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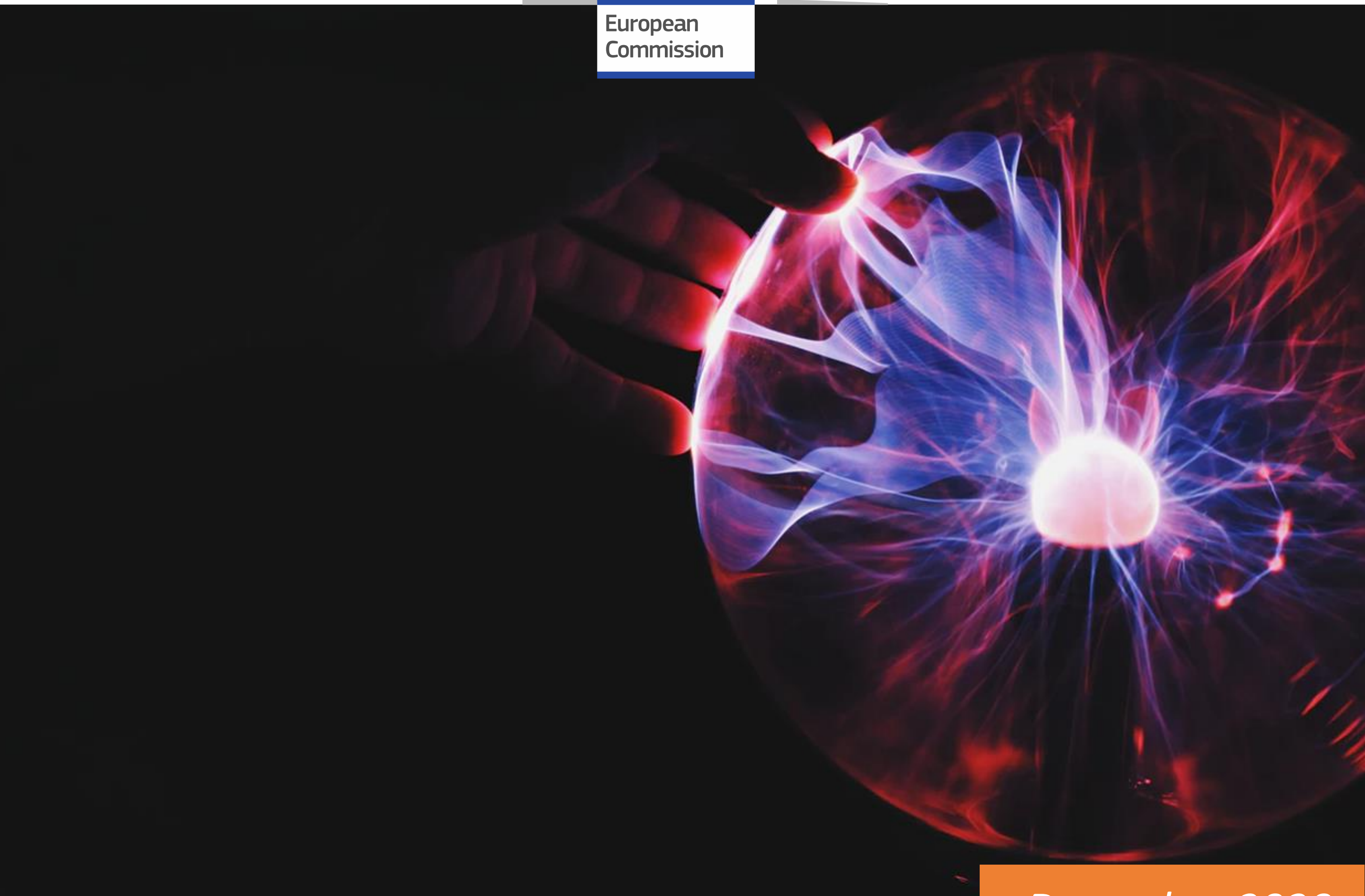

December 2020

Advanced Technologies for Industry – AT WATCH

Technology Focus on Cloud Computing

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1 Introduction

This Advanced Technology Watch report has been developed in the framework of the Advanced Technologies for Industry (ATI) project, initiated by the European Commission, Directorate General for Internal Market, Industry, Entrepreneurship and SMEs and the Executive Agency for Small and Medium-Sized Enterprises.

As a part of a series of analytical reports on trends in advanced technologies, this report represents the second issue of a comprehensive monitoring tool endowing policymakers, industry players, researchers and other relevant stakeholders with regularly updatable research. The ATI Watch report series is meant to play a complementary role to the other analytical, policy and statistical reports of the project, by focusing on the market, business and socioeconomic trends driven by technology innovation. This Advanced Technology Watch therefore encompasses a whole set of advanced technologies that are a priority for European industrial policy. These technologies enable process, product and service innovation throughout the economy, thus fostering industrial modernisation.

The qualitative and quantitative analysis included in this Advanced Technology Watch report is specifically designed to provide novel insight and up-to-date content to technology users across all European industries, with the aim of revealing potential opportunities emerging from the most recent applications of advanced technologies.

The ATI Watch report series targets:

- A primary audience of industry stakeholders, including SMEs and industry associations interested in learning about upcoming technology trends and business opportunities
- A complementary audience of national, regional and local policy makers interested in supporting industry in the exploitation of technology innovation and emerging business opportunities by removing barriers and creating favourable market conditions
- A complementary audience of research and technology stakeholders interested in the applied research challenges to be solved to capture emerging business opportunities

Each report is thus structured using two main sections:

- A brief overview of the uptake of all advanced technologies and demand trends by industry (Section 1: Technology Landscape)
- A more in-depth analysis of one advanced technology, selected because of its relevance in terms of emerging business opportunities and disruptive potential (Section 2: Technology Focus).

This report focuses on the evolution of cloud computing, which is being transformed by technology innovation and evolving supply-and-demand dynamics.

The targeted industry audience of this report is twofold:

- European IT service providers and cloud service providers: As shown in chapter 2.1.1, large numbers of stakeholders are active in the ecosystems of large players at the local and national levels, particularly in the IT services and software-as-a-service (SaaS) market segments. The market trends discussed in this report open new opportunities for these industry stakeholders. European policy strategies to support European data infrastructure sovereignty and cloud services federations will also create a more favourable environment for European cloud actors.
- European cloud users, particularly SMEs, adopting cloud computing both directly and indirectly (i.e. companies producing for instance connected cars embedding 5G connectivity modules over which services are provided using the cloud as a backend): Users should be aware of technology and evolving supply trends to make the best choices for the cloud infrastructures they need to support their digital transformation initiatives.

1.1 The Advanced Technologies Industry Landscape

Digitalisation and industry modernisation processes in Europe are progressing at **different speeds across the various industry sectors**, driven by a whole set of changing priorities, challenges and use cases. In such a dynamic scenario, the deployment of advanced technologies may take different forms across industries in Europe, depending on the levels of those industries' technological maturity, the availability and relevance of industry-specific applications and the expected and desired business, operational and societal outcomes of such sectors.

The different mix of advanced technologies adopted in each industry is visualised in Figure 1, below. The figure shows the percentage share of enterprises in each industry adopting or planning to adopt each technology. (The bubble sizes correspond to the uptake levels, with the highest value being 88%.) The data is based on the Advanced Technologies for Industry Survey (July 2019)[1] and on a sample of European enterprises from 11 Member States, representing 85% of the EU total 2019 GDP.

Figure 1: The Uptake of Advanced Technologies in Europe by Industry, 2019

Source: Advanced Technologies for Industry Survey, July 2019, (N = 900). Legend: The bubble size represents the % of enterprises in the industry adopting the technology in the same row. The maximum value is 88%. Appendix A provides the definition of each technology.

The visualisation highlights how a distinct group of technologies **features a marked horizontal diffusion** across all industries – general purpose technologies, including public cloud, security, mobile solutions, Big Data (BD) analytics, the Internet of Things (IoT), advanced connectivity and artificial intelligence (AI). They represent a technology portfolio that is necessary (but insufficient) for digital transformation. **Other technologies clearly display a niche or industry-specific orientation**. However, this does not mean they do not provide opportunities for investments outside of their main industry niches. Taking blockchain as an example, the technology initially found its ground in financial applications. New areas of application are now emerging and the adoption of multiple novel use cases in other industries is expanding rapidly, driving business value. For instance, in manufacturing, blockchain is used to keep track of and certify product sources along the value chain. Similarly, blockchain exhibits great potential in the art market, where it can be used not only for the tokenisation of artworks sales, but also to verify the provenance and authenticity of artworks – one of the biggest challenges for the industry.

[1] The survey interviewed a sample of 900 enterprises, each with more than 10 employees, in CZ, DK, DE, FR, ES, HU, IT, NL, PL, SE and UK.

When looking at European industries in more detail, we observe that:

- Organisations in the **manufacturing industry** have a strong focus on the development of Industry 4.0 strategies, prioritising technologies that can provide clear benefits in terms of driving operational performance and reducing costs. **Automation** is a strong focus and will help companies simplify complex tasks and processes and relieve human resources of heavy and time-consuming workloads. **Robotics** and collaborative robots (cobots) play important roles, helping manufacturers achieve efficiency benefits, such as by enabling staff to save time. **Augmented reality/Virtual reality (AR/VR)** solutions also offer efficiency gains, such as enabling experts to provide remote field support to operators, guiding them through processes, step by step. R&D and product innovation are strong manufacturing priorities driving experimentation with several emerging technologies. In this context, **AI and Big Data analytics** are helping manufacturers improve how they design, manufacture and deliver their products. **3D printing** is also poised to grow, as it will automate ways to create prototypes and new product parts, reducing production times and improving products. Product innovation is also driving the adoption of advanced materials, micro- and nanoelectronics, other nanotechnologies and photonics with the aims of improving products and reducing costs.

- In **finance,** besides operational efficiency, the other main business goal driving investments in advanced technologies is the need to attract and retain customers. This is pushing the industry towards piloting new service delivery models. **AI**, **Big Data** and **blockchain** are the most promising technologies for the industry, as they enable the automation of internal operations, improved customer service and greater protection against security threats. Key AI trends in the industry include the automation of IT operations and opening new digital channels to improve customer experience, leveraging voice banking and chatbots. Blockchain's main applications include cross-border payments and settlements. The industry has also been central in the emergence of a new digital economy, open banking. The open banking digital economy is connected to the European payment services directive (**PSD2**[2]). The core of this initiative is the request for banks to share more customer information than ever before via technologies such as application programming interfaces (APIs).

- For **telecom and media** providers, new technologies and new customer behaviours are generating several opportunities to boost current income sources and generate new revenue streams. **5G technologies**, for example, are expected to provide many monetisation opportunities for telcos, unleashing the potential of other technologies, such as AR/VR and IoT. Streamlining processes, improving network efficiency and improving customer support will be the main drivers of telcos' digital investments. Interesting pockets of growth can also be found in other advanced technologies, such as **photonics**, which is supporting the development of fibre optic network communications. Media transformation has been driven by changing customer needs and behaviours. New channels and platforms for distributing and accessing content and new ways of producing content are driving innovation in the industry. Streaming, content as a service and new technologies for creating engaging entertainment experiences, such as wearables and **AR/VR** technologies, are major trends.

- **Utilities** and **oil & gas** show interesting opportunities from many advanced technologies. Hot spots in the industry include the **e-mobility revolution** and **AI-powered home energy management**. Electric vehicles are expected to be a mass-market revolution, driven by increasing sustainability concerns and blurring industry boundaries across power distribution, retail, transportation and automotive. Large and small utilities can play different roles across the entire value chain, from electric vehicle equipment supplies and management platforms to meter and grid services and home and network charging. The quest for **alternative and sustainable energy sources** is also paving the way for the use of advanced technologies, such as **photonics** and **nanotechnologies** for power generation and for new and more efficient lighting solutions. Another growing trend is the smart home ecosystem, in which utilities can play a big role in providing advanced home energy management solutions and automation functionalities using devices such as smart plugs, thermostats and lighting to optimise energy consumption and gain insight into consumers' habits.

- **Healthcare** industry players are investing in **biotechnology, AR/VR, nanotechnology, advanced materials and photonics**. The uptake of advanced technologies in healthcare is strictly linked to the need to innovate and improve patient care and provide integrated and personalised services. The need is strong for data sharing among doctors, different medical units and hospitals to enable faster services and to avoid duplicating efforts. Higher investments

[2] https://ec.europa.eu/info/law/payment-services-psd-2-directive-eu-2015-2366_en

in **cloud** suggest interest in the optimisation of infrastructure and operations. **Robots**, especially for surgery and logistics purposes, are becoming more affordable and hospitals will start to invest more significantly in them in the coming years. Investments in **wearables, IoT and AI** are growing with the need to monitor the behaviours of patients with medical conditions, enabling, for example, alerts to initiate emergency assistance when elderly people have accidents. **AR/VR** devices, for instance, are helping doctors improve surgery and diagnosis and are also used for therapeutic purposes (e.g. rehabilitation).

- Due to the highly customer-centric nature of **retail**, efforts to provide superior and differentiated customer experience are key in this industry. The **ecommerce** channel remains a priority for retailers, given the channel's popularity and success during the COVID-19 crisis. With more customers switching to mobile commerce, customer assistance and support are also changing. Through **AI-enabled chatbots**, customers can contact companies on social platforms to track shipments, request product refunds and raise complaints. AI investments, such as those in deep learning and text and voice recognition, will be heavy across the distribution sector and will focus on improving customer experience. **Real-time contextual personalisation** represents a growing customer-related opportunity in the industry – one that will enable retailers to shape the customer experience across multiple parameters, such as demographics, location, day and time, weather and purchasing patterns.

- Technology adoption patterns in the **government** and **education** sectors are influenced by the national context. Investments in innovation among public administrations mirror budget availability at the Member-State or regional level. Governments are working to streamline internal bureaucratic processes through **automation**, since time-consuming back-office tasks slow critical government work, resulting in longer waiting times for citizens to access services. **AI** solutions based on facial recognition are seeing significant investment – for example, to help police recognise and identify criminals. **Smart city** projects, which combine **mobile, IoT and Big Data analytics** solutions, are expected to drive investments in technology, especially for safety purposes (e.g. video surveillance) and public transport optimisation. Another driving trend in the industry is that of **open data portals**, with the aim of improving transparency, openness and interaction by sharing public data with citizens. **Education institutions** in Europe are prioritising investments in **mobile solutions** – for example, investing in the provision of mobile devices. Schools are also showing increasing interest in **distance learning,** with the development of online platforms and e-learning apps for students. Following the emergency-driven experience of distance learning during the first COVID-19-induced lockdown, the adoption of technologies that enable remote schooling will likely accelerate, as many schools have benefited from their advantages, as well as having acknowledged their disadvantages. Many governments and schools are likely to increase investments in distance learning to complement in-presence education.

- Client expectations – including good value for money, fast delivery times and high-quality work – and increasing competition are putting a lot of pressure on the **professional services** industry. The industry will thus continue to invest in advanced technologies to add value to services and business models. Digital technologies are changing industry players' client-facing and back-end processes – for example, automatically processing legal, shareholder and market-related documents – freeing up staff time for other tasks. **Cloud computing** continues to attract interest, mainly driven by the flexibility that cloud offers, such as access to information at any time, improved collaboration between teams and low-cost technology deployments. Professional services firms are investing in data security that aligns with the EU's General Data Protection Regulation (GDPR), implemented in May 2018, to protect client sensitive information and avoid data breaches.

- Advanced technologies in the **transport industry** are **customer and data-centric**, aiming at providing customers with enhanced experiences while leveraging data and analytics to optimise operations and streamline processes. **IoT** and **AI** play key roles for transport companies, such as regulating traffic flows, streamlining security checkpoints with biometrics (e.g. facial recognition) and reducing the number of lost consignments using electronic tags. In logistics, heavy workloads can be eased by introducing solutions to create collaborative environments in which **humans coexist with robots**, with the latter taking over heavy, repetitive and time-consuming tasks. **Smart trucks**[3] are gaining in popularity, as they enable automated processes

[3] The 'smart' adjective refers to multiple tech-enabled solutions that make trucks 'intelligent', such as e-calling (i.e. automatic emergency calling in the case of a crash) and driver-fatigue monitoring (i.e. a system that tracks the driver's attention level and notifies the driver in the case of risk).

through the integration of different technologies to provide real-time emergency and incident reactions.

- **The agriculture** sector faces many challenges, including rising demand for food, climate change and lack of workers. Advanced technologies are increasingly playing roles in responding to some of these challenges. **Data-driven innovation** is transforming farm management through **precision agriculture**. **Satellites, drones and IoT sensors** enable livestock, crop conditions, soil and other key farming elements to be monitored and provide an unprecedented amount of data for analysis. Such solutions allow farmers to manage farming processes, such as irrigation and fertilisation, in a scientific way, minimising costs and the use of pesticides and maximising outputs. The digitalisation of farming processes also represents the first step in emerging food track-and-trace systems developed to guarantee quality and safety, which are highly valued in food/agriculture value chains. Such developments represent the true digital transformation of this sector, which used very little ICT in the past. Such innovation is profoundly changing the culture, organisational processes and skill requirements in a sector facing the barrier of a reluctance to adapt. Advanced technologies also offer interesting means to counteract **climate change and related risks** (such as the loss of arable land and increased urbanisation). For example, **urban/vertical farms** are a growing trend. These farms leverage technologies to minimise the use of natural resources, such as soil, water and energy. This is done by using IoT and photonics to manage parameters, such as humidity, light and irrigation, to get the most out of crops. **Industrial biotechnology** also shows promise in terms of obtaining raw materials for alternative foods that are balanced, healthy, protein-rich and nutritious and responding to increasing populations and demand for food.

The overall picture outlined above of the deployment of advanced technologies in Europe is, to a certain extent, supported by demand and supply analysis of the skills needed for advanced technologies[4]. In terms of skills supply and based on profiles of registered users on LinkedIn, the share of professionals skilled in advanced technologies (vis-à-vis the total number of professionals) in select industries reveals that Europe’s manufacturing industry absorbs the highest number of skilled professionals. This is particularly true in the automotive sector, in which advanced manufacturing technologies and IoT are clearly instrumental for the development of Industry 4.0 strategies.

Other industries, such as electronics and, to a lesser extent, chemicals, employ large numbers of skilled professionals – especially for advanced manufacturing technologies and IoT in electronics and advanced material technologies and industrial biotech in chemicals – confirming that manufacturing as a whole remains at the forefront of digital transformation and modernisation processes in Europe.

In terms of skills demand, manufacturing exhibits high levels of hiring measured by the number of online job advertisement requiring specific skills. Again, the automotive sector requires specific skills in advanced manufacturing, AI and robotics. Likewise, the electrical & electronics industry exhibits strong demand for skills in advanced materials, micro-nanoelectronics, other nanotechnologies and robotics. The prominence of the manufacturing industry is challenged only by the finance sector (both banking and financial services), in which specialised skills for Big Data analytics, blockchain, cloud computing and cybersecurity are very much in demand across Europe.

[4] ATI General Findings (D3.4), Section 5, June 2020, available at https://ati.ec.europa.eu/reports/eu-reports/report-technology-trends-technology-uptake-investment-and-skills-advanced

Section 2

2 Technology Focus: Cloud Computing

2.1 Definition and Scope

2.1.1 The History of Cloud

Cloud computing essentially defines the storing, processing and use of data on remotely located computers accessed over the internet. This means that users can command almost unlimited computing power on demand, do not have to make major capital investments to fulfil their needs and can access their data from anywhere with an internet connection[5]. Cloud services represent alternative commercial and distribution models to offer, deliver and consume IT services, now implemented in most industries across the economy[6]. The EC has promoted cloud computing models because of their capability to make advanced computing services and software accessible to SMEs and other consumers at reasonable cost, thereby accelerating digitalisation in society and the economy.

The most authoritative definition of the cloud model is issued by the US National Institute for Standards and Technology (NIST),[7] which defines cloud as being based on five main technology features: on-demand self-service, broad network access, resource pooling, rapid elasticity and measured service (monitoring and constantly optimising the use of computing resources). This explains why cloud computing is often likened to a utility model, similar to electricity or gas distribution.

The business public cloud market is further broken down into three broad cloud service categories: software as a service (SaaS), platform as a service (PaaS) and infrastructure as a service (IaaS) – the first of which is the largest. But the public cloud market also offers personal data storage, easy access and file sharing (Apple's iCloud is the best known). Data stored in the cloud, such as photographs and music, can be shared with friends – for example, using a smart phone or a laptop – without personal-data loss or damage.

The adoption of cloud computing in the business market has been growing since the end of the 1990s (evidenced, for example, by the pioneering success of Salesforce in providing customer relationship management [CRM] services based on cloud)[8]. Key milestones were the launch of Amazon Web Services in 2006 (AWS), followed by Google Cloud and then Microsoft Azure – still the dominant players on the public cloud market. But the cloud model is also widely used by universities and research centres for scientific computing and by governments for online public services.

2.1.2 The Future of Cloud

Today, as indicated in the ATI project survey, public cloud is widespread across most industries, but it is mostly used at a relatively basic level – for the on-demand elastic provisioning of computing resources. But, instead of slowly maturing, cloud computing is actually moving towards a new phase of technology innovation and demand evolution, supported by insatiable demand for data-driven services that can only be delivered via cloud. As companies continue to pursue cloud (both public and private) for data processing needs, cloud data centres are becoming the new enterprise data repository.
By 2025, 46% of the world's stored data will reside in public cloud environments[9].

Driven by new demand, cloud computing is moving to a transparent environment and the 'everything as a service' provisioning concept, including applications. As shown by the ATI survey analysis, cloud is the instrument chosen by most enterprises to deliver services and applications based on Big Data analytics, IoT and artificial intelligence. Cloud offerings need to evolve to deal with the increasing demands of real-time processing capabilities, computing power and data scalability.

The current technological and social landscape calls for a shift to a hybrid cloud paradigm that follows a computing continuum from the edge of the network to federated clouds, with cloud providers located and accessed from anywhere in the world. This would require combining various platforms to execute

[5] Unleashing the Potential of Cloud Computing in Europe, European Commission, 2012, available at https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX:52012DC0529
[6] IDC's Worldwide IT Cloud Services Taxonomy, 2019
[7] The NIST Definition of Cloud Computing, NIST, 2011
[8] https://www.dataversity.net/brief-history-cloud-computing/
[9] https://www.seagate.com/gb/en/our-story/data-age-2025/

computing environments ubiquitously and seamlessly as a foundation for a complete computing continuum. Billions of devices and things will be connected to the internet in the coming years, resulting in mass network usage and an ever-increasing need for computing power and capacity. As stated in 'Swarm Computing Concepts, Technologies and Architecture',[10] 'Swarm computing combines network and cloud capabilities to create on-demand, autonomic and decentralised computing, thus taking the functionality and flexibility delivered by IoT ecosystems to a new level.' In the coming years, research challenges to be met will concern the creation of novel solutions for federating infrastructures, programming applications and services and composing dynamic workflows capable of reacting in real-time to unpredictable data volumes, availability, locations and rates. End-to-end service orchestration plays a key role in addressing the need for overall resource and service lifecycle management, while ensuring end users' seamless access to computing capacity in a transparent and secure way. This will open new business opportunities across industries, while requiring a new level of attention from IT users in selecting and managing multiple cloud service providers.

In this context, this report looks at the most relevant of new cloud computing market trends, with a specific focus on the following.

2.1.3 Edge Computing

Digitalisation is happening in three primary locations, where digital content is also created: the core (traditional and cloud data centres), the edge (enterprise-hardened infrastructure, like cell towers and branch offices) and endpoints (PCs, smart phones and IoT devices)[11]. Edge computing processes data away from centralised storage, keeping information on the local parts of the network – edge devices. When the data is sent to the edge device, it can be processed directly on it, without being sent to the centralised cloud. Its main benefits are[12]:

- No delays in data processing: The data stays at the 'edges' of the IoT network and can be acted on immediately.
- Real-time data analysis: It works very well when large amounts of data have to be processed immediately.
- Low network traffic: The data is first processed locally and only then sent to the main storage.
- Reduced operating costs: Data management takes less time and computing power because the operation has a single destination, instead of circling from the centre to local drives.

For example, IoT edge computing is an optimal solution for immediate small operations that have to be processed in milliseconds. When many small operations are happening simultaneously, performing them locally is faster and cheaper.

2.1.4 Federated Clouds

Cloud federation can bring an array of locally available compute and storage nodes together to solve a problem or analyse data locally and hence more efficiently. Such distributed infrastructure instantly eliminates bottlenecks, single points of failure and the concentration of infrastructure and data in the hands of a few monopolies. On the other hand, federating existing cloud resources is organisationally complex, requires the collaboration of multiple different stakeholders and needs to solve technical challenges in terms of interoperability and energy efficiency.

To escape the high scalability costs and customer lock-in issues of the global cloud providers now dominating the market (i.e. Amazon Web Services and Microsoft Azure), the EU is promoting alternative **cloud federation models** based on cloud interoperability and seamless connectivity across European cloud services, with the idea of exploiting synergies from existing public and private cloud infrastructures. This is a policy promoted in the context of the European Commission's recent Data Strategy, with the aim of enabling access to more secure, sustainable, interoperable, environmentally friendly and scalable cloud infrastructures and services for European businesses[13].

Currently, the EC is researching potential cloud federation models and investigating supply/demand drivers and barriers, as well as willingness among national policy makers and industry stakeholders to co-fund federated clouds.

[10] https://atos.net/wp-content/uploads/2018/12/atos-swarm-computing-white-paper.pdf
[11] https://www.seagate.com/gb/en/our-story/data-age-2025/
[12] https://www.dataversity.net/what-is-edge-computing/
[13] https://ec.europa.eu/digital-single-market/en/cloud

2.1.5 Cloud and Green Computing

In the context of the increasing digitalisation of society and the economy, the energy consumption and related environmental consequences of cloud computing and its data centres are among the most demanding challenges of information processing technologies. Already in 2016, data centres were estimated to contribute approximately 2% of global greenhouse gas (GHG) emissions[14], with one of the fastest growing carbon footprints in the industry[15]. By 2018, data centres accounted for 2.7% of the electricity demand in the EU28, with an expectation to increase by 21% to 92.6 TWh/a by 2025[16]. Cloud data centres drive this increase, representing 35% of data centres energy consumption in 2018 with expectation to rise to 60% in 2020, plus an additional 12% represented by edge data centres.

The ICT industry has been fighting these challenges and investing in efficient energy consumption (at hardware, software and infrastructure level) and sustainability design and development. Nevertheless, the fast growth of demand is outstripping efficiency gains. Most recently, in February 2020, the International Telecommunication Union (ITU) announced a new standard to help the industry to reduce GHG emissions by 45% by 2030, with the support of the main actors and industry associations[17].

EU policies are also adding further pressure in this direction. The green transformation of the ICT industry is one of the strategic objectives of the European Union's 'Shaping Europe’s Digital Future'[18] strategy – specifically including the launch of initiatives to achieve highly energy-efficient climate-neutral and sustainable data centres no later than 2030. President Ursula von der Leyen further raised ambitions in her recent 'State of the Union' address, announcing that the EC is proposing to cut net greenhouse gas emissions by at least 55% by 2030 (based on 1990 levels), up from the previous target for 2030 of at least 40%.

From the demand side, European organisations are now including the sustainability of IT equipment in their supplier requirements. Consequently, green IT and energy efficiency have become design criteria for next-generation IT infrastructure. This includes defining standards and guidelines for the lifecycle management of equipment and infrastructures so that the next generation of cloud infrastructures are designed with energy efficiency and circular economy principles in mind.

In summary, the drivers of the green transformation of cloud computing are relevant in terms of achieving environmental and economic sustainability (reducing the carbon footprint and energy costs). But greening cloud infrastructures is more difficult in the context of edge computing and federations of small providers' resources. Centralised computing in large data centres is more energy efficient than decentralised computing in smaller data centres or at the edge. Technology and organisational challenges need to be solved to achieve energy efficiency goals in the decentralised and shared resources scenario foreseen by the edge computing and federated computing described above.

2.2 Market Potential

2.2.1 Public Cloud Market Value

Cloud services have become the de-facto source of digital transformation for enterprises in every industry and the preferred IT consumption model for consumers. Public cloud platforms in particular have become the primary choice for fuelling innovation using next-generation technologies such as AI, robotics, data services, IoT services and others. The pressure to improve customer experiences and speed of business is making cloud-like infrastructure a natural destination for organisations across all sectors.

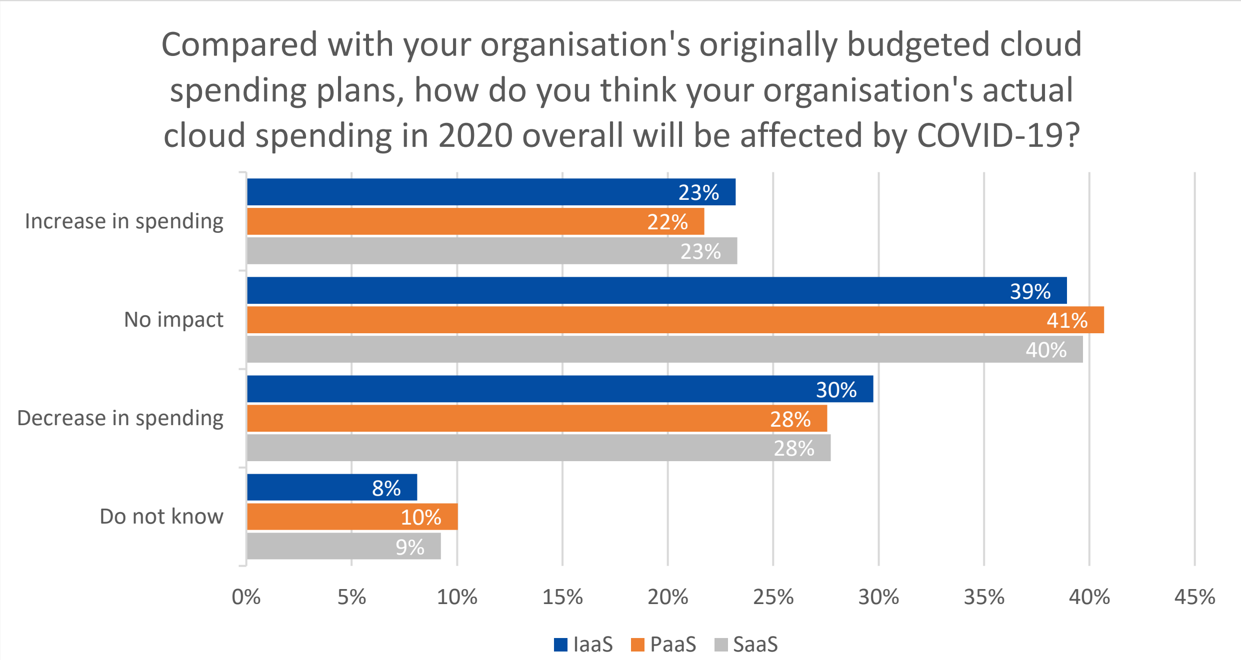
Even though the recession caused by the COVID-19 pandemic has negatively impacted IT investments, cloud spending has been resilient in 2020[19] (see Figure 2 below), with the majority of European enterprises expecting no reductions, or even an increase, in spending on cloud services. A major reason is that most cloud services are deployed as subscriptions through long-term contracts (one to three years), particularly software as a service (SaaS) and infrastructure as a service (IaaS). European organisations are continuing with their existing contracts, while coping with the recession by reducing

[14] United Nations Climate Change: https://unfccc.int/news/ict-sector-helping-to-tackle-climate-change
[15] https://op.europa.eu/en/publication-detail/-/publication/ef17c01f-ea7c-49e0-91aa-878f16ba6361/language-en
[16] https://ec.europa.eu/digital-single-market/en/news/energy-efficient-cloud-computing-technologies-and-policies-eco-friendly-cloud-market
[17] https://www.itu.int/en/mediacentre/Pages/PR04-2020-ICT-industry-to-reduce-greenhouse-gas-emissions-by-45-percent-by-2030.aspx
[18] https://ec.europa.eu/info/strategy/priorities-2019-2024/europe-fit-digital-age/shaping-europe-digital-future_en#documents
[19] IDC's COVID-19 Impact Survey, Wave 11, August 21, 2020

new projects and curtailing expansions. Demand for cloud remains strong, driven by the increasing need for digital services, such as those that support remote working and distance learning.

Consequently, it is expected that the cloud market will continue growing at a fast pace, with an estimated compound annual growth rate (CAGR) of approximately 16% over the 2019–2024 period, reaching a value of €96 bn in 2024. IaaS and PaaS services are expected to grow faster than SaaS (which represented 68% of the market in 2019 and will remain the largest share in value). IaaS is expected to expand at a CAGR of 24% through to 2024, PaaS at a CAGR of 19% and SaaS at a CAGR of 12%[20].

Figure 2: The Impact of COVID-19 on Public Cloud Spending, August 2020



Source: IDC's COVID-19 Impact Survey, Wave 11, August 21, 2020, Western Europe N = 430
Western Europe includes AT, BE, DK, FI, FR, DE, EL, EI, IT, NL, PO, ES and SE, plus CH, NO, and UK

According to data based on a group of EU-EEA countries, the European cloud market is dominated by US-based global players, particularly in the IaaS segment, in which AWS (which basically invented this market) held 58% market share in 2019. This market segment has 5 European players ranked in the top 10, but the level of concentration is so high that they account for only a small part of overall revenues. Furthermore, the US-based vendors have been consistently increasing their market shares in recent years[21]. The public cloud PaaS market is moderately concentrated, with the top 4 vendors (Microsoft, AWS, Salesforce and Google) holding 55.5% of the market. Only 2 European vendors (i.e. SAP and Siemens) are in the top 10.

Finally, the SaaS market is not concentrated, with the top 3 vendors (Microsoft, Salesforce and SAP) holding 20.6% of the market. The remaining 7 vendors in the top 10 account for a 17.4% market share. While the leading vendors are US-based, with only 2 European vendors in the top 10 (SAP and Visma), market power is more evenly distributed. Furthermore, because of the massive variety of use cases, Western European vendors are in a better position to compete. The SaaS market is very dynamic, as many software vendors are transforming into SaaS providers and are looking for partners in the IaaS and PaaS spaces to support their new offerings.

The cloud ecosystem also includes a wide range of IT service providers, which deliver services ranging from advisory and consulting to systems integration and deployment services and managed & support services. Most public cloud services vendors maintain ecosystems of partners to deliver their services to end customers. Fragmentation in the IT service provider landscape pertaining to professional and managed services associated with cloud is high, largely reflecting the fragmentation found in the traditional IT services domain.

[20] Ibidem
[21] IDC's Worldwide Semiannual Public Cloud Services Tracker, May 2020

Table 1: The Level of Public Cloud Market Concentration, 2019, Western Europe

	Value in billion € (2019)	Value Share	Growth 2018–2019	Concentration	Leading EU Players in top 10	Players Tracked
IaaS	6.9	17.4%	34%	Highly concentrated: Top 3 (AWS, Microsoft and IBM) = 58.0%	Orange, T-Systems, Vodafone, Atos	27
PaaS	5.9	14.9%	43.2%	Moderately concentrated: Top 4 (Microsoft, AWS, Salesforce and Google) = 55.5%	SAP and Siemens	141
SaaS	26.8	67.7%	26%	Fragmented: Top 3 (MS, Salesforce, SAP) = 20.6%	SAP and Visma	429

Source: IDC's Worldwide Semiannual Public Cloud Services Tracker, May 2020
Western Europe includes AT, BE, DK, FI, FR, DE, EL, EI, IT, NL, PO, ES and SE, plus CH, NO, and UK

2.2.2 Demand Trends

Multicloud Adoption

Cloud adoption brings operational efficiency and accelerates innovation, but cloud does not offer a universal fit because of the varying needs of enterprise applications. As a result, cloud has become multifaceted:

- **Public Cloud**: A multitenant data centre where shared (non-exclusive) compute resources are available on demand or by subscription. The compute resources may be shared (partitioned) between tenants. Compute infrastructure is managed by an independent managed service provider or cloud service provider, commonly referred to as 'off premises'.
- **Private Cloud**: A single-tenant data centre or portion of a data centre for which the tenant has exclusive use of defined compute infrastructure, usually via license or long-term lease. While often referred to as 'on premises', this model includes infrastructure located at a third-party data centre when the infrastructure is exclusive and unavailable for use by other parties.
- **Hybrid Cloud**: A combination of public and private cloud resources to support a specific workload.
- **Multicloud**: A combination of public cloud resources to support a specific workload. Multicloud describes an organisational strategy around, or an architectural approach to, consuming cloud services from more than one cloud service provider. These may be directly competing cloud services, such as IaaS and SaaS, from one or more cloud service providers. Multicloud encompasses a much larger universe than hybrid cloud and is only gated by the cost/complexity associated with enabling consistent management/governance of many different cloud options.

Today, these models are converging and by 2021, over 90% of enterprises worldwide are expected to rely on a mix of on-premises/dedicated private clouds, several public clouds and legacy platforms to meet their infrastructure needs[22].

As more workloads from European businesses, including those from regulated sectors, need to become cloud ready to accelerate digital transformation, it is possible that the next big wave of cloud adoption will be fuelled by European enterprises adopting cloud across distributed locations and seeking the ability to support hybrid and multicloud deployments. This wave represents the era when critical applications – Windows apps, SAP apps, Oracle apps, Java apps, etc. – will be lifted and shifted or refactored and modernised en masse for cloud. Such 'cloudification' of critical applications will take place alongside the development of new cloud-native applications, making hybrid and multicloud the only sustainable, compliant and successful cloud adoption strategy for most enterprises.

Cloud usage in Europe is catching up with US levels, with 67% of European organisations already operating multicloud environments, but some significant differences still exist. Great scepticism around cloud services in Europe remains and private cloud is still a popular option for maintaining control of

[22] IDC FutureScape: Worldwide Cloud 2020 Predictions, IDC (#US44640719), October 2019

company data. Only 2% of European organisations operate exclusively in public cloud. Hybrid cloud with a strong on-premises component is the preferred operating model in Europe.

The key 2020 data centre priorities are security, agility and modernisation, all of which have come to the fore during the COVID-19 crisis. Key technology initiatives are centred around the implementation of multicloud services, programmable infrastructure and intelligent security solutions. To handle the operational complexity of operating a multicloud environment and to handle cost monitoring and dynamic workload migration, European organisations are increasingly setting up cloud centres of excellence (COEs) to pool their cloud resources and expand their cloud strategies[23].

Sustainability is a big topic for European organisations and cloud providers that can offer carbon-neutral services are very attractive, as they help companies to reduce their carbon footprints significantly. This is now frequently arising in requests for proposal (RFPs).

The absence of a Europe-headquartered cloud hyperscaler (a global provider such as AWS) raises concerns about the competitiveness of European organisations and about data sovereignty. The German and French governments have launched GAIA-X[24], an initiative to create a data overlay on top of hyperscalers' services, which will handle European organisations' data according to European values and legislation. This initiative might strengthen the position of European cloud providers.

In this context, Brexit will represent an element of disruption to the European economy until all the details of an agreement will be specified. Cloud might emerge as an enabler in a changing economic environment, as continental European data centre locations will be preferred by European organisations.

Cloud Demand in the Public Sector

European governments have adopted all cloud computing deployment model types, from public cloud to on-premises private cloud. Thus, they have organically built more complex hybrid and multicloud environments.

It must be noted that differences exist across countries because of different stages of maturity. The UK government was the earliest adopter of a program, with more than 30% of government organisations adopting public cloud. In the two largest members of the European Union, Germany and France, strict data sovereignty requirements and a fragmentation of IT demand across levels of government have kept public cloud adoption at below 20%[25]. Unlike France and Germany, countries such as Spain, Italy, the Netherlands and the Nordic states have learned lessons from the UK and cautiously followed a similar model of creating cloud policies, supplier certification guidelines and government-wide cloud contract frameworks.

Notwithstanding the progress, cloud adoption in government remains well below that of other industries, such as education, retail and manufacturing, where rates of adoption of public cloud surpass 30%[26]. The top barriers to public sector cloud adoption include policy and regulatory concerns, architectural constraints and organisational barriers. In the public sector, a specific issue with cloud computing is the shift to operating expenditure rather than capital expenditure. This requires adjustments in accounting practices in the public sector, moving part of IT from investments to current expenditures. In addition, the cloud payment model tends to open the door to 'shadow IT' purchases from mission executives and managers, who do not have a comprehensive overview of how their choices impact overall costs, interoperability or system security.

Cloud Demand by SMEs

Companies' adoption of cloud technologies has varied across EU Member States, which is also true across company size segments, SMEs included. Regardless of company size, 26.2% of companies in the EU28 made use of cloud computing services in 2018. When one looks at the figures for large companies and SMEs, it is clear that SMEs have lagged far behind in terms of cloud computing adoption. Indeed, between 2014 and 2018, large companies using cloud computing jumped from around 35% to over 50%. By comparison, cloud adoption among SMEs increased at a far slower rate, from under 20% in 2014 to 26.2% in 2018[27].

The difference here shows two broad trends. Cloud uptake is certainly increasing across the board. But, whilst large companies have quickly migrated in just a few years and now often see cloud as the norm, SMEs' progress suggests more actions and assistance are needed for these entities to consider cloud

[23] IDC European Mutlicloud Survey, 2020 (N=1,187)
[24] https://www.data-infrastructure.eu/GAIAX/Navigation/EN/Home/home.html
[25] IDC European Tech and Industry Pulse Survey - conducted in Q3 2019 and including 291 central and local government IT and non-IT executives, across Europe
[26] Ibidem
[27] https://ec.europa.eu/eurostat/statistics-explained/index.php/Cloud_computing_-_statistics_on_the_use_by_enterprises

computing as a general standard. This situation is particularly pronounced in countries that have lagged behind in adoption. It also reflects diversity in the comparative strengths of national industries, with certain industries moving much faster than others (such as the IT industry, in which progress has been rapid).

SMEs' reluctance to adopt cloud computing is focused around three main groups of issues: uncertainty about the business value and return on investment; concerns about privacy, confidentiality, data integrity and security in the interaction with cloud providers; lack of skills and resources to manage the transition to cloud and the relationship with the cloud providers.

Coherently with these concerns, SMEs migrating to the cloud tend to select one of the three largest international providers (Amazon Web Services, Microsoft Azure, Google Cloud) because of brand awareness, a belief in the market leaders' ability to guarantee security, cheap prices (at least at the entry level) and flexibility (unlimited capability to scale up computer power on demand)[28]. However, many SMEs (about a quarter of them[29]) then do not receive the service as indicated in the contract, with most frequent problems concerning the unsatisfactory availability or discontinuity of the service, low speed of the service and forced updates. Because of lack of skills and resources, SMEs do not negotiate with cloud providers but accept the standard terms. In addition, SMEs are more at risk than large enterprises to suffer from customer lock-in because of barriers to data and service portability[30] preventing them from switching provider when they are unsatisfied. To fight this risk the EC has promoted Cloud Service Providers industry self-regulatory codes on non-personal data portability as recommended by the Free Flow of Non-Personal Data Regulation adopted in 2019[31].

As European SMEs become more familiar with cloud computing, they will refine their criteria of cloud provider selection progressing beyond simply relying on best-known brands. This will open new opportunities to the European cloud industry which needs to step up their marketing and visibility. Amazon, Microsoft and Google have very steep price scales to satisfy increasing computing power demand, which is a sore concern for European smaller companies[32]. These global players offer standard contracts and solutions, while European providers can offer more flexible pricing, value-added services better tailored to SMEs needs and multi-language capabilities. Global cloud providers take care to be compliant with GDPR and overall EU regulation, have multiple data centres in Europe and can comply with data residency requirements, but they are also subject to US regulation which may in some circumstances interfere with GDPR (see also next section 2.3.2 on main challenges - regulatory compliance). In any case, European cloud providers are better positioned than US ones to leverage the European data governance approach in a proactive way, helping their clients to use it as a competitive advantage rather than a formal obligation.

Edge Computing

The 'edge' is one of the most talked about topics in the IT industry today, as well as a top area of strategic IT investment due to the rising number of organisations undertaking digital transformation initiatives. As a result, infrastructure functions such as data processing are expanding beyond centralised data centres. The development of edge computing is strongly influencing the cloud market. It is predicted that edge-to-cloud infrastructure balance will have shifted by 2023 from today's 20% data at the network edge and 80% in cloud-based infrastructure to 80% at the network edge and 20% in cloud-based infrastructure[33]. European businesses need to understand this trend to be able to make well-informed decisions on whether and when to invest into edge solutions. More relevantly, also by 2023, over 50% of new enterprise IT infrastructure deployed will be at the edge rather than in corporate data centres, up from less than 10% today[34].

Strong interest and investment in edge computing are evident worldwide across the IT industry, such as among IT vendors, cloud providers and telecom service providers, as well as among organisations across many industries, like oil and energy providers and retailers (i.e. demand for HPE Edgeline

[28] Drivers and Barriers of the Cloud Computing in SMEs: the Position of the European Union, P. R. Palos-Sanchez, the University of Sevilla, October 2017: https://www.researchgate.net/publication/320866331_Drivers_and_Barriers_of_the_Cloud_Computing_in_SMEs_the_Position_of_the_European_Union

[29] https://ec.europa.eu/info/business-economy-euro/doing-business-eu/contract-rules/cloud-computing/study-economic-detriment-unfair-and-unbalanced-contractual-terms_en

[30] Switching of Cloud Services Providers, http://publications.europa.eu/resource/cellar/799e50ff-6480-11e8-ab9c-01aa75ed71a1.0001.01/DOC_1

[31] https://ec.europa.eu/digital-single-market/en/free-flow-non-personal-data

[32] See for example the cloud costs documented in D.4.3 "Evaluation of Business Performance", DataBench project, https://www.databench.eu/wp-content/uploads/2020/11/databench_d4.3_v1.0.pdf

[33] IDC FutureScape: Worldwide Datacenter 2020 Predictions, IDC (#US44747919), October 2019

[34] IDC FutureScape: Worldwide Datacenter 2020 Predictions, ibidem

Converged Edge Systems and Dell's Edge Gateways). Most major IT companies and cloud providers have mature portfolios and strategies in place when it comes to edge computing.

Worldwide, the numbers of companies present in the edge computing market and investing in related capabilities continue to grow and these companies continue to diversify. Amazon Web Services (AWS), Equinix, Google, IBM, Microsoft, Oracle and Switch are among the familiar companies in the hyperscale space. Physical infrastructure providers include INTEL, AMD, NVIDIA, Dell Technologies, Ericsson, HPE. On the network side, AT&T, Lumen and Verizon, for example, deliver critical networking capabilities to connect the thousands of planned and deployed edge data centres.

In Europe, investment in the adoption of edge computing is still limited, driven mainly by IoT-intensive sectors such as manufacturing[35]. The emergence of autonomous vehicles and connected car infrastructure, and the need for lightweight frameworks and systems to enhance the efficiency of edge computing solutions will drive demand in the next years. Edge computing allows streaming services such as Disney and Netflix to improve their network performance for end users. Large enterprises are driving the adoption of edge computing while SMEs show a lower level of readiness due to cost, a lack of skills and a lack of public offers tailored for small enterprises[36]. The deployment of 5G networks will generate a new range of applications requiring low latency and therefore edge computing technologies[37]. The shift to edge computing may represent a competitive advantage for the European industry by leveraging European strength in industrial applications, sensors and CPS (Cyber-physical systems)[38].

Market data confirms that the edge computing ecosystem is still emerging in Europe, and development will depend a lot on the timeframe of the rollout of 5G technologies. The edge market (including hardware, software and provisioned and professional services) in aggregate will grow at a five-year CAGR of 10% and reach €40.6 bn in 2024 (see Figure 3). The year-on-year growth for this market will be lower in 2020 due to the current capital preservation strategies in place to counteract the negative effects of the COVID-19 pandemic.

On the optimistic side, from 2021, it is very likely that the edge market will gain momentum, with a rapid growth over the following years, fuelled by a robust worldwide economic recovery and strong adoption of edge technologies[39].

Edge expenditures will be concentrated in the US and Western Europe over the next few years. In 2020, the global regional spending shares of the Americas, EMEA and Asia/Pacific will be 45.0%, 27.9% and 27.2%, respectively. From an industry perspective, 11 of the 19 standard industry sectors will deliver 5% or more of total worldwide spending in 2020. The top 2 industries for edge spending throughout the forecast are discrete manufacturing and professional services, while retail will overtake process manufacturing to become the third largest industry by the end of the forecast. Professional services will record the fastest growth in edge spending, with a five-year CAGR of 15.4%.

A growing focus among public cloud providers on edge delivery services over the past three years reflects increasing customer demand for edge technologies. Growth in offerings indicates that the major providers will bring the same momentum and innovation to edge computing platforms and solutions as they do to core computing platforms in their respective public clouds. Public cloud core-integrated core-edge-endpoint stacks will represent a significant portion of the edge ecosystem, creating standardisation across multiple use cases and a platform for further innovation for both customers and third-party providers[40].

[35] IDC European Tech and Industry Pulse Survey, 2019–2020, IDC, 2019

[36] https://www.marketsandmarkets.com/Market-Reports/edge-computing-market-133384090.html?gclid=CjwKCAiAoOz-BRBdEiwAyuvA69EIZPSGJaxELHCP3ILGuJ3Dbbh3T-6GVES6fsMciZdTHm90fQWRMBoCzGEQAvD_BwE

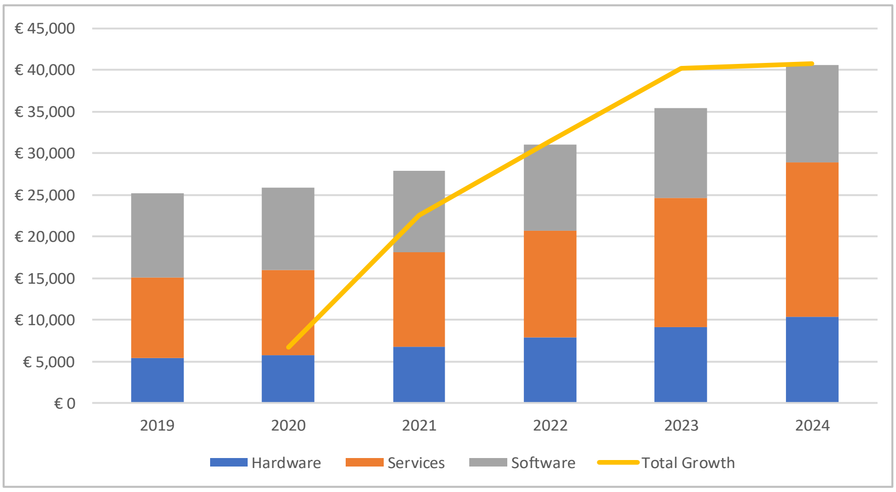
[37] https://www.accenture.com/us-en/blogs/business-functions-blog/5g-and-edge-unlocking-new-possibilities

[38] Rolf Riemenschneider, Head of Sector, IoT, DG CONNECT, European Commission, Workshop on IoT and Edge Computing, September 2020 https://www.ngiot.eu/event/iot-and-edge-computing-future-directions-for-europe/

[39] IDC Worldwide Edge Spending Guide, July 2020

[40] IDC Worldwide Edge Spending Guide, ibidem

Figure 3: Western Europe Edge Spending (€ m) (2019–2024)



Source: IDC Worldwide Edge Spending Guide, July 2020. Western Europe includes AT, BE, DK, FI, FR, DE, EL, EI, IT, NL, PO, ES and SE, plus CH, NO, and UK

2.2.3 The Main Challenges

As discussed above, deploying and adopting seamless and interoperable cloud infrastructures to respond to demand and needs from across industries and to ensure greater data-infrastructure sovereignty in Europe is critical. However, technical and organisational challenges on both the supply side and the demand side must be solved to achieve this goal. Policy support is needed at the EU and national levels to promote the standardisation, interoperability and sustainability of cloud offerings. Below is a summary of the main challenges:

- **Cloud Management Challenges:** Cloud computing is evolving fast towards an integrated approach to the development of value-added services, reflecting organisations' increasing need to seamlessly leverage edge and cloud resources from multiple cloud providers[41]. This requires new approaches, processes and tools that link different platforms via a common methodological foundation that addresses all infrastructural layers. Over two thirds of European enterprises have created cloud centres of excellence to serve as focal points for defining business KPIs and operational processes, which are in turn used for decisions about where to deploy applications. End-user experience, cloud cost tracking, transaction health, compliance and security policies all need to be consistent across multiple clouds and applications.
- **Cloud Data Privacy and Security:** Requirements regarding security, privacy and traceability in cloud environments are increasing with the number of organisations involved in data-driven services, as well as with the growing complexity of distributed networks. Organisations along the value chain require more than just to connect; they must also meet all data security, protection and governance policy requirements. Global hyperscalers insist that local data residency is not a necessary requirement for security which can be guaranteed by their global networks[42]. When data is transferred across company boundaries, new data security and privacy challenges arise around protecting stakeholders' interests. New technologies – such as those used for distributed ledgers, homomorphic encryption, multiparty computation and federation – can enhance security-framework traceability and privacy during cross-company data exchange and acquisition. The trade-off is that storing data (hashes and signatures) in a blockchain or distributed ledger and performing operations using homomorphic encrypted data leads to the additional consumption of computing and storage resources. These challenges must be met by suppliers and users at the industry-value-chain level, not simply at the individual-enterprise level.
- **Standardisation, Interoperability and Data Portability:** European organisations want data and workload portability across providers and the ability to integrate cloud with legacy systems. They expect application data architectures, application logic and user interfaces to adapt to their business processes. And they demand fine-grained elasticity at low or marginal cost, including

[41] Cost-Efficient Request Scheduling and Resource Provisioning in Multicloud for Internet of Things, Xin Chen, Yongchau Zhang and Ying Chen, IEEE Internet of Things Journal, 2020
[42] https://d1.awsstatic.com/whitepapers/compliance/Data_Residency_Whitepaper.pdf?did=wp_card&trk=wp_card

the ability to create new workloads in emerging technology areas, such as training machine-learning algorithms and managing IoT devices at the edge, such as video cameras and environmental sensors. European suppliers must rise to these challenges and develop their offerings to respond to the outlined industry needs. Investments are needed in the development of standards and interoperability in the multicloud environment. Non-personal data portability is also a key condition to enable switching cloud provider and avoiding customer lock-in, as well as enabling cross-border data flows. This is a key objective of the "Free Flow of non-personal data" Regulation[43] that is applicable as of 2019.

- **Cloud Provider Management:** Buying a public cloud subscription from one of the main global providers is apparently easy, but enterprises quickly discover several pitfalls, including the risk of lock-in – most frequently, because of the difficulty and cost of transferring data and applications developed in the provider's cloud environment. Micro-enterprises and SMEs suffer economic detriment because of contract-related problems, such as non-conformity with the contract or unfair contract terms[44]. Moving towards multicloud environments is also problematic, as managing multiple cloud providers requires specific skills and competences in outsourcing and contract management. The EU's regulation on the free flow of non-personal data[45] outlines several initiatives to facilitate data portability and remove unjustified barriers to switching cloud provider, including the promotion of cloud industry voluntary self-regulation codes. The SWIPO (switching and porting) codes were finalised in May 2020[46] and a new legal entity (SWIPO AISBL[47]) was created to support their implementation and enforcement, which is always the weak point of self-regulation because of its voluntary nature. However, the process is moving slowly, the SWIPO members are only 26 and some stakeholders are not satisfied of its effectiveness (for example CIGREF, French association of enterprises and public administrations[48]). Industry codes as instruments are effective insofar the majority of providers and users decide to use them, with a proactive approach. This again underlines the need for cloud users to invest in their skills and capability to use such instruments, manage multiple technology providers and align their infrastructure and service choices with their business goals.
- **Regulatory Compliance:** On the one hand, European organisations must understand and comply with EU regulations, including the General Data Protection Regulation (GDPR)[49] and the Network Information Services (NIS) directive[50], which protect the privacy of personal data and resilience of critical digital services. On the other hand, uncertainty persists about the full compliance of international cloud service providers with important EU rules and standards – for example, on data protection and the localisation of critical datasets. Service providers operating in the EU may also be subject to the legislation of third countries, which presents the risk that the data of EU citizens and businesses is accessed by third country jurisdictions, contravening the EU's data protection framework. Particularly the management of data flows between the US and Europe is in a state of flux, because of the tension due to very different privacy regimes. In July 2020 the EU Court of Justice declared inadequate the "Privacy Shield" agreement between the EU and the US[51] meant to align data protection agreement between the two regions. The EU Court of Justice left standing the SCC (standard contractual clauses) which allow cloud hyperscalers to move data to the US, but according to privacy advocates this may be challenged. In addition, the US in 2018 published the US Cloud Act[52] (Clarifying Lawful Overseas Use of Data Act, March 2018), which defines terms for bilateral agreements between the US and other governments to allow access to electronic data no matter where it is held. The only agreement stipulated so far is with the UK, and negotiations are ongoing with the EU. This is of interest also to European law enforcement authorities interested to access data stored in the US.[53] In particular, concerns have been voiced about several Chinese laws relating to cybersecurity and national intelligence. These uncertainties may prevent some enterprises, particularly smaller ones, from adopting more sophisticated cloud services to pursue innovation.

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[43] https://ec.europa.eu/digital-single-market/en/free-flow-non-personal-data
[44] Study on the economic detriment from unfair and unbalanced cloud computing contract terms, European Commission
[45] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32018R1807
[46] https://ec.europa.eu/digital-single-market/en/dsm-cloud-stakeholder-working-groups-cloud-switching-and-cloud-security-certification
[47] https://swipo.eu/
[48] https://www.cigref.fr/swipo-failure-regulate-european-cloud-market
[49] https://eur-lex.europa.eu/eli/reg/2016/679/oj
[50] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2016.194.01.0001.01.ENG&toc=OJ:L:2016:194:TOC
[51] https://cloudcomputing-news.net/news/2020/aug/07/privacy-shield-ruling-could-lead-to-dark-clouds-ahead-for-hyperscalers-privacy-advocates-warn/
[52] https://iapp.org/news/a/questions-to-ask-for-compliance-with-the-eu-gdpr-and-the-u-s-cloud-act/
[53] https://www.csis.org/blogs/technology-policy-blog/cloud-act

- **Skills and Organisational Challenges:** Many European entities, particularly small and medium-sized enterprises, have insufficient budgets to gain (through acquisition and/or training) the technical and supplier management skills necessary to develop, deploy and manage cloud services. Their budgeting and procurement policies and processes are geared towards a strict distinction between capital expenditure to acquire systems and operating expenditure to run them. IT operating models often rely on a centralised function that manages IT assets and services. Cloud services require a shift towards operating expenditure, which opens the door to shadow IT purchases from line-of-business executives and managers who do not have a comprehensive view of how their choices impact overall costs, interoperability, or system security.
- **The Dominance of Non-EU Global Providers:** As illustrated in section 2.2.1, the European cloud market is dominated by a few global hyperscale providers. The European industry includes only a few large players, which have small market shares and a multitude of small local IT services and cloud software providers with little market influence. The risk is that these enterprises will lack the funds and willingness to develop cutting-edge technologies to enhance their offerings and keep pace with innovation and demand requirements. Improving the competitiveness of the European cloud industry is a relevant objective of EU policies to insure European digital sovereignty, as indicated in the EU MS Joint Declaration on "Building the next generation cloud for Europe".[54] Initiatives planned include launching a European Alliance on Industrial Data and Cloud to pool investments for cloud infrastructures and defining a common EU approach on federating cloud capacities, building on synergies between the myriad public and private cloud services existing in Europe. The forthcoming Digital Europe and Horizon Europe programmes will support public-private cooperative research and deployment projects to solve cloud interoperability, security and energy efficiency challenges.
- **Sustainability and Energy Efficiency Requirements:** The cloud paradigm can improve sustainability through resource sharing, autoscaling and the greater efficiency of first-class data centres. However, these mechanisms focus on hardware usage optimisation, rather than on software optimisation. Software design inefficiencies are very common, particularly in Big Data and analytics (BDA) projects and are often disregarded by programmers, especially when programmers are under pressure due to productivity targets. This aspect of sustainability is less often addressed even in academic literature and rarely features in the sustainability initiatives of cloud providers.

2.3 Use Cases and Business Opportunities

2.3.1 Cloud Computing Use Cases

Use cases can be defined as discretely funded digital projects that support specific business or societal goals (e.g. remote health monitoring in the healthcare sector, grid monitoring for utilities, fleet management in transportation). A use case is not defined by the technology itself. The parameters of a use case are defined by the value being created and recognised by the organisation in question. Use cases can be categorised by the three primary benefits they provide:

- Creating new products and services
- Optimising operations
- Transforming customer experience and/or creating customer loyalty

The conversation is shifting from a technology discussion to a use-case discussion. European organisations are interested in the use cases they want to implement and only investigate technologies as a secondary step[55].

Cloud computing is an enabler of many other capabilities – such as application modernisation, analytics at scale, IoT and digital innovation – rather than an end in itself. It accelerates testing, developing and deploying services that are natively designed for consumption across multiple channels (online, mobile apps and chatbots). Cloud enhances elasticity to accommodate usage peaks, such as those experienced while managing high-volume services (e.g. the receipt of tax declarations, student applications, farm subsidy applications) and emergency events. It helps increase the ability to ingest data and process events from new sources, such as Internet-of-Things device feeds in Smart Cities.

For example, European companies use public cloud to build and train AI models, a practice that will drive up public cloud use as this market develops. In 2019, 15% of model training happened in the

[54] https://ec.europa.eu/digital-single-market/en/news/towards-next-generation-cloud-europe
[55] https://www.idc.com/getdoc.jsp?containerId=US46291215

cloud; in 12 to 24 months, it will be more than 20%[56]. Public cloud providers' AI-related solutions offer easy and cost-effective access to computing power and various machine-learning functions to facilitate ready-to-use AI models, thus removing users' need to develop advanced functions, such as speech and image recognition.

To identify the most interesting business opportunities enabled by cloud, we have classified digital transformation use cases based on current and forecast cloud computing spending. Figure 4, below, maps Europe's largest digital transformation use cases by cloud spending across industries, representing their expected short-term (horizontal axis) and long-term (vertical axis) spending growth, updated in July 2020 (revised based on post-COVID-19 outbreak research). The size of the bubble reflects the value of cloud spending in 2019. Overall, the CAGRs forecast for the next few years are quite high, ranging from 27% to 39% – very promising markets.

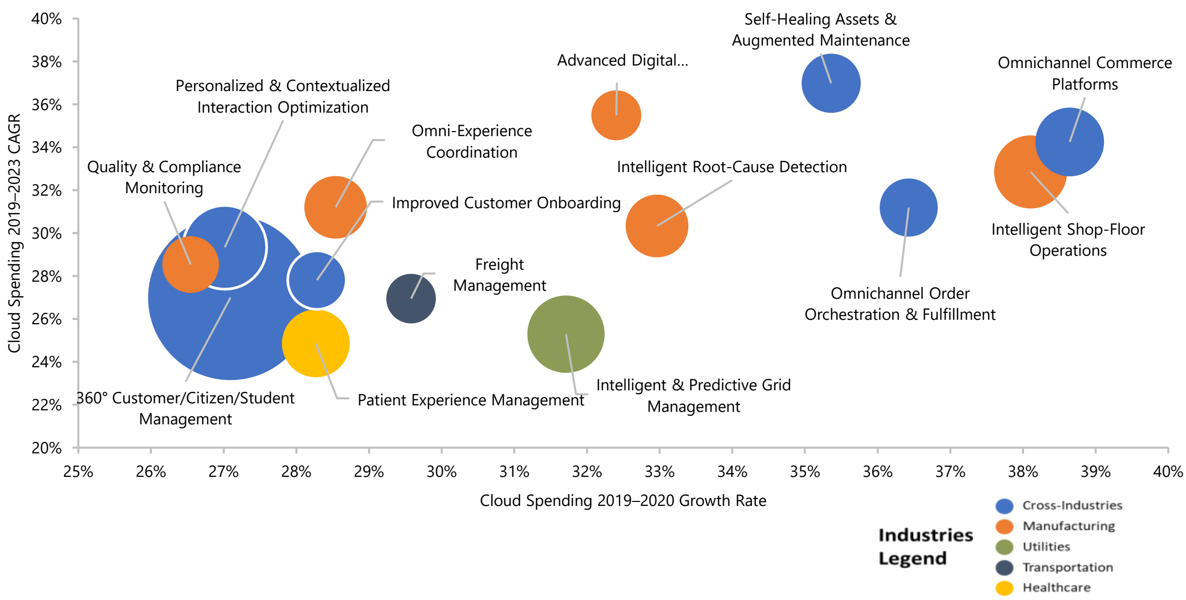
A slew of factors support digital use cases' suitability for cloud technologies, such as the need for one use case to be applied across multiple locations (e.g. intelligent shop-floor operations in multiple factories of a large manufacturing organisation), the use of various types of data and the need for real-time data sharing (e.g. for omnichannel order orchestration and fulfilment, for which real-time data transmission is key). Recognition of cloud's suitability for digital use cases stems from a general awareness and knowledge of cloud computing's benefits.

In terms of value and growth, the use cases expanding most quickly and achieving the highest value are those that can be applied across industries. Five out of the top six highest-value use cases concern customer marketing and interaction; the last one concerns smart asset management. The top use case – 360° customer/student/citizen management – generates three times as much spending as its closest rival and still has potential to grow.

For industry-specific use cases, our list includes five focused on manufacturing – a very large sector with a strong propensity to use cloud computing – and one each specific to healthcare, utilities and transportation services. The use of cloud computing to deliver innovative use cases is widespread, but the manufacturing industry still has the highest growth potential.

Below, we provide a detailed description of each use case.

Figure 4: European Largest Digital Transformation Use Cases by Cloud Spending



Source: IDC Worldwide Digital Transformation Spending Guide, July 2020

**Bubble size represents 2019 European spending. Table 2 indicates the actual spending amount justifying the bubble size*

[56] IDC, The Importance of Public Cloud for AI Model Training, August 2019

Table 2: Top 14 Digital Transformation Use Cases by Cloud Spending (€ m) (Ranking by Value)

Top Digital Transformation Use Cases by Level of Cloud Spending	Industry	2020/2019 GR	2019–2023 CAGR	2019 Cloud Spending (€ m)
360° customer/citizen/student management	Cross-industry	27%	27%	1 542
Personalised & contextualised interaction optimisation	Cross-industry	27%	29%	417
Intelligent shop-floor operations	Manufacturing	38%	33%	303
Omnichannel commerce platforms	Cross-Industry	39%	34%	268
Patient experience management	Healthcare	28%	25%	261
Intelligent root-cause detection	Manufacturing	33%	30%	223
Omni-experience coordination	Manufacturing	29%	31%	222
Improving customer onboarding	Cross-industry	28%	28%	208
Intelligent & predictive grid management	Utilities	32%	25%	339
Self-healing assets & augmented maintenance	Cross-industry	35%	37%	198
Omnichannel order orchestration & fulfilment	Cross-industry	36%	31%	192
Quality & compliance monitoring	Manufacturing	27%	29%	182
Advanced digital simulation	Manufacturing	32%	35%	142
Freight management	Transportation	30%	27%	139

Source: IDC Worldwide Digital Transformation Spending Guide, July 2020

2.3.2 Use-Case Descriptions by Industry

Cross-Industry Use Cases

360° Customer/Student/Citizen Management

Providing a 360° view of the customer/student enables better engagement and experience throughout the customer journey. The objectives concern converting prospects into clients/students and generating higher revenues, higher levels of customer satisfaction and greater customer loyalty. Students obviously are not customers in the commercial sense, but education institutions carry out marketing and recruitment initiatives for which these solutions are useful. Multiple solutions come together to fulfil the objective, including but not limited to customer relationship management (CRM), artificial intelligence applications, loyalty applications and social media. The result is improved customer experience, engagement and lifetime value with a 360° view of the customer via engagement tools.

Concerning citizens, the focus is more complex. The use case relates to aligning constituent-facing business processes, actions and connection points to support comprehensive needs and deliver optimal experience. It provides a one-stop shop for access to government services and information to make it easier and more convenient for users to conduct business with government. Duplicative steps and friction points in applying for services are eliminated. Cognitive computing/AI systems emulate natural capabilities to ensure citizens, based on their needs and requirements, are directed to the correct government bodies/programs and to assist them in their interactions with such agencies and with any related processing. This includes working with omni-portals to understand citizen context in real time, to recommend actions to civil servants who are most relevant for the specific citizen interactions and to recommend to citizens the best next steps and services.

Personalised and Contextualised Interaction Optimisation

This use case aims at aligning customer dialogue with the role, behaviour and location of the person who needs, buys and uses the provider's products in the context of the person's current world. Contextualisation is informed by data about the person and the dynamic state of his/her world based on what is happening, said, needed and expected 'now' in the context of achieving the provider's goals for the relationship, campaign and message. This utilises multiple data sources to help personalise interaction with clients, providing context to the communication in relation to the customer's lifestyle, situation and status. By acknowledging the specific needs of the individual (or business), organisations gain competitive advantage and increase share of wallet with existing customers. This use case also includes the ability to create a more engaging marketing environment at the local sales point – one that speaks directly to the customer visiting the location – while providing feedback to the marketing and sales organisations through interactive marketing.

Omnichannel Commerce Platforms

Omnichannel commerce platforms support the customer engagement process before, during and after the provision of services. The goal of this use case is to orchestrate sales and service channels (mobile first, ecommerce, omnichannel and travel agency) for optimal guest/passenger paths to purchase, sell and service, enabling a seamless omnichannel experience throughout the customer journey and in the stream of life (search, discover, buy and fulfil and service).

Improving Customer Onboarding

Customer onboarding is an umbrella term that is often used to describe the entire process that users go through when they start their journeys as customers of a product or service. Onboarding is often the first chance an organisation has to make a good impression with the customer; it is an opportunity to establish a good relationship from the start. Organisations need to leverage that opportunity not only to deliver a good experience, but also to gain insight into the customer for future opportunities. The goal of this use case is to reduce the time and complexity of product and service onboarding (for both new and existing customers). The information collected during the onboarding process can be leveraged by the organisation in the future.

Self-Healing Assets and Augmented Maintenance

This use case applies to the construction, manufacturing, utility and resource industries. The goal is to leverage data and AI to predict potential failures and improve maintenance. This use case is based on owners and operators remotely tracking, monitoring and maintaining machinery, assets and other equipment. The challenge is to regularly assess asset conditions and remotely diagnose asset failures before they happen. By analysing the live stream of data produced by the assets (predictive maintenance), companies can reduce the probability of facing 'dangerous' situations, since the equipment under consideration is likely to be maintained before a possible failure or an all-out breakdown occurs. Machine-learning algorithms help to build an accurate predictive model of potential failures. Self-healing assets can not only self-diagnose; they can also diagnose other assets within other systems visible to them. These systems can then reroute, shed load or shut down to avoid cascading failures. This improves uptime and eliminates unnecessary maintenance, with the end goal of improving process efficiency and reliability. It also increases the chances of using the asset for longer and more effectively than under traditional maintenance mechanisms. Higher levels of asset availability result in less factory downtime and lower capital appropriation spending, including lower maintenance costs. Augmented and virtual reality enables the provision of relevant information and guided work instructions to maintenance technicians. The objectives are reduced repair time and cost, longer mean time between failures (MTBF), higher first-time-fix (FTF) rates and less factory downtime. Robots and drones offer support, inspecting machinery and relaying real-time information and feedback.

Omnichannel Order Orchestration and Fulfilment

The goal of this use case is the fast and efficient capture, management and fulfilment of all store-bound and direct-to-customer orders to optimise fulfilment cost and capacity, inventory risk and customer service from enterprise-wide and supply network inventory sources. Order capture signals multitier replenishment and secures capacity for downstream fulfilment activities. The orchestration of custom/build-to-order fulfilment encompasses design, buy and make workflows. This is based on real-time, context-aware analytics and curated network data to anticipate and balance direct-to-customer and store-bound order fulfilment to meet customer service levels at lower total cost to serve.

Manufacturing

Intelligent Root-Cause Detection

This use case refers to the monitoring of production systems and machinery and automatically detecting, predicting and anticipating production deadlocks and failures, including understanding the root causes. Connected quality metrology feeds an analytics model that can support the automated Six Sigma analysis of quality anomalies with the ability to adjust processes in an automated way. Better error proofing lowers costs related to quality issues, particularly repeat errors.

Omni-Experience Coordination

The objective is to enable easier commerce and thus increase the prospect-to-customer conversion rate. A shared commerce network/platform enables seamless transactions. Shared pan-market visibility in near real time enables smart inventory allocations. The ability to efficiently meet customer demands by deploying specialised cognitive/AI analytics to ensure the right product is in the right place at the right time shortens the channel between the manufacturer and end user.

Quality and Compliance Monitoring

This use case refers to the monitoring of end products' quality while automating final products' compliance-related activities. The objectives are more-effective designs, lower costs related to quality issues and fewer engineering changes resulting in lower related costs. Informed analysis of potential individual end-product failures is achieved through real-time data acquisition and simulation based on historical performance (from machine data). With the support of artificial intelligence, this will allow companies to more efficiently address immediate regulatory compliance issues, moving beyond the use of traditional structured data to leverage unstructured information and external data. This can be applied in real time to help deliver actionable insights, limit exposure and reduce the impact of compliance and quality issues that arise.

Advanced Digital Simulation

The objectives are to determine manufacturing capacity and capability, to achieve higher formulation-effectiveness levels and to better fulfil customer requirements and thus improve customer satisfaction, reduce rework and optimise manufacturing efficiency. The product, process and plant are modelled and simulated together to ensure the highest levels of productivity. Simulation is tightly integrated with the model and with awareness of the broader impact and opportunity of the application of the formulation. Augmented and virtual reality capabilities support product development to produce more effective work-process outputs, with users being able to simulate formulations – optional modifications, supply chain impacts and cost implications – in advance.

Healthcare

Managing the Patient Experience

The creation and maintenance of a comprehensive 360° view and managing the product lifecycle in a payer organisation are multi-departmental processes that require orchestration, governance, cooperation, shared decision making and discipline. This use case offers an end-to-end view of the customer and includes integrated data and common customer experience in sales channels, enrolment portals, service desks, marketing campaigns, claims adjudication and appeal and all health-management cases. It provides actionable advice based on the comprehensive and the continuous/real-time segmentation of risk, as well as offering next steps to customers/patients. This use case includes all components related to managing interactions with patients/consumers across the various touch points and is used by healthcare providers to build comprehensive pictures of their patients, leading to far better engagement with patients and supporting omnichannel engagement capabilities.

Utilities

Intelligent and Predictive Grid Management (Electricity, Gas and Water)

The intelligent component of this use case relates to the connection of all subsystems, enabling the adjustment of operations based on upstream and downstream events, an increase of power quality and efficiency and a reduction of outages. The predictive component of the use case employs predictive analytics and access to multiple data sources to predict grid performance and strengthen the just-in-time capabilities of utility management. Grid subsystems control and adjust themselves to account for upstream and downstream performance in real time. IoT components are important enablers of distribution automation in terms of controlling and optimising power flow to ensure efficient, safe and reliable service. This applies to the distribution grid, including line sensing, substation automation, and feeder and line equipment control and optimisation. Smart metering systems support intelligence by collating technical and non-technical data for power quality and power outage purposes. Cognitive capabilities supported by advanced analytics enable systems to learn more complex automation and management competencies.

Transportation

Freight Management

This use case tracks transportation assets (trucks, railroad, cars and ships) and determines/controls optimal routes. These systems can monitor both vehicle condition and driver behaviour. They typically offer route guidance, track idle or stopped time, and offer geofencing; they can include remote diagnostics for the engine and other systems. In addition, this use case carries out the intelligent recognition, location, tracking and monitoring of freight and cargo through exchanging information and real-time communications via wireless, satellite and other channels.

2.4 Social and Sustainability Impacts

2.4.1 Introduction

Cloud computing's impacts on business, as an enabler of innovation, particularly for SMEs and as a driver of productivity and efficiency, are widely recognised. The flexible pay-as-you-go cloud model has enabled organisations to achieve cost savings and to scale up their use of digital and other advanced technologies. But equally relevant are cloud computing's impacts at social and economic levels. Briefly, we should consider:

- The role of cloud computing in driving economic growth and job creation at the macroeconomic level, as estimated in several economic modelling studies (the cloud 'multiplier' impacts, as documented in section 2.4.2).
- The impacts of cloud computing in e-science, the research paradigm heavily dependent on the use of computing power and Big Data analytics, which has revolutionised science methods in the recent decades, particularly in the humanities. Cloud computing has been instrumental in enabling the geographically dispersed and fragmented European research community to access computing power and to leverage and share scientific data. This process is today enhanced by the policy drive to develop the European Open Science Cloud.
- The impacts of cloud on public services, particularly in government, as public administrations leverage cloud in combination with other technologies, such as Big Data analytics, IoT and AI, to improve the citizen experience and ensure openness and transparency. This is particularly true for Smart Cities, where digital transformation technologies are centred around cloud computing and are expected to drive a strong increase of cloud computing demand in the coming years.
- Last but definitely not least, cloud computing plays an important role in the green transformation of the ICT industry – namely, in achieving the environmental and economic sustainability of digital transformation (reducing the carbon footprint and energy costs).

2.4.2 Cloud Macroeconomic Impacts

According to several economic studies conducted in recent years, cloud computing has a multiplier effect on economic growth. This means that, thanks to the productivity improvements generated at the company level and the acceleration of innovation and the deployment of new products and services, cloud computing investments accelerate macroeconomic growth[57]. Cloud computing could add a **cumulative total revenue of €449 bn to the EU28's GDP** (including the public sector) in the 2015–2020 period[58]. Of this amount, €57.7 bn and €103.2 bn would be net new GDP generated in the years 2016 and 2020, respectively, representing a share of 0.40% and 0.71% of total EU GDP. Even if the estimate for 2020 is now obsolete because of the economic crises generated by COVID-19, a rebound

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[57] Measuring the economic impact of cloud computing in Europe, study prepared for the European Commission (DG Communications Networks, Content and Technology) by Deloitte, available at https://ec.europa.eu/digital-single-market/en/news/measuring-economic-impact-cloud-computing-europe

[58] Uptake Cloud in Europe, study prepared for the European Commission (DG Communications Networks, Content and Technology) by IDC, available at https://op.europa.eu/en/publication-detail/-/publication/7f0f48ca-32ef-489d-aa19-bc62e5044f1f

is expected from 2021 and the adoption of cloud computing will again, without doubt, have a positive impact on European GDP growth.

Economic studies also agree that cloud computing has a positive impact on job creation and employment. While the adoption of cloud tends to reduce the number of staff employed in IT departments[59], this negative is more than counterbalanced by the number of jobs created in other company departments, thanks to the launch of new products and services and by the creation of start-ups and innovative companies providing services based on cloud computing across numerous sectors. A model estimating the number of potential new jobs in the 2015–2020 period counted between 1 million and 2.5 million in the EU28, depending on a more or less favourable scenario[60].

2.4.3 Cloud in e-Science

Due to the continuous growth of demand for computing power and Big Data technologies in science and research, the e-science paradigm has become the new standard for all disciplines, including humanities. Cloud computing infrastructures and services have filled the gap between traditional offerings from national research networks & big science projects and this new demand, helping to transform science across a much wider community than in the past. European policy strategies for the implementation of the European Research Area (ERA) and the pursuit of excellence in science under Horizon 2020 have supported this trend through investments and the deployment of European e-infrastructures for research, in which cloud has played an important part. These e-infrastructures represent an enabling condition for 'the fifth freedom' of knowledge and data mobility in the EU, responding to emerging demand for open, flexible and scalable computing capacity that national resources cannot satisfy. European cloud infrastructures for research are a key component of the European Cloud Initiative[61], which was launched in 2016 to avoid any potential digital divide between the large countries and small countries and between big science projects and small & medium-sized science projects, ensuring equal access to computing resources across the EU.

More recently, a key policy initiative in this field has been the development of the European Open Science Cloud (EOSC), a trusted digital platform for the scientific community that provides seamless access to data and interoperable services to address the whole research data cycle, from discovery and mining to storage, management, analysis and reuse across borders and scientific disciplines. In support of the EU policy of Open Science, the implementation plan of EOSC was launched in 2018 with the goals of giving the EU a global lead in research data management and ensuring that European scientists reap the full benefits of data-driven science. The EOSC will be further supported by the forthcoming Horizon Europe Programme[62], which will implement the Open Science principle as a modus operandi for all projects and researchers.

The research community has pioneered an approach to federated clouds. The federative approach to cloud provisioning has been successfully adopted by research infrastructures in the recent years, providing data-centric exabyte-scale computing facilities, with national investments pooled to implement distributed European extreme-scale infrastructure that offers inherent secure access to computing resources, storage, data and applications. Research cloud federations typically address the need to share access to Big Data research repositories across international communities that collaboratively participate in international research projects. Examples of such infrastructures include the EGI Cloud Federation[63], which federates more than 20 research clouds, and, at the national level, the Network for Bioinformatics Infrastructure (de.NBI)[64], in Germany, and Nectar[65], an Australian research facility that provides computing infrastructure, software and services and enables Australia's research community to store, access and analyse data.

2.4.4 Cloud in e-Government

Governments continuously improve their ability to deliver efficient, trusted, responsive, inclusive and convenient services for all. Digital technologies, such as mobile computing, analytics, artificial intelligence, the Internet of Things and cloud computing are empowering public sector executives to accelerate this transformation.

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[59] Uptake Cloud in Europe, ibidem
[60] Uptake Cloud in Europe, ibidem
[61] https://ec.europa.eu/digital-single-market/en/news/communication-european-cloud-initiative-building-competitive-data-and-knowledge-economy-europe
[62] https://ec.europa.eu/digital-single-market/en/european-open-science-cloud
[63] https://www.egi.eu/federation/egi-federated-cloud/the-egi-federated-cloud-architecture/
[64] https://www.denbi.de/
[65] https://nectar.org.au/

European governments, with support from European Commission strategic policies, such as the Digital Single Market eGovernment Action Plan[66] and funding programs, such as Horizon 2020, have piloted, adopted and scaled the usage of cloud computing to accelerate digital transformation. However, challenges remain in terms of realising the full potential of cloud in the public sector. Data sovereignty concerns, system migration, data portability constraints and skill gaps are among the hurdles facing public sector entities in the adoption of cloud.

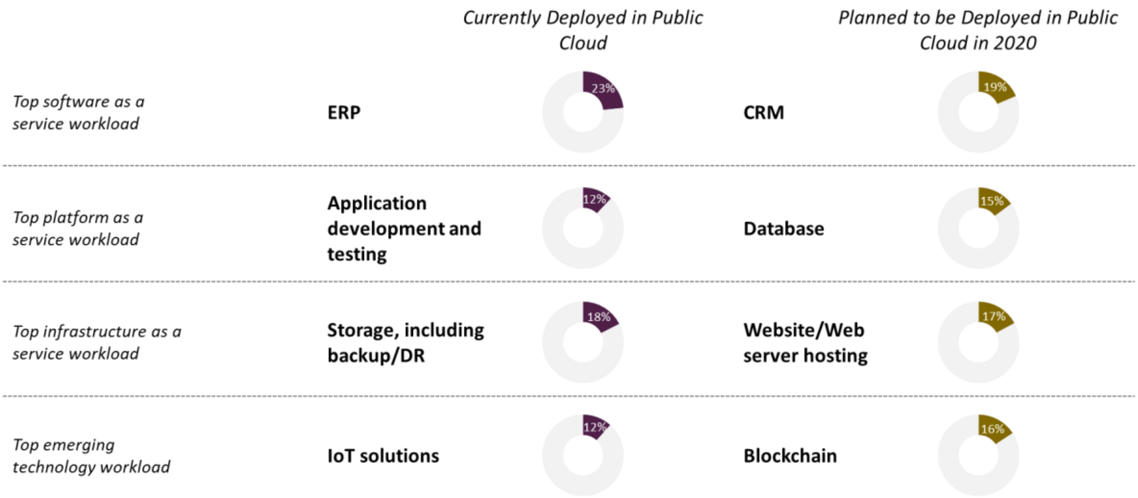
European government cloud adoption is not equal across use cases. Different applications have different needs in terms of regulatory compliance, architecture and organisational attributes. The combination of all factors determines whether governments run some of their systems in their own on-premises cloud data centres versus hosted private cloud and public cloud.

Use cases **for which security and data protection regulatory requirements are less stringent,** elasticity and scalability requirements are more pressing and organisational change is less complex to implement tend to run in public clouds or hosted private clouds. This is the case, for example, for application development and testing (see Figure 5), website hosting, storage and, increasingly, ERP and CRM applications, with global software suppliers having migrated their portfolios to the cloud for use cases such as HR, order management and contact centre management.

Conversely, use cases **for which security and data protection requirements are more stringent,** elasticity and scalability requirements are not as important, the need to integrate with many legacy systems and processes prevails and organisation change is complex because it touches the core of government operations tend to run on legacy architectures in on-premises data centres. This is the case for industry-specific solutions, like public safety command and control centres, tax and other revenue collection applications and welfare benefit management.

Emerging technologies such as the Internet of Things, artificial intelligence and blockchain are at an early stage of adoption in the public sector. This means they require **fast iterations** to develop and test new solutions before they can be scaled. Also, they can be **computing intensive** in terms of the volume and speed of data ingestion (e.g. security camera data feeds), the consumption of vast amounts of data (e.g. training of anti-fraud machine-learning algorithms) and the recording of transactions (e.g. blockchain-enabled land registries). These characteristics make IoT, AI and blockchain use cases suitable for far more than cloud computing. In many cases, the implementation of these emerging technologies almost requires the use of cloud computing, since on-premises deployments are impractical. For example, in the context of Smart Cities, which need to scale capabilities like device management, data exchange, predictive analytics and dashboarding across use cases, these capabilities are readily available as cloud services.

Figure 5: European Governments' Top Public Cloud Use Cases



Source: IDC European Tech and Industry Pulse Survey, conducted across Europe in Q3 2019 and including 291 central and local government IT and non-IT executives

[66] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52016DC0179

2.4.5 Cloud Sustainability Impacts

Besides minimising energy consumption through the support of virtualisation and multicore architectures, cloud computing can be used to achieve energy efficiency through efficient resource scheduling in the cloud environment[67]. Cloud providers are very aware that they need to respond to their customers' requirements and that they have a critical role to play in helping their customers to reduce their carbon footprints. Sustainable and environmental initiatives, initially disseminated by academics, environmental activists and NGOs, have shifted gear over the last two years, with the private sector and financial community starting to take issues such as climate change, carbon footprint and energy efficiency seriously.

The two main reasons technology service providers in general and cloud providers in particular are paying more attention to green computing are that, firstly, the financial community (rating agencies and investors) is investing in sustainable companies and, secondly, policies such as the European Green Deal are making it mandatory to commit to meeting sustainable development goals[68]. Consequently, the forces shaping the market (investors and clients) on the one hand and employees and public opinion on the other are pushing cloud providers to show a strong commitment to and find concrete solutions for, energy efficiency and the reduction of environmental impacts.

Beyond considerations about stakeholders, though, leading cloud providers have no choice but to invest in energy efficiency. Hyperscale environments spanning almost 2 000 m^2 and housing tens of thousands, or even hundreds of thousands, of power-hungry servers consume vast amounts of electricity and continuously emit heat, contributing to higher global greenhouse gas emissions. There are more than 400 hyperscale data centres in the world and the impact they are having is unsustainable, as increasingly recognised by business stakeholders as well as policy makers and society. Today, 77% of storage and compute resources are concentrated in the hands of eight hyperscale data centre operators (Google, Microsoft, Facebook, Amazon, Apple, Tencent, Alibaba and Baidu)[69]. Increasing demand for data and computing power is likely to require further massive expansion of already giant and sprawling data centres, with a consequent environmental impact.

Global cloud providers are aware of this challenge and are investing heavily in sustainability strategies, with a range of concrete initiatives. The following initiatives illustrate how cloud providers are moving to achieve their sustainability goals for their data centres[70]:

- Amazon Web Services (AWS), the market leader, is committed to powering its global infrastructure from 100% renewable energy sources by 2040, having achieved 50% in 2018[71] This is still a work in progress, but AWS is investing in projects expected to generate more than 2.9GWh of renewable energy each year, mainly through wind and solar farms. In Europe, for example, Amazon has added a solar farm in Spain and wind farms in Scotland, Sweden and Ireland; it has also made a series of innovative power deals with BP to source energy from renewable sources for its European data centres. AWS is investing in increasing the efficiency of cooling systems in its data centres to reduce energy and water consumption. AWS was accused by Greenpeace[72] in 2019 to be slowing down in its sustainability efforts, but the company denied the accusation and reconfirmed its goals.
- The Amazon Sustainable Data Initiative leverages Amazon Web Services' technology and scalable infrastructure to stage, analyse and distribute data. This is a joint effort between the AWS Open Data and Amazon Sustainability teams. The initiative identifies foundational data for sustainability and works closely with data providers like NOAA to stage their data in AWS Cloud by giving them complete ownership and control over how their data is shared. For example, BlueDot Observatory[73] leverages AWS Open Data and the cloud to monitor at-risk bodies of water.
- Microsoft has stated working towards its goal of becoming carbon negative by 2030 – that is, removing more carbon than it emits – by focusing on three carbon emissions stacks: 1) direct emission production by the firm's own activities, 2) emissions generated by the use of energy for firm's activities and 3) emissions created throughout the entire supply chain. The Redmond-

[67] https://dl.acm.org/doi/abs/10.1145/2742488
[68] Data Center Efficiency and Carbon Footprint: The New Battleground for Cloud Providers in Europe, IDC (#EUR246764820), August 2020: https://www.idc.com/getdoc.jsp?containerId=EUR246764820
[69] Data Center Efficiency and Carbon Footprint: The New Battleground for Cloud Providers in Europe, ibidem
[70] Data Center Efficiency and Carbon Footprint: The New Battleground for Cloud Providers in Europe, ibidem
[71] https://www.wired.com/story/amazon-google-microsoft-green-clouds-and-hyperscale-data-centers/
[72] https://www.greenpeace.org/usa/news/greenpeace-finds-amazon-breaking-commitment-to-power-cloud-with-100-renewable-energy/
[73] https://www.blue-dot-observatory.com/

based company aims, by 2050, to remove from the environment all the carbon the company has emitted since it was founded in 1975. To achieve this, Microsoft is increasing its usage of renewable energies and natural resources, such as wind power, solar power and hydropower. The company has been carbon neutral since 2012. Its data centres run on 60% renewable electricity, to be increased to 70% by 2023, while the rest is offset through RECs (Renewable Energy Certificates bought on the market)[74]. The most interesting recent initiative for cloud concerns the construction of large-scale data centres in Sweden, designed to be the most sustainable to date and to be powered by 70% renewable energy by 2023 and 100% by 2025. The plan is also to share some of the energy with the local community.

- In January 2020, Microsoft announced the availability of Microsoft Sustainability Calculator, a Power BI application for Azure enterprise customers that helps quantify both estimated Azure carbon emissions and the savings achieved by moving on-premises services to Microsoft Azure. The calculator enables enterprises to filter consumption data by Azure service type, region and timeframe to identify the carbon impact of their workloads and to help them make better decisions around sustainability.
- Google's energy consumption is so large that it consumes 0.01% of the world's electricity by itself. The corporation runs and operates 21 data centres on four continents, 5 of which are in Europe[75]. However, Google claims to have ran a carbon neutral business for 12 consecutive years. To achieve and maintain that goal, Google has a three-pronged approach, consisting of 1) energy efficiency initiatives targeting the reduction of total energy consumption; 2) fully matching the entire electricity consumption with the purchase of renewable energy and 3) buying carbon offsets for the remaining emissions. According to the Greenpeace report, Google is the largest non-utility corporate buyer in the world of renewable energy. For hyperscale data centres specifically, Google designed its Carbon-Intelligent Computing Platform to match data centres' energy use with peaks in renewable power generation and to align energy peak needs with the availability of the low-carbon power sources, such as wind and solar. In 2019, the power usage effectiveness (PUE) score – the leading indicator for energy consumption – for Google's data centres was 1.10 PUE, as compared with an industry average of 2.4 PUE for enterprise-owned data centres[76].
- According to IBM's energy efficiency targets, 55% of the vendor's worldwide electricity consumption will be from renewable sources by 2025, resulting in a 40% cut in its operational CO_2 emissions associated with energy consumption. Unsurprisingly for a technology giant, IBM heavily utilises automated analytics-based systems for data centre and building operations optimisation, which together accounted for 64% of IBM's energy conservation savings in 2018.
- An interesting trend is moving data centres to countries with a cooler climate to save the costs associated with cooling and to reduce emissions. In Europe, Iceland has the perfect weather conditions for data centres, as the average temperature is -10°C in winter and 5°C in summer. Iceland also provides access to renewable energy sources, such as geothermal and hydroelectric power and is becoming an interesting location for data centres.

Even though hyperscale data centres have made impressive progress in improving their energy efficiency, making their operations more environmentally friendly, this may not be sufficient to win the sustainability challenge and reduce the overall environmental impact of cloud computing. The increase of demand and therefore the implementation of additional capacity is forecast to continue driving an increase of energy consumption, even considering efficiency gains, up to 2025[77]. Studies show that the remaining energy-efficiency potentials after the last years' progress are becoming smaller as technology is moving closer towards the physical limits. The trends toward edge computing, decentralised architectures and federated cloud models represent alternative cloud evolution paths, promoted by European policies. These alternative cloud architectures will also need to ensure sustainability but achieving energy efficiency may be harder for distributed cloud services[78]. Cloud federation, for example, effectively pools the resources of many smaller providers, rather than consolidating their services to a few locations, and this is not energy efficient in principle. Edge is even less efficient in that the processors and data storage at the edge will consume more resources, and those resources are supplied with energy over greater distances. However, by

[74] https://www.wired.com/story/amazon-google-microsoft-green-clouds-and-hyperscale-data-centers/
[75] https://www.google.com/about/datacenters/locations/
[76] IDC 2020 Datacenter Operational Survey — Cloud to Edge Datacenter Trends: https://www.idc.com/getdoc.jsp?containerId=US46752920
[77] https://ec.europa.eu/digital-single-market/en/news/energy-efficient-cloud-computing-technologies-and-policies-eco-friendly-cloud-market
[78] Ongoing research from the Horizon Cloud project https://www.h-cloud.eu/

pooling efforts and investments distributed cloud services can enable a higher utilisation of compute resources, a faster renewal of custom-made hardware with better performance and higher quality technical management, resulting in improved energy-efficiency. The EC also defined criteria of Green Public Procurement for data centres to support environmental-friendly choices for cloud services[79].

In addition, plenty of research will focus on the technical challenges and environmental impacts of edge computing and cloud federation models in the forthcoming European programmes Horizon Europe and Digital Europe. Cloud sustainability is also a primary theme for initiatives such as GAIA-X the industry promoted alliance for a European Federated cloud and the future EU High Impact Project related to European data spaces and federated cloud infrastructures (see also section 2.5 on European cloud policies). Experts' recommendation for an RTD environmentally-friendly cloud policy which are likely to be adopted by the EU include also the stipulation of transparency requirements and fostering of uniform indicators for energy-efficiency, promoting the use of cloud native optimisation tools for cloud computing and improving software efficiency (green software)[80]. Current energy efficiency methods tend to focus on hardware usage optimisation, rather than software optimisation.

This lack of attention is partly due to the technical difficulty of green software development which will be hopefully overcome in the next years.

2.5 European Policies on Cloud

Cloud computing is a key enabler of the European Commission's digital agenda, Shaping Europe's Digital Future. In fact, cloud can deliver business and technical benefits to both public institutions and private enterprises in Europe. It is also at the nexus of other technology trends, such as edge computing and green IT, which are expected to play a relevant role in implementing the European Data Strategy, the European Industrial Strategy and the European Green Deal.

In recent years, the European Commission invested in the establishment of the Digital Single Market, including a number of actions specific to cloud computing[81]. With the upcoming Multiannual Financial Framework (MFF) of the European Union, covering the 2021–2027 period, the European Commission is setting new priorities and directions that complement and expand the strategies defined in previous MFFs.

The EC communication titled 'Shaping Europe's Digital Future' provides an overall strategic plan for the European digital agenda in the coming years. In this new agenda, cloud computing will continue to play a key role in tackling the digital challenge in Europe, complementing and extending actions defined in previous strategies. The cloud computing role is to unlock access to future and emerging technologies, such as 5G, artificial intelligence, high performance computing, the Internet of Things and distributed ledgers.

Cloud computing (and digital technologies in general) will play an even stronger role in the European economy and society by embracing core European values, spanning fundamental individual rights (e.g. security and data privacy), market openness (e.g. interoperability and free flow of data) and environmental friendliness (e.g. reduced carbon footprint and energy consumption) with the ambition to support the transition to a sustainable planet.

The European Data Strategy pays specific attention to cloud computing in the context of data infrastructures and technologies, stating that, 'The EU needs to reduce its technological dependencies in these strategic infrastructures at the centre of the data economy'[82]. To do so, it is necessary to overcome both the supply and the demand issues preventing the deployment and uptake of 'more secure, sustainable, interoperable, environmentally friendly and scalable cloud infrastructures and services for European businesses'. Supply-side issues include the low market share of EU-based cloud providers; uncertainty about the compliance of foreign cloud providers with EU regulations such as GDPR and, conversely, the risk that European business and citizen data may be subject to legislation of third countries; and economic disadvantages for micro-enterprises due to contract-related problems. Demand-side issues concern insufficient uptake, particularly among SMEs, and organisational and regulatory barriers preventing migration to more sophisticated and advanced cloud services. Lack of

[79] https://publications.jrc.ec.europa.eu/repository/bitstream/JRC118558/jrc118558_2020_0605_data_centres_technical_report_jrc_clean_with_id.pdf

[80] https://ec.europa.eu/digital-single-market/en/news/energy-efficient-cloud-computing-technologies-and-policies-eco-friendly-cloud-market

[81] European Cloud Initiative – Building a Competitive Data and Knowledge Economy in Europe, European Commission Communication, 19 April 2016

[82] A European Strategy for Data, European Commission, 19 February 2020

standardisation and interoperability between cloud services weakens EU offerings in competition with global integrated hyperscalers such as AWS and MS Azure.

To promote the development of suitable cloud infrastructures and services, the data strategy includes several initiatives, such as investments into the establishment of common EU-wide interoperable data spaces in strategic sectors, including connectivity and data processing capabilities; the interconnection of existing computing capacities at national and European levels, including high performance computing capacities; the launch of a European cloud services marketplace, integrating the full stack of cloud service offerings; and the creation of an EU (self-)regulatory cloud rulebook. The overall aim is 'to "help" common data and world class cloud infrastructures to emerge for the public good, enabling secure data storage and processing for the public sector and research institutions.'

The EC also plans to continue to support the interconnection of existing cloud services with the European Open Science Cloud (EOSC) and the Data and Information Access Services (DIAS) cloud-based platform, which provides access to services based on earth observation data from the Copernicus Programme. In this context, the Commission will foster synergies between the work on European cloud federation and Member States' initiatives such as GAIA-X[83]. In this way, the EC hopes to achieve synergies between private and public cloud offerings and to avoid a proliferation of fragmented cloud federation and data-sharing initiatives; success depends on pan-European participation and capacity to scale. To create a favourable environment for this federation-of-clouds process, the EC plans to facilitate memoranda of understanding with Member States, starting with those that have existing cloud-federation and data-sharing initiatives.

The most specific initiative outlined in the data strategy will be the new High Impact Project related to European data spaces and federated cloud infrastructures planned by the EC for the 2021–2027 period, in collaboration with Member States and industry bodies. The project will fund infrastructures, data-sharing tools, architectures and governance mechanisms for thriving data-sharing and artificial intelligence ecosystems. It will be based on the European federation (i.e. interconnection) of energy-efficient and trustworthy edge and cloud infrastructures (providing infrastructure as a service, platform as a service and software as a service). It will address the specific needs of industries in the EU, including hybrid cloud deployment models that enable data processing at the edge with no latency (cloud to edge). This project will involve and benefit the European ecosystem of data-intensive companies and will support European companies and public sector organisations in their digital transformations.

An important step towards the implementation of these initiatives was taken in October 2020 with the announcement of the Joint Declaration on Cloud[84] by the EU Member States. In the Declaration the MS agreed to work together towards deploying resilient and competitive cloud infrastructure and services across Europe, by collaborating on:

- Combining private, national and EU investment in deploying competitive, green and secure cloud infrastructures and services. This will mean pursuing the next steps together with industry and experts to shape the European Alliance on Industrial Data and Cloud.
- Defining a common European approach on federating cloud capacities, by working towards one set of joint technical solutions and policy norms in order to foster pan-European interoperable EU cloud services.
- Driving the uptake of more secure, interoperable and energy-efficient data centres and cloud services in particular for small and medium enterprises, start-ups and the public sector.

The Member States also agreed to develop together a set of common technical rules and norms (future EU Cloud Rulebook) which should be launched in 2022.

[83] GAIA-X: A Federated Data Infrastructure for Europe: https://www.data-infrastructure.eu/GAIAX/Navigation/EN/Home/home.html
[84] https://ec.europa.eu/digital-single-market/en/news/towards-next-generation-cloud-europe

2.6 Conclusions

Public cloud computing is evolving from a generic way to access additional computing power to a hybrid computing environment realising the everything-as-a-service provisioning concept, including applications. As revealed in ATI survey analysis, cloud is the instrument chosen by most enterprises to deliver services and applications based on Big Data, IoT and artificial intelligence. To deal with increasing demand for real-time processing capabilities, computing power and data scalability, cloud offerings are evolving rapidly.

In this report, we examine:

- The most relevant trends shaping the evolving cloud market and industry;
- strategies around migration to multicloud environments;
- The development of edge computing and the movement of data processing capability away from the core of cloud networks;
- The emergence of alternative cloud models based on distributed/federated cloud services;
- The need to deal with environmental challenges and reduce the carbon footprint of the cloud industry.

Public cloud investments have only been marginally hit by the economic crisis caused by the COVID-19 pandemic, with most European enterprises planning to maintain or increase their cloud spending in the coming years. Nevertheless, scepticism around cloud services remains; hybrid cloud with a strong on-premises component is the preferred operating model in Europe. In this way, companies can still maintain a certain control over their data.

The report shows the most interesting business opportunities enabled by cloud, classifying digital transformation use cases. The analysis has highlighted that the use cases expanding most quickly and achieving the highest value are those that can be applied across industries. Customer marketing and interaction is the application domain in which cloud plays the most relevant role, with five out of the top six use cases. For example, the use case with the highest level of cloud spending is 360° customer/citizen/student management, which is based on pulling together CRM, AI, loyalty and social media applications to provide coherent customer experience and engagement and increase the conversion of prospects into clients. This approach is enabled by cloud computing, which manages the data flows and interactive functioning of the apps. The broad scope of this use case means it is applied to consumers, citizens and students in various ways, confirming the usefulness of cloud infrastructures.

When looking at the evolution of the cloud supply scenario, some trends are disrupting the cloud computing offering and will require adaptation capability by European enterprises, particularly SMEs, but also offer new opportunities.

The first is the development of edge computing. Edge/cloud infrastructure balance will switch from today's 20% data at the network edge and 80% in cloud-based infrastructure to 80% at the network edge and 20% in cloud-based infrastructure. As a consequence, technology suppliers and end-user organisations are looking at edge innovation to gain business benefits. Although the approach of distributing computing capabilities is not a new trend, edge can be seen as an emerging technology being still in its infancy so time will be needed to observe actual developments. Other challenges are represented by compliance concerns (i.e. hurdles related to GDPR) and the need to make sure that the shift to edge computing is also energy efficient and sustainable, with reduced environmental impacts.

The second element to take into account is the need and opportunity to develop alternative cloud models based on federated cloud services. To escape the high scalability costs and customer lock-in issues of the global cloud providers now dominating the market, the EU is promoting alternative cloud federation models based on cloud interoperability and seamless connectivity. From the technical point of view, decentralised architectures represent an increasing trend in the ICT environment – not only in cloud computing, but also in IoT, 5G, blockchain-based security and distributed AI. Decentralisation is characterised by greater resilience and the provision of scale, speed and efficiency to IT networks due to a distributed network of multiple service and infrastructure providers. The multi-provider approach eliminates the risk of single points of failure, which can bring down centralised architectures. This is particularly appreciated for digital innovations such as autonomous cars, for which a failure of always-on data and network flows is an unacceptable risk.

The federated cloud model has been successfully implemented in the research environment but scaling it up to make it a realistic alternative to global hyperscalers is a definite challenge. Important ecosystems in different sectors (such as public administration, healthcare and transport) need to enable the secure access, sharing and analysis of sensitive data already stored and managed by multiple ecosystem participants – players that are already looking with interest at the federated cloud model. The German and French governments have launched an initiative called GAIA-X to develop a pioneer federated cloud service. On the plus side, federated clouds could have better resilience and scalability than centralised public clouds, help to create a more balanced playing field in the market, support European technological sovereignty and create opportunities within the European cloud industry. European clouds would guarantee compliance with privacy and data protection regulations, mitigate contractual risks for SMEs and remove European cloud users' data from the influence of foreign countries' regulations.

However, federated clouds are very far from large-scale adoption due to:

- technology and security challenges resulting from the immaturity of interoperable architectures and insufficient standards;
- organisational challenges resulting from the complexity of networking disparate suppliers and data from different locations while guaranteeing the same quality of services as centralised public clouds;
- and business model challenges about the creation and distribution of revenues and profits among the federated providers, a topic for consideration that is in its infancy.

Federated clouds need to be able to develop the right incentives for suppliers and customers. According to our report, the federated cloud model has today a better chance of being developed in the public sector thanks to a long tradition of building shared networks and services. For private industry, strong 'champions' need to lead the way.

The third relevant element is environmental sustainability. The last years have seen great progress in cloud datacentres energy efficiency but further progress will be harder as the potential for additional gains is getting smaller. Global hyperscalers have invested heavily in sustainability strategies and all of them boast of their achievements and renewable energy investments. But the increase of demand and the instalment of additional capacity in these huge data centres is forecast to continue driving increased energy consumption. The emergence of edge computing and federated or distributed cloud services will meet some of the emerging demand, but this trend poses new sustainability challenges which also need to be met. Distributed cloud services may have more difficulty in principle in achieving energy efficiency than centralised data centres. However, by building synergies and leveraging innovative technology solutions, these alternative cloud models to hyperscalers can also achieve energy efficiency while meeting European objectives of cloud infrastructures independence and resiliency. A critical success factor will be represented by the level of investments in sustainable cloud technologies through the forthcoming Horizon Europe and Digital Europe Programmes, particularly in green software and efficient distributed cloud services.

In this evolving context, European policies have played an important role in shaping the cloud market in Europe, acting in support of European organisations and in particular of SMEs, to ensure their access to advanced and competitive cloud services. From the launch of the European Cloud Strategy in 2012 until the European Data Strategy announced in February 2020, several steps have been carried out for the deployment and uptake of more secure, sustainable, interoperable, environmentally friendly and scalable cloud infrastructures and services for European companies. The EU MS Joint Declaration on Cloud of October 2020 reflects the commitment of national governments to collaborate for these goals and represents an important step forward for their achievement. Through these and other policies, investments and initiatives, the European Union is engaged in addressing many of the challenges described in this report with the objective of increasing Europe's sovereignty and ensure the development of the cloud computing market as an essential condition for an innovative European economy.

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Appendix A: Technology Definitions

The advanced technologies covered in the Advanced Technologies for Industry project include the following:

Advanced Manufacturing Technology

Advanced manufacturing technology encompasses the use of innovative technology to improve products and/or processes that drive innovation in manufacturing. It covers two technology types: process technology used to produce any other advanced technologies and process technology based on robotics, automation, or computer-integrated manufacturing. The former typically relates to production apparatus, equipment and procedures for the manufacture of specific materials and components. The latter includes measuring, control and testing devices for machines and machine tools and various areas of automated or IT-based manufacturing technology.

Advanced Materials

Advanced materials lead to both new reduced cost substitutes to existing materials and new added-value products and services. Advanced materials offer major improvements in a wide variety of fields, such as aerospace, transport, building and healthcare. They facilitate recycling and lowering energy demand and the carbon footprint, as well as limiting the need for raw materials that are scarce in Europe.

Artificial Intelligence

Artificial Intelligence is a term used to describe machines performing human-like cognitive functions (e.g. learning, understanding, reasoning, or interacting). It comprises different forms of cognition and meaning understanding (e.g. speech recognition and natural language processing) and human interaction (e.g. signal sensing, smart control and simulators). Artificial Intelligence is a heterogenous field in terms of its technology base. While some aspects, like sensors, chips, robots, and certain applications, including autonomous driving, logistics, and medical instruments, refer to hardware components, a relevant part of AI is rooted in algorithms and software.

Augmented/Virtual Reality

Augmented reality devices look to overlay digital information or objects with a person's current view of reality. As such, the user is able to see his/her surroundings while also seeing the AR content. Virtual reality devices place end users into a completely new reality, obscuring the view of their existing reality.

Big Data

Big Data is a term describing the continuous increase in data and the technologies needed to collect, store, manage and analyse it. It is a complex and multidimensional phenomenon, impacting people, processes and technology. From a technology point of view, Big Data solutions encompass hardware and software that integrate, organise, manage, analyse and present data. Big Data technology is characterised by the 'four Vs' – volume, velocity, variety and value. Big Data solutions represent a new generation of technologies and architectures designed to extract economic value from very large volumes and a wide variety of data by enabling high-velocity capture, discovery and/or analysis.

Blockchain

Blockchain is a digital distributed ledger of transactions or records in which the ledger stores the information or data and exists across multiple participants in a peer-to-peer network. Distributed ledger technology enables new transactions to be added to an existing chain of transactions using a secure digital or cryptographic signature. Blockchain protocols aggregate, validate and relay transactions within the blockchain network. Blockchain technology enables the data to exist on a network of instances, or 'nodes', allowing for copies of the ledger to exist rather than being managed in one centralised instance.

Connectivity

Connectivity refers to all those technologies and services that allow end users to connect to a communication network. It encompasses an increasing volume of data, wireless and wired protocols and standards and combinations within a single use case or location.

Standard connectivity includes fixed voice and mobile voice telecom services to allow fixed or mobile voice communications, but also fixed data and mobile data services to have access to and transfer data via a network.

Advanced connectivity, which is in the focus of the ATI project, refers to the rise of Internet of Things scenarios, whereby connectivity technology boundaries expand beyond wired and cellular (e.g. 4G and 5G) services to low-power wide area network (LPWAN), satellite and short-range wireless technologies.

The survey analysis encompasses all these three elements of the connectivity definition mentioned above.

Cloud Computing

Cloud computing includes the delivery of tools and applications such as data storage, servers, databases and software based on a network of remote servers accessed through the Internet. Cloud computing services enable users to store files and applications in a virtual place, the cloud and access all the data via the Internet.

Public cloud services, as explored in the ATI survey, are available on public networks and are open to a largely unrestricted universe of potential users. Public clouds are designed for a market, not a single enterprise.

Industrial Biotechnology

Industrial biotechnology is the application of biotechnology for the industrial processing and production of chemicals, materials and fuels. It includes the practice of using microorganisms, or components of micro-organisms like enzymes, to generate industrially useful products in a more efficient way (e.g. less energy use or fewer by-products) and to generate substances and chemical building blocks with specific capabilities that conventional petrochemical processes cannot provide. Many examples of such bio-based products are already on the market. The most mature applications relate to enzymes used in the food, feed and detergents sectors. More recent applications include the production of biochemicals and biopolymers from agricultural and forest wastes.

Internet of Things (IoT)

The Internet of Things (IoT) refers to a network of interconnected smart devices and services that are capable of sensing, or even listening to, requests. IoT is an aggregation of endpoints that are uniquely identifiable and that communicate bi-directionally over a network using some form of automated connectivity. Objects become interconnected, make themselves recognisable and acquire intelligence in the sense that they can communicate information about themselves and access information that has been provided by another source. The Internet of Things relies on networked sensors to remotely connect, track and manage products, systems and grids. The Industrial Internet of Things (IIoT) – a subset of the larger Internet of Things – focuses on the specialised requirements of industrial applications, such as manufacturing, oil & gas and utilities. IIoT systems connect non-consumer devices used by companies, governments and utility providers in their service delivery.

Micro- and Nanoelectronics

Micro- and nanoelectronics deal with semiconductor components and highly miniaturised electronic subsystems and their integration into larger products and systems. They include the design, fabrication, packaging and testing of nano-scale transistors to micro-scale systems that integrate multiple functions on a chip.

Mobility

IT for Mobility

Mobility covers a large number of different technology areas and markets, which encompass not only vehicles that take people from point A to point B, but also include all kinds of technology that make people more mobile (mobile phones, etc.). These, however, consist of a large subset of technologies that are hard to capture. In this project, the patent, trade, PRODCOM, investment and skills analysis focuses on a subset of mobility, which relates to vehicles only, such as satellite navigation and radiolocation, which are also the core technologies necessary to make autonomous driving possible.

Enterprise Mobility

Survey analysis looks at mobility from a workforce perspective. The enterprise mobility market is made up of a conglomeration of mobile solutions and technologies, including hardware, software and services, empowering a borderless workforce to securely work anywhere, at any time and from any device. It includes not only the provision of smartphones or tablets to the workforce, but also all the tools and applications necessary for transforming key processes, from internal operations to operations with customers and suppliers, all the way from the shop floor to the top floor and from the back office to end customers.

Other Nanotechnologies

Nanotechnology is an umbrella term that covers the design, characterisation, production, and application of structures, devices and systems by controlling shape and size at nanometre scale. Nanotechnology holds the promise of the development of smart nano and micro devices and systems and to radical breakthroughs in vital fields, such as healthcare, energy, environment and manufacturing.

Photonics

Photonics is a multidisciplinary domain dealing with light, encompassing its generation, detection and management. Among other things, it provides the technological basis for the economic conversion of sunlight to electricity, which is important for the production of renewable energy and a variety of electronic components and equipment, such as photodiodes, LEDs and lasers.

Robotics

Robotics is technology that encompasses the design, building, implementation and operation of robots. Robotics is often organised into three categories:

- **Application Specific:** This includes robotics designed to conduct a specific task or series of tasks for commercial purposes. These robots may be stationary or mobile but are limited in function, as defined by the intended application.
- **Multipurpose:** Multipurpose robots can perform a variety of functions and movements determined by a user who programs the robot for tasks, movement, range and other functions and who may change the effector based on the required task. These robots function autonomously within the parameters of their programming to conduct tasks for commercial applications and may be fixed, moveable, or mobile.
- **Cognitive:** Cognitive robots are capable of decision making and reason, which allows them to function within a complex environment. These robots can learn and make decisions to support optimal function and performance and are designed for commercial applications. When measuring production and uptake of robotics, industrial applications are considered.

Security

Security products are tools designed using a wide variety of technologies to enhance the security of an organisation's networking infrastructure – including computers, information systems, internet communications, networks, transactions, personal devices, mainframes and the cloud – as well as to help provide advanced value-added services and capabilities. Cybersecurity products are utilised to provide confidentiality, integrity, privacy and assurance. Through the use of security applications, organisations are able to provide security management, access control, authentication, malware protection, encryption, data loss prevention (DLP), intrusion detection and prevention (IDP), vulnerability assessment (VA) and perimeter defence, among other capabilities.

Appendix B: Advanced Technology Uptake

Figure 6: The Uptake of Advanced Technologies in European Industries – Question: Which of the following technologies is your organisation using or planning to use?

Technology	Finance	Gov/Edu	Healthcare	Manufacturing - discrete	Manufacturing - process	Professional Services	Retail, Wholesale	Telecom, Media	Transport/ Logistics	Utilities, Oil, Gas	Agriculture
Public Cloud	56%	63%	76%	82%	68%	81%	84%	82%	81%	73%	78%
Big Data and analytics solutions	79%	44%	49%	45%	36%	61%	53%	63%	34%	47%	25%
Mobile solutions	53%	58%	40%	34%	32%	49%	56%	61%	32%	47%	38%
IoT	72%	48%	44%	58%	45%	58%	55%	73%	36%	64%	30%
AI	74%	33%	41%	45%	37%	60%	51%	70%	32%	60%	11%
Robotics	7%	1%	18%	72%	64%	7%	21%	7%	29%	53%	18%
ARVR	21%	38%	36%	10%	5%	10%	26%	48%	3%	13%	0%
Blockchain	62%	3%	1%	1%	1%	3%	4%	7%	1%	0%	0%
Security	88%	79%	78%	79%	73%	73%	75%	79%	68%	81%	51%
Advanced Manufacturing	0%	0%	0%	92%	79%	0%	0%	0%	0%	0%	0%
Advanced Connectivity	58%	63%	48%	37%	37%	54%	42%	82%	34%	63%	37%
Nanotechnologies	3%	0%	33%	37%	9%	3%	1%	6%	1%	19%	0%
Micro and nano electronics	2%	0%	4%	32%	5%	2%	1%	6%	1%	4%	0%
Advanced Materials	2%	0%	19%	24%	27%	2%	1%	3%	9%	13%	0%
Biotechnology	2%	0%	39%	0%	5%	2%	0%	0%	0%	14%	1%
Photonics	2%	1%	19%	24%	14%	1%	1%	12%	0%	19%	19%

Source: Advanced Technologies for Industry Survey, July 2019
Legend: Sum of the percentages of respondents already using and planning to use each technology

About the 'Advanced Technologies for Industry' Project

The EU's industrial policy strategy promotes the creation of a competitive European industry. In order to properly support the implementation of policies and initiatives, a systematic monitoring of technological trends and reliable, up-to-date data on advanced technologies are needed. To this end, the Advanced Technologies for Industry (ATI) project has been set up. The project provides policymakers, industry representatives and academia with:

- Statistical data on the production and use of advanced technologies, including enabling conditions such as skills, investment and entrepreneurship
- Analytical reports, such as on technology trends, sector-based insights and products
- Analyses of policy measures and policy tools related to the uptake of advanced technologies
- Analysis of technology trends in competing economies, such as in the US, China and Japan
- Access to technology centres and innovation hubs across EU countries

You may find more information about the 16 technologies here: https://ati.ec.europa.eu.

The project has been undertaken on behalf of the European Commission – the Directorate General for Internal Market, Industry, Entrepreneurship and SMEs and the Executive Agency for Small and Medium-Sized Enterprises (EASME) – by IDC, Technopolis Group, Capgemini, Fraunhofer, IDEA Consult, and NESTA.

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