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# CROSS FERTILISATION THROUGH ALIGNMENT, SYNCHRONISATION AND EXCHANGES FOR IoT

## H2020 – CREATE-IoT Project

# Deliverable 04.01

# IoT as a key pillar of the EU digital economy

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# 1. EXECUTIVE SUMMARY

## 1.1 Publishable summary

This document addresses the recommendations based on different visions across Europe for maximising impact of IoT in the implementation of the digital single market and for analysing the potentials of IoT as enabler of the Circular Economy.

The document is part of the initial work to propose a European IoT Value Chain integration framework and includes recommendations for IoT technologies and applications as key pillar for the digital economy and potentially as an enabler of the new Circular Economy paradigms.

The aim is to foster links between communities of IoT users and providers, and with Member States' (MS') initiatives, through extension and consolidation of the EU IoT community, including start-ups and small and medium-sized enterprises (SMEs).

The primary objective is to streamlining goals and ensuring unified visions across Europe for data and information flows, policy coordination and knowledge in the implementation of the digital economy.

## 1.2 Non-publishable information

This is document public.

# 2. INTRODUCTION

## 2.1 Purpose and target group

The target group are the stakeholders of the IoT European Large-Scale Pilots Programme, the public authorities at the regional and national levels in the MSs and other initiatives including contractual Public-Private-Partnerships (e.g. in the area of Big Data, Factories of the Future, 5G-infrastructure PPPs), Joint Technology Initiatives (e.g. ECSEL JTI), European Innovation Partnerships (e.g. on Smart Cities), other FAs (e.g. on autonomous transport), and RRI-SSH issues.

## 2.2 Contributions of partners

**GRAD**: GRAD provides knowledge of undergoing IoT innovation initiatives at regional, national and European levels. GRAD is also involved in the activities behind the Digitising European Industry initiative. GRAD has acted as main editor of this deliverable, and has provided content related to the impact of IoT on the EU's digital economy, the silo-breaking potential of IoT, Digital Innovation Hubs and the links between the IoT and the circular, outcome-based and sharing economies.

**SINTEF**: SINTEF liaises with public research/innovation agencies in order to better streamline the IoT activities. SINTEF is one of the major contributors and worked on the recommendations addressing the role of IoT in the digital economy and circular economy paradigms based on different visions across Europe focussing on connectivity and IoT platforms. SINTEF defined and worked on the European IoT Value Chain integration framework and proposed a number of recommendations for IoT technologies and applications as key pillar for the digital economy and potentially as an enabler of the new Circular Economy.

**ATOS**: ATOS contributes to establish strong links with existing European initiatives in which ATOS is already present. ATOS has provided input mainly related to the data dimension of the IoT and its impact on the digital economy.

**ISMB**: ISMB contributes to strengthen links with existing European initiatives where ISMB is involved in. ISMB has provided content related to standards and interoperability, Digital Innovation Hubs (based on their links to the Italian IoT ecosystem and relevant initatives at regional and national level) and the impact of Iot on the circular economy.

**MI**: MI liaises with relevant IoT related organizations in support of an inclusive European market integration. MI has provided input mainly on the economic impact of IoT, with focus on the circular economy, the outcome-based economy and the sharing economy.

## 2.3 Relations to other activities in the project

The delivery is part of the work in WP04 addressing the creation of a European IoT Value Chain integration framework that will foster links between communities of IoT users and providers, as well as with Member States' initiatives, to offer multiple ways to improve sustainability and competitive advantage that can result in improvement in productivity and profitability of IoT technology development and IoT applications deployment.

The IoT value chain integration framework is vital in streamlining goals and ensuring unified visions across Europe for information flows, policy coordination and knowledge in the

implementation of the digital economy. The WP04 will develop a recommendations report of IoT as key pillar for the digital economy by contributing quantifiable drivers and barriers in the IoT area to the Digital Single Market implementation in Europe and an assessment of the common challenges and the collaboration potential across Europe.

The work is interlinked with the activities in WP01 Coordination and Support to the IoT Focus Area, WP02 IoT Large Scale Pilots Ecosystems Arena for Sharing Common Approaches, WP03 Creation, Innovation and Adoption, WP05 IoT Policy Framework - Trusted, Safe and Legal Environment for IoT and W06 IoT Interoperability and Standardization.

# 3. THE IMPORTANCE OF IOT FOR THE EU'S DIGITAL ECONOMY

## 3.1 Setting the scene

The global economy is becoming more and more dependent on digital technologies, which nowadays are everywhere, permeating virtually all economic sectors and leveraging them. As of 2015, 75% of inhabitants in the OECD area have access to mobile wireless broadband, and up to 95% of businesses are connected to the Internet [3]. Digital technologies are transforming value chains, business operations, relationship with customers, inter-sectorial relations... Because of this close relationship, we talk nowadays about **digital economy**. Multiple definitions of this term can be found. According to Accenture [1], it is *"the share of total economic output derived from a number of broad "digital" inputs. These digital inputs include digital skills, digital equipment (hardware, software and communications equipment) and the intermediate digital goods and services used in production.* According to Deloitte [2], digital economy is *"the economic activity that results from billions of everyday online connections among people, businesses, devices, data, and processes. The backbone of the digital economy is hyperconnectivity which means growing interconnectedness of people, organisations, and machines that results from the Internet, mobile technology and the internet of things (IoT)."*

Regardless of the particular definition, it is clear that the **Information and Communication Technologies** (ICT) are in the foundations of the digital economy [5], and we will continue to see a progressive convergence between ICT and economy at a large scale. Within this process of **digital transformation**, there are seven key enabling digital technologies (according to the Digital Transformation Scoreboard [6], part of the recently established Digital Transformation Monitor [7]), un-lockers of the potentials of digital economy: big data and data analytics, cloud technology, cybersecurity, Internet of Things, robotics and automated machinery, mobile services, and social media.

The other pillar of the digital economy is **data**, leading to the concept of **data economy** or **data-driven economy**.

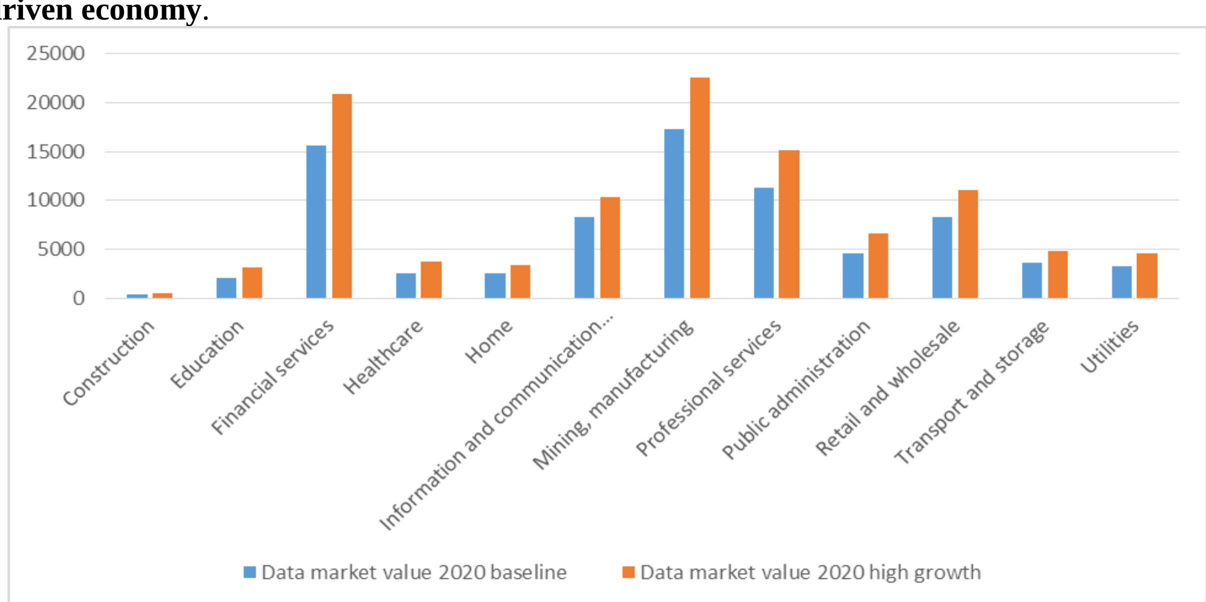



*Figure 1: Prediction of the EU data market value by industry. Values are in M €. Source: European Data Market Monitoring Tool [9]*

According to the EC, in its recent communication on building a European data economy [4], data is a key asset for economic growth, job creation and societal progress, being essential for taking the best decisions with the potential to optimise not only the industrial/business processes in multiple sectors (health, manufacturing, smart cities, energy, transport systems, food production, etc), but also our daily lives. According to the studies [7] referenced in [4], the value of the EU data economy was estimated in 2015 at 257 billion € (1.85% of the EU GDP), raising to 272 billion (1.87% EU GDP) in 2015, and predicting that such value could reach up to 643 billion € by 2020, representing more than 3% of the overall EU GDP. According to the estimates of the European Data Market Monitoring Tool [9], that value will steadily increase until 2020, being manufacturing and financial services the industry sectors (according to NACE rev.2 codes) with the largest value share.

For these predictions to be fulfilled, however, it is essential that regulatory conditions evolve in a way that technological innovations are not unnecessarily constrained. In this regard, policy measures are being launched in the EC [4] dealing, among other issues, with promoting data flow across EU MS borders, facilitating access to data, and defining a framework for the portability of non-personal data.

The digital economy at large is supported by a diverse ecosystem involving multiple stakeholders:

- The **ICT providers**, including manufacturers, researchers, providers of marketplaces, data platforms, application developers for vertical sectors… creating a plethora of digital innovations with the potential to lever economic and societal progress.
- The **demand side**, representing the multi-sectorial market players (including the citizens) that are the real drivers of growth, supported by the digital innovations and data to generate value.
- The **regulators**, providing a level playing field and an appropriate policy framework to pave the way for digital innovations and economic growth.

Europe is taking seriously the digital transformation of economy, as witnessed by the number of high-priority measures which are being put forward to support the development of digital economy. The best example is the **Digital Single Market (DSM) strategy** [10] [11] adopted by the EC in May 2015. According to the EC, *"a Digital Single Market (DSM) is one in which the free movement of persons, services and capital is ensured and where the individuals and businesses can seamlessly access and exercise online activities under conditions of fair competition, and a high level of consumer and personal data protection, irrespective of their nationality or place of residence. Achieving a Digital Single Market will ensure that Europe maintains its position as a world leader in the digital economy, helping European companies to grow globally"*. The DSM strategy encompasses a number of initiatives, closely related to digital economy enabling technologies, which are grouped in three priorities as listed (non-exhaustively) below [12]:

1. Better access for consumers and businesses to digital goods and services across Europe:
   - Proposals for simpler cross-border contract rules for consumers and businesses
   - Proposals for preventing geo-blocking in cross-border e-commerce
2. Creating the right conditions for digital networks and services to flourish:
   - Proposals to reform a number of telecommunications regulations, including the 5G action plan [13] and the Wi-Fi4EU initiative [13]
   - Proposal of an e-Privacy regulation [15]
   - Adoption of a cybersecurity strategy, including the establishment of a cybersecurity cPPP [16]
3. Maximising the growth potential of the Digital Economy, including:
   - Initiatives on free flow of data [12] (addressing as well data ownership and data usability), and on a European Cloud [20]
   - ICT standardization and European Interoperability Framework (EIF) [19]

- A new e-government action plan

One of the main actions under the DSM strategy, in particular under the third priority, is the **Digitising European Industry (DEI) initiative** [21]. As acknowledged by the EC, having a highly competitive digitised industry (across all sectors) in EU is a key condition for realizing the benefits of a digital single market. The general objective of the DEI initiative is indeed "*to ensure that every industry in Europe, in whichever sector, wherever situated, and no matter of what size can fully benefit from digital innovations*". The current situation is that there is a high disparity among different EU countries regarding the adoption of digital technologies, and in general a low adoption rate of the aforementioned key enabling technologies [6]. In addition, the digital adoption largely varies across industry sizes and types: whereas companies from high-tech sectors are adopting digital innovations at good pace, in general, a significant part of SMEs, mid-caps and non-tech industries are well behind.

Moreover, many of the challenges faced by regional/national industries are common at EU level, thus demanding for a coordinated European effort. The DEI initiative is setting the framework for such coordination and harmonization, which is becoming urgent in view of the number of industry digitization initiatives which are being put in place across different MS in Europe, yet with uneven degrees of maturity and implementation. The measures considered under this coordination effort include:

- Investments in digital innovations and infrastructures
- Accelerating the development of ICT standards
- Regulatory framework conditions for digital innovations: data protection, security, safety of autonomous systems and IoT…
- The Digital Innovation Hubs and Digital Industrial Platforms, two initiatives to be discussed in more detail in Section 0
- Upskilling human capital, not only in digital skills but also other complementary skills, such as entrepreneurship

The aspect of digital skills is particularly relevant to the digital economy, which is increasingly demanding a workforce well skilled in digital technologies. A digitally skilled population is also essential to fully get the benefits of a digital single market and a digitised industry. However, currently 44% of EU citizens lack a sufficient level of digital skills, as well as 37% of the workforce. Moreover, in the EU there is already a lack of ICT professionals to fulfil the job demands. This is why the "digital skills and jobs coalition" [22] was recently launched, considering the following high-level goals: raising awareness about the importance of digital skills, modernization of education to prepare young people for the digital economy, and supporting the re-training of the workforce, paying special attention to the SMEs.

When approaching the digital economy from a perspective of digital technologies, several dimensions have to be considered: industry verticals, cross-sectorial effects, business models, value chains... without forgetting their role in the new economic paradigms: the circular economy, the sharing economy, or the outcome-based economy. In this document, those dimensions will be addressed under the particular view of the IoT.

## 3.2 Why IoT is a key pillar to the EU's digital economy

As introduced above, seven key enabling digital technologies have the potential to unlock the full benefits of digital economy: big data and data analytics, cloud technology, cybersecurity, **Internet of Things (IoT)**, robotics and automated machinery, mobile services, and social media.

IoT is a real game changer [3]: it blends the physical world with the digital world through cyber-physical systems and it is recognized as the next step in convergence between ICT and the economy [5].

The ICT sector in the EU has a significant share of the economy, representing about 4% of GDP and more than 6 million jobs, with a value above 580 billion €, which amounts to nearly 10% of the overall industrial activity [21]. According to the OECD Digital Economy Outlook 2015 [5], the productivity in the ICT sector, in the OECD in 2013, was 79% higher than the rest of the economy, and regarding employment, the ICT sector contributed to 4% in 2011 and 2012, and 22% in 2013. The potential impact of IoT alone in the economy is huge. According to a study [23] conducted by IDC and TXT Solutions in 2014, the number of connected objects is still small (less than 1%), but this number in the EU is expected to increase from 1.8 million in 2013 to nearly 6 billion by 2020, leading to an IoT market above 1 trillion € by 2027. The estimates by Ericsson in 2010 [5] state that there would be 50 billion IoT devices connected worldwide by 2020. McKinsey, in a more recent report from 2015 [24], estimates the global economic impact of IoT in between 3.9 trillion $ and 11.1 trillion $ per year in 2025, representing about 11% of the world economy.

The enormous increase in the number of connected devices will lead to the redefinition of many industries, as they are known today, making them more competitive. The borders between industrial sectors will also be blurred because of such high degree of interconnection. In general, the wide adoption of IoT technologies will bring the following benefits:

- Improve the efficiency of industrial and business processes, increasing productivity.[1]
- Engage better with customers, allowing for increased personalization of products and services, anticipating demand changes, supporting fast decision-making, and in general enhancing customer service.
- Optimise value chains through sharing of data across multiple stakeholders and phases of the business processes.
- Monitor products' use by customers and products' performance, to gain insight on their lifecycle.
- Decrease environmental footprint of industry and human activities by reducing waste
- Trace goods and services throughout the value chain, bringing more transparency
- Breaking silos across industry sectors through sharing of data and cross-cutting digital platforms. Some illustrative examples will be provided in Section 3.7.
- Redefine the business models [33], allowing the creation of novel business ecosystems integrating the traditional actors and bringing new ones into the picture.

The list of benefits will be experienced across all vertical industries: intelligent transport (including autonomous vehicles), health and wellbeing, wearables, smart cities/communities, etc. For the purpose of illustration, we briefly analyse two such examples below: the manufacturing industry.

**Example: smart manufacturing**

The irruption of digital technologies in all economic sectors has one of its major drivers in the manufacturing industry. During the last decades, manufacturing has been witnessing a progressive "robotisation". However, traditionally robots have been limited to operate on very specific and controlled conditions. This situation is changing thanks to the combination of IoT with artificial intelligence and other digital technologies, which are making manufacturing systems more autonomous, in the context of what is often known as the "fourth industrial revolution"[62]. In fact, manufacturing is deemed to be the industrial sector with the greatest potential and the largest economic impact derived from IoT, followed by smart cities, according to several studies [24] [6].

[1] According to the Digital Transformation Scoreboard 2017 [6], 64% of EU companies have seen (significant) productivity gains upon adoption of digital technologies.

The digital transformation of the manufacturing industry is taking place under the auspice of multiple simultaneous initiatives with different names [63]: Connected Industry, Smart Industry, Smart Manufacturing, Industry of the Future, Industry 4.0… The manufacturing industry is a driver of economic growth, and digital technologies such as IoT will play a determinant role in giving back to Europe a leadership position. However, the impact of IoT will be progressive and it is expected to evolve through four phases [39], as illustrated in Figure 2. The first two phases represent immediate opportunities that will foster short-term adoption of IoT and digital technologies. Currently we are immersing in those first two phases, which will probably experiment an acceleration in the next years. Phases three and four are expected to be happen in the long term, since they demand deeper structural changes.


*Figure 2: Adoption and impact of the industrial internet. Source: World Economic Forum*

The main value drivers for IoT in the smart manufacturing industry can be summarised in four categories

- Production
  - Improved production planning
  - Fast decision making
  - Real-time
  - Flexible production: personalisation of products
  - Optimisation of machine usage
  - Predictive maintenance
  - Optimised energy management
  - Optimisation of raw material usage
  - Recycling, re-usage and valorisation of waste
- Quality
  - Quality and production control: reduction of manufacturing errors and production defects.
  - End-to-end identification and traceability of manufactured products
  - Continuous improvement, thanks to the availability of vast amounts of data related to the manufacturing process
- Products and services
  - Prediction of demand
  - New products, with new IoT-enabled features
  - Co-creation of products: personalisation, more interaction with customer
  - New data-enabled services
  - Energy-efficient products
  - Remote maintenance
- Work (people)
  - Improvement of working conditions: reduction of risks for workers, monitoring of the working environment parameters that influence quality of the work and wellbeing.

- Ergonomics: use of IoT-enabled supporting technologies, such as cobots (collaborative robots) and wearables.

According to McKinsey [24], optimisation of operations and predictive maintenance are expected to be the two main drivers.

The development of IoT, as well as its potential benefits, goes hand in hand with those of big data and cloud computing. Converting the large amounts of data generated by IoT devices into actionable, useful information, will require advancing significantly the state of the art in big data and data analytics (artificial intelligence). Likewise, fast processing of massive amounts of data will increase the demand of high-performing cloud computing services.

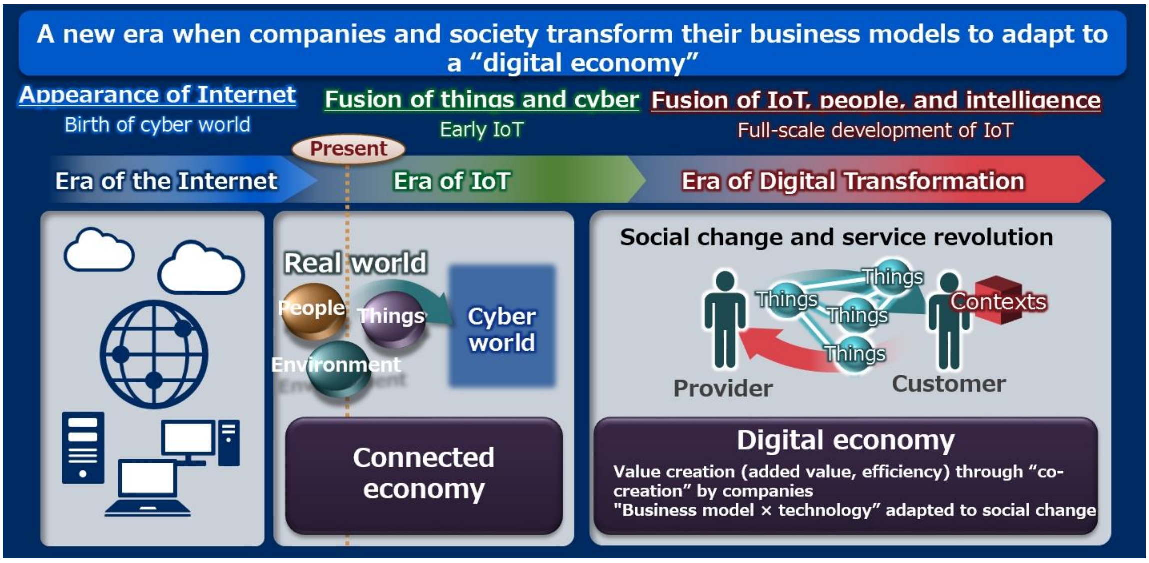



*Figure 3: Role of IoT in the digital economy transformation according to NEC [61]*

### IoT as a pillar of the Digitizing European Industry (DEI) Strategy

All industry sectors are being impacted by the digital revolution. Digital technologies are rapidly transforming the way of doing business, not only in high-tech areas (e.g. electronics, automotive, banking) but also in more "traditional" sectors such as agrifood and health. In some cases the main impact is in the manufacturing process, but in other cases digital technologies are radically changing the business model, blurring the borders between products and services, and redefining the value chain.

This paradigm shift in industry is a global trend, and Europe must take action in order to stay at the forefront of competitiveness. The Digitising European Industry (DEI) initiative [21], launched by the EC in 2016, is indeed a lever to ensure that Europe keeps the pace in the process of digital transformation of its industry. One of the most remarkable initiatives under the DEI strategy is the fostering of the **Digital Innovation Hubs (DIHs)** [27] [28]. As explained, the degree of adoption of digital technologies varies significantly depending on the industry size, and also across industrial sectors. This is a serious stopper for the good progress of European industries. The DIHs are, in a nutshell, "one-stop-shops" to provide the companies (especially SMEs) services to help them in their digitisation process, such as:

- Infrastructures, within working distance, for testing and experimenting with digital technologies relevant to their business
- Training in digital skills, advise on digital technologies
- Access to funding for developing innovative projects relying on digital technologies
- Access to private financing (for start-ups) to develop innovative projects based in digital technology
- Networking with other actors (customers, technology providers, etc.) to jointly develop products and projects.

Regions in Europe with a high digitisation level usually have well established DIHs. The DIH pivots largely over the so-called "competence center" (typically a public, or public-private research and technology organisation) although it is built on the whole "innovation ecosystem" with the capability to interconnect all the actors.

For the full benefits to be materialized, it is necessary that IoT technologies are widely adopted across all industries in Europe. However, nowadays the rate of adoption of IoT technologies is quite slow. For instance, in industries like healthcare, mechanical engineering or automotive, the average adoption rate is about 19% [6]. And even if the spread of digital innovations can happen fast, their impact on economy and productivity can take considerably longer, as recognized by the OECD [3]. This is why the EC promoted, in March 2015, the launch of AIOTI [25] in collaboration with major EU IoT players from the industry, with the overall objective to facilitate and accelerate the wide adoption of IoT by the major industrial sectors in the EU.

**Digital Industrial Platforms: A key element in the industries of the future**

Digital platforms can be defined from different perspectives [21]. In a narrow sense, platforms can be defined as *"multi-sided market gateways creating value by enabling interactions between several groups of economic actors"* or "*like operating systems that integrate different technologies and various applications and services"*. However, from a broader perspective, platforms can be seen as *"agreements on functions and interfaces between industry players that create markets and market opportunities leading to ecosystems and standards. This encompasses platforms (in the narrow sense) together with reference architectures, interaction protocols, and interoperability frameworks."* Thus, in a broad sense, digital platforms are key elements for digital innovation to happen in the new economic context. Their impact can be analysed from three different points of view [29]:

- **Community building**: platforms allows users (providers, consumers, third-party developers…) to connect with each other, creating communities or networks where items or services can be exchanged as in marketplaces. The community itself can be a key asset of the platform, and in fact largely determines its value: in general, the more users, the most valuable it is.
- **Infrastructure provision**: platforms allow users and partners to build applications and services, creating value on top of this infrastructure. In general, the infrastructure in itself does not provide any value unless the platform gains acceptance and diffusion in a wide community of users. Such infrastructure includes cloud services, protocols, standards, and programming interfaces that isolate the users of the platform from the underlying complexity.
- **Data access**: as explained before, data is the essential asset over which value can be created. In some cases, the value of the platform lies exclusively in the capability of aggregating data from heterogenous sources (sensors, personal devices, databases, etc) and making them accessible in a simple manner by the stakeholders. In other cases, it is the platform itself which provides an intelligence layer.

A significant number of platform-building initiatives from the private sphere exist, combining IoT with other digital technologies such as cloud, big data and artificial intelligence to develop cross-cutting integrated platforms. Such platforms are often built on proprietary technology and open APIs, and some of them are gaining traction in industrial applications, as it is the case of the Microsoft Azure IoT platform, Google Cloud, or Amazon Web Services IoT, to name a few. In other cases, platforms for specific industrial sectors are being completely built on open technologies and standards to facilitate their diffusion and adoption by developers and users. In fact, the EC considers open platforms as one of the pillars to achieve leadership in IoT innovation for Europe [26], and consequently it is pushing several initiatives in this direction, such as the European Large-Scale Pilots Programme [64]. As of today, the global landscape of digital industrial platforms is highly fragmented without any clear dominant actor.

Even if Europe is not in a leadership position regarding consumer-oriented platforms, it is better positioned when it comes to industrial platforms, as shown by the multiple initiatives (both open and proprietary) at EU level in this area [38]: RAMI [65], Industrial Data Space [66], FI-WARE-FITMAN [67], BeinCPPS [68], etc.

IoT will impact the EU digital economy across many dimensions

IoT involves many layers and dimensions that are not only related to technology, but also to broader concepts. For example, the increased demand in connectivity linked to the growing uptake of IoT in the EU's economy is expected to have a relevant impact. The availability of growing data sources and datasets, and how these data are managed, shared and exploited will be key facilitating (and also challenging) factors with great impact on the EU's digital economy. On across-sectoral plane, IoT has the potential of breaking siloes between economy sectors that have operated traditionally with little to no interaction or synergy. At the same time, the IoT will be a key topic of most digital innovation hubs (DIHs) that have been or will be established across the EU to facilitate the digitization of the EU's economic sectors.

All these dimensions will be analysed in the remainder of Section 3, and the analysis will be summarized in sets of recommendations for each of them.

## 3.3 Connectivity

In IoT applications any device is connected and every IoT platform includes a connectivity layer. It has the function of bringing different protocols and different data formats into one "software" interface. This is necessary in order to ensure all devices can be interacted with and data is read correctly.

There has been a swift acceleration in the evolution of connected devices, in terms of both scale and scope, and a greater focus on interoperability. Hyperconnectivity is supported by rapid developments in various communication technologies, including Wi-Fi, Bluetooth, low-power Wi-Fi, Wi-Max, Ethernet, long-term evolution (LTE), and Li-Fi (using light as a medium of communication between the different parts of a typical network including sensors). The hyperconnected and wireless 5G future, which will feature billions of interconnected wireless devices, will require new ways of sharing the spectrum dynamically, using dynamic spectrum access solutions (DSA) for low-band, mid-band, and high-band spectrums that will be available for various IoT applications and requirements.


*Figure 4: IoT communication technologies [46]*

Wireless dedicated IoT communication technologies-such as 3GPP's narrowband NB-IoT, LoRaWAN, or Sigfox-have been deployed in various IoT applications. In this context, standardization and interoperability are critical, as developers, end users, and business decision-makers need to consider more than 36 wireless connectivity solutions and protocols for their applications.

The digital economy is based on three pillars: supporting infrastructure (e.g. hardware, software, telecoms, networks), e-business (i.e. processes that an organization conducts over computer-mediated networks) and e-commerce (i.e. the transfer of goods online) [45]. In this new digital environment, IoT software is distributed across cloud services, edge devices, and gateways. New IoT solutions are built on microservices (i.e. application-built modular services, with each component supporting a specific business goal and using a defined interface to communicate with other modules) and containers (i.e. lightweight virtualization) that are deployed and work across this distributed architecture. Machine learning, edge computing, and cloud services, together with AI algorithms, will be used in conjunction with data collected from IoT edge devices.

In the case of autonomous vehicle applications five communication domains are defined that cover the communications of vehicle to everything (V2X) that addresses vehicle to infrastructure (V2I), vehicle to pedestrian (V2P), vehicle to device (V2D) vehicle to grid (V2G) and vehicle to vehicle (V2V) as important communication building blocks of the IoT ecosystems. Wireless technologies used in autonomous vehicles are ranging from AM/FM, satellite, Bluetooth, Wi-Fi, cellular 2G-4G/5G to DSRC technologies (IEEE 802.11p) Different applications have different networking criteria, network attributes and communication protocols parameters.

Vehicular communication systems are used complementary with of Radar/LiDAR/active sensing systems. The IEEE 802.11p-based dedicated short-range communications - DSRC using the two wireless modes, V2I and V2V, allow the autonomous vehicles to acquire traffic data to optimize their driving strategy. In addition, the use of Wi-Fi, Bluetooth, ZigBee, WiMax, and cellular 2G-4G technologies into vehicles enhance the functions provided to support the autonomous vehicles. Conventional wireless communications have limited bandwidth (i.e. maximal bit rate of DSRC is 27 Mb/s) and the next generation wireless technology, millimeter-wave (mmWave) that works at up to 300 GHz with channel bandwidth up to several gigahertz can achieve multi-gigabit transmission for high data rate delivery.

5G networks will deliver 1,000 to 5,000 times more capacity than 3G and 4G networks today and will be made up of cells that support peak rates of between 10 and 100Gbps. The networks need to be ultra-low latency, meaning it will take data 1-10 milliseconds to get from one designated point to another, compared to 40-60 milliseconds today. The goal is to separate communications infrastructure and allow mobile users to move seamlessly between 5G, 4G, and Wi-Fi, which will be fully integrated with the cellular network.

Applications making use of cloud computing, and those using edge computing will have to co-exist and will have to securely share data. The right balance needs to be found between cloud/mobile edge computing to optimize overall network traffic and optimize the latency. Facilitating optimal use of both mobile edge and cloud computing, while bringing the computing processing capabilities to the end user. Local gateways can be involved in this optimization to maximize utility, reliability, and privacy and minimize latency and energy expenditures of the entire networks. Future networks have to address the interference between the different cells and radiations and develop new management models control roaming, while exploiting the co-existence of the different cells and radio access technologies. New management protocols controlling the user assignment to cells and technology will have to be deployed in the mobile core network for a better efficiency in accessing the network resource. Satellite communications need to be considered as a potential radio access technology, especially in remote areas. With the emerging of safety applications, minimizing the latency and the various protocol translation will

benefit to the end to end latency. Densification of the mobile network strongly challenges the connection with the core network. Future networks should however implement cloud utilization mechanisms to maximize the efficiency in terms of latency, security, energy efficiency and accessibility. The evolution and pervasiveness of present communication technologies has the potential to grow to unprecedented levels in the near future by including the world of things into the developing IoT. Network users will be humans, machines, things and groups of them [46].

**Recommendations**

1. Maintain and improve the connectivity capabilities and connectivity infrastructure.
2. Increase the connectivity coverage. Used of standardised and interoperable broadband and wireless protocols enabling the hyper-connected IoT infrastructure.
3. Adopt interoperability concepts.
4. Converge different communication standards.
5. Heterogenous existence of different communication technologies, cellular (5G/4G, LTE, etc.), Wi-Fi, (Wi-Fi), LPWAN (NB-IoT, LoRa, Sigfox, etc.), WSNs (ZigBee, 6LoWPAN, etc.), and satellite technologies.
6. Software defined, cognitive, artificial intelligence and machine learning based communication networks.
7. Spectrum requirements, considerations and global harmonisation
8. Improving the spectral efficiency of communication systems
9. Coverage for remote areas.
10. Mobility management and context awareness approaches including localisation solutions for the communication protocols.
11. Networks based end-to-end security and network access management, including authorisation, authentication, etc.
12. Heterogenous communication protocols for always connected massive machine/thing type communication combine with intelligent/cognitive robotic things.
13. Convergence of communication protocols for operation and information technology
14. Alignment of V2X over cellular networks (3GPP RAN) LTE (Long Term Evolution) new releases (with beginning of 5G) to fulfil requirements for V2X over licensed and unlicensed spectrum and IEEE 802.11/ITS-G5-based V2X communication technology is a short-range ad hoc broadcast system developed for the exchange of object information and not for the exchange of sensor data.
15. Address the digital and connectivity divide.

## 3.4 Data dimension

As explained above, data is already a central building block of today’s economy. It is a core asset, and together with artificial intelligence, large datasets are essential to optimization and decision making. Economic growth will not be possible without guaranteeing proper access to data and the use of such data. In this regard, IoT technologies will play an enabling role as in many cases they will be the only providers (generators) of data over which services and applications will be built.

The expected growth of IoT during the next decade is very likely to impact each and every industry in Europe. This is sustained by state of the art inexpensive sensors, as a core source of data streams, combined with other emergent technologies such as scalable and secure cloud platforms and smarter advanced analytics. This combination is translated into estimated market size for IoT worldwide around $1.3 trillion by 2019[41], which will for sure boost novel business opportunities while providing organizations better knowledge about their products, which will be transposed into better customer service and experience.

We should not forget that the IoT is not only about sensors (simply put, ‘things’ able to measure relevant variables in the physical world, such as sunlight intensity), but also about actuators (‘things’ that can effect a change in the physical world when instructed to do so, such as a remote light switch). In this sense, IoT does not play only the role of data source or generator, but it can play the role of eventual consumer at the other end of the data processing chain.

By late 2016, almost half of business players were already using or planning to use IoT [41]. Most organizations understand that the quantification of their activities/products/services/assets through IoT technologies is crucial to be competitive and maintain a continuous growth in terms of quality and customer engagement. Some industries, such as logistics, oil/gas/energy utilities and/or manufacturing have been early IoT adopters, and they are experiencing currently a positive return of their investments in the form of cost savings, better asset utilization and general efficiency on all their activities.

The Smart City concept is also a key aspect of IoT adoption and a flagship in terms of novel efficient models based on IoT and making intelligent use of data. Governments and municipalities all over the world, and especially in Europe, are making extensive use of connected devices to optimize public services. Energy/water use optimization on buildings, individual/programmed lighting management, waste monitoring with optimum disposal schedules, efficient parking slot management or air quality assessment and alerting are current services being exploited in major EU cities.

A number of external conditions will be necessary for the IoT to realize its maximum impact in the implementation of the European DSM. Setting up a coherent and fair framework, from the legal al security perspective, would be critical in this sense to pave the way to even more extensive data utilization on the coming years. Data ownership, anonymization and efficient analysis are three pillars that will sustain an adequate growth and will boost new business opportunities. At infrastructure level, the availability of wide and capable connectivity will be essential.

IoT-generated data is one of the pillars sustaining the data economy paradigm. This shift requires the adoption of new approaches and business models. New opportunities accompany this change in the form of cost containment and value attainment with IoT data. Companies are reinforcing their investment on IoT and the number of new players is increasing rapidly. IoT data and data economy’s growths are tied, making it possible for companies to sell and exchange data [50].

**Recommendations for developing a data-oriented model**

1. When setting up a new service to collect data (or actuate on data), setting clear objectives is critical. This includes:
    a. Defining the desired role of the organization inside the data economy. Gain knowledge on monetization strategies.
    b. Establishing a corporate data economy policy and mission
2. Put the focus on the customer, trying to study their need and identifying the gaps or insights this new data is bringing, paying special attention to
    c. Need for real-time action/decisions or periodic reporting of historical trending.
    d. Type of industry and customer target.
3. Build a meaningful data model understanding each data point. It is not just about storing unconnected data, but to extract value out of it by properly reviewing, correlating and analysing the information.
4. Understand clearly the data ownership, setting a fair scenario to share your data and get access to third party resources if needed.
5. Stablish the link between the data and the visualization. The collected data is just as valuable as the tool used to make it actionable, easy to understand and insightful.
6. Identify potential use cases and opportunities for market disruption, considering even

different industries.

7. Once all previous knowledge about the data interactions is obtained, and not before, it is time to translate into practical requirements: hardware, OS, platforms, etc. A strategy to put this IoT plan in place is set up with this stage.

This plan should be adopted step by step, targeting achievable small objectives subsequently. There is a big room for improvement in a nearly limitless environment with rapidly evolving mechanisms and techniques ready to get the most out of greater and greater datasets.

**Recommendations for data economy stakeholders to optimize their value**

For IoT market actors

1. Maintaining or improving the data value of an organization implies continuous enhancement of capabilities. This can be achieved through several strategic approaches:
   a. Adding new resources to an already existing service. This helps on gaining a bigger portion of a particular use case.
   b. Incorporating different capabilities on top of the data collection, including aggregation, analytics and/or visualization. This allows differentiation, increasing interoperability and enhancing user experience.
   c. Pursue platform ownership, fully controlling the channel and getting close to the customers. Larger data usage attracts new customers/partnerships which also produce even more data that feeds the loop.
2. Increase connectivity. Cheaper broadband and wireless protocols are enabling an hyper-connected world.
3. Adopt Open Source and public APIs. Interoperability and replication is boosted through these concepts, enabling stakeholders to work directly with each other.
4. Follow data standards. Although there is not currently an accepted dominant on IoT data models, efforts are currently being put in place to this respect. Influencing the standard bodies and early adopting the normalized solution will provide competitive advantage.
5. Invest on automation and analytics. They both ease the data handling and value extracting.
6. Exploit your data and data taxonomies. Selling or exchanging raw data or even offering data taxonomies on the market could help monetize the efforts, as optimal use of data gathered is a challenging topic for most companies.
7. Put the focus on data presentation. This is the link with the customer. Making complex datasets easy to consume is critical to obtain a sustainable business model.

For policy-makers:

1. Facilitate the increase in connectivity (broadband). The huge IoT scalability will cause a large demand in network connectivity.
2. Foster the adoption of Open Source platforms to facilitate the participation in coming ecosystems.
3. Foster the adoption of Open Standards to avoid communication problems and technological slavery.
4. Establish regulations that facilitate the flow of data across platforms, entities and borders.

## 3.5 IoT Platforms

IoT platforms are emerging as the central backbone in the overall IoT infrastructure and today there are more than 450 platforms available as presented [42][43][44].It is expected that in the next five years, IoT platforms will manage the interoperability of around 25 billion newly connected devices and their ~44 zettabytes of generated data. The platforms will integrate basic device connectivity, data storage and advanced features such as device management, action management, analytics, and integration with external interfaces.

The IoT platform market is expected to grow 35% per annum and attain a size of $1.16B by 2020. Today there are more than 450 IoT platforms are available, which differ by technological depth, segment-focus, and technology implementation offering.

An IoT Platform can be defined as an intelligent layer that connects the things to the network and abstract applications from the things with the goal to enable the development of services. The IoT platforms achieve a number of main objectives such as flexibility (being able to deploy things in different contexts), usability (being able to make the user experience easy) and productivity (enabling service creation in order to improve efficiency, but also enabling new service development). An IoT platform facilitates communication, data flow, device management, and the functionality of applications. The goal is to build IoT applications within an IoT platform framework. The IoT platform allows applications to connect machines, devices, applications, and people to data and control centres. The functionality of IoT platforms covers the digital value chain of an end-to-end IoT system, from sensors/actuators, hardware to connectivity, cloud and applications. Different types of platforms have emerged [47].

The IoT platforms assist with data ingestion, storage, and analytics, so developers can focus on building applications and services, which is where the real value lies in IoT. Cloud based IoT platforms are offered by cloud providers to support developers to build IoT solutions on their clouds. Infrastructure as a Service (IaaS) providers and Platform as a Service (PaaS) providers have solutions for IoT developers covering different application areas. PaaS solutions, abstract the underlying network, compute, and storage infrastructure, have focus on mobile and big data functionality, while moving to abstract edge devices (sensors/actuators) and adding features for data ingestion/processing and analytics services [47].

IoT platform definitions include the description of the functionalities and the components Gartner [48], defines the IoT platform as a software suite or a PaaS cloud offering that monitors, and may manage and control, various types of endpoints, often via applications, end users build on the platform. It facilitates operations involving IoT endpoints and integration with enterprise resources. Platforms should be capable of:

- Provisioning and management of devices and their application software
- Data aggregation, integration, transformation, storage and management (often collectively referred to as "data digestion")
- Event processing: Rule engine/orchestration/BPM
- Customizing and building applications (SDK, app server, IDE and others)
- IoT data analysis and visualization
- Cybersecurity
- IoT device communications (network and/or Internet)
- Adapter (API hub, gateway software but also to the application on endpoint)
- User interfaces for both end users and developers

An IoT platform facilitates communication, data flow, device management, and the functionality of applications based on the definition provided in [49]. A platform is not the application itself, although many applications can be built entirely within an IoT platform framework. It links machines, devices, applications, and people to data and control centres. It is not confined to brick-and-mortar central command: ideally, it can be accessed and managed from many different locus points. It employs better, quicker search engines and data storage systems with the capacity and sophistication to handle volume far beyond what has brought industry to the present moment. Most of its elements are cloud-based and running on wireless connectivity, which may be established via third-party providers, application programming interfaces (APIs), cellular capabilities, or-most likely-a combination of these technologies [49].

The IoT platforms can be classified based on different criteria and include capabilities such as device connectivity, connectivity backend, normalization, device management, database,

processing/action management, analytics, visualization, development tools, cloud/edge storage, external interfaces and application enablement.

The layered IoT architecture used in autonomous systems implementations integrates new components in the different IoT architecture layers to address the challenges for connectivity and intelligence, actuation and control features, linkage to modular and ad-hoc cloud services, data analytics and open APIs and semantic interoperability across use cases and conflict resolution by addressing object identity management, discovery services, virtualization of objects, devices and infrastructures and trusted IoT approaches.

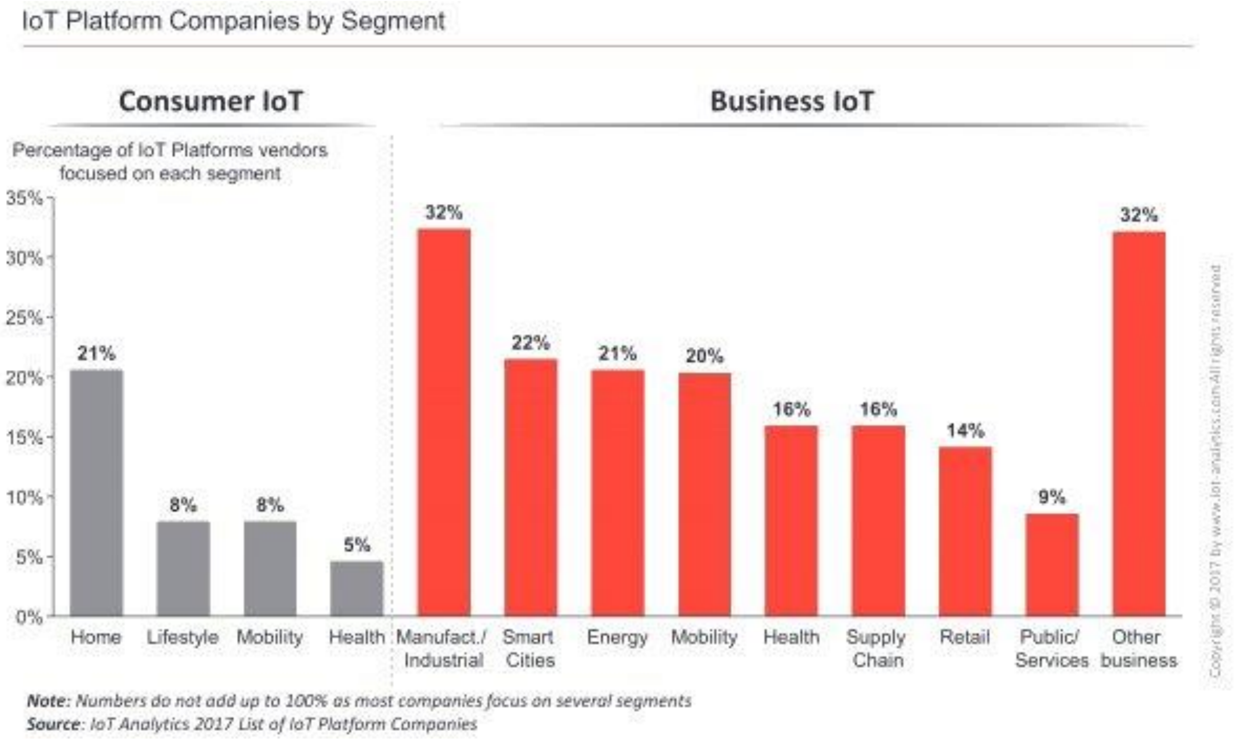



*Figure 5: IoT Platform companies by segment [44]*

**Recommendations**

1. Trade-off analysis of the maturity of digital industrial platforms, components available, business models, monetisation and development time.
2. Develop the IoT platforms ecosystem and encourage the federation of platforms.
3. Building the IoT platform or use existing IoT platforms. The most mature IoT platforms on the market have a cumulated twenty years of development behind, while the new ones still lack the business models and the ecosystem to support them.
4. IoT open distributed architectural concepts for the platform, interoperability and standardised components.
5. Concepts for federation of IoT platforms. Focus on developing and deploying IoT technologies and applications using a federation of IoT platforms and a strong IoT ecosystem of integrators, aggregators, service providers, RTOs across various industries.
6. Heterogenous coexistence of different IoT platforms based on open standards and interoperability. Increasing standardisation and joint efforts in open source development across major players to see a more aligned landscape emerging.
7. IoT platforms designed to act as complete IoT/IT/OT ecosystems converging the consumer/business/industrial applications by collecting and sharing data broadly within an organization, sectors, and IoT applications as part of the digital value chain
8. Address integrated IoT platforms that bring the devices, networks and endpoints together in the companies' and IoT ecosystems that develop various IoT applications.
9. Focus on providing disruptive, innovative solutions or value-added services around emerging dominant IoT platform ecosystems.

10. Create IoT ecosystems including industrial, consumer, business stakeholders that enable customers/end-users/stakeholders to create managed services offerings, co-create value (products, services, experiences) based on new business models and exchange data thus unlocking the true data value chain in order to deploy solution for digital single market.
11. Support for integrated cloud, mobile edge computing and edge analytics solutions in current IoT platforms.
12. Scalable IoT platforms integrating new components and modules for emerging industrial IoT applications, Tactile Internet and autonomous/robotic systems that require integration of actuators and much faster reactivity at the edges of the networks.
13. On the market there are more than 450 IoT platforms that require a process of evaluating the IoT platforms maturity, monetisation, interoperability and the new IoT business models.
14. Artificial intelligence, cognitive and machine to machine (thing to thing) learning frameworks in place to enable effective synchronisation and adaptability.
15. IoT platforms distributed scalable end-to-end security (E2E) and blochain mechanisms

## 3.6 Standardisation and interoperability

It is known that IoT intends to support a large number of different applications covering a wide array of vertical industries and disciplines, thus generating a high level of complexity when considering interoperability and standardization aspects.

By bringing together new technologies and solutions to solve global challenges and needs, new requirements, architectures models, interfaces, protocols, testing methods and certification schemes have emerged, and thus it is extremely important to address standardization and interoperability aspects.

The existence of such a wide range of IoT technologies and corresponding standards poses a risk of slow market penetration and society adoption at a large scale. To meet the rapid deployments expectations, key high-level challenges have been identified [34] by the IoT community that need to be adopted and accepted by traditional industries, citizens and society.

- Leverage on hyper-connectivity
- Facilitate object and data reuse across application vertical domains/silos
- Softwarize up to services including virtualisation, artificial intelligence and augmented reality
- Enable interoperability of solutions and semantically enriched information distributions

### 3.6.1 Standards mapping and overall standardisation and interoperability gaps

Several standardization initiatives currently co-exist [69], in individual Standards Development Organisations (SDOs) or partnerships (e.g. ETSI SmartM2M, ITU-T, ISO, IEC, ISO/IEC JTC 1, oneM2M, W3C®, IEEE™, OASIS®, IETF®, etc.) and also in conjunction with a number of industrial initiatives (e.g. All Seen Alliance, Industrial Internet Consortium (IIC), Open Connectivity Foundation (OCF), Platform Industrie 4.0, Thread group, etc.).

The standardization organisations have started a mapping exercise in 2016 at European level under the coordination of AIOTI[2] WG03 to provide an overview of IoT SDOs, Alliances and Open Source Software (OSS) landscapes and the standards related to IoT technologies and applications.

[2] AIOTI is the Alliance for IoT Innovation www.aioti.eu. It was initiated by the European Commission in 2015 to strengthening the dialogue and interaction between Internet of Things (IoT) stakeholders in Europe and to contribute to the creation of a dynamic European IoT ecosystem. The Alliance today is a legal entity established under Belgian jurisdiction: www.aioti.org

The mapping allows for a better understanding and eases the way to navigate among this "multitude of technologies and standards" by focusing on the different aspects of IoT. AIOTI WG03 has chosen three ways for this representation and has produced five classifications.

Based on the Deliverable 05.01 IoT Standards Landscape of the **H2020 UNIFY-IoT** project [34], regarding the identified gaps in the different IoT domains (i.e. Smart Cities, Smart Health, Smart Farming, Smart Mobility and Smart Environment) the following considerations can be stated:

- Overall not a clear winner can be identified among all the existing IoT architectures in all IoT application domains
- A lack of global data model and/or translation mechanisms between different specific models is a big issue in several IoT domains
- Very different network technologies and communications protocols are employed. The use of Multiple communication infrastructures is inevitable (LoRa, GPRS/3G/4G, mSatellite, etc.), especially when dealing with sensor networks.
- In some domains (i.e. Smart Farming) most of the platforms are proprietary solutions and no specific standards have been defined to address common platform
- Security and privacy are still clearly big issues that need to be addressed in the different IoT domains.

For further detail on the existing standards and technologies in the different IoT domains please refer to the official document of the AIOTI WG03 AIOTI "IoT Standards landscape and future evolutions" available at: https://aioti.eu/wp-content/uploads/2017/03/tr_103375v010101p-Standards-landscape-and-future-evolutions.pdf

Based on the previous considerations and the general IoT landscape a series of recommendations can be made to overcome the identified gaps regarding interoperability and standardization in the IoT.

**Recommendations**

1. Considering the current lack of standardization and the variety of protocols and technologies emerging in the IoT domains, this moment represents a good opportunity for Europe to take the lead and define a common framework of standards to enable interoperability among technologies and domains.
2. The adoption of a common IoT architecture reference model continues to need to be promoted among the different IoT domains and players.
3. A common data model is needed to facilitate integration (assembly of sub-systems) and interoperability (interoperation of heterogeneous sub-systems).
4. IoT platforms need to ensure data privacy, and integrity according to the data/information sensitivity.
5. High network availability with certified performance figures, are needed necessary, to make sure no sensitive data is lost.
6. Promoting and encouraging the regulatory bodies (SDOs/SSOs) to strengthen collaboration is necessary to converge into an interoperable and standardized IoT adoption.

## 3.7 Breaking siloes: IoT as enabler of cross-sectorial fertilization

In the digital economy, data is one of the key assets at the basis of innovative services and products [4], because data is essential to optimise processes and take business decisions. In fact, economic growth in the digital age is strongly linked to the possibility of making data more accessible and usable. By connecting diverse data sources, value chains are becoming increasingly larger and interconnected, and borders between industries are being progressively

blurred allowing to create innovative business models and generate competitive advantages. This growing degree of interconnection is what allows to break down the information siloes that prevented so far innovation to spread throughout the value chains. The future of digital economy unavoidably builds on the capability to connect the existing siloes, both vertically and horizontally, to fully exploit the value of the data which otherwise would remain constrained and isolated.

Vertical siloes are still numerous within organisations and value chains. Clear examples of vertical siloes can be found, for instance, in the manufacturing industry. Nowadays, production lines count on SCADA systems, which communicate with PLCs deployed to control and monitor the manufacturing processes. However, the information gathered by such systems usually does not flow to the other systems of the company, at least in an automated/electronic manner (data about industrial processes is often still collected in paper and later aggregated to other data). Horizontal siloes are even more frequent: manufacturers and providers, for instance, do not always share inventory information that could be used to enable seamless supply chain integration.

Actuating in siloes prevents value chains from being optimised and innovative business models from flourishing. IoT, by nature, has the capability to connect both vertical and horizontal siloes, enabling (real time) decision and actuation based on the knowledge extracted by data analysis algorithms applied on multiple data sources. Indeed, more and more examples of the use of IoT to break siloes can be identified nowadays, in many cases creating new connections between value chains that did not exist before.

**Examples of siloes being broken**

**Example 1: logistics**

Logistics processes are deeply involved in all industries delivering goods: manufacturing, e-commerce, agrifood, etc. Efficient logistics are key to competitiveness and business sustainability. Thus, proper integration of the information managed by the logistics provider with the companies' own processes (specially, when logistics services are outsourced) is a must. Implementation of lean manufacturing, for instance, requires precise stock control and extremely good synchronisation with components providers, aspects which can be taken care of by means of IoT technology.

In livestock farming, farmers need to keep control of the amount of available forage in their silos for feeding the animals.

Automated IoT systems for silo monitoring allow forage providers to anticipate the forage needs of their customers in a way that they can optimise the delivery routes, thus allowing the reduction of the individual prices to each farmer.

**Example 2: Healthcare**

The borders between traditional healthcare and wellbeing (at home) systems are being blurred at a significant pace. The future of healthcare goes hand in hand with that of IoT wearable technology for monitoring patients at home and during their daily lives, collecting and sending data about activity patterns and vital parameters which can be continuously analysed thanks to intelligent systems that can alert doctors when something needs further checking. Future healthcare will be much more about prevention than curing thanks to IoT technology, and much of this technology will not necessarily be "medical", but consumer-oriented.

Moreover, the healthcare industry is becoming more patient-centric than ever, looking for ways to be continuously in touch with patients and empowering them, something that can also be greatly facilitated by IoT technology.

**Example 3: Smart cities**

Smart cities are probably the paramount example of cross-sectorial service integration: the concept of smart city integrates transport, health, energy, buildings, waste management, eGovernment, citizens… into a single, hyperconnected system where all sources of data are susceptible to be used in the provision of any service. Public transport and traffic management, for instance, can be optimised by analysing the information collected from the tracking of vehicles, persons, pollution parameters, etc. Energy generation can be adapted to the needs foreseen by analysing the behaviour of citizens, buildings, etc.

**Potential unlocked by IoT**

IoT has the potential to connect multiple actors across the value chains of multiple industries, breaking down the siloes to enlarge the innovation ecosystems (indeed, creating ecosystems of ecosystems).

Broken silos mean new opportunities for creating value by exploiting unexplored relationships, uncovering hidden patterns and extracting new knowledge from aggregated data.

Together with the capability to automate the workflows by automating decisions and actuations, this can lead to large optimisations of the processes across the value chain. This will happen not only in the classical manufacturing scenarios, but in more complex scenarios involving multiple industries and sectors. For instance, IoT in combination with secure transaction technology like blockchain enables smart contracts involving physical objects connected through IoT sensors. Insurances in agriculture or driving could benefit from this paradigm.

Breaking silos also means generating new business opportunities by introducing innovative business models:

- Traceability of goods and services throughout the value chain, with different purposes: transparency, certification, usage analysis, etc.
- Selling and interchanging of data: e.g. farmers can pay for information related to pest spreading based on data captured from sensors in the field and the intelligent processing of such data.
- Creating marketplaces to exchange goods and services. Often, marketplaces redefine the value chains by bringing in new actors and taking others out.

Last, but not least, sustainability will be during the next years one of the largest drivers for cross-sectorial innovation. In particular, the concept of circular economy, to be discussed in Section 4, will be strongly linked to sustainability but also to the concept of efficient manufacturing and production which, as discussed, will need from IoT technology to interconnect the value chain and the business processes.

**Recommendations**

For “enabling” cross-sector fertilization

1. Foster the development of common IoT platforms for aggregating and interchanging data by multiple actors from different sectors and industries.
2. Foster and adopt standards for data exchange which support interoperability between different sources.
3. When standards are not sufficiently deployed, data gateways must be provided for achieving semantic interoperability

For “facilitating” cross-sector fertilization

1. Define appropriate data governance models taking into account multiple actors accessing data: who can access which data, for what, under which conditions…
2. Foster large scale pilots connecting multiple industries for testing cross-sector IoT platforms and new cross-sector business models

## 3.8 Digital Innovation Hubs and the IoT

In essence, a Digital Innovation Hub (DIH) is a support facility that helps companies to become more competitive by improving their business/production processes as well as products and services by means of digital technology. [28] DIHs act as a one-stop-shop, serving companies within their local region and beyond to digitalize their business.

DIHs are regarded as adequate tools to support businesses in their digital transformation. DIHs are set to be catalysts not only for digital innovation but, most importantly, for the penetration and take up of digital technologies across most productive sectors and vertical markets. The number and importance of established DIHs is increasing steadily across the EU, and they are receiving special attention under the Digitizing European Industry initiative [28].DIHs offer a wide combination of services such as ecosystem building, collaborative research, prototyping, testing/validation, market intelligence, business incubation/acceleration, mentoring education and skills development, just to name a few.

Interestingly, the European Commission is undertaking efforts to map and categorize all existing DIHs across the EU territory. Currently existing and prospect DIHs are being compiled in the DIH tool of the Smart Specialization Platform. [59] There is a great variety in the format and purpose of DIHs across the EU. Some of them are focused on specific digital technologies (Cyber-Physical Systems, High-Performance Computing, Big Data, IoT) and serve many potential market sectors; others focus primarily on a specific market segment and cover multiple digital technologies; some others expand over non-digital technologies.

**IoT as a key element in Digital Innovation Hubs**

According to data available in September 2017 [59], there are over 200 DIHs across the EU that claim IoT as one of their key technical competences


*Figure 6: Mapping of Digital Innovation Hubs with competences in IoT [59]*

Despite the varying operational maturity of those over 200 DIHs, their large number and wide geographical distribution is a clear indicator of how IoT has become a very important component (if not the most important one) in the wave of industrial digitization that is taking place across the EU.

It is therefore crucial that IoT stakeholders participate and get involved in the activities and services offered by DIHs existing in their areas of influence, since these DIHs will be instrumental for their success.

### Examples of DIHs with focus on IoT

An important number of the existing IoT-related DIHs focus on the digitization of manufacturing industry. Some of them are clustered under the ICT for Manufacturing SMEs (I4MS) initiative promoted by the European Commission. This initiative has started in 2013 with the aim to support SMEs and mid-caps in the manufacturing sector. I4MS promotes a European Network of Digital Innovation Hubs and Competence Centres, with the basic idea to enable and foster the collaboration of manufacturing SMEs and mid-caps across their value chains through the help of European competence centres/innovation hubs (some of them focused on CPS/IoT) in predominantly cross-border experiments to create a win-win situation for all actors, through networking, matchmaking, brokering and dissemination of innovative digital technologies and good practices for using them.

Just as an example, the Italian Digital Innovation Hubs Network of I4MS [70] is composed of Italian Digital Innovation Hubs of the EU I4MS network are the following hubs:

- DIMA HUB [71]: Promoted by Polytechnic of Turin, University of Turin, Mesap and Unione Industriale Torino with focus on advanced laser-based applications and additive manufacturing.
- t2i Trasferimento Tecnologico e Innovazione [72]: Consortium for Innovation of Chambers of Commerce Treviso-Belluno, Verona and Venice Rovigo Delta Lagunare, supported by Confindustria Servizi Innovativi e Tecnologici (CSIT) with focus on cloud-based hpc simulation.
- SMILE (Smart Manufacturing Innovation & Lean Excellence centre) [73]: SMILE is promoted by Unione Parmense degli Industriali and University of Parma with focus on Lean Innovation, Cyber Physical Systems (CPS) and Industrial Internet of Things (IIoT).
- 4M.0 (Marche innovation Machine and Market Manufacturing 4.0) [74]: 4M.0 is promoted by Confindustria Marche – Consulta del Terziario Innovativo e Marche Manufacturing with focus on HPC/robotics.
- CICERO Hub (CPS/IOT Ecosystem of excellence for manufacturing innovation) [75]: CICERO Hub is promoted by Unindustria – Unione degli Industriali e delle imprese Roma, Frosinone, Latina, Rieti, Viterbo with focus on Cyber-Physical Systems (CPS) e Internet of Things (IoT).
- Apulia Manufacturing - (CPS/IoT Hub for Regional Digital Manufacturing SMEs) [76]: Apulia Manufacturing is promoted by Confindustria Bari BAT , Polytechnic of Bari and the Meccatronical district of Puglia with focus on Cyber Physical Systems (CPS) e Internet of Things (IoT).

As examples of DIHs working in a different vertical such as agriculture are the following:

- BioSense Institute - Institute for research and development of information technology in biosystems [77]: BioSense exists to generate, apply and disseminate research findings through a global ecosystem of forward-looking stakeholders and build capacity in the field by empowering the next generation of technology-enabled professionals in the agrifood sector.

- Digital Innovation Hub for the Galician Agrifood Sector [78]: It is fostered by Gradiant and the University of Santiago de Compostela, and already involves over 60 agro businesses, cooperatives, ICT companies and research and innovation centers from the Galician region in Spain.

**Recommendations**

1. From a policy perspective, support should be given to the implementation of DIHs that are focused in servicing the industrial sectors in which their areas are specialized (locally, regionally or at Member State level).
2. The supply side of the IoT value chain should engage deeply in existing DIHs operating in their areas of influence and vertical markets.
3. From the demand side, industries and businesses willing to advance in their IoT take up, and more generally, in their digital transformation, should turn to DIHs as their primary source of information, advice, training and business/service provision.

# 4. IoT AS ENABLER OF THE CIRCULAR ECONOMY

## 4.1 Setting the scene

A circular economy is one that emphasises the reuse or redeployment of some or all waste products in the economy. The primary motivation for this type of economy is sustainability which applies to every aspect of the economy including:

- How raw materials are sourced,
- What raw materials are sourced,
- From where raw materials are sourced.

By ensuring that the maximum amount of raw materials in your sector is being redeployed from the same sector or any other, this will simultaneously maximise the sustainability of the system. There is an additional consideration that is not implicit in the expression of the circular economy and that is the sustainable disposal of material that cannot be reused. Although not integral to the circular economy ethos, it is still important for sustainability and is something that can be improved with digital technologies.

The major problem with trying to implement a circular economy is the direction in which the problem is approached: a) identifying waste materials and invent new products or services that use them; or b) inventing new products and services and trying and finding waste materials that can be used in building or implementing them?

No matter which one is chosen, there will be some inefficiency in the system with both options leading to an unnecessary excess in use of raw materials that are not sustainably sourced. This is where the implementation of digital technology can lead to an optimised solution.

By digitising input and output lines, it will be possible to accurately track what is being used, where it is coming from, what the waste product of a particular process is, and where it is going. By recording all this information and storing it in a sensible and logical way, it would be possible to design algorithms that could allocate materials being released as waste in one system to be used as input in another system. In addition, newly created products and services could submit needs and have them registered in the system. By cross-checking those needs with registered reusable materials, it would be possible to allocate appropriate reusable materials to new industries without the need for having them run for a certain period of time first.

As for waste materials that cannot be reused, digital technology can be used to analyse the composition of whatever remains and determine the most sustainable method for disposing of it whether that is in regard to ecological factors or more pragmatic reasons such as available land and technological feasibility.

This process sets up the need for intermediaries (or an intermediary) that will be required to moderate the algorithms and ensure that resources are being allocated in an efficient manner. It would not be unreasonable to use a second-level algorithm to regulate the first-level algorithms and identify space for improvement. What form these intermediaries take will fall to political or governmental considerations and are likely to vary from state to state. In any case, it will be a positive step for sustainability.

For the EU, such a body may be public or private but will certainly be restricted by a number of rules imposed by the European Commission. This will involve considerations for the rights of individuals, businesses, and the environment. In this regard, any set-up of this type in the EU is likely to be ecologically efficient but subject to obstacles in terms of oversight and regulation. The result would be an improvement in the sustainability of the European economy.

Indeed, the need for Europe to move towards a resource-efficient and ultimately circular economy was highlighted in the manifesto (back in 2012) of the European Resource Efficienty Platform (EREP) and subsequent policy recommendations [53]. Among others, the recommendations address innovation in resource-efficient technologies and systems, and promoting new resource-efficient business models such as "*service-based business models (e.g. leasing and sharing) that sell performance instead of transferring product ownership."* The expectation is that Europe will increase its resource productivity by 15% by 2030, but it is estimated that thanks to the circular economy implementation such increase could reach 30% [39].

However, without external impetus, uptake of the circular economy would likely be slow or non-existent with little change taking place in the short-to-midterm. A decent rollout would require significant backing from governments and a focus on making the system as easy to adopt as possible. If this took place and was successfully adopted by industry, markets would become much more efficient, goods would become cheaper, the environment would improve, and jobs would shift toward sustainability [35]. In terms of industry competitiveness and jobs creation, the the opportunity has been quantified in recent studies [55] to 7% growth in GDP, and up to 3% more jobs by 2030. Long-term success, however, would require continuous effort and sustained assistance to industry.

In addition to the circular economy, there are two other types of economy that become feasible with the improvement of digital technology: outcome-based and sharing. An outcome-based economy is one in which prices accurately represent the direct value the customer expects to receive from the item. This is ostensibly how pricing in theory is supposed to work, however, in order to determine such a thing is largely impossible.

With digitisation, it is now easier to determine the real value of something by perpetual analysis of its use through sensors, etc. than by relying on market forces to deliver the correct price despite lacking the correct environment in which market forces can work adequately.

A sharing economy is one in which members of the economy make products and services available to other members of the economy while minimising the need for currency or financial transactions. This can take the form of overt bartering systems or more of a faith-based system where economy members take no form of payment directly on the understanding that they will receive other products or services without payment elsewhere. This is just two interpretations of the sharing economy with many others possible. A digitisation of the marketplace would make either case eminently more feasible by side-stepping currency's primary use, which is to enable exchanges to take place over large distances and time periods.

More information on the outcome-based and sharing economies is given in Section 4.3.

## 4.2 IoT as enabler for the Circular Economy

The circular economy describes sustainable business principles whereby components and raw materials are continually reused and recycled. Through this approach, materials retain their value reducing the use of precious resources, processes increase their efficiency, and the use of clean energy is boosted [60].A circular economy prizes sustainability above all else, especially environmental and ecological sustainability. The primary contribution of digitisation to this goal is the recording of input and output data of the various systems in the circular economy and the optimisation of allocation of reusable resources from the outputs of one set of systems to the inputs of another set of systems.

The role that IoT technologies can play in the circular economy has been acknowledged in recent studies [54]. IoT is a key step in this digitisation because it allows the gathering of data of things for which it was previously impossible to gather data. For example, companies or individuals

throw their waste away and sensors in the waste receptacles determine the composition of the materials that have been thrown away. This data can be recorded and processed in the system. In the meantime, a similar process is taking place when companies receive materials.

If the companies record what goes to consumers and what is thrown away, then a near-complete picture of the resource ecosystem of the economy is created. All that is required after that is the deployment of algorithms to determine the most efficient way to reuse materials in a way that waste is minimised but also that the production of raw materials from non-sustainable sources is minimised. The equipment used at landfills and resource extraction would also benefit from being fitted with IoT technology. Figure 7 illustrates a simplified product lifecycle in the circular economy paradigm. IoT technologies can contribute directly to circular economy in a number of ways, in different phases of the lifecycle which are discussed in the table below.

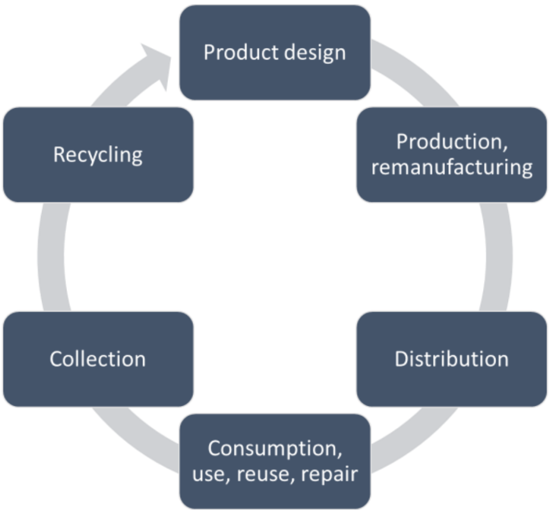



*Figure 7: simplified product lifecycle in the circular economy [41]*

*Table 1: IoT elements contributing to circular economy*

| Contributions of IoT to Circular Economy | Lifecycle phase | Impact of IoT |
|---|---|---|
| **Increasing the efficiency of goods production**, by reducing the amount of raw materials and energy use. This obviously includes the application of industrial IoT technologies in digital manufacturing, as introduced in Section 3.2, to optimise operations. Use of IIoT to achieve a lower rate of manufacturing defects will also lead to less waste and lower environmental footprint. | Production | High |
| **Better integration of supply chains**. Automated sharing of inventories and demand facilitates the coordination of suppliers and producers, contributing to make supply chains much more efficient. | Production | High |
| **Shortening value chains**, connecting consumers directly with producers through digital marketplaces and collaborative platforms. This allows to look for consumers in local markets, and in general to reduce the steps needed to put products in the hands of consumers, making product distribution more efficient and consequently with a lower footprint. | Distribution | High |
| **Optimising distribution** according to consumption patterns (built through information generated by on-chip and embedded sensors) and up-to-date demand of specific products (thanks to automated inventory at points of sale), leading to CO2 reduction in logistics operations. | Distribution | Moderate |
| **Provide information to consumers** about product provenance, product authenticity, lifecycle, etc. through smart tags that increase value chain transparency and allow consumers to perform informed decisions regarding "responsible" and "sustainable" consumption. | Distribution, consumption | Low |

| | | |
|---|---|---|
| **Reducing energy consumption** during products' usage, thanks to built-in sensors and smart algorithms that optimise the use of energy according to environmental conditions and consumer's needs. | Consumption | High |
| **Increasing durability of products** thanks to built-in sensors and smart algorithms, which allow to perform predictive maintenance and extend their correct operation for longer. | Consumption | High |
| **Support service-based business models**: instead of acquiring products, consumers rent or share them, thus saving resources and facilitating their recycling. Pay-per-use models, for instance, are feasible alternatives nowadays thanks to existing IoT technologies (one example can be found in the batteries of electric cars by certain manufacturers). | Consumption | Moderate |
| **Measuring product use**, energy use, interaction between product and consumers. Smart products can generate accurate usage profiles that can help in the design phase to better adapt them to the actual use made by consumers. | Design, consumption | High |
| **Incentivising proper collection of products** at the end of their lifecycle and recycling. IoT-enabled objects can provide information about the best choices for their disposal. | Collection, recycling | Low-moderate |
| **Trace products** from origin (production) to end (recycling). IoT-enabled products can generate information throughout their whole lifecycle to better understand their usage patterns and trace the materials they are built of, from manufacturing to disposal/recycling. | All phases | High |

IoT and digital technologies are already helping to implement the circular economy paradigm in certain industries. Four examples are provided below for illustrative purposes.

**Example 1: manufacturing industry**

As introduced in Section 3.2, the optimisation of operations is nowadays the main driver behind the use of IoT in smart manufacturing. According to some studies [56], the manufacturing industry could boost its operational efficiency up to 30% thanks to the introduction of IIoT technologies.

One of the paradigmatic use cases of IIoT is predictive maintenance [57]:

- Predictive maintenance on the production line. Through real-time analysis of data such as number of days in operation, days from last service, failure history, and specific data of the machinery involved in the manufacturing process (which are continuously communicated through M2M connectivity), failure patterns can be quickly detected and maintenance operations can be performed just in time to prevent failures (thus preventing machines from breaking and faulty pieces from being produced). Million-dollar savings are reported from large equipment manufacturers in real use cases.
- Predictive maintenance for field-level customer service: car manufacturers can determine if certain production runs fail more often than others and under which conditions. Thanks to sensors embedded in the cars, the company can identify when the equipment in the field is likely to fail. Car manufacturers have reported to save millions of euros annually thanks to this predictive maintenance.

The other use case which is driving IIoT is the optimisation of production operations. Multiple examples can be found where such solutions are being tested in many industries. One of such examples is the BeinCPPS EU project [79] and its experiment CPPLEAN, which consists of a discrete event simulator-based tool as a Finite Capacity Scheduler in order to optimize manufacturing orders and processes of a factory. The proposed software is basically a Big Data based scheduler application to minimize the impact of incidents on productivity and optimise fabrication costs. Claimed improvements reach up to 21% and 20% in manufacturing productivity and production capacity (use of equipment), respectively.

The above are just two examples of the close interplay between digital technologies and the circular economy. This relationship will get stronger, in a way that the digitised industry and circular economy will progressively converge.

**Example 2: agrifood industry**

Agriculture is intensive in use of natural resources: it consumes 70% of the world's fresh water supply, and in Europe uses roughly 40% of the total land area. Moreover, food production is expected to increase 70% by 2050 in order to satisfy world feeding demands [58]. Clearly, optimisations in the use of resources can have a large impact in the environment and greatly contribute towards the circular economy paradigm.

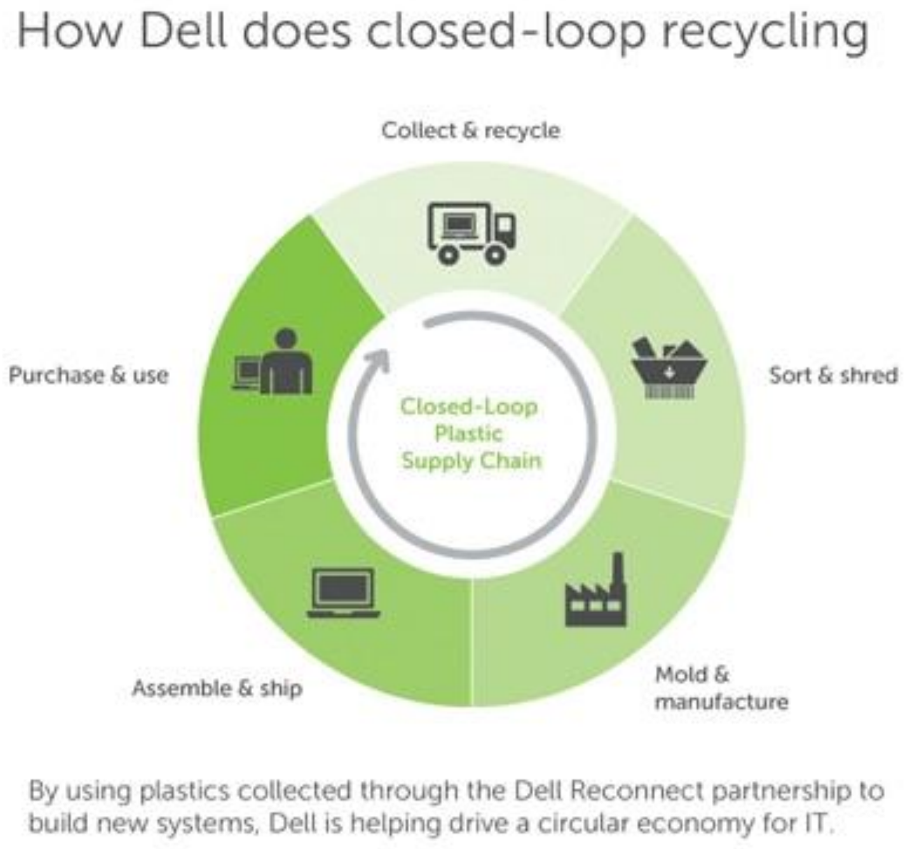
Precision farming, enabled by IoT technology, is indeed about maximising the yield while maintaining or even reducing the use of resources. This means increasing productivity while decreasing the usage of pesticides and fertilisers, optimising the use of water (precision irrigation) to generate a lower environmental footprint. Numerous examples can be found nowadays where IoT technologies, combined with decision support systems, are being used to improve traditional agriculture through precision farming techniques. A remarkable effort is being made at the European level, where the flagship project IoF2020 [80] is taking precision farming to the next level by addressing the challenges in large-scale implementations.

IoT is not only about improving traditional farming, but it is enabling new forms of agriculture which hint that the future of farming goes hand in hand with digital technologies. For example, the US company Aerofarms [81] is using IoT and advanced, real-time data analytics tools to enable growing of plants in controlled indoor conditions, by means of a closed-loop aeroponic system which results (as claimed by the company) in reducing water use by 95%, growing plants as twice as fast, and reducing soil demand by a factor of 400x (compared to traditional field farming). Food waste is another area of agriculture with strong implications in the circular economy, where the application of IoT technologies is promising. About one third of the food produced worldwide gets lost or is wasted [58], thus making a great environmental impact but at the same time a great opportunity for improvement. In fact, food waste is one of the specific areas being addressed by the Circular Economy Action Plan set out by the EC, which aims at reducing food waste to 50% by 2030 [52]. Solutions based on IoT, such as the US company Zest Labs [82], are being deployed in the market to finely monitor, at pallet-level, the supply chain conditions of fresh products in order to detect inefficiencies and risks of ruining fresh food. Other IoT technologies are still under validation, but on their way to the market, as it is the case of the EU project TagItSmart [83] which is evaluating the use of smart tags to trace products throughout the value chain (a use case is provided with beer bottles).

**Example 4: Philips: Light as a service at Schipol airport in Amsterdam [84]**

Philips, Cofely and Schipol Group have entered into a collaboration for the new lighting in the terminal buildings at Amsterdam Airport Schiphol. According to one of the innovative Business Models that enable the Circular Economy (namely Product as a Service), Schiphol pays for the light it uses, while Philips remains the owner of all fixtures and installations. This means that Philips and Cofely Nederland NV will be jointly responsible for the performance and durability of the system and ultimately its re-use and recycling at end of life. By using energy-efficient LED lamps, a 50% reduction in electricity consumption will be achieved over conventional lighting systems. Lighting fixtures were designed to improve the serviceability and the lifetime: in fact, they are expected to last 75% longer than other conventional fixtures. In addition, the fixture components can be individually replaced. This will reduce maintenance costs and means that the entire fixture does not have to be recycled, resulting in the greatest possible reduction in raw material consumption.

**Example 4: DELL and the closed loop plastics** [85]




The closed-loop project by DELL starts from the principle of designing products with the whole lifecycle in mind – enabling reuse, repair and recyclability of the chosen materials and easy recycling options for the customers. DELL uses the plastics recovered from technology collected through their recycling efforts to make new plastic parts. This gives these plastics an extended life, has a smaller carbon footprint, and even reduces costs. As the IoT begins to integrate cloud, networking, sensors, Big Data and analytics, it will drive new learnings that affect how resources are deployed. Dell's work with The Pecan Street Project and smart grid technologies, for example, is helping everyone better understand home energy use. DELL has also opened the Dell Internet of Things Lab in partnership with Intel as a working site for customers to test new ideas, software and solutions.

**Recommendations**

1. Speed up research on enabling IoT technologies for fine tracing of goods and products throughout the full value chain, including low-cost tags for objects, energy-efficient tags (ideally running without batteries)
2. Simplify the sharing and access to data (generated by connected products) from different points of the value chain to allow for better tracing and collective decision making
3. Speed up large-scale testing and validation of IoT technologies to increase resource productivity in all industries
4. Further develop the interplay between IoT technologies and service-based business models

## 4.3 IoT as enabler of other economic paradigms

### 4.3.1 Outcome-Based Economy

An outcome-based economy prizes economic fairness and is the principle on which foundational pricing theory is centred. In order to give a true price to something, it is necessary to determine exactly how valuable it is relative to all other products and services and, to determine this as accurately as possible, it is necessary to measure the absolute use that one gets from each individual product or service. This is then scaled across all products and service and an outcome-based economy is produced. Due to the granular nature of this task, IoT is the perfect technology to deploy in order to collect all the necessary data. One paradigmatic example of outcome-based economy, well before the advent of digital technologies, is the case of Rolls-Royce, which already in the 60's switched its business model from selling engines to sell "power by the hour" [86]. The original model by Rolls-Royce was updated over the years to include fine-grained engine monitoring by means of embedded sensors that provide the data needed to guarantee the agreed service level.

Thanks to IoT, traditional product-selling companies have the opportunity to become more service-oriented. As in the Rolls-Royce example, manufacturers of household appliances (e.g. washing machines [87]) are starting to roll out service-based models, which are enabled by fine-grained appliances monitoring thanks to IoT technology.

It is likely that this kind of paradigm shift would make prices fairer. However, it would undermine the free market if implemented. It is a standard result in behavioural economics that people do not perceive the true value of things due to the large number of energy-saving short cuts our brains make in their thought processes. As such the true value of any one thing to any one person is more akin to a random number than a fixed value. This means that, even if prices become fairer, it is not guaranteed that consumers would view at as such and, if one were determined to enforce this economy, probably heavy regulation would have to be put in place.

### 4.3.2 IoT as enabler for the Sharing Economy

A sharing economy prizes minimisation of financial transactions by opening up access to all products and services to as many people in the economy as possible. This is practically the opposite of the outcome economy in which granularity of value is focussed on, permitting instead a fluidity of value that saves time but potentially opens up the market to individuals taking advantage of the system. From a simplistic point of view, the sharing economy is based on users that offer services and users that demand those services, resorting to some platform of marketplace for putting them in contact and enabling the transaction. As connected devices proliferate and smart algorithms become more autonomous, IoT technology can greatly facilitate the sharing process by allowing "automated" matching of offer and demand, as well as monitoring shared usage.

The big loser in this type of economy would be currency which was originally introduced as a method for conducting transactions over protracted distances and periods of time but, with new types of digital technology, a modern form of exchange economy is becoming more and more feasible. Since this model simplifies financial transactions, IoT technology can be used to automatically calculate payments and record transactions in a large and diverse number of ways. Record-keeping will also adapt to take account of the minimal amount of information individuals will need to pay attention to in their lives and business.

# 5. CONCLUSIONS

This deliverable provides a comprehensive set of recommendations oriented to maximize the impact of the IoT in the implementation of the Digital Single Market, and the potential of IoT in enabling the practical implementation of the circular economy paradigm.

This report provides a solid rationale that identifies IoT as one of the enabling digital technologies that are, and will be, key pillars of the EU's digital economy and the digital industrial transformation efforts currently underway. The report provides analysis and links to important initiatives, such as the Digitizing European Industry initiative.

In terms of the impact of IoT on the EU's Digital Single Market (DSM), this report provides analysis and recommendations along a number of dimensions where IoT plays a most important role:

- Connectivity, data, platforms, standards and interoperability, as key dimensions linked to the technology and its implications.
- Digital Innovation Hubs and the potential of IoT as sectoral silo breaker, as cross-cutting dimensions where IoT will have a transformational impact on the economy.

The recommendations provided in Section 3 of this report, as well as the analysis supporting those recommendations, are based on a unified, consensus-based vision that the members of the CREATE-IoT consortium have gathered from their involvement in a wide variety of initiatives related to IoT and digitization both at European and national level. The recommendations provided are directed to variety of the different stakeholders involved in making the DSM a reality and the digital transformation possible. A number of recommendations are targeted to the economic actors involved in the roll-out and take up of the IoT in the productive economy, but there is also an important number of recommendations for policy makers.

This report gives special attention to the impact that the IoT is set to have as enabler of the Circular Economy, as well as other related paradigms, such as the outcome-based economy and the sharing economy. This report provides a detailed analysis indicating the many ways the IoT is expected to impact the circular economy, and an estimation of these impacts. Examples of such impacts are the changes IoT may induce in the value chain, its capacity to improve efficiency during the production phase, or the durability and the traceability of products.

As single, take-away message, this report exposes the large and positive impact that a proper rollout and take up of the IoT may have for the EU's economy along the coming years. The potential of the IoT to generate benefits for economic actors, administrations, and ultimately citizens, is perceived as really high. Proper measures and actions will be, however, needed to turn this potential gradually into a reality for all Europeans. Our report provides specific recommendations for such measures and actions.

# 6. REFERENCES


[1] Accenture Strategy report. "Digital Disruption: the growth multiplier". 2016. https://www.accenture.com/_acnmedia/PDF-4/Accenture-Strategy-Digital-Disruption-Growth-Multiplier.pdf

[2] https://www2.deloitte.com/mt/en/pages/technology/articles/mt-what-is-digital-economy.html

[3] OECD. "The Next Production Revolution: Implications for Governments and Businesses". May 2017. http://dx.doi.org/10.1787/9789264271036-en

[4] Communication from the commission to the european parliament, the council, the european economic and social committee and the committee of the regions "building a european data economy" {SWD(2017) 2 final}. January 2017. http://ec.europa.eu/newsroom/dae/document.cfm?doc_id=41205

[5] OECD. "OECD Digital Economy Outlook 2015". http://dx.doi.org/10.1787/9789264232440-en

[6] Digital Transformation Scoreboard 2017: http://ec.europa.eu/DocsRoom/documents/21124

[7] Digital Transformation Monitor. https://ec.europa.eu/growth/tools-databases/dem/monitor/

[8] IDC and Open Evidence. "European Data Market study", SMART 2013/0063, February 2017. https://sites.google.com/a/open-evidence.com/download/repository/SMART20130063_Final%20Report_030417_2.pdf?attredirects=0&d=1

[9] European Data Market Monitoring Tool. http://www.datalandscape.eu/european-data-market-monitoring-tool

[10] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. A Digital Single Market Strategy for Europe. COM/2015/0192 final. http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1447773803386&uri=CELEX%3A52015DC0192

[11] Shaping the Digital Single Market. https://ec.europa.eu/digital-single-market/en/policies/shaping-digital-single-market

[12] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on the Mid-Term Review on the implementation of the Digital Single Market Strategy. A Connected Digital Single Market for All. COM/2017/0228 final. http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1496330315823&uri=CELEX:52017DC0228

[13] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. "5G for Europe: an Action Plan". COM(2016) 588 final. September 2016. http://ec.europa.eu/newsroom/dae/document.cfm?doc_id=17131

[14] Wi-Fi4EU – Free WiFi for Europeans. https://ec.europa.eu/digital-single-market/en/policies/wifi4eu-free-wi-fi-europeans

[15] Proposal for an ePrivacy regulation. https://ec.europa.eu/digital-single-market/en/proposal-eprivacy-regulation

[16] European Cybersecurity contractual Public Private Partnership. https://ecs-org.eu/cppp

[17] Commission staff working document on the free flow of data and emerging issues of the European data economy Accompanying the document Communication Building a European data economy {COM(2017) 9 final. January 2017. http://ec.europa.eu/newsroom/dae/document.cfm?doc_id=41247

[18] http://ec.europa.eu/newsroom/dae/document.cfm?doc_id=15266

[19] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. "European

Interoperability Framework – Implementation Strategy". COM/2017/113 Final. March 2017. http://eur-lex.europa.eu/resource.html?uri=cellar:2c2f2554-0faf-11e7-8a35-01aa75ed71a1.0017.02/DOC_1&format=PDF

[20] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. "European Cloud Initiative - Building a competitive data and knowledge economy in Europe". COM(2016) 178 final. April 2016. http://ec.europa.eu/newsroom/dae/document.cfm?doc_id=15266

[21] Communication: "Digitising European Industry - Reaping the full benefits of a Digital Single Market", COM/2016/0180 Final. April 2016. http://eur-lex.europa.eu/legal-content/TXT/?uri=CELEX:52016DC0180

[22] EU digital skills and jobs coalition. https://ec.europa.eu/digital-single-market/en/digital-skills-jobs-coalition

[23] IDC and TXT Solutions. Study for the European Commission. "Cloud and IoT combination". SMART 2013/0037. 2014. http://www.telit2market.com/wp-content/uploads/2015/02/TEL_14016_P_112-114.pdf

[24] McKinsey Global Institute. "The Internet of Things: mapping the value behind the hype". 2015. http://www.mckinsey.com/~/media/McKinsey/Business%20Functions/McKinsey%20Digital/Our%20Insights/The%20Internet%20of%20Things%20The%20value%20of%20digitizing%20the%20physical%20world/The-Internet-of-things-Mapping-the-value-beyond-the-hype.ashx

[25] AIOTI - Alliance for Internet of Things Innovation. https://aioti.eu/

[26] Commission staff working document. "Advancing the Internet of Things in Europe" accompanying the document "Digitising European Industry: Reaping the full benefits of a Digital Single Market", April 2016, http://eur-lex.europa.eu/legal-content/TXT/?uri=CELEX:52016SC0110

[27] Smart Specialisation Platform – Digital Innovation Hubs http://s3platform.jrc.ec.europa.eu/digital-innovation-hubs

[28] Report of WG1: Digital Innovation Hubs: Mainstreaming Digital Innovation Across All Sectors, final version, June 2017. https://ec.europa.eu/futurium/en/system/files/ged/dei_working_group1_report_june2017_0.pdf

[29] Report of WG2: Digital Industrial Platforms, final version, Aug 2017. https://ec.europa.eu/futurium/en/system/files/ged/dei_wg2_final_report.pdf

[30] EIP-AGRI Seminar "Data revolution: emerging new data-driven business models in the agri-food sector". 22-23 JUNE 2016 https://ec.europa.eu/eip/agriculture/sites/agri-eip/files/eip-agri_seminar_data_revolution_final_report_2016_en.pdf

[31] EIP-AGRI workshop: "Data sharing: ensuring fair sharing of digitisation benefits in agriculture". Final report. July 2017. https://ec.europa.eu/eip/agriculture/sites/agri-eip/files/eip-agri_workshop_data_sharing_final_report_2017_en.pdf

[32] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions "ICT Standardisation Priorities for the Digital Single Market". COM/2016/0176 final. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52016DC0176

[33] O. Vermesan, R. Bahr, A. Gluhak, F. Boesenberg, A. Hoeer and M. Osella, "IoT Business Models Framework", 2016, online at: http://www.internet-of-things-research.eu/pdf/D02_01_WP02_H2020_UNIFY-IoT_Final.pdf

[34] P. Guillemin, P. Moretto, O. Vermesan, F. Bösenberg, "IoT Standards landscape", 2017, online at: http://www.unify-iot.eu/wp-content/uploads/2016/06/D05_01_WP05_H2020_UNIFY-IoT_Final.pdf

[35] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. "Upgrading the single market: more opportunities for people and businesses". COM(2015) 550 final. October 2015. https://ec.europa.eu/transparency/regdoc/rep/1/2015/EN/1-2015-550-EN-F1-1.PDF

[36] Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. "On the implementation of the Circular Economy Action Plan". COM(2017) 033 final. January 2017. http://ec.europa.eu/environment/circular-economy/implementation_report.pdf

[37] Annex to the report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. "On the implementation of the Circular Economy Action Plan". COM(2017) 033 final. January 2017. http://ec.europa.eu/environment/circular-economy/implementation_report_annex.pdf

[38] Report from the Workshop on Platforms for Connected Factories of the Future", EC & EFFRA, 2015. http://ec.europa.eu/information_society/newsroom/image/document/2015-48/workshop_report_platforms_oct15_finaldocx_12361.pdf

[39] World Economic Forum. "Industrial Internet of Things: Unleashing the Potential of Connected Products and Services". 2015. http://www3.weforum.org/docs/WEFUSA_IndustrialInternet_Report2015.pdf

[40] O. Vermesan and P. Friess (Eds.). *Digitising the Industry - Internet of Things Connecting the Physical, Digital and Virtual Worlds*, ISBN: 978-87-93379-81-7, River Publishers, Gistrup, 2016.

[41] Gartner. "Survey Analysis: Early Adopters of Internet of Things Poised to Make 2016 the Year of the Customer." http://www.gartner.com/document/3210417?ref=solrAll&refval=163427311&qid=564c6f8ac915bcf189b34c83738eb034

[42] IoT platforms – Central backbone for the IoT, IOT Analytics, online at: http://iot-analytics.com/wp/wp-content/uploads/2016/01/White-paper-IoT-platforms-The-central-backbone-for-the-Internet-of-Things-Nov-2015-vfi5.pdf

[43] IoT Platforms: Market Report 2015-2021, IOT Analytics, online at: https://iot-analytics.com/product/iot-platforms-market-report-2015-2021-3/

[44] List Of 450 IoT Platform Companies, IOT Analytics, online at: https://iot-analytics.com/product/list-of-450-iot-platform-companies/

[45] Digital Economy Collaboration Group (ODEC), online at http://archive.oii.ox.ac.uk/odec/

[46] O. Vermesan and J. Bacquet (Eds.). Cognitive Hyperconnected Digital Transformation Internet of Things Intelligence Evolution, ISBN: 978-87-93609-10-5, River Publishers, Gistrup, 2017.

[47] A. Gluhak, O. Vermessan, R. Bahr, F. Clari, T. Macchia, M. T. Delgado, A. Hoeer, F. Boesenberg, M. Senigalliesi und V. Barchetti, „Report on IoT platform activities," online at http://www.internet-of-things-research.eu/pdf/D03_01_WP03_H2020_UNIFY-IoT_Final.pdf, 2016.

[48] A. Velosa, Y. V. Natis, M. Pezzini, B. Lheureux und E. Goodness, Gartner's Market Guide for IoT Platforms, 2015, online at: https://www.gartner.com/doc/3086918/market-guide-iot-platforms.

[49] M. J. Perry, Evaluating and Choosing an IoT Platform, 2016, online at: https://www.thingworx.com/wp-content/uploads/WP_oreilly-media_evaluating-and-choosing-an-iot-platform_978-1-491-95203-0_EN.pdf.

[50] IBM. The Rise of the Data Economy: Driving Value through Internet of Things Data Monetization. 2016. http://www-01.ibm.com/common/ssi/cgi-bin/ssialias?subtype=WH&infotype=SA&htmlfid=WWW12367USEN&attachment=WWW12367USEN.PDF

[51] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. "Towards a circular economy: A zero waste programme for Europe". COM(2014) 398 final. July 2014. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52014DC0398&from=EN

[52] Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. "On the implementation of the Circular Economy Action Plan". COM(2017) 33 final. January 2017. http://ec.europa.eu/environment/circular-economy/implementation_report.pdf

[53] European Resource Efficienty Platform (EREP) manifesto and policy recommendations. March 2014. http://ec.europa.eu/environment/resource_efficiency/documents/erep_manifesto_and_policy_recommendations_31-03-2014.pdf

[54] Ellen MacArthur Foundation. "Intelligent assets: unlocking the circular economy potential". 2016. https://www.ellenmacarthurfoundation.org/assets/downloads/publications/EllenMacArthurFoundation_Intelligent_Assets_080216.pdf

[55] Ellen MacArthur Foundation and McKinsey Center for Business and Environment. "Growth within: a circular economy vision for a competitive Europe". June 2015. https://www.mckinsey.de/files/growth_within_report_circular_economy_in_europe.pdf

[56] Deutsche Bank Research. "Industry 4.0: Huge potential for value creation waiting to be tapped". May 2014. https://www.i40.de/wp/wp-content/uploads/2015/04/Industry-4.0-Huge-potential-for-value-creation-waiting-to-be-tapped.pdf

[57] IBM Software Business Analytics. "Predictive maintenance for manufacturing. How to improve productivity, minimize downtime and reduce costs". 2011. http://tolerro.com/site-content/Whitepaper-Predictive-maintenance-for-Manufacturing.pdf

[58] Alliance for Internet of Things Innovation – AIOTI. "Smart farming and food safety Internet of Things applications: challenges for large scale implementations". October 2017. https://aioti.eu/wp-content/uploads/2017/03/AIOTIWG06Report2015-Farming-and-Food-Safety.pdf

[59] European Commission – Smart Specialization Platform: Digital Innovation Hubs Tool. http://s3platform.jrc.ec.europa.eu/digital-innovation-hubs-tool

[60] David Langley, "How the IoT can bring about a circular economy", in IEEE IoT Newsletter, May 2017. https://iot.ieee.org/newsletter/may-2017.html

[61] NEC, "Business Innovation driven by IoT". http://www.nec.com/en/global/solutions/iot/concept/index.html

[62] World Economic Forum. "The Fourth Industrial Revolution". Online at: https://www.weforum.org/focus/the-fourth-industrial-revolution

[63] Map of digitising industry national initiatives, updated to June 2017. Online at: https://ec.europa.eu/digital-single-market/en/cordination-european-national-regional-initiatives

[64] European Large-Scale Pilots Programme. Online at: https://european-iot-pilots.eu/

[65] RAMI. Online at: www.plattform-i40.de

[66] Industrial Data Space. Online at: http://www.industrialdataspace.org/en/

[67] FI-WARE-FITMAN. Online at: http://www.fitman-fi.eu/

[68] BeinCPPS. Online at: http://www.beincpps.eu/

[69] ETSI Technical Report. "SmartM2M; IoT Standards landscape and future evolutions", ETSI TR 103 375 V1.1.1 (2016-10). Online at: https://aioti.eu/wp-content/uploads/2017/03/tr_103375v010101p-Standards-landscape-and-future-evolutions.pdf

[70] Italian Digital Innovation Hubs Network of I4MS. Online at: http://italian-dih.eu/the-italian-dih-network-and-the-national-industry-strategy-4-0/?lang=en

[71] DIMA HUB. Online at: http://www.dimahub.polito.it/

[72] t2i Trasferimento Tecnologico e Innovazione. Online at: http://www.t2i.it/who-is-t/

[73] Smart Manufacturing Innovation & Lean Excellence centre (SMILE). Online at: http://smile.italian-dih.eu/?lang=en

[74] Marche innovation Machine and Market Manufacturing 4.0 (4M.0). Online at: http://www.confindustria.marche.it/sp/i4ms-progetto-4m0.3sp

[75] CPS/IoT Ecosystem of excellence for manufacturing innovation (CICERO Hub). Online at: http://cicero.italian-dih.eu/ (English version not available)

[76] CPS/IoT Hub for Regional Digital Manufacturing SMEs (Apulia Manufacturing). Online at: http://www.dihapulia.it/web/ (English version not available)

[77] BieSense Institute. Online at: http://biosense.rs/

[78] Polo De Innovación Dixital, Digital Innovation Hub for Galician agrifood sector. Online at: http://polodeinnovaciondixital.org/en/

[79] BeinCPPS EU project. Online at: http://www.beincpps.eu/

[80] IoF2020 EU project. Online at: https://www.iof2020.eu/

[81] AreoFarms (US). Online at: http://aerofarms.com/

[82] Zest labs (US). Online at: http://www.zestlabs.com/

[83] TagItSmart EU project. Online at: http://tagitsmart.eu/

[84] Philips. "Philips provides Light as a Service to Schiphol Airport", April 2015. Online at: https://www.philips.com/a-w/about/news/archive/standard/news/press/2015/20150416-Philips-provides-Light-as-a-Service-to-Schiphol-Airport.html

[85] DELL. "Design for Environment". http://www.dell.com/learn/us/en/uscorp1/corp-comm/circular-economy?c=us&l=en&s=corp&cs=uscorp1

[86] Rolls-Royce. "Rolls-Royce celebrates 50th anniversary of Power-by-the-Hour", October 2012. Online at: https://www.rolls-royce.com/media/press-releases/yr-2012/121030-the-hour.aspx

[87] Ellen MacArthur Foundation. "In-depth - Washing Machines", October 2012. https://www.ellenmacarthurfoundation.org/circular-economy/interactive-diagram/in-depth-washing-machines