of social and economic development and host a large portion of the Brazilian population. Regarding ICT adoption, over the last decade, there has been a significant increase in basic connectivity among Brazilian enterprises, with most companies having Internet connections via fibre optics. However, using ICT is far from widespread, a decisive factor in their overall performance. For instance, although most companies use ICT in their everyday tasks, only 54% have a website and 36% pay for online advertising.[3]

Broadband access via fibre connections is available in all Brazilian regions. In 2019, 67% of all firms with Internet access had a fibre connection. In the South and Southeast regions, where manufacturing is concentrated, this share was 66% and 69% respectively. However, 91% of large firms in Brazil had a fibre connection against only 65% of small ones (CGI.br, 2020[26]). The availability of fibre connections makes it possible for firms to access fast-speed Internet, a key feature for the adoption of the IoT: in 2019, 70% of Brazilian firms reported download speeds of over 10 Mbps (CGI.br, 2020[26]).

Cloud computing is another key requisite for the large-scale use of the IIoT. Indeed, the need to process and store large volumes of data in real time and with high speed requires companies to use cloud services to optimise their processes. The available evidence suggests that Brazil occupies an intermediate position in comparison to European countries (Figure 4.10).

In 2021, 14% of Brazilian enterprises reported using smart devices or IoT applications, a proportion that was higher among large enterprises (21%). The use of the IoT was lower in manufacturing (11%) relative to information and communication (36%) and real estate, professional, scientific and technical, and administrative and support service activities (18%). Among manufacturing firms, the main purpose for using IoT sensors and smart devices was to support security (86%) and energy consumption (51%). Applications directly connected to production processes were less mentioned (46%) (CGI.br, 2022[27]).

Figure 4.10. Use of cloud computing services in enterprises with Internet access, Brazil, 2019, and European countries, 2020



Sources: CGI.br (2020[26]), *ICT Enterprises 2019: Survey on the Use of Information and Communication Technologies in Brazilian Enterprises*, https://cetic.br/en/pesquisa/empresas/indicadores/; Eurostat (2022[7]), *Comprehensive Database*, https://ec.europa.eu/eurostat/web/digital-economy-and-society/data/comprehensive-database (accessed on 1 February 2022).

Industrial IoT in Brazil: Case studies and lessons learned

Overview

The case study in Brazil comprises in-depth interviews[4] with six IIoT-using enterprises in the manufacturing sector and four IIoT-supplying enterprises, complemented by further company information. The interviews were conducted on line between 23 February and 27 April 2022.

The process of selection and invitation of the enterprises were supported by recognised organisations in the field, such as the Centre for the Fourth Industrial Revolution (C4IR Brazil)[5] and the Brazilian Industrial Internet Association (ABII).[6] Field data collection was co-ordinated by Cetic.br/NIC.br, with the support of an outsourced research company (Ipec). All results were transcribed (in Portuguese) for supporting analysis.

Most of the IIoT providers are small companies involved in the integration of sensor parts, installation of devices and data analysis for customers. There was greater diversity for IIoT-using enterprises, with companies of different sizes and economic activities. Due to the geographic distribution of manufacturing activities in Brazil, most enterprises interviewed were in the South and Southeast regions of the country. Table 4.5 shows the main characteristics of the enterprises studied.

Table 4.5. Main characteristics of the Brazilian firms selected for the case study in manufacturing

Company	Role in the industrial IoT	Technological focus/industry	Geographical market	Company size	Experience in the IoT
Ergomais	Industrial enterprise/user	Manufacturing of ergonomic products	National	Small	Starter
ASW Brasil Tecnologia em Plástico	Industrial enterprise/user	Manufacturing of power grid distribution components	International	Small	Starter

Company	Role in the industrial IoT	Technological focus/industry	Geographical market	Company size	Experience in the IoT
Selco Tecnologia	Industrial enterprise/user	Manufacturing of compressors and automotive parts	International	Medium	Starter
Indústrias Mangotex Ltda	Industrial enterprise/user	Rubber components for the automotive industry	International	Large	Early adopter
Rochel Ferramentaria Ltda	Industrial enterprise/user	Machinery devices	National	Small	Starter
Embraer	Industrial enterprise/user	Aviation	International	Large	Early adopter
Hedro Sistemas Inteligentes	Enabler/solution provider	Firmware IoT solutions	National	Small	Early adopter
HarboR Informática Industrial Ltda	Enabler/solution provider	Cloud and data IoT and AI solutions	International	Small	Starter
AIQuatro	Enabler/solution provider	Firmware, cloud and data IoT and AI solutions	National	Small	Starter
Dynamox SA	Enabler/solution provider	Firmware, cloud and data IoT and AI solutions	International	Medium	Early adopter

Main results

The following section presents the main findings from the interviews as well as further information from the studied cases. The dimensions covered by the questionnaire were divided into four parts: i) implementation and solutions; ii) connectivity and technologies; iii) perceived benefits and barriers; and iv) lessons learned. Further details about the case studies' findings are provided in Annex 4.B.

Implementation and solutions

Most IIoT implementation projects in the firms studied were in an early phase. The projects were limited to only some of their machines in order to evaluate the opportunity to enlarge the use of these technologies. Although most enterprises stated that the cost of installing sensors in their machines was modest, they were quite reluctant to scale up their use.

In general, respondents reported that the implementation of IIoT solutions brought benefits to enterprises, in particular in functions related to predictive maintenance. Energy efficiency or production automation solutions were rarely mentioned and there was no mention of uses related to quality control or product customisation. Therefore, among the enterprises interviewed, the IIoT seems to be used in specific segments of the production line, mainly to improve production support processes.

The limited scope of IIoT use suggests that implementation is at an experimental stage. This hypothesis was confirmed by several respondents, who pointed out that the IIoT applications were being tested to learn about their benefits and to prepare the enterprise for a possible, larger utilisation of the IIoT. Most IIoT applications are used in old machinery to optimise their use or in pilot projects to evaluate new solutions. The interviewees indicated that projects were perceived as a transition to new modes of production.

In the enterprises interviewed, IIoT sensors are mainly used for monitoring and collecting data on production machines, thus, digitising processes previously carried out by employees. Digitisation has made data collection more efficient and has improved data quality. Some respondents stressed the importance of the daily operation of IIoT sensors, which makes it possible to collect data throughout the day and generate more accurate and timely information about the performance of machines that are crucial for enterprises.

Few IIoT-using enterprises reported strategic use or advanced analysis of the data generated through the IIoT. In general, the companies providing IIoT solutions provided the sensor data analysis as an additional service. IIoT-using enterprises reported either that they were satisfied with a basic use of the information collected through the IIoT or that it was difficult to motivate their teams to carry out more complex analyses of the IIoT data.

Regarding machine adaptation, IIoT-using firms reported that IIoT solutions do not demand complex specifications and only require the installation of sensors, which are usually plugged into the existing equipment. As for the IIoT providers, the interviewees pointed out the low production costs of the sensors and their flexibility of use and indicated that their revenues come mainly from maintenance and data analysis services.

Connectivity and technologies

Most IIoT-using firms reported that few modifications were required to connect the machinery in use to the Internet in order to implement IIoT solutions. Some indicated that it was necessary to increase the contracted Internet speed or change the routers' positions. The need to install private networks was not mentioned and some reported using mobile connections. IIoT-producing enterprises confirmed that IIoT devices have few requirements for connectivity, a characteristic that, in their view, makes their implementation feasible for firms.

Very few enterprises reported using the IIoT in combination with other Industry 4.0 technologies, such us 3D printing and AI. Many respondents stated that greater integration of production lines with customers and suppliers would be necessary to implement Industry 4.0. Most enterprises reported using cloud services and even before the implementation of the IIoT.

Perceived benefits and barriers

Most respondents reported that the use of IIoT applications increased their firm's competitiveness by reducing the costs associated with machine breakdowns and production outages. Interestingly, some firms expressed the view that implementing the IIoT in their processes was inevitable since their competitors were already using this technology.

Although the strategic use of the data generated by the IIoT seems basic, the enterprises interviewed regard it as a valuable resource to improve their performance. They also expressed the view that the development of data-driven decision making was inevitable and should be promoted. However, it is likely that IIoT-using firms will continue to rely on the use of data intelligence provided by IIoT suppliers, as most respondents pointed out a lack of human and technical resources and regarded the creation of a data department in their firm as unnecessary.

Despite the simplicity and the low cost of IIoT solutions, the interviewees showed some reluctance to scale up their use. Some respondents stressed that the implementation of IIoT solutions needs the support and commitment of senior management. Others pointed out the importance of effective strategies to change long-established routines in firms. This involves showcasing the potential benefits of the IIoT for the firm and dealing with workers' concerns about their being replaced by the technology. Similarly, some IIoT suppliers pointed out the need to convince company managers of the benefits of the IIoT as well as resistance to changes in production and organisation in adopting firms.

Importantly, the interviews showed low awareness among IIoT-using firms of digital security risks that may arise from greater interconnection between machines and devices. As most firms rely on standard Internet connections to operate their IIoT devices, the respondents did not reference the need to improve network security or implement digital security risk mitigation practices. On the contrary, IIoT providers seem to have been made more aware of digital security risks by the cloud computing companies through which they provide IIoT services.

Lessons learned

Among the requirements for successful implementation of the IIoT in firms, the interviewees highlighted the need to involve teams from all relevant departments, raise their awareness of the benefits of the technology and promote a company mindset more open to change. IIoT implementation is generally regarded as a process driven by the whole firm rather than limited to a specific area or department.

Respondents also stressed the importance of public-private partnerships in providing financial and technical support to firms. Demonstration environments for IIoT solutions appear to be important for enterprises, as they put providers and users in relation, thus raising awareness of the potential benefits of the technology. Dedicated business events are also regarded as critical for sharing experiences about IIoT adoption by firms.

Public policies were widely cited as an important channel to finance technological upgrades in firms, in particular in the form of non-refundable loans and tax relief on the acquisition of components. For instance, one IIoT-using firm reported having benefitted from the support of C4IR Brazil as part of its programme to promote Industry 4.0 among SMEs. IIoT providers are also regarded as key stakeholders for IIoT deployment, in particular to raise skills in IIoT-using firms.

Final remarks

In most cases, the use of the IIoT in the manufacturing industry in Brazil appears still incipient and limited to a few processes and machines. All enterprises interviewed, whether implementing a one-off project or in an advanced stage of adoption, have stressed the benefits of adopting IIoT solutions, in particular in terms of improved predictive maintenance, less severe breakdowns and less frequent production outages.

All respondents have highlighted that IIoT solutions are relatively easy to install, affordable and do not demand major adaptation of the machines in use. Connectivity requirements are also considered simple, making it feasible to expand IIoT solutions to all machines in the firm. Changing the firm's mindset and ensuring senior management's commitment are key factors for successful IIoT adoption.

At present, data analysis services are mainly provided by IIoT providers and account for a large part of their revenues. These firms are moving towards AI and cloud computing applications that constantly monitor customers' machines.

As for the role of policy, non-refundable loans, tax relief, technology demonstrations and business events are all regarded as important measures to promote IIoT diffusion.

Conclusion

The case studies presented in this chapter provide examples of the potential benefits of IoT use in manufacturing. However, these findings are qualitative in nature. They should be supported by more quantitative analysis on the effects of IoT adoption on firms' performance, e.g. productivity and growth. The scope of the analysis should also be enlarged so as to cover all firms and sectors.

Annex 4.A. Case studies on the IIoT in Germany

IIoT providers

PANDA GmbH

The company PANDA GmbH[7] was founded in 2018 as a spin-off of a project with the Helmut Schmidt University in Hamburg. The company has about 30 employees and serves mainly larger industrial companies, especially in the national market. The company's main focus is on the use of AI in industrial manufacturing. PANDA's main customers are machine manufacturers that integrate AI solutions into new machines and machine operators that use AI as part of retrofit solutions. The better the data quality in the production processes, the more efficiently AI methods can be applied.

PANDA supports its customers in identifying and sustainably eliminating the causes of system downtimes and rejects with the help of sensors and AI. For this purpose, an AI construction kit was developed that is specially tailored to the needs and challenges of German mechanical engineering champions. This enables customers to find the causes of production problems in a data-driven manner and to implement pattern-based control strategies. After an onsite inspection and a sensor selection, a customised AI solution is designed based on a modular system. The solutions are scalable and can be easily integrated into the customers' existing technical infrastructure (mostly in the switch boxes of machines). Subsequently, the technical implementation on site, e.g. attaching sensors, cables and network, can be completed within one week. After a two-week period of collecting data from the customer, an evaluation of the production data can commence on site.

Most customers decide to evaluate and control individual production chains or individual machines in an automated way. For example, the AI algorithm can be used for quality control, advanced condition monitoring and predictive maintenance.

The modular AI system comprises more than 40 algorithms that process data from mainly visual and acoustic sensors. The algorithms are based on open-source software. PANDA also uses inhouse hardware, such as industrial computers and a variety of (standardised) plug-and-play sensors.

Implementing PANDA's AI solutions has had a very positive impact on the efficiency of the customers' production processes. Overall, data from PANDA's customers prove that 50% of machine failures and malfunctions can be detected and recognised in due time with relatively simple sensors. For production processes of critical products with rare defects (due to human error), automating quality control can achieve cost savings of 30-50%. In the case of common errors, the AI can identify and correct causes far more quickly and easily.

AI also helps customers optimise machine settings and improve fine-tuning during production. By reducing cycle times, cost savings can be achieved and an increase of 5-10% in the number of products can be realised. AI can also automate manual work steps, e.g. in robotics: robots are programmed and tend to be inflexible for unexpected events. Therefore, the work of the robots can be improved by using AI in the camera systems for example, making the robots "smarter" so that they can better handle fluctuations and deviations.

However, since AI is only relevant in business since about 2016, industrial enterprises do not yet have sufficient awareness of the commercially viable use of AI in their business model. Mechanical engineering in particular is a very traditional industry. They need to be convinced by traceable economic arguments such as cost savings and reduction of competitive pressure.

The IIoT also poses a major infrastructure issue due to its complexity and the paradigm shift of introducing IT technologies into the mechanical engineering world. Through close involvement and consultation with customers and the demonstration of benefits, possible concerns can be resolved for practical implementation.

LAP GmbH Laser Applikationen

LAP [8] was founded in 1984 and is a leading global supplier of systems that improve quality and efficiency through laser projection, measurement and other processes. The company has more than 300 employees who work at 8 locations in America, Asia and Europe and generated a turnover of EUR 63 million in 2019. LAP's customers are companies of different sizes from a wide range of industrial sectors in the national and international markets; however, the focus lies on industrial manufacturing and healthcare applications.

The company's laser solutions are used in various industrial IoT environments. Laser projection systems are used as visualisation aids (digital templates) to guide their customers' employees. The target group is workers in the production process who are supported by laser contours displayed on a wide variety of material surfaces. The laser system projects clearly visible assembly instructions directly onto the work tool or components, e.g. where a hole must be drilled or a rivet must be placed. The application possibilities in industrial production are broad. The solution is utilised, for example, for the production of large-scale rotor blades for wind turbines, on which the digital template guides the workers step by step through the production process.

On the other hand, the aerospace industry relies on composite parts manufactured using LAP's laser projection systems. The information for the laser projection system is obtained from customers' computer-aided design data and is processed in the laser projectors (hardware) and the corresponding control software installed on site. LAP's project management and service department is involved in delivering the projects to customers. Since manual production remains very important in many industries, laser technology leads to a noticeable increase in efficiency and quality. In many production scenarios, laser projection systems and digital laser templates are now a recognised standard manufacturing tool. The solution is flexible, scalable and can be integrated into most existing customer environments.

The experience of LAP indicates that increasing efficiency for the production process constitutes the main driver to adapt the IoT solution. Many customers state their intention to produce more efficiently, in a more cost-effective and faster way, while maintaining overall product quality.

The solution must be flexible, scalable and versatile from a customer's perspective. Some customers use laser systems to manufacture small batch sizes since laser systems are cost-effective and can be implemented quickly. Due to production complexity, the equipment needs to be increasingly deeper integrated into the customers' technical infrastructure. At the same time, the technical infrastructure has to be flexible and versatile. Thus, standardised interfaces and protocols are essential so that a large number of customers can deploy these solutions.

The customers' data represent the solution's driver and prerequisite. The more data are generated in production, the more these can be specifically evaluated. In this context, laser systems are one additional source of data within the overall production process.

The customers' workers have to be included in the implementation process from the beginning: the laser projection does not represent a full automation solution but rather a partial automation which means that workers are supported in selected manufacturing activities while still performing the manual work. However, it is highly important that workers perceive the benefits and relief in their daily activities.

Therefore, companies are advised to include system users in the implementation process and train them accordingly. Positive experiences during the implementation phase and also later during operation are key success factors. In addition, the visibility and measurability of efficiency gains in industrial production are also important for companies. In an evaluation, it was observed that production speed could be increased by 50% through laser support, in addition to the increase in production quality.

q.beyond AG

q.beyond[9] was established in September 2020 by a rebranding of QSC AG, which was founded in 1997. The company has about 1 100 employees nationwide and generated about EUR 155 million in revenue in 2021. This information technology (IT) solutions provider integrates relevant technologies in the field of IoT, cloud and IT outsourcing, and systems applications and products (SAP) services and operates its own data centres. The customer focus of q.beyond is on German SMEs, mainly medium-sized businesses in the retail, industry and energy sectors. q.beyond generated about two-thirds of its revenues in these three sectors in 2020.

The IoT first played a role for q.beyond in 2011 when Federal Ministry of Education and Research (*Bundesministerium für Bildung und Forschung*)-funded project SensorCloud was launched to transfer sensor-based data to the cloud. At that time, however, no standardised devices were available. In 2018, q.beyond decided to take up IoT deployment with a focus on edge computing, especially for the industry segment. It developed its own hardware and related services in the context of its product and service portfolio, enabling SMEs and the German Mittelstand to implement Industry 4.0. Industrial IoT solutions are provided to machine producers to develop smart machines as well as machine users to connect their existing machines (retrofit). These clients typically intend to provide remote services (machine manufacturers), optimise their processes (machine users) or develop new services and business models.

q.beyond provides customer-oriented IoT solutions combining consulting, hardware and software development, and a scalable IoT cloud solution based on hyper scalers such as Amazon Web Services, Microsoft Azure, SAP and others. The offers reflect the clients' demand for low risks and operating costs. For example, a functional IoT demonstrator is ready within 100 days at a fixed rate and fully managed edge devices are provided on a rental basis, including applications at a monthly rate of approximately EUR 150, depending on the number and complexity of applications licensed or hosted on those edge devices. Data centres operated in Germany are able to meet the need for high data security. q.beyond reported growing revenues in its cloud and IoT segment (about 18% in 2020) and sees IIoT integration as a growth driver.

Overall, q.beyond observes that industrial enterprises are aware of the IoT potential for their business in a very general sense. They understand that the IoT can strengthen their competitiveness and can also help to overcome the shortage of skilled workers, which is one of their most pressing problems. Nevertheless, it is a challenge for companies to make the necessary decisions in day-to-day business and to move projects forward. Small companies have no fixed responsibilities for digitisation projects or specialised departments. According to q.beyond, this can be typically found in companies with at least 250 employees. Very small companies need a public support structure to get closer to the IoT. A cost-benefit analysis is important for them, as they are concerned about costs and vendor lock-ins. If the benefits are obvious, they are convinced to implement the IoT.

German SMEs in the industry sector are a very heterogeneous group; accordingly, their needs for the IIoT are very different, e.g. their machine parks differ regarding age and connectivity. A comprehensive initial analysis is often required to create a uniform database to proceed with further data analysis. Most clients are very sensitive about the data generated by their machines and would prefer the data to remain in the device or on premises as this is also associated with value creation. The IoT, however, requires connectivity of the machines, at least to provide software updates, remote services or manage disruptions.

The concerns about allowing access to the machine data need to be met by trustful services. Moreover, the clients themselves need control to work with the data.

Schildknecht AG

Schildknecht[10] is a provider of industrial wireless solutions based in Baden Wurttemberg. It was founded in 1981, has 15 employees and generates about EUR 2 million in revenue per year. The company has a strong engineering focus and specialises in software development. Schildknecht's customers include companies of different sizes from a wide range of industrial branches in the national and international markets.

Schildknecht is an "IoT pioneer" with long-standing experience: it started to develop IoT solutions in 2009 and launched its first IoT edge gateway in 2013. Since then, Schildknecht has developed its own product line (DATAEAGLE) for radio data transmission systems. In addition, it is an IoT system provider in the field of remote maintenance, telemetry and machine to machine (M2M) solutions, as well as condition monitoring. Its focus is on the provision of safe and stable radio transmissions for industrial use (e.g. for cranes, transport vehicles, the paper and pulp industry). Tasks outside the core business (e.g. hardware production or data analytics) are consistently outsourced.

The IoT focuses on connecting machines and plants across the value chain, i.e. between different locations and companies. This approach often requires international connectivity, e.g. cranes in remote places worldwide. In order to connect IoT devices, Schildknecht makes use of cellular connectivity.

International connectivity challenges are solved by roaming via embedded subscriber identity module (eSIM) to automatically connect to the most suitable network out of 400 mobile service providers. Given the heterogeneous customer group of Schildknecht, the size and duration of IoT projects vary significantly: they range from highly standardised short projects to complex projects in close co-operation with their customers.

According to Schildknecht's experience, the customer's motivation to start IoT projects strongly depends on the sector conditions and requirements (e.g. companies in the crane industry generally have similar needs). Besides that, the reasons for implementing the IoT are company-specific and can be driven either by technical or marketing issues. Moreover, some companies have a demand to solve a narrowly defined specific task (e.g. to optimise the maintenance of a specific machine), while others have a vague plan to implement the IoT or are forced into stronger digitalisation, e.g. by their shareholders. Overall, the "pain point" needs to be persistent and inconvenient enough to trigger the IoT investment.

Schildknecht states that small companies typically have limited budgets for digitalisation and often prefer uncomplicated projects at low costs to start with the IoT. To meet this need, Schildknecht has developed low-threshold retrofit projects that can provide a ready-to-run solution within three days for a fixed budget. The scalability of those projects can become a challenge, as clients are reluctant to deal with this issue from the beginning. At a later stage, however, it is more difficult to solve. Schildknecht perceives that an adequate strategic priority for IoT projects set by top management is key for their successful implementation. This precondition can often be found in family-owned medium-sized businesses with fast and uncomplicated decision-making processes. Conversely, large companies tend to have unclear responsibilities in their hierarchical structures that could delay the implementation of IoT projects. Besides that, they often prefer insourcing IoT projects, even if this approach involves many more resources.

In line with the strategic priority and top management support is the need to involve the employees in the IoT implementation from the beginning in order to ensure broad acceptance across the company. Overall, IoT projects are perceived as most useful if they are able to deal with specific "pain points" and result in obvious benefits. Then, hurdles are easy to overcome. For example, a small greenhouse operator with a strawberry plantation invested in sensor-based watering to avoid getting up at night. Another example is the automatic, radio-based recording of user frequency at rest areas of Austrian railways that enables databased optimisation of the cleaning service. The rapid improvement of quality and cleanliness of the rest areas immediately proved the IoT solution's advantages.

TELOGS GmbH

TELOGS GmbH[11] was founded in 2000 and now has its headquarters in Wettenberg in the district of Gießen in central Germany and another service location near Berlin. The company has about 60 employees and generates a turnover of more than EUR 10 million. The company's main focus is providing automated intralogistics systems and support services, including maintenance, inspection and servicing, as well as consulting and planning. TELOGS is a general contractor and a specialist in brownfield approaches, i.e. the modernisation and expansion of older machinery (retrofit).

Germany represents the company's core market, where the company serves medium to large customers from a very wide range of sectors, including pharmaceuticals, mechanical engineering, food industry, among others. An important business area of the company is (digital) retrofit, an important concept in the IoT context: old machines and plants are integrated into modern IT systems. The reasons for retrofit solution demand among TELOGS' customers are manifold: higher probability of failure of electrical components, spare parts no longer available, technical know-how in the companies decreasing with regard to old machines, equipment manufacturers no longer on the market or with a different business model (i.e. support for the machine no longer given), outdated IT landscape and lower equipment safety. As a result, the availability of many machines usually decreases noticeably after 10 to 12 years. Nevertheless, in many companies, there is little motivation to switch off the old machines, as they tend to be very customised in design and installation and thus can only be replaced with great effort. With many TELOGS solutions, the machines remain in operation almost continuously during the retrofit.

TELOGS' portfolio of solutions in intralogistics ranges from IT and/or programmable logic controller (PLC) modernisation and upgrading of the control system to complete conversion, including replacement and expansion of the mechanical assemblies (with the modernisation of mechanics, control technology and drive technology).

TELOGS supports its customers during and after implementation via the IoT: with the help of remote maintenance, the customer's current system status is visible to TELOGS. Through networking, TELOGS can connect to the displays of the machines and directly support technicians on site with troubleshooting and maintenance.

Customers generally fear operational downtime when retrofit measures to maintain machine performance are carried out. Therefore, TELOGS often implements a multistage plan with continuous modernisation that is implemented over several weeks, months or even years (with larger machine parks) and carries out the retrofit while the machines remain in operation. The retrofit measures significantly reduce maintenance costs for TELOGS' customers and extend the machine's life to 10 years with 97-98% operational reliability.

TELOGS closely involves its customers in the retrofit process. First, a joint concept is developed and the actual and target status is defined from scratch. Clear objectives, a common understanding and a jointly agreed plan at the beginning of an IoT project are key success factors. In this context, it has also proven important that process risks are significantly reduced, e.g. through the development of fallback scenarios, and that machines typically continue to be productive during the retrofit.

TELOGS' customers positively emphasise that there is also no intervention in the building structure and that resources are conserved. Some fundamental challenges of retrofitting are the different technical interfaces and lack of technical standards. Technical integration can only be resolved through close co-operation and co-ordination between TELOGS and the technicians on site. Due to interferences in the processing or storage area and high process risks with wireless solutions, TELOGS relies on optical transmissions while using Ethernet to connect the controls to the host system. TELOGS uses virtual private network access for the remote maintenance connection to the customer's machines. Although TELOGS' portfolio in terms of retrofit covers a very large variety of solutions, some limitations remain, as it is impossible to increase the performance of the mechanics of the machines. Likewise, process changes can only be implemented to a limited extent. Furthermore, retrofitting is not economical with a massively damaged machine fleet.

IIoT users

Kreyenberg GmbH

Kreyenberg[12] is a family-owned company headquartered in the Norderstedt area in northern Germany near Hamburg. Kreyenberg has developed into a major supplier of precision mechanics and machining technology. The company has over 200 employees and generates a turnover of over EUR 20 million. Kreyenberg has a high level of vertical integration in mechanical engineering and frequently supplies its (mostly national) customers with components that they are unable or unwilling to manufacture themselves. The company serves customers from a very wide range of sectors, including automotive, aerospace, mechanical engineering and medical technology, among others.

One major focus of the company is on computer-controlled manufacturing using the IoT for process optimisation. Within the scope of machining, the company masters many production processes and is a supplier of complex components and electronic modules. During production, networked computer numerical control (CNC) machines are used. By using control technology, these machines can automatically produce high-precision pieces and even complex shapes. For this type of manufacturing, 3D data (digital twin) of the desired component is always necessary. Based on these data and its tool database, a numerical control (NC) programme is created describing the strategy to manufacture the component.

The NC programme is then transferred to the machine, where the tool stock is monitored. A software-supported comparison between the tools needed for manufacturing and the tools mounted in the machine delivers the net requirement of tools. The setup processes derived from this are then made available to the employee in digital instructions. The process data made available by the deployed software are used to optimise the production flow and work processes. The data are also used to evaluate which tools are frequently used so that setup costs are reduced and there is less tool wear. This approach has saved Kreyenberg from purchasing new tools for the last three machines. Other technologies are used throughout the production process: for example, AI is used for calculations and robotics for machines that autonomously refill materials.

The use of the IoT in the company is strongly strategically motivated: competitive and cost pressures at home and abroad and the motivation to maintain a location in a high-wage region are contributing to a steady increase in the use of digital technologies. Implementing a high degree of autonomy is difficult, as the processes are sometimes very specific and vary greatly due to customers' requests. In order to still be able to satisfy many customers, Kreyenberg has a wide range of machines available for different materials (with regard to the type and dimensions of the parts). Kreyenberg owns a very modern machine park; all machines are connected to the network. Using process automation in the company and standardised interfaces facilitates internal work processes and improves external communication with customers and suppliers.

In metal processing, technical difficulties arise when using wireless technologies. Due to these specific challenges, RFID-based tracking was classified as insufficient for use in intralogistics in a proof of concept. Ethernet is mainly used to network the equipment. At the same time, the company had strong support and backing from its management with an intrinsic motivation for making processes more efficient. Due to the high degree of technical and organisational complexity, change management is very important and practised throughout the company. In this environment, establishing IoT processes is relatively easy.

However, the fact that employees are open to embracing change management requires that the benefits of digitalisation projects are clearly communicated and demonstrated. A constructive working atmosphere (average length of employment 10 years; about 20% of the employees were trained in the company) and positive experiences, in the implementation of pilot digital processes for example, also facilitate the implementation of further IoT solutions. Furthermore, the use of an internal digitisation advisor in the company, who is deployed at the request of the management, represents a significant success factor. However, it should be noted that Kreyenberg is a big enough company to be able to afford such a consultant, whereas smaller companies would find this much harder to realise.

Siegwerk Druckfarben AG & Co. KGaA

Siegwerk[13] is a leading manufacturer of printing inks and coatings for packaging, as well as magazines and catalogues. Headquartered near Cologne and with sites around the world, Siegwerk provides its services to clients in the international market. In 2020, Siegwerk had 4 965 employees (about half of them work in the Europe, Middle East and Africa region) and EUR 1 141 million in global sales.

At Siegwerk, the IoT forms part of a comprehensive digital transformation strategy that has been developed since 2017. IoT-related projects are designed to contribute to different strategic objectives, i.e. high customer service quality, high efficiency of internal processes and being an innovation leader in the industry. Besides that, these projects are considered to provide potential for innovative business models.

More specifically, the IoT plays a role in different digitalisation projects, among them:

- A fully automated production facility at the Blending Centre in Siegburg, which is the largest European project of its kind (opened in December 2019).
- A digital platform for automatic ink management for customers, which allows resource management, make orders and estimate future needs (MyInkRoom, launched in May 2018).
- An augmented reality-based solution that enables Siegwerk experts to interact remotely with customers or inhouse technicians in real time (INKonnect, launched in June 2021).

The IoT at Siegwerk has an international scope and is deployed at sites across the world. It covers several parts of the value chain, including clients and suppliers. Siegwerk operates the IoT platform and incorporates open-source solutions, which brings the benefits of using state-of-the-art technology and offering high flexibility to company requirements simultaneously. The platform is scalable and divided into micro services to efficiently implement new solutions despite the high heterogeneity of sites.

IoT implementation poses challenges for the company. According to Siegwerk, it is most critical to address these challenges at an early stage. As IoT projects involve a dramatic growth of connected machines and devices, IT security risks significantly increase. Moreover, IoT solutions have to be integrated with machines from different suppliers and in different environments. In addition to that, some industry-specific requirements, e.g. regulations and standards for “ex zones” provide complex conditions to implement IoT solutions.

Clear responsibilities are needed to deal with both technical and operational issues. At Siegwerk, the management guarantees a high level of strategic support and is perceived as a major success factor for successful IoT implementation. This is all the more important as the added value of a large number of such projects cannot always be precisely quantified at the start of the project.

Project management and communication across cross-functional and transregional project teams are key to bringing the solutions to international business locations, co-ordinated by a central department for digitalisation. Various third parties, e.g. for software development, must be involved. For instance, MyInkRoom was developed by a software partner within four months and then first tested in two Siegwerk factories. A further 26 months were needed in an agile approach to iterate and expand the applications’ functionality and to deploy it across 20 sites.

At Siegwerk, the benefits of IoT implementation have been clearly demonstrated in various projects:

- In the production process, the IoT has improved quality and efficiency due to the optimisation of previously manual tasks. For example, using networked scales in combination with an own application could reduce errors in the use of materials and achieve full transparency about the existing stocks as well as automate information flows through several systems, resulting in a reduction of correction cycles by an average of nearly 10% in these workshops and, at the same time, the process' cycle time could be significantly reduced. The collected data can also be used to plan ahead.
- The digital platform MyInkRoom enables significantly decreased downtime of printing machines. Moreover, it allows Siegwerk's customers to check their stocks and place orders within seconds. For Siegwerk, the service helps to further strengthen partnerships with their customers.
- The augmented reality-based INKconnect solution allows technicians to use both hands for troubleshooting on site while being advised and instructed by Siegwerk experts. The customer can increase its productivity and efficiency as waiting time and machine downtime go down, and thus costs are reduced. For Siegwerk, the service strengthens its quality of customer service.
- Using IoT data in combination with ML applications, Siegwerk was able to reduce quality induced cost of specific production lines by nearly 70%. In particular, ML is used to identify trends in product quality, predict future machine failures and support Siegwerk quality management experts in doing root cause analysis.

TRUMPF SE + Co. KG

TRUMPF[14] is a family-owned company with headquarters in southern Germany near Stuttgart. It is one of the world's leading companies for machine tools, laser technology and electronics for industrial applications. In the 2020/21 business year, the company generated a turnover of more than EUR 3.5 billion with more than 14 000 employees. With upwards of 80 operating subsidiaries, the group is present in almost all European countries, Aisia, North and South America.

The IoT has been a central part of TRUMPF's business model for many years. Remote access to machines has been implemented since the mid-1990s, at that time, via modem technology. In the following years, remote services were further developed to achieve optimal use for business customers. The offered customised solutions are very adaptable using a variety of communication technologies.

Recently, one major focus has been placed on processes in flexible sheet metal manufacturing. IoT solutions are used in machines for their own products as well as machines for customers. This includes, for example, remote services on machine tools and the networking and connection of production planning and order planning systems. Thus, TRUMPF helps to optimise processes and make smaller orders more efficient for their customers.

The IoT in its own company has also become increasingly advanced, with TRUMPF opening its smart factory in Chicago in 2017. In this technology ecosystem with its own data centres and cloud infrastructure, employees, machines and software interact through fully digitised and automated solutions, e.g. sheet metal workers experience networked manufacturing solutions. This increases the transparency of the production so that the processes can be better planned, executed and controlled. At the same time, production can be faster and more flexible. This is a decisive advantage, especially for smaller batch sizes. In addition, all learnings from applying those new technologies within the smart factory are directly transferred and integrated into the customer solutions TRUMPF provides with its products. In the future, TRUMPF plans to develop its smart factory further along the supply chain.

Several reasons led to the increased development and use of IoT solutions for TRUMPF itself and for its business customers, for example the optimisation of business processes, the extension of existing products and services, and the realisation of completely new business models.

For TRUMPF, in addition to networking within a location, which has been practised for a long time, networking across different company locations has become increasingly important. In addition, networking across several layers of the value chain, for example with customers, which also has been in practice for some time, and with suppliers, is becoming strategically all the more important.

Since the connectivity of IoT solutions is an essential prerequisite, TRUMPF has aimed to design all solutions to be as technology-neutral as possible. Depending on the application and industry, there are different requirements for connectivity, not only in terms of bandwidth but also in relation to response times, reliability and security. In addition, in some industries, the connectivity solution must take into account additional issues, such as liability in the event of accidents or when the factory line is at a standstill, or specific requirements, such as explosion protection in some process industries.

Due to the different technologies and systems, the complexity of specific IoT solutions has also increased significantly. TRUMPF has therefore decided to include network operators and equipment suppliers in its IoT solutions, which has proven to be a success factor due to the reduced uncertainty and cost benefits. TRUMPF also emphasises the soft factors in the implementation of IoT solutions: an open exchange with employees before and during the implementation of the IoT solution, as well as the development of joint solutions for technical, organisational and corporate culture issues, are success factors both in the company itself and with its customers.

Wanzl GmbH & Co. KGaA

Wanzl[15] is the world's largest manufacturer of shopping trolleys and luggage transport trolleys. It produces more than 2 million shopping trolleys per year. The business focus is on retail systems and shop solutions. In addition, solutions for logistics, industry, airports and hotels are offered. Wanzl has about 4 600 employees in total, 2 200 of which in Germany. Sales amount to EUR 710 million. The company operates 8 production plants, 27 subsidiaries and 50 agencies worldwide.

At Wanzl, the IoT plays a significant role in its comprehensive digital strategy and innovative retail concepts. In this context, the IoT is deployed to enhance the existing product portfolio and to develop new services. For Wanzl's retail customers, IoT implementation focuses on process optimisation with related benefits for customer satisfaction and an increase in profits.

Wanzl launched IoT-based services at the EuroShop Fair in March 2017. At that time, several pilots were conducted at retail companies in Germany, Switzerland and the United Kingdom. The core of Wanzl's IoT activities is wanzl connect, which has been developed to provide the related analytics and management tools for connected shopping trollies, entrance control systems, cash register systems and other connected devices. This software is able to cover various applications and services for different IoT use cases, ranging from basic functions to highly complex scenarios. Among the most important projects are innovative concepts and new shopping formats for the retail sector to establish 24-hour self-service. These are based on automatic quick response (QR)-code-based entrance and self-scanning solutions, including payment via an application that has to be installed on the customer's smartphone. Here, Wanzl deploys hybrid concepts for big flagship stores and very small markets (minimarket). Hybrid concepts combine traditional shopping during normal opening hours with e-shop offers for authorised business customers day and night. Minimarkets in different forms provide store revenues in addition to big stores and local supply in rural areas.

Overall, IoT implementation differs a lot between individual retailers and is also subject to country-specific characteristics (e.g. the United Kingdom has shopping trolleys without a deposit system and, therefore, a higher risk of disappearance; Germany has strong regulation for data protection).

Regarding connectivity, shopping trollies are equipped with RFID; additional sensors are distributed in the shops. Different connectivity technologies transfer data and build on the existing network at the client site. Wanzl claims that the technical solution options are highly developed: however, data analytics have not yet reached the market relevance they expected a few years ago. The current focus is on the retail sector because of its size and scale effects. Other sectors are addressed with digital solutions according to customer requirements and on a project basis. Overall, IoT technology is considered to have significant potential for future growth strategies at Wanzl. A digitisation department with 15 employees is responsible for driving these projects.

Wanzl stresses that understanding the customer needs is essential to implement projects. The project process should be closely co-ordinated with the client and the initial situation and objectives clearly defined from the beginning. Retailers often have concerns about IT security and data protection. These must be reflected in security concepts and secure networks. Typically, Wanzl makes use of standard products whose high-security level is recognised. Data protection is critical, especially in Germany, due to its legislation. Here, Wanzl ensures a high level of transparency, which is contractually guaranteed. The technical implementation is designed to meet security concerns, e.g. certified sensors and data protection-compliant video surveillance. One design principle at Wanzl is to deploy as few sensors and deal with the lowest amount of data as possible to meet the client's data protection needs and keep costs and risks under control.

Reference projects can prove the benefits of the IoT. First of all, connected shopping trolleys enable retailers to improve processes and better calculate the optimal number of shopping trolleys at their shopping sites. In countries without a deposit system, shrinkage can be reduced. The potential to maximise profits is closely related to better availability of shopping trolleys. Here, additional benefits can be generated with shopping concepts that enable extended opening hours. These benefits have been proven in Würth24 flagship stores, operated by German manufacturer of assembly and fastening technology Würth that has implemented this concept in several locations globally.

Annex 4.B. Case studies on the IIoT in Brazil

IIoT providers

Hedro Sistemas Inteligentes

Founded in 2016, the company's mission is to support other companies entering the paradigm of the Fourth Industrial Revolution, providing a series of solutions for connecting the brownfield industries to the IoT.

The company supplies sensors that, when attached to machines, generate several pieces of performance information, to understand the state of the machinery with relatively low investment and rapid delivery of results. The company supports the use of smart devices that generate information about equipment degradation.

The company develops and assembles the sensors while their components are imported. These sensors have firmware that collects the inertial data from the machines, enhances the data using edge computing techniques and sends them to the cloud, in which the company offers a dashboard system for data visualisation and an application programming interface to stream the data to other companies and start-ups specialised in data analytics and AI.

According to the company, there is a growing market and room for increasing interest in the potential of the IIoT since most industrial companies are interested in monitoring tasks, with the opportunity of enhancing the analysis of the generated data, without having to afford large investments in new equipment that are already connected to the cloud. The company believes in a continuum that begins with the monitoring, generation and treatment of data, enabling AI application development.

It is emphasised that the basic requirements for implementing the IIoT are Internet connection and energy. Awareness must be raised among customers of the importance of process improvements that are brought about by the solution, providing support and training throughout the implementation.

The company must be prepared to deal with resistance from customers. For some companies, transferring their data to an environment outside their boundaries can be seen as a risk. At the same time, digital security issues must be considered because there is a risk of leaving the control of machines exposed on the Internet and it is better to keep parts of the process still fully controlled in the places where the sensors are installed.

As a provider of IIoT solutions, there is a need to demonstrate their functioning with close monitoring and management. This builds trust regarding the quality and accuracy of the data generated by the sensors.

The company feels that it is also necessary to act educationally, insofar as it is essential to demonstrate the importance of technological updating, not only for customers but also to sensitise the public sector about the need to support companies in adopting the IIoT. The creation of technology demonstration hubs could provide a place for stakeholders to meet and discuss the challenges and advantages of implementing the IIoT.

HarboR Informática Industrial

The enterprise has been working for 25 years in the development and integration of industrial systems for production planning and control, with customers in several countries in Europe and Latin America. Recently, it closed an agreement with a Brazilian institution that supports industry in facilitating the transition of companies to the productive paradigm of Industry 4.0. It developed a product that integrates several characteristics of Industry 4.0: the IoT, cloud, big data, vertical and horizontal integration, and digital security.

As a company capable of providing solutions for customers with the most diverse technological backgrounds, there is an understanding that digitisation is the first step in technological adoption, while the most advanced stage is automation. In this sense, implementing the IIoT is the gateway to more complex uses, with the digitisation of processes being a simpler way to make companies treat data strategically.

When looking for solutions for their companies, customers are interested in increasing or maintaining their competitiveness and this requires them to have more control of their production processes, generating efficiency. Company solutions provide a series of parameters, which can be monitored in real time by applications, such as the performance of machines, thus enabling quick responses to any problems.

The simplicity of implementation of solutions is considered crucial to their success because there are no complex connection requirements and they work seamlessly from companies' Internet connections. The challenge is to combine the data generated by the devices with the tacit knowledge of the operators, generating a broad understanding of the processes.

Therefore, the company's business model lies in providing devices and consultation for analysing the generated data. For this purpose, the company offers a monthly subscription that customers can sign up for to access complete monitoring of the performance of their machinery based on monthly reports.

The lesson that the company draws from its IIoT implementation projects is that technology is only part of the solution. Also required is close monitoring of customers by its team, helping them to use the information generated. Allied with this, the company states that cultural change is more complex than technical change insofar as the implementation of solutions is a simple process.

From the point of view of the relationship with large companies, it is important to note that the business model of a provider of IIoT solutions can conflict with the way large companies operate. In contrast with the flexibility of smaller companies, they have standardised ways of dealing with suppliers.

AIQuatro

The company was founded in 2019 and operates in the supply of sensors for monitoring and predictive and prescriptive maintenance. Their hardware is manufactured in house and the company offers a series of complementary services to its customers, gathered on an AI platform.

According to AIQuatro, its differential lies in the in-house manufacturing of IIoT sensors and the AI service offered. In addition, the company provides customers with full access to the generated data, understanding that companies are increasingly acknowledging the strategic value of data analysis for their operations, in view of transparency between the company and customers.

According to the firm, its customers come from companies that use continuous production, in which raw material is transformed into products by going through every step of the process with no breaks in time. This type of company is more prepared to use IIoT solutions since constant monitoring of the process is necessary to avoid machinery downtime and damage to the entire production process.

The installation of sensors makes it possible to find out exactly what happens inside the machines through vibration and sounds, allowing identification and prediction of failures. With the data generated, the company uses AI applications to plan the maintenance of machines, which provides predictability for customers, reduces downtime, and significantly impacts maintenance costs.

The company understands that the implementation of IIoT must count on the support of the IT team, overcoming resistance that arises from teams that deal directly with the machines. Concerns related to the company's IT, for example, digital security given to the online exposure of sensors, must be taken into consideration and it is necessary to demonstrate the reliability of the IIoT solutions offered. Currently, customers are requesting broader solutions, with more requests for data access. It is important to be prepared to act in the entire process of creating, processing and analysing data.

Dynamox SA

The company provides solutions for monitoring the condition of machines and equipment, collecting vibration and temperature data for predictive maintenance. It is present in about 15 countries.

The company provides sensors that capture the vibration and temperature of machines for data generation and support statistical analysis to identify failures, providing a complete hardware and software solution that helps companies make decisions about the maintenance of machines and equipment. The sensors are connected to a gateway that sends the data to a cloud platform, which performs data processing and analysis.

The company considers that few companies are prepared to implement the entire Industry 4.0 cycle, which involves integration of enterprise resource planning (ERP), the IIoT (with sensors validating the information) and decision making. The vision is to increasingly show companies the need for a closed cycle of digitisation of processes aimed at greater efficiency.

The company believes it is important not only to sell its solutions but also to customers that will use its technologies, generating positive publicity. The company assesses the technological maturity of its potential customers since installing sensors in companies requires technological updating. Therefore, customer empowerment is an important asset for this technology supplier company: indeed, customers unsure of their needs and what they can have can damage the company’s image.

The company believes that it is critical to help customers to understand their capabilities and the nature of the services they can offer so that the use of the IIoT is profitable and the image of the provider company is not affected. Therefore, it is important that customers do prior planning about which stage they want to reach since the IIoT is the gateway to more complex steps within the digitisation of processes.

Currently, the company has started to invest more in digital marketing in order to be able to offer material explaining the advantages of IIoT solutions,. Therefore, although having basic customer projects is essential, knowing how to sell the IIoT solution beyond technical requirements is also important. Providing a global view of how technology adoption can help companies gain in competitiveness and enter a new productive paradigm is essential.

IIoT users

Ergomais

The company was founded in 2007 and manufactures ergonomic products, such as office chairs. It has international operations, exporting products mainly to South American countries.

The use of the IIoT in the company made it possible to digitise the data previously generated in an analogue manner, replacing paper-based processes. After installing the IIoT sensors, the company was able to track specific points on the production line, getting a broader view of the manufacturing steps.

The use of the IIoT allowed production optimisation, making it possible to gather data on steps that generated inefficiencies. End-to-end data generation in the production process allows greater control over the production of parts, which makes a critical contribution to avoiding the waste of energy and material. Sensors were installed in the company’s machinery, mainly CNC, with prior internal communication. It was understood that the IIoT is crucial for increasing the company’s productivity and placing it in the market more competitively, especially as regards improvement of delivery times.

The use of a cloud service was already in place in the company, which facilitated the technological requirements of IIoT devices as well as adaptation of the team to the new communication standards.

The interviewee did not report any specific needs to improve the Internet connection. Training the team to deal with the tablets that support the system used was reported. The role of the public sector in providing both financial and advisory support in the implementation of IIoT projects was highlighted.

With the improvements achieved by the IIoT implementation, the company aims to seek constant technological updating. Dialogue is an important aspect for this purpose, as well as the integration of the different teams involved in implementing the technology. Therefore, the company needs to maintain a culture of learning in which the search for new solutions is encouraged and no process is made unchangeable. The company's participation in public technology upgrade initiatives brought it into contact with consultancies that helped raise awareness of the IIoT technologies' benefits. Once a culture that always seeks to improve processes was established, the company became more open to novelty and the search for information, always seeking to learn and keep up with the most advanced technologies on the the market.

ASW Brasil Tecnologia em Plásticos

The company has been operating since 2008 in the supply of products for the electricity distribution segment. Its manufacturing unit, located in the state of São Paulo, has its own laboratory, where products following required quality recommendations are tested. The company has commercial offices in several Latin American countries.

The main motivation for installing IIoT devices was to implement overall equipment efficiency (OEE) control, which gave the company exact information about the time spent in manufacturing, facilitating the projection of production. The system tracks and sends real-time production status updates to the person in charge, which is very important since the company operates 24 hours a day.

The production information provided by the IIoT system allows controlling the number of parts produced as well as the manufacturing speed, resulting in cost reductions and avoiding material waste. The system can provide performance reports for each machine involved in the production process, providing information about elements like downtime and enabling predictive maintenance actions.

There was no need for substantial connectivity improvements for implementation as the company already had spare Internet connections. However, training, offered by the IIoT provider company, was needed for some employees to understand the implemented system.

The company outsources 3D printing projects for prototyping parts but this is a small part of the process and unrelated to IIoT systems. There is an understanding that investment in new technologies can reduce costs and increase the company's productivity, with the IIoT project being an example of a successful paradigm shift in the company.

Integrating different areas of the company in the IIoT implementation process is seen as one of the crucial actions for the success of technological innovation. The involvement of several players in the steps to be taken helped to reduce resistance from people engaged in processes established for a long time. Involving the entire company is also important to defend the project in front of the company's management board, showing the extent of the applicability of the technology and the beneficial effects in different areas of the organisation.

The successful implementation of the IIoT in the company led to the reflection that technology needs to be understood beyond costs, seeking to recognise the holistic impact it can have on the organisation. There is a perception that short-term concern with costs can prevent the understanding of the long-term benefits of the same costs that an investment in technology can provide. Participation in technology demonstration networks was crucial in this regard, with people trained to demonstrate the advantages of the IIoT, facilitating the implementation decision.

Selco Tecnologia e Indústria Ltda

The company has been operating since 1984 with two business units, one that supplies parts and services for manufacturers or owners of reciprocating compressors and another that provides precision machining of parts mainly used in the automotive industry. In 2021, the company started automating and digitising the automotive unit.

In both units, the company has modern machinery, the main applicable certifications and a strong international presence with a branch established in Argentina and regular exports to countries such as Canada, France, India, the Russian Federation and the United States.

The IIoT implementation project was conducted after a study on the feasibility and impact of the organisation. The machining of parts in the automotive unit is labour-intensive, so the line of production that was chosen for the project presented the highest demand and the strictest process tolerances, allowing the quickest return on investment from savings associated with labour costs and quality issues.

In terms of labour costs, robot arms were introduced to perform the loading and unloading of parts from CNC lathes. Each robot arm was able to replace three shifts of work carried out by two machines. In addition, since the demand was susceptible to temporary cuts for inventory balancing, the use of automation prevented losses associated with overcapacity.

Regarding quality issues, introducing an automated measurement system that communicates instantly with the machining stations allowed fast correction of machining parameters to prevent mounting losses.

Therefore, the company understands that implementing labour-saving technologies will benefit its operation insofar as the standardised operation of machines reduces the uncertainty inherent to human action. Communication between machines adds another advantage since the operation can be adjusted immediately, not being a static production line.

Seeking to update the enterprise technologically, IIoT implementation is considered critical for the company’s competitiveness and reputation in the market, showing that the organisation is innovating and constantly seeking to improve its performance. From a practical point of view, the part made with a robot arm, with greater precision, will, in the end, have its price set without labour costs, reducing its price significantly and giving it a differential impossible to match by companies that do not employ the same technology.

The main lesson from the IIoT implementation process was related to selecting adequate technologies that can impact how the company operates. Given investment limitations, information on where to invest is required, with well-specified projects and clear goals.

Even with a well-defined project, the company understands that flexibility is required during the implementation process since there are uncertainties involved when it comes to technological updating. Team engagement is important so the senior management board funds the project and viable solutions are found to the dilemmas that arise.

Another important aspect highlighted is the need to make workers aware of the benefits of technology, ensuring that its implementation will bring benefits to the company as a whole. This made it possible to increase engagement on the factory floor, which facilitates the technological update process.

Mangotex Ltda

The company has been operating since 1965, supplying products to the automotive industry, for which it produces rubber and plastic components such as oil and fuel transmission hoses. It exports to Europe and North America and has distribution centres in some countries on these continents.

The implemented IIoT solution is on the finishing line, performing the production count, a process that was previously performed manually. With the data generated, it is possible to calculate the OEE and a loss tree, indicating inefficiencies throughout the process. The system extracts data and process variables from the equipment, providing temperatures, line speed and electricity consumption, as well as a series of parameters that are important to understand how they speak to the quality of the product and enabling traceability since it records the time and day of production of each part. The project allows for the generation of several quality parameters in real time, allowing more exact and immediate corrective actions. The entire implementation process was structured in stages, digitising one production line at a time and choosing solutions that were useful to the company's reality.

The company recently carried out its migration to cloud computing services and 3D printing projects were already in place. The team analyses the data generated by the IIoT using statistical software. Due to the size of the plant, the connectivity solution chosen was cabling since routers would have to be installed at different points.

The company invested in creating an internal culture based on the use of data. The company highlights the need not to underestimate the complexity of IIoT implementation projects. To be successful, a project must be well specified in advance and, if necessary, can have a very limited scope. Another important point is the engagement of the management board in implementation projects, seeking to be informed about market news and, above all, exercising leadership in technological change processes.

Rochel Ferramentaria

Founded in 1996, the company operates in the segment of clamping devices and special machines, operating with machining centres and CNC lathes. Its clients include Brazilian and multinational industries operating in the country.

The company's IIoT project is still in an early process, based on a wired communication network between machines. The company plans to implement management software to manage this system remotely while generating data about its operation.

Rochel Ferramentaria's objective with the IIoT solution is to systematise information in a virtual environment, accessible at any time, drastically reducing the use of paper throughout its processes. Later, the company will seek to activate machines through the system since this process is still analogue. It aims for complete interconnection among its machines, which today work by programming entered by operators.

The company understands that digitalised processes bring more dynamism to the operation, which can in turn provide more competitiveness and reduce uncertainties arising from human actions. In addition, the idea is to integrate the process with other systems in use, such as enterprise resource planning (ERP), enabling better management of all production stages.

The firm seeks to fully integrate machine communication and its management software. Having a vision of where they want to go is important for internal planning and getting support within the organisation to move the project forward. The initial results of greater process integration proved to be positive, enabling the company to seek new solutions and envision more intensive use of new technologies.

Embraer

Founded in 1969, Embraer is one of the main Brazilian companies operating in the commercial aviation sector. It has a long tradition of innovation and operation with cutting-edge technologies. It is one of the few Brazilian companies to have reached the global market, competing with companies in Europe and the United States. In 2021, the company achieved a net revenue of BRL 22.7 billion,[16] which represents a growth of 15% compared to 2020.

The IIoT is essential for the company's operation and is already part of the routine of several departments. The first projects started about eight years ago and the IIoT is currently present in the most diverse processes, from production to customer service.

IIoT solutions are used to provide real-time technical information from manufacturing equipment, enabling monitoring of equipment operations and efficiency at physical and remote stations. Another relevant application of the IIoT is the connectivity of project information on tablets, allowing for consultation of information, confirmation of operations and requests for immediate support in the event of doubts in the production process.

The complete digitalisation of information generated within the company is seen as something with wide-ranging effects: by not using paper, the company is contributing to sustainability principles, reducing the environmental impact of its operations. Due to regulatory issues, the company must keep records of its operation for 30 years and the possibility of digitising all information is a facilitator.

Predictive maintenance is also central to the company's use of the IIoT, with the state of machines being monitored by sensors that calculate OEE. According to the company, critical assets are constantly monitored since they are unique items, with daily analysis of their state and operation.

To implement IIoT projects, the company operates by forming groups responsible for the solutions, called "core teams", adding people from areas that may be affected. Embraer is conducting several projects within the Industry 4.0 paradigm, such as 3D printing and AI, and estimates that it will have productivity gains in the future. Regarding IIoT projects, the company understands that they are a means by which processes can be optimised. Technology must serve as an instrument for improvement that has to be planned.

As a company that already works in a high-technology sector, it experiences fewer mishaps when making process changes via technological updating. The need to prepare well-designed projects for the implementation of IIoT solutions was highlighted, understanding all of the specifics of the technology and its impacts on the organisation.

IIoT systems must be compatible with processes already underway, and the enterprise must be accurate in its technological choices. The company has a technology development department responsible for preliminary studies on implementing technologies and developing knowledge-building blocks.

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Notes

[1] This section was prepared by the Regional Center for Studies on the Development of the Information Society (Cetic.br) of the Brazilian Network Information Center (NIC.br), with the support of the Centre for the Fourth Industrial Revolution (C4IR Brazil). The project was co-ordinated by Alexandre Barbosa and Fabio Senne. Research and reporting was developed by Leonardo Lins and Thiago Meireles from Cetic.br|NIC.br. The field management was conducted by Ipec – Inteligencia em Pesquisa e Consultoria.

[2] Companies that are in any of the categories of section C of ISIC 4.0, that is, codes from 10 to 33.

[3] One of the main sources of data on the digital economy in Brazil is the ICT Enterprises survey, conducted by the Brazilian Internet Steering Committee (CGI.br, Comitê Gestor da Internet do Brasil in Portuguese). Its primary objective is to measure access to and use of ICT in Brazilian enterprises with ten or more employed persons. The survey is designed following international standards, such as those developed by the United Nations Conference on Trade and Development and OECD. Indicators on new technologies are based on the Eurostat community survey on ICT usage and e-commerce in enterprises, which allows comparison with European figures.

[4] Interviews took up to 90 minutes and were carried out by remote video conference.

[5] For more information: https://www.weforum.org/centre-for-the-fourth-industrial-revolution/c4ir-brazil.

[6] For more information: https://abii.com.br/.

[7] See https://panda.technology/en/.

[8] See https://www.lap-laser.com/.

[9] See https://www.qbeyond.de/en/.

[10] See https://www.schildknecht.ag/.

[11] See https://telogs.de/.

[12] See https://kreyenberg.eu/.

[13] See https://www.siegwerk.com/en/home.html.

[14] See https://www.trumpf.com/en_INT/.

[15] See https://www.wanzl.com/en_GB.

[16] See https://www.wsj.com/market-data/quotes/BR/BVMF/EMBR3/financials/annual/income-statement.

5 Case study on the Internet of Things in healthcare

This chapter presents the findings from a case study on Internet of Things (IoT) adoption in healthcare. While data from information and communication technology (ICT) usage surveys provide information on the uptake of IoT health monitoring devices by individuals, limited information is available on the adoption of such devices by hospitals and general practitioners. Information on the effects of their adoption is also scattered. The case study's findings contribute to filling this information gap, particularly regarding the use of smart devices for remote patient monitoring.

This chapter presents the findings from a case study on Internet of Things (IoT) adoption in healthcare.[1] The case study is intended to complement data from the information and communication technology (ICT) usage surveys on the drivers of and obstacles to IoT diffusion in the sector as well as on the impact of IoT applications.

Main uses of the IoT in healthcare

Digital transformation in the health sector has been rather slow due to regulations, a lack of funding and low investment (Socha-Dietrich, 2021[1]). However, the COVID-19 pandemic has acted as an accelerator (The Economist, 2020[2]). Following the lockdowns imposed in most countries in response to the pandemic, several countries have lifted regulatory restrictions or overcome barriers, e.g. payment methods for telemedicine services, which have increased significantly as a result (OECD, 2020[3]).

From a healthcare perspective, the IoT comprises any device that collects health-related data from individuals and transmits them on a network, including computing devices, mobile phones, smart bands and wearables, digital medications, and implantable surgical devices (Table 5.1). While there are multiple digital tools and applications in the health sector (eHealth), the main uses of the IoT are remote monitoring, automation, nursing, and transportation (OECD, 2018[4]).

Table 5.1. Examples of IoT devices in the healthcare sector

IoT device	Brief description
Wearables	Technological infrastructure worn by the user that interconnects wearable technology with wearable sensors through wireless connections.
Digital (smart) medications	Ingestible sensors. Sensors made from copper, magnesium and silicon, in minute quantities, which communicate with an external body sensor such as a wearable sensor patch.
Vital sign patches	Designed primarily to wirelessly track and monitor heart rate, respiration rate, temperature, step count, sleep cycle, stress levels and falls or incapacitation.
Continuous glucose monitors and smart insulin pens	Track dose and time, and recommend the correct type of insulin dosage.
Therapeutic extended reality	Augmented, mixed and virtual reality can visualize data collected from IoT sensors. These create a sense of being transported into lifelike, three-dimensional worlds and can be applied as an innovative treatment modality to manage a broad range of health conditions.
Bluetooth-enabled inhalers	Use a Bluetooth sensor, mobile application (app), predictive analytics and feedback.
Smart voice assistants (conversation agents)	Installed in the home setting to provide support to users through conversations (e.g. Amazon Alexa and Google Home).
Smart cameras	Smartphone cameras that can capture changes in the environment.

Source: Kelly, J. et al. (2020[5]), "The Internet of Things: Impact and implications for health care delivery", https://doi.org/10.2196/20135.

At home, remote monitoring reduces the need for patients to see a doctor in person or go to a hospital. Simple consultations can be administered via online video systems, health data can be collected remotely via mobile health-specific wellness devices (e.g. to monitor heart rate or glucose level) and emergency situations can be identified via implantable electronic devices. Furthermore, personal wellness wearable devices, e.g. fitness monitors and calorie counters, can track a wealth of data that can be used to identify patterns and alert people of risk factors, potentially leading to predictive and personalised healthcare.

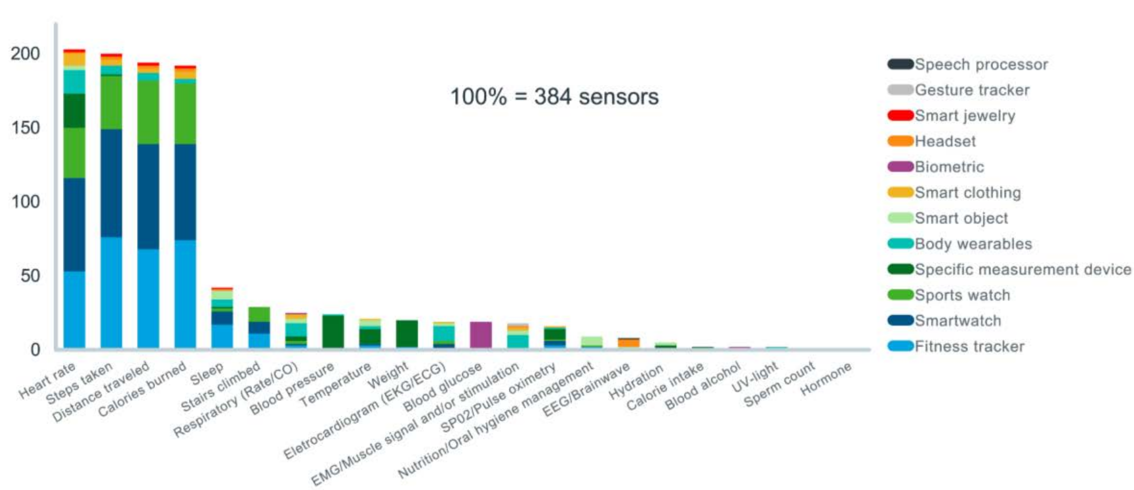
Outside the home, healthcare facilities can be equipped with the IoT to control all aspects of their operations, reduce operating and administrative costs and increase the quality of care. Hospitals can become more efficient while providing more information to patients and orienting them through the healthcare system. Potentially, these technologies would be able to exchange information with wearables and mobile health apps used by patients to generate a richer picture of the health condition and behaviour of users. However, health systems are still trying to figure out how to integrate data generated by these IoT devices into existing information systems (OECD, 2019[6]).

The IoT can also improve prevention and monitoring of chronic diseases, thus enhancing life quality and expectancy, enable patients and health providers to connect remotely and help reduce hospitalisation, thus leading to time and cost savings. Telemonitoring has been found to improve health outcomes, for instance, by reducing the mortality of patients with heart failure and improving the care of some chronic diseases (Oliveira Hashiguchi, 2020[7]).

Most IoT wellness and healthcare devices can be applied to the care of older people, helping to maintain them in their own homes rather than in residential facilities. Smart homes can have sensors that monitor movement and automatically calculate normal activities of daily living, reporting when an occupant deviates from the norm. Two promising areas of IoT application in this area are detecting falls and mitigating the effects of diminished cognitive function and memory loss (OECD, 2018[4]).

At present, most of the wearable devices on the market are of the like of smartwatches, sports watches and fitness trackers (Figure 5.1). They are linked to wellness and activity monitoring, such as heart rate, steps taken, distance travelled and calories burned. These account for 75% of measures tracked by wearable devices. Apps related to these wearables (e.g. Fitbit, Mi Fit, Huawei Health, Google Fit) have been downloaded more than 10 million times and, in aggregate, account for almost 50% of total app downloads. Wearable devices measuring specific health parameters, e.g. heart rate and blood pressure, account for about 15% of overall devices, showing the increasing importance of personalised health monitoring. Other body wearables, including electrocardiogram (ECG) devices and breathing monitors, represent 10% of all devices (IQVIA, 2021[8]).

Figure 5.1. Parameters measured by consumer health digital devices by type, 2021



Note: The chart includes data from 384 sensors. The total exceeds 384 due to multiple measures being tracked by a single sensor. Specific measurement devices include vital measurements.
Source: IQVIA (2021[8]), *Digital Health Trends 2021*, https://www.iqvia.com/insights/the-iqvia-institute/reports/digital-health-trends-2021.

COVID-19 has acted as an accelerator for IoT adoption in healthcare (Umair et al., 2021[9]). In the early phases of the pandemic, track and trace apps were used to monitor and control the spread of the disease (OECD, 2020[10]). Hong Kong (China), Israel, Korea and other countries (see below the results from the case study) used wearables and communication technologies to remotely monitor patients with COVID-19 at home, catching signs of possible deterioration and helping health researchers understand how the disease develops (OECD, 2020[3]). IoT technologies have also been used to track and monitor COVID-19 vaccines during shipment, help manage temperature and react to events with potential impact on the supply chain (Controlant, 2020[11]). Additionally, several countries have adopted emergency regulations to authorise the use of IoT devices for health purposes: for instance, the United States Food and Drug Administration (FDA) issued six Emergency Use Authorisation certificates for remote or wearable patient monitoring devices in 2020 (FDA, 2021[12]).

COVID-19 has also triggered faster changes in the national health systems: in Italy, for instance, telemedicine has been officially recognised and covered by the national health system since the end of 2020. Smart devices and apps for remote control and monitoring of vital and clinical signs are also covered. Italy's National Recovery and Resilience Plan (NRRP) foresees EUR 4 billion in investments for the policy objective "home as first place of care and telemedicine" (MEF, 2021[13]). France's NRRP also foresees investments of EUR 2 billion to strengthen digital health in the country (Ministère de l'Économie, des Finances et de la Relance, 2021[14]).

Results from the case study

While data from ICT usage surveys provide information on the uptake of IoT health monitoring devices by individuals, limited information is available on the adoption of such devices by hospitals and general practitioners (GPs). Information on the effects of their adoption is also scattered. The objective of this case study is to start filling this information gap, particularly regarding the use of smart devices for remote patient monitoring (RPM). RPM refers to the activities aimed at monitoring patients' health condition outside the hospital through connected devices. The data collected by such devices are then transmitted electronically to healthcare providers, who follow the patient's health status remotely and decide on any action to be taken.

A set of questions on the use of IoT devices at home for RPM in national health systems were included in the OECD ad hoc survey on telemedicine undertaken in the first half of 2022.

The following questions were included:

- This section focuses on the extent to which applications of the IoT and, especially, hospital-at-home are being deployed in OECD countries (If you do not have data or information at the national level, data and information at the subnational level are welcome).

1. To what extent do hospitals in your country use smart devices, systems and apps for RPM? If your response refers to a subnational territory, e.g. a region or a city, please provide details in the box below.
    - Most hospitals make regular use of smart devices for RPM.
    - The use of smart devices for RPM is in the testing phase or limited to a few hospitals.
    - No hospital currently uses smart devices for RPM but there are plans to introduce them in the near future.
    - No hospital currently uses smart devices for RPM and there is no plan to introduce them in the near future.

2. To what extent do your country's general practitioners or GPs (i.e. primary care physicians) use smart devices, systems and apps for RPM? If your response refers to a subnational territory, e.g. a region or a city, please provide details in the box below.
   - Most GPs make regular use of smart devices for RPM.
   - The use of smart devices for RPM is in the testing phase or limited to a few GPs.
   - No GPs currently use smart devices for RPM but there are plans to introduce them in the near future.
   - No GPs currently use smart devices for RPM and there is no plan to introduce them in the near future.
3. For what purposes are smart devices, systems and apps used to remotely monitor patients and what is the source of financing for such devices?

	Type of device (please report connected devices only)	Health condition monitored	Estimated number of hospitals covered	Estimated number of patients covered	Adoption stage (i.e. deployed, testing phase)	If available, please describe the financing model (multiple options are possible)
Pre-admission						
Post-discharge						
Ongoing chronic care management						
Other: non-chronic care						
Other RPM						

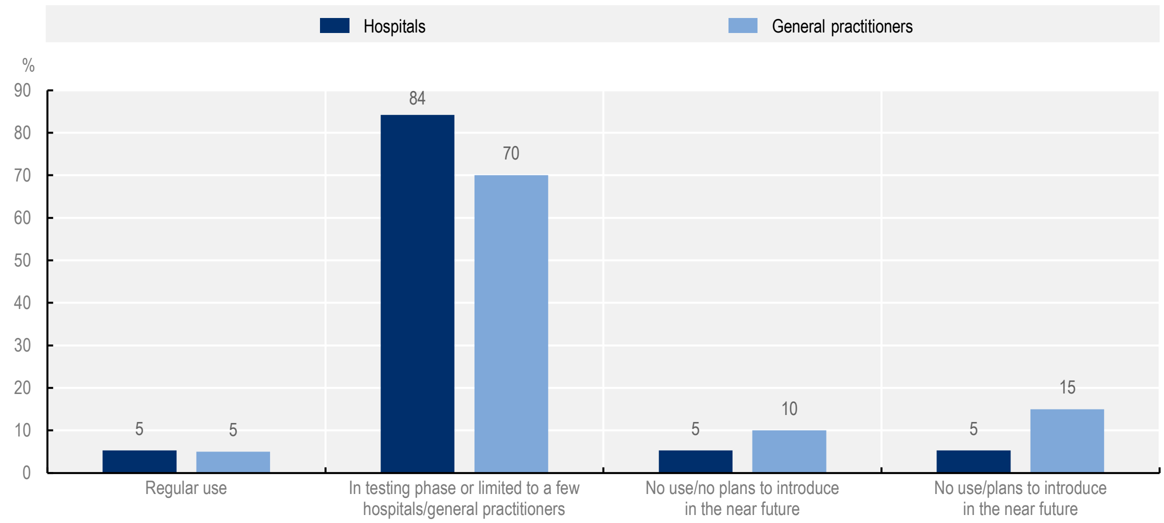
4. Does the ministry of health, a government agency or an academic institution have data or studies on the impact of RPM enabled by smart devices, systems and apps in your country, e.g. on clinical outcomes or healthcare costs? This can also refer to RPM of a specific disease/health condition (e.g. COVID-19 or health failure).
5. If hospitals/GPs do not use or make limited use of smart devices, systems and apps for patient remote monitoring, what are the main barriers to further adoption, both for hospitals/GPs as well as for patients?
6. The OECD would like to undertake a case study in your country on RPM enabled by smart devices, systems and apps. We would be grateful for your co-operation. Please provide the name and contact details of one or more experts in your country.

The responses from 25 countries show that using smart devices for RPM is still in the testing phase or limited to a few hospitals or GPs (Figure 5.2). Belgium is the only country reporting regular use of smart devices in hospitals, where RPM is undertaken in several fields, e.g. oncology, diabetes, sleep monitoring and cardiology. For instance, 11 000 patients with cardiac conditions are monitored through connected cardiovascular implantable electronic devices. England (United Kingdom) reported that a small number of hospitals are testing smart devices for RPM but they are not yet in regular use in the majority of hospitals.

Regarding GPs, Norway is the only country reporting regular use of smart devices, although no information is collected on their specific uses and effects. Several respondents commented that the decentralised administration of hospitals and GPs makes it difficult to obtain a general picture of the use of smart devices in their countries.

Figure 5.2. Use of smart devices for RPM in hospitals and by GPs

As a percentage of countries responding to the OECD Survey on Telemedicine, n = 23, 2022



Note: Response to the questions: "To what extent do hospitals in your country use smart devices, systems and apps for remote patient monitoring?" and "To what extent do general practitioners or GPs (i.e. primary care physicians) in your country use smart devices, systems and apps for remote patient monitoring?".
Sources: OECD ad-hoc data collection from the OECD Survey on Telemedicine and COVID-19, 2021-22; OECD (2023[15]), *The COVID-19 Pandemic and the Future of Telemedicine*, https://doi.org/10.1787/ac8b0a27-en.

Several countries reported further information on the RPM pilot projects. In England, between November 2020 and May 2021, 78 000 patients received home assistance for several medical conditions using remote monitoring technologies as part of the NHSX National Innovation Collaborative project. In Canada, Health PEI, which is responsible for the delivery of publicly funded health services in Prince Edward Island (PEI), has developed a free province-wide RPM programme spanning multiple care settings, including hospitals and primary care sites, for citizens living with heart failure or chronic obstructive pulmonary disease. In Latvia, P.Stradiņš Clinical University Hospital provides state-paid remote monitoring for people, including children, with heart rhythm disorders, while in Lithuania, smart devices are currently used in pilot projects for several conditions, such as blood pressure monitoring and glucose and pulse monitoring. In Belgium, a pilot project – involving 12 hospitals and about 280 patients – makes use of smartphones and a specific app (moveUP Coach App) to monitor knee and hip arthroplasty rehabilitation.

The respondents also reported that several RPM projects were undertaken during the COVID-19 pandemic to provide patients affected by the disease with home monitoring. England implemented the "COVID virtual ward" model in some areas of the country, a secondary-care-led initiative to support early and safe discharge from hospitals for COVID patients by monitoring them remotely via pulse oximetry. In Belgium, a pilot project for both the pre- and post-hospitalisation phases of COVID-19 was run in 19 hospitals, with about 500 patients monitored in each phase. Likewise, in 2021, in Latvia, a pilot project by the National Health Service developed a platform where doctors can monitor, treat and communicate with COVID-19 patients remotely. In the United States, the COVID-19 Telehealth Program by the Federal Communications Commission offers investment grants to improve hospitals' capacity to provide telehealth services, including home monitoring. The Office of Connected Care of the Veterans Health Administration also has an RPM programme (Home Telehealth), which was scaled up during the pandemic.

Results from these programmes show RPM's positive impact on several health outcomes. Canada Health Infoway conducted several studies to evaluate the impacts of RPM tools. A study published in 2015 (Gheorghiu and Ratchford, 2015[16]) found moderate-to-high evidence for a number of positive effects of RPM: increased patient satisfaction and compliance, improved quality of life, a lower caregiver burden as well as a decrease in hospitalisation and per-patient costs. In 2018, Canada Health Infoway conducted an evaluation of RPM programmes in PEI and Newfoundland (NL). In PEI, the evaluation found an 80% decrease in hospital admissions, while 90% of participants reported an improvement in managing their own health (Canada Health Infoway, 2017[17]). In NL, the evaluation found a 58.5% decrease in hospital admissions while 82% of participants strongly agreed the programme improved quality of life (Canada Health Infoway, 2018[18]). The home-based telecare for complex chronic patients operated by the Israeli Maccabi Telecare Center was also found to have reduced hospitalisation days and costs (Porath et al., 2017[19]).

On the other hand, the Health Technology Assessment (HTA) in Belgium reported more nuanced outcomes, concluding that RPM was as safe and effective as traditional monitoring via hospital visits. The HTA found several advantages for the patients, such as a decrease in in-clinic visits, earlier detection of events, a reduced risk of inappropriate shocks and a lower burden of atrial arrhythmias. However, there was no evidence of significant effects on hospitalisations, patients' quality of life, mortality or the workload of healthcare practitioners (Gerkens et al., 2021[20]).

In Belgium, an evaluation of 12 projects receiving financial support by the National Institute for Health and Disability Insurance concluded that it was not possible to draw any firm conclusion on the quality and efficiency of healthcare services, mainly due to the heterogeneity of the RPM devices used and the lack of a control group (Cornelis et al., 2022[21]).

For hospitals, economies of scale are a significant advantage for innovation procurement relative to primary care settings. In the Netherlands, most hospitals have one or more departments using smart devices. However, RPM tends to be organised separately from daily healthcare service or in a pilot setting. The Czech Republic also reported that larger hospitals, e.g. University Hospital Ostrava, have the most advanced or extensive applications, as they can experiment with various technologies and rely on funds provided by local, national or European Union projects. In the Republic of Türkiye, a pilot app has been realised for remote monitoring of type 2 diabetes patients as a part of a Horizon 2020 project (EC, 2020[22]), while other pilot apps are planned for remote monitoring of hypertension and chronic heart failure, with the perspective of scaling up their use.

The use of smart devices by GPs is limited to a few functions, for instance, to monitor diabetes in Finland and Norway. Norway has also piloted projects for remote 24 hours a day, 7 days a week blood pressure monitoring or of different chronic diseases. The country reported that there are several bodies, e.g. municipalities, hospitals and the Norwegian Directorate of Health are exploring different remote monitoring solutions for patient care.

The respondents to the survey pointed out several factors that may hinder the adoption of smart devices for RPM. The lack of a specific framework for financing, e.g. reimbursement mechanisms, was frequently cited, together with patients' low health literacy and digital skills of both patients and the medical staff. Other factors include technical aspects such as poor Internet connectivity, a lack of infrastructure, low interoperability between remote monitoring and the e-patient records/clinical systems in place and, more broadly, a low degree of digitalisation of the healthcare sector. Countries also reported patients' preference for in-person consultation and concerns about privacy and digital security.

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Note

[1] The survey (OECD Survey on Telemedicine and COVID-19, 2021-22) was undertaken by the OECD Working Parties on Health Statistics and on Health Care Quality and Outcomes and the OECD Working Party on Measurement and Analysis of the Digital Economy. See OECD (2023[15]), Box 1.2.

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This report explores the current state of Internet of Things (IoT) adoption and usage in OECD countries among businesses, households, and individuals. It analyzes IoT trends based on semiconductors, patents, venture capital investments, and firms. Additionally, it includes two case studies that examine the implementation of IoT in manufacturing and healthcare.

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