# Large-scale EXecution for Industry & Society

## Deliverable D9.11

# Updated market analysis of converged HPC, Big Data and Cloud Ecosystems in Europe and positioning of the LEXIS Platform

Co-funded by the Horizon 2020 Framework Programme of the European Union
Grant Agreement Number 825532
ICT-11-2018-2019 (IA - Innovation Action)

| | |
|---|---|
| **DELIVERABLE ID \| TITLE** | D9.11 \| Updated Market Analysis of Converged HPC, Big Data and Cloud Ecosystems in Europe and positioning of the LEXIS Platform |
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| **WORKPACKAGE ID \| TITLE** | WP9 \| Impacts on Targeted Sectors |
| **WORKPACKAGE LEADER** | TESEO |
| **DATE OF DELIVERY (CONTRACTUAL)** | 31/12/2021 (M36) |
| **DATE OF DELIVERY (SUBMITTED)** | 29/01/2022 |
| **VERSION \| STATUS** | 1.0 \| Final |
| **TYPE OF DELIVERABLE** | R (Report) |
| **DISSEMINATION LEVEL** | PU (Public) |
| **AUTHORS (PARTNER)** | EURAXENT; LINKS; LRZ; IT4I; ATOS; TESEO; CYC |
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## DOCUMENT VERSION

| VERSION | MODIFICATION(S) | DATE | AUTHOR(S) |
|---|---|---|---|
| **0.1** | Initial ToC and allocation of sections<br>Introduction and sections 5 & 6<br>Section 4 Initial Version<br>Section 5.5 content added | 13/09/2021<br>25/10/2021<br>04/11/2021<br>15/11/2021 | Piyush Harsh (CYC)<br>Piyush Harsh (CYC)<br>Stephan Hachinger (LRZ)<br>Piyush Harsh (CYC) |
| **0.2** | Initial contribution on LEXIS market positioning<br>Updated HPC Market Analysis | 03/12/2021<br><br>03/12/2021 | Marc Derquennes (EURAXENT)<br><br>Katerina Slaninova (IT4I) |
| **0.3** | Executive Summary and conclusion added | 06/12/2021 | Piyush Harsh (CYC) |
| **0.4** | Integrated internal review comments | 18/12/2021 | Piyush Harsh (CYC) |
| **0.5** | Final check of the deliverable | 27/12/2021 | Katerina Slaninova (IT4I) |
| **0.6** | Formal changes in Section 7 | 04/01/2022 | Marc Derquennes (EURAXENT) |
| **0.7** | Final updates by the coordinator and LRZ | 26/01/2022 | Jan Martinovič (IT4I); Stephan Hachinger (LRZ) |
| **1.0** | Final check No. 2 of the deliverable | 28/01/2022 | Kateřina Slaninová (IT4I) |

## GLOSSARY

| ACRONYM | DESCRIPTION |
|---|---|
| **HPL** | High Performance Linpack |
| **HPDA** | High performance data analytics |
| **FPGA** | Field programmable gate array |
| **HPC** | High performance computing |
| **SME** | Small to medium enterprise |
| **GFLOPS** | 1 billion (Giga) floating point operations |
| **RPEAK** | Theoretical peak performance of a supercomputer using LINPACK benchmark |
| **IAAS** | Infrastructure as a service |
| **PAAS** | Platform as a service |
| **SAAS** | Software as a service |
| **FAAS** | Function as a service |
| **BPASS** | Business process as a service |
| **AWS** | Amazon web services |

| | |
|---|---|
| **IOT** | Internet of things |
| **DC** | Data centre |
| **LL** | Lessons learned |
| **GIS** | Geographic Information System |
| **EO** | Earth Observation |
| **RS** | Remote Sensing |
| **SDI** | Spatial Data Infrastructures |
| **LEO** | Low Earth Orbit |
| **KPI** | Key performance indicator |
| **DDI** | Distributed data infrastructure |
| **API** | Application programming interface |
| **ISV** | Independent software/service vendor |
| **ROI** | Return on investment |
| **EU** | European Union |
| **PID** | Persistent identifier |
| **DOI** | Digital object identifier |
| **CAGR** | Compound annual growth rate |
| **GDPR** | General data protection regulation |
| **NCC** | National Competence Centre |
| **FEMA** | Federal Emergency Management Agency |

## TABLE OF PARTNERS

| ACRONYM | PARTNER |
|---|---|
| Avio Aero | GE AVIO SRL |
| Atos | BULL SAS |
| AWI | ALFRED WEGENER INSTITUT HELMHOLTZ ZENTRUM FUR POLAR UND MEERESFORSCHUNG |
| BLABS | BAYNCORE LABS LIMITED |
| CEA | COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES |
| CIMA | CENTRO INTERNAZIONALE IN MONITORAGGIO AMBIENTALE - FONDAZIONE CIMA |
| CYC | CYCLOPS LABS GMBH |
| ECMWF | EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS |
| EURAXENT | MARC DERQUENNES |
| GFZ | HELMHOLTZ ZENTRUM POTSDAM DEUTSCHESGEOFORSCHUNGSZENTRUM GFZ |
| ICHEC | NATIONAL UNIVERSITY OF IRELAND GALWAY / Irish Centre for High-End Computing |
| IT4I | VYSOKA SKOLA BANSKA - TECHNICKA UNIVERZITA OSTRAVA / IT4Innovations National Supercomputing Centre |
| ITHACA | ASSOCIAZIONE ITHACA |
| LINKS | FONDAZIONE LINKS / ISTITUTO SUPERIORE MARIO BOELLA ISMB |
| LRZ | BAYERISCHE AKADEMIE DER WISSENSCHAFTEN / Leibniz Rechenzentrum der BAdW |
| NUM | NUMTECH |
| O24 | OUTPOST 24 FRANCE |
| TESEO | TESEO SPA TECNOLOGIE E SISTEMI ELETTRONICI ED OTTICI |

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# EXECUTIVE SUMMARY

While the world is awaiting the deployment of true Exascale systems, the deployment of Petascale systems is increasing. Many of the systems are no longer built and used according to the traditional HPC patterns. The market is seeing a convergence trend towards a cloud-centric approach within the traditional HPC world. Market uptake for Big Data technologies has not changed much, but pandemic related cloud adoption may hint at acceleration in adoption soon. Recent advocacy for Digital Continuum is seeing accelerated validation due to an increase in time-constrained applications and trends towards decentralised coordination in data management. The Cloud market analysis highlights the growing adoption of PaaS (Platform as a Service) and serverless platforms, indicating a growing adoption of cloud-native application development paradigm and an increased appetite for "code execution as-a-service". Cloud adoption remains strong, with a marked growth across all forms - IaaS, PaaS, and SaaS (Infrastructure, Platform, Software as a Service). The increased adoption of containerisation solutions highlights how PaaS providers are slowly gaining global acceptance in the development community. The large incumbent providers continue to improve their market share, although a relatively new entrant - Huawei - makes its presence felt. The trend towards cloud computing adoption in Europe is influenced by the strong involvement of various governments in cloud computing initiatives. Concerted efforts by EC to shape public policy around European data sovereignty also has led to increased awareness about the benefits of cloud among SMEs across all participating member blocks.

Emerging market segments such as earth observation, precision agriculture, banking and digitisation of health data managements have all brought in significant convergence to cloud and Big Data technologies. Emerging markets are also seeing massive engagement by incumbent cloud operators including Amazon, and Microsoft. In emerging markets, HPC and cloud convergence has a huge potential to bridge the digital divide between smaller players and large enterprises. On a particular note, hybrid cloud technologies adoption by the financial services industry is projected to hit 90% by 2023 (see Section 4.3). The trend is primarily due to consumer expectations than anything else. Forced by the pandemic requirements, the healthcare sector's adoption of cloud and data analysis technologies have accelerated. By 2026, the cloud computing market for healthcare is likely to grow at a CAGR of 28.5% (see Section 4.5). The Covid-19 pandemic has had a marked influence on digital and cloud adoption among practically all sectors; 90% of surveyed companies reported accelerated spending and adoption due to pandemic. The digital adoption due to the pandemic has leapfrogged to a level previously estimated to be in five years, in just a matter of eight weeks.

The LEXIS market positioning analysis shows the future readiness of the platform for the digital continuum, in line with the desired goal of data sovereignty, data security and preserving the data privacy goals of the EU. Furthermore, the services approach validated during the LEXIS Open Call phase demonstrates the one-stop solution to the target customers of a federated, converged HPC + Cloud offering to multiple stakeholders within Europe.

## Position of the deliverable in the whole project context

This deliverable is the 2nd report in the series that analysed emerging market trends and positioning of the LEXIS outcomes within those trends. This report concludes the activities carried out within Task 9.3 of WP9 and has been developed with the active participation of HPC centres, SMEs and large enterprises that make up the LEXIS consortium. The outputs from the technical work packages, WP3 the LEXIS Data System, WP4 - Orchestration and secure HPC/Cloud Services Provisioning, and WP8 - LEXIS Portal for 3rd Party Companies and SMEs, are used to position LEXIS in the correct context with respect to its potential to disrupt the current market.

## Description of the deliverable

As the title suggests, this deliverable analyses the key market indicators such as market growth trends and application drivers in three marquee IT sectors: HPC, Big Data and Cloud. It presents both global and European trends. This report presents the recent convergence trends in these sectors and the emerging trend of heterogeneity in datacentres as a key validator in the LEXIS approach. This report places the LEXIS innovation in the overall market context and presents the potential for disruption and a unique opportunity for European SMEs for easy consumption of converged Cloud/HPC services that will be available once the LEXIS results are available.

# 1 INTRODUCTION

The still-unfolding global pandemic - Covid-19, together with global climate change, will be the defining moment in many of our lives. We are already seeing a marked shift in the mindset of governments and the workforce globally. The global workforce being forced to work remotely, and strategic policy shifts by governments towards a globally coordinated action against warming have led to accelerated adoption of computing technologies across the entire stakeholder spectrum - citizens, decision-makers, etc. Additionally, in Europe, efforts by organisations such as EOSC[1], EuroHPC-JU[2], ETP4HPC[3], PRACE[4], or GAIA-X[5] are also influencing the adoption of HPC and cloud technologies. In this deliverable, we will focus on updates to market analysis of converged HPC, Big Data and Cloud ecosystems in Europe, especially through the post-pandemic lenses and whether this has changed the LEXIS market positioning at all.

## 1.1 SOCIETAL IMPACT OF BIG DATA, HPC, CLOUD ON EUROPE

Big data and cloud offerings have already significantly impacted Europe [1]. This has created numerous market opportunities especially opening traditional non-IT centric sectors such as agriculture to use of data-driven processes, use of HPC resources in drug discovery, advanced simulation-driven manufacturing processes to improve the fuel efficiency of mass-transit systems, digitisation of health, etc., are only a handful of numerous opportunities which have been created in the last decade.

This deliverable will investigate how emerging sectors in Europe and elsewhere have impacted the adoption of HPC and Cloud technologies and present updated trends as a follow-up from Deliverable D9.5 [2].

## 1.2 STRUCTURE OF THIS DOCUMENT

The rest of the deliverable is structured as follows: Section 2 deals with updates to HPC market analysis with special analysis with respect to the impact created due to activities from PRACE, ETP4HPC, EuroHPC JU as well as findings from recent activities by BDVA[6], this section also reports updates on Big Data market analysis. Section 3 reports updates on Cloud market analysis - each of these sections also reports findings from recent European policy coordination activities. Section 4 is a new addition compared to Deliverable D9.5 [2], where we exclusively treat impact from emerging markets. Covid-19 pandemic and its impact on HPC, Big Data and Cloud adoption are analysed in Section 5. LEXIS positioning in this revised market spectrum is presented in Section 6. And finally, we conclude this deliverable in Section 7.

[1] EOSC (European Open Science Cloud): https://eosc-portal.eu
[2] EuroHPC JU (EuroHPC Joint Undertaking): https://eurohpc-ju.europa.eu
[3] ETP4HPC: https://www.etp4hpc.eu
[4] PRACE (Partnership for Advanced Computing in Europe): https://prace-ri.eu
[5] GAIA-X: https://www.gaia-x.eu
[6] BDVA (Big Data Value Association)/DAIRO (Data, AI and Robotics): https://www.bdva.eu

# 2 HPC AND BIG DATA MARKET ANALYSIS UPDATE

Concerning report in Deliverable D9.5 [2], the HPC world is still waiting for real exascale systems. The TOP500 list[7] of the world most powerful supercomputers (November 2021) is still led by the Japan Fugaku system installed in RIKEN with its HPL benchmark score of 442 Pflop/s. From the last supercomputing conference, SC 2021, held in St. Louis, USA, in November 2021 was obvious that the traditional HPC world is slightly changing towards the convergence with the cloud approach. It can also be seen from the fact that at TOP500 position No. 10 occurred a Microsoft Azure system Voyager-EUS2 installed at Microsoft in the U.S. with 30.05 Pflop/s on the HPL benchmark. A disproportion in the number of supercomputers and their power between Europe, Asia and America remains. Only a slight increase in Europe's and America's percentage can be seen while Asia slightly lost (compared to the last situation reported in Deliverable D9.5 [2]). The number of European countries operating supercomputers large enough to make it to the TOP500 list increased to 18 out of the 44 while the first positions slightly changed (the leadership is taken by Germany now).

## 2.1 TRENDS WITHIN EUROPE FOR ADVANCEMENT OF HPC CAPACITY

Several activities towards creating a more cohesive ecosystem in the HPC in Europe took place. In expanding the number of HPC systems in Europe, nine new supercomputers are being installed across Europe. Five of them are new petascale systems (Karolina at the IT4Innovations Czech Republic, Deucalion at Minho Advanced Computing Centre Portugal, Discoverer at Sofia Tech Park Bulgaria, Vega at the Institute of Information Science Maribor Slovenia, and Meluxina at LuxConnect's Data Centre DC2 Luxembourg) and three so-called pre-exascale systems (LUMI at Datacenter CSC Kajaani Finland, MaroNostrum5 at Barcelona Supercomputing Centre Spain and Leonardo at Bologna Technopole Italy).

Together with the installation of these systems, a document was prepared and published describing the Access Policy to the Union's share on the access time to the pre-exascale and petascale supercomputers [3].

Under the umbrella of EuroHPC Joint Undertaking initiative projects, EuroCC and CASTIEL [4] started on 1st September 2020. The goal of the EuroCC project is to establish a single National Competence Centres (NCCs) in HPC and associated technologies such as Artificial Intelligence (AI) and High-Performance Data Analysis (HPDA) in the counties participating in EuroHPC JU. The role of CASTIEL is to provide support and coordination action for NCCs on European Level. The mission of each NCC is to become a reference and a single point of contact in the HPC domain in respective countries. Its mission is to analyse, implement, and coordinate all necessary activities and offer end-user services to meet their needs: from access to supercomputers and technology consulting to providing training for industry, public administration, and academia. The main target group of the NCCs and EuroCC, in general, is to support industry, mainly small and medium enterprises, to increase their uptake of HPC technologies.

Two open calls of project FF4EuroHPC[8] were organised to provide direct financial support to the SMEs. The FF4EuroHPC is the project of cascade funding providing funds for application experiments proposed by consortia consisting of SMEs, technology, and HPC resource providers.

Another activity of EuroHPC JU was the launch of advanced pilots towards European exascale supercomputers and a pilot on a quantum simulator [5].

It is expected that new calls by EuroHPC JU will follow in next year further to support the development of the HPC ecosystem in Europe.

[7] TOP 500: https://www.top500.org
[8] FF4EuroHPC project: https://www.ff4eurohpc.eu/

## 2.2 BIG DATA MARKET ANALYSIS UPDATE

With respect to what has been reported in Deliverable D9.5 [2], the market outlook for Big Data technologies has not changed significantly in numbers. On the other hand, we may expect that the pandemic-related acceleration of cloud adoption [6, 7] may act as a flywheel for some closely related fields, including Big Data analytics, increasing the market size forecast soon.

### 2.2.1 Digital Continuum and emerging European vision on data sharing

#### Big Data and computing continuum

Research and industrial organisations in Europe are advocating a converging vision (see Figure 1) of concepts like HPC, Cloud, Edge computing and IoT into what is called Digital Continuum [8, 9].

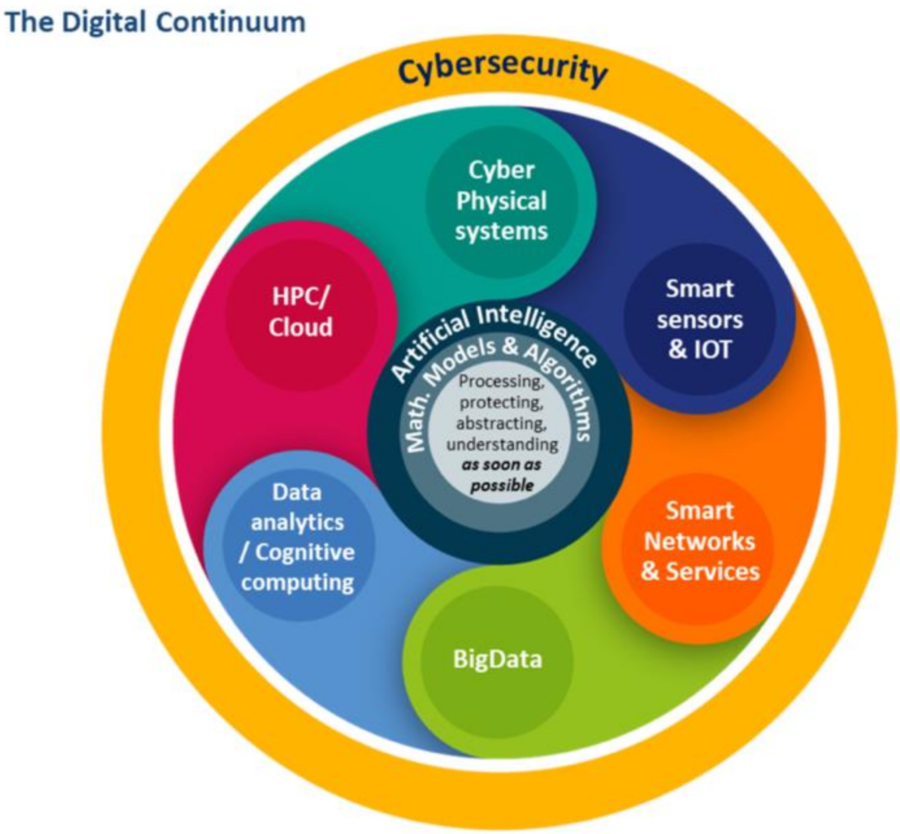



**Figure 1 TransContinuum Initiative vision [10]**

Within this vision, a spectrum of agents produces and consumes data along the whole continuum, from HPC to the Edge and to connected sensors. In addition to what has been identified by Deliverable D9.5 [2], a few more technical challenges can be highlighted in this context:

- **Volume:** the number of data generators is growing in an unprecedented manner, and the analysis algorithms are ever more complex and computationally demanding. Also, tight time constraints are posed if these data should be used effectively for decision support in critical environments [11].
- **Coordination:** the granularity of data generation and consumption is too small to be effectively managed with a centralised approach. To effectively extract value from data in the digital continuum, novel approaches for loosely coupled and decentralised coordination are needed. Correctness and tolerance to unreliable connections and untrusted data sources will represent a significant technical challenge. This aspect is closely related to the trending topic of data fabric technologies [12].

#### European Data Sharing Space

During the time between Deliverable D9.5 [2] and this document, the vision for a European-governed data sharing space was refined [13] (see Figure 2).

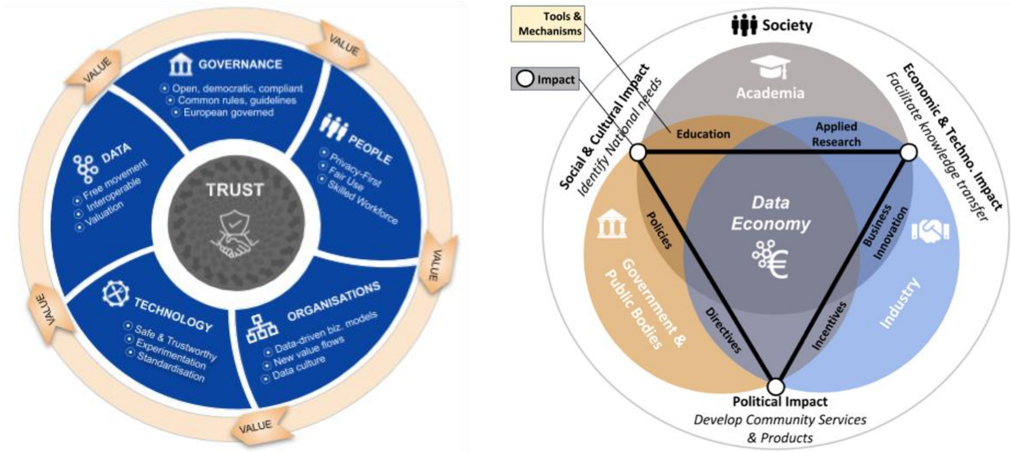



**Figure 2 Core pillars and principles of the envisioned European-governed Data Sharing Space generating value for all sectors of society (left). Tools and mechanisms to realise a data sharing space, boost European data economy and create various lasting societal impacts (right) [13].**

In the context of this vision, the impact of known challenges (e.g., the 'Vs of Big Data': Volume, Velocity, Variety, Veracity, etc.) along the data lifecycle needs revisiting the following arising opportunities for data sharing which, in addition to conventional raw data and its transformations along the processing chain, also extend to metadata, models and processing algorithms.

# 3 CLOUD MARKET ANALYSIS UPDATE

In Deliverable D9.5 [2], we analysed the Cloud Computing market (and to a minor extent also the storage cloud market), focusing on the offerings relevant for LEXIS stakeholders and future customers. These include commercial customers and academic/research customers. For both these groups, the ability to quickly scale computing power and costs with the workload is certainly one of the main arguments for Cloud Computing, as well as the avoidance of establishing a maintenance scheme for on-site clusters. Clearly, data protection issues can make on-premises solutions attractive; here, LEXIS offers an intermediate solution with Cloud Computing nodes at trustworthy European supercomputing centres.

While the following sections will concentrate on updating our market analysis from Deliverable D9.5 [2], we will shed light on one important aspect of cloud solutions: the rise of PaaS and serverless-computing platforms in the so-called "Cloud Native" [14] sector. Solutions such as remote-accessible Kubernetes (K8S) clusters [15] or serverless computing platforms [16, 17], as offered by the major cloud vendors for already some years, are rapidly gaining popularity. As customers are packaging more and more of their workload in containers (cf. docker [18], singularity [19]) - to warrant portability, just to name one motivation - they prefer a container orchestration environment such as K8S to a heavier IaaS solution. In more extreme cases, they want to run code without caring about the computational infrastructure; this segment is targeted by serverless computing or "Function as a Service" (FaaS) platforms. Both concepts, in particular the container-based computing concept, have influenced the LEXIS co-design: LEXIS software execution is - with a few exceptions where appropriate, in HPC - based on containerisation. Future versions of the LEXIS Platform can be adapted without conceptual problems to use K8S clusters as computing facilities in addition to HPC and IaaS-Cloud systems, so that LEXIS can contribute to a convergence of all these ecosystems. An increasing number of template containers and application examples of the platform allow for usage in a mere "code execution as a service" approach, which may be further developed in the serverless-computing direction. In any case, LEXIS can be considered ready to serve customers in this market.

In the following sections, we first update our analysis of market shares of providers (Section 3.1) and Cloud-Computing approaches (IaaS vs. other solutions, including those mentioned above, Section 3.2). We continue with a glimpse of how public-cloud solutions have fared compared to private-cloud and other on-premises solutions (Section 3.3). After a comment on recent developments in the European Cloud market (including developments on Gaia-X, Section 3.4), we conclude with a short overview illustrating how LEXIS development strategy has been (and may further be) aligned with these trends (Section 3.5).

## 3.1 SHARES AND REVENUES OF PROVIDERS - DEVELOPMENT SINCE DELIVERABLE D9.5

The worldwide IaaS cloud services market grew by 40.7% in 2020, as per a report by Gartner from July 2020 [20]. The leading providers: Amazon, Microsoft, Alibaba, and Google saw their growth in line with the expected trends and probably will continue to dominate the market. The biggest jump in revenue was seen in the "Other" category by Huawei, surpassing dominant providers in overall growth compared to 2019 revenue numbers [21].

Table 1 captures the summary revenue for IaaS providers and confirms the accelerated adoption of cloud technologies globally.

| COMPANY | 2020 REVENUE [US$BN] | 2019 REVENUE [US$BN] | 2018 REVENUE [US$BN] | 2017 REVENUE [US$BN] | 2020 - 2019 GROWTH [%] | 2018 - 2017 GROWTH [%] |
|---|---|---|---|---|---|---|
| Amazon | 25,201 | 20,365 | 15,495 | 12,221 | 28.7 | 26.8 |
| Microsoft | 12,658 | 7,950 | 5,038 | 3,130 | 59.2 | 60.9 |
| Alibaba | 6,117 | 4,004 | 2,499 | 1,298 | 52.8 | 92.6 |
| Google | 3,932 | 2,367 | 1,314 | 820 | 66.1 | 60.2 |
| Other | 15,378 | 10,997 | 8,096 | 7,231 | 39.8 | 12.0 |
| **Total** | **64,286** | **45,684** | **32,441** | **24,699** | **40.7** | **31.3** |

Table 1 Worldwide IaaS Cloud Computing Infrastructure Revenues - Public Cloud Providers [20, 21]

## 3.2 MARKET SHARE OF IAAS VS. OTHER APPROACHES - DEVELOPMENT SINCE D9.5

The last few years saw continued strong growth of IaaS (as expected) and the unexpectedly large growth of the Cloud Application Infrastructure Services sector. This can be explained by a decreased willingness of companies to manage their own infrastructures, even if such infrastructures are virtual. The increased adoption of Dev-Ops in software development may also point to preference in users to focus on software development instead of on facilities where the code runs. Table 2 captures the trend discussed above.

| SERVICE TYPES/REVENUE | 2019 BASELINE [US$BN] | 2020 [US$BN] | 2021 [US$BN] | 2022 [US$BN] |
|---|---|---|---|---|
| Cloud Business Process Services (BPaaS) | 43.7 | 46.9 | 50.2 | 53.8 |
| *Cloud Application Infrastructure Services (PaaS)* | *32.2* | *39.7* | *48.3* | *58.0* |
| Cloud Application Services (SaaS) | 99.5 | 116.0 | 133.0 | 151.1 |
| Cloud Management and Security Services | 12.0 | 13.8 | 15.7 | 17.6 |
| *Cloud System Infrastructure Services (IaaS)* | *40.3* | *50.0* | *61.3* | *74.1* |

| | | | | |
|---|---|---|---|---|
| **Total Market** | **227.8** | **266.4** | **308.5** | **354.6** |

| SERVICE TYPES/REVENUE | 2020 BASELINE [US$BN] | 2021 [US$BN] | 2022 [US$BN] |
|---|---|---|---|
| Cloud Business Process Services (BPaaS) | 46.1 | 50.2 | 53.1 |
| *Cloud Application Infrastructure Services (PaaS)* | *46.3* | *59.4* | *71.5* |
| Cloud Application Services (SaaS) | 102.8 | 122.6 | 145.4 |
| Cloud Management and Security Services | 14.3 | 16.0 | 18.0 |
| *Cloud System Infrastructure Services (IaaS)* | *59.2* | *82.0* | *106.8* |
| **Total Market** | **270.0** | **332.3** | **397.5** |

**Table 2 Worldwide Cloud Computing Revenue Forecast by service type: 2020 [22] (lower table) vs. 2019 [23] (upper table) forecasts.**
**Application Infrastructure Services (such as K8S) and System Infrastructure Services (such as OpenStack-based IaaS Clouds) are highlighted with italic font.**

## 3.3 PUBLIC CLOUD VS. ON-PREMISE SOLUTIONS - DEVELOPMENT SINCE D9.5

In Deliverable D9.5 [2], it was observed that Cloud solutions are generally on the rise for IT workloads [24], with private cloud solutions gaining market share. With a look at current Public vs. Private Cloud market shares [25], it is evident that the proportions of these two market segments have behaved relatively constant, with the public cloud spending being roughly 2.5 times those of private cloud spending. In general, the cloud sector continues to grow, further diminishing the share of on-premises solutions, albeit clearly at a lower rate than in the past ten years. The growing cloud market reflected in the numbers displayed in Section 3.2 is thus the result of a somewhat further increased market share and a growing IT demand in general.

## 3.4 CURRENT DEVELOPMENTS ON THE EUROPEAN CLOUD MARKET

In their report update, GMInsights [26] have updated the European cloud market trends.

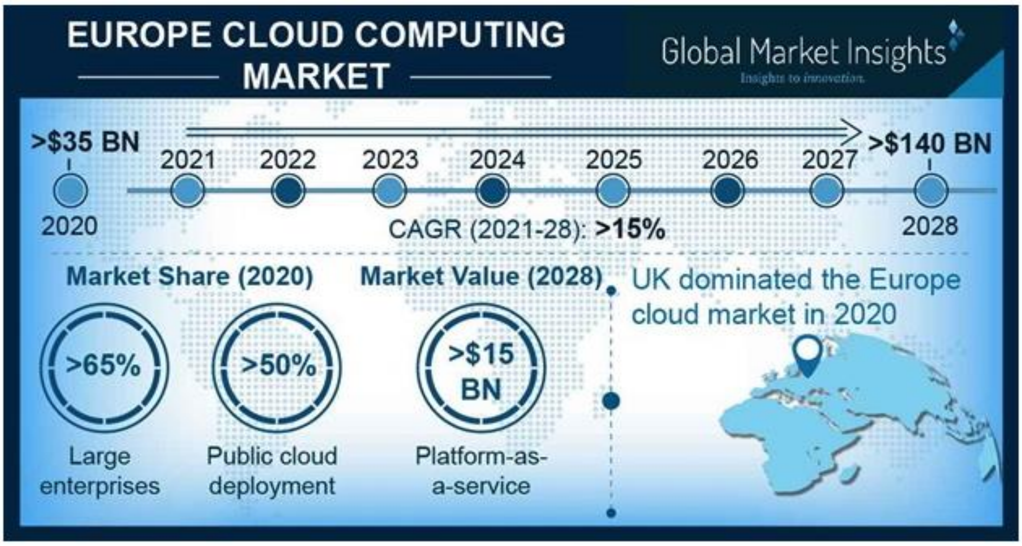



**Figure 3 Europe cloud computing market growth projection - GMInsights report (June 2021)**

Figure 3 captures the projection in Europe. It shows that the market is expected to grow at 15% CAGR between 2021 and 2028. The trend is influenced due to significant investments by various governmental agencies across the EU in cloud computing initiatives. In Germany, SaaS is likely the dominant component (see Figure 4). The German trend is likely due to higher adoption by SMEs in the market.

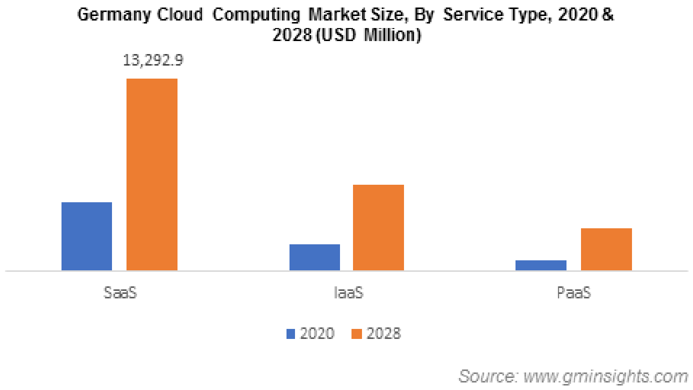



**Figure 4 Germany cloud Computing market size projections**

In France, the growth is largely predicted due to SMEs shifting from traditional on-premises models to cloud (Figure 5).

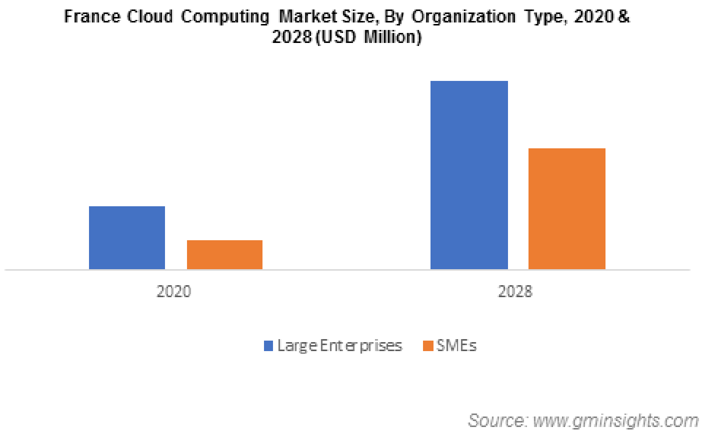



**Figure 5 Cloud computing adoption by SMEs and large enterprises in France**

The SMEs in France have significant part-time employees along with frequent changing offices. Remote computing becomes critical for business success. In Italy, a hybrid cloud deployment model is projected to see 25% growth from 2021 to 2028, which is largely powered by the benefits of scalability and data security. Similarly, in the Netherlands, the migration of telecom service providers to the cloud is defining the market trends (see Figure 6).

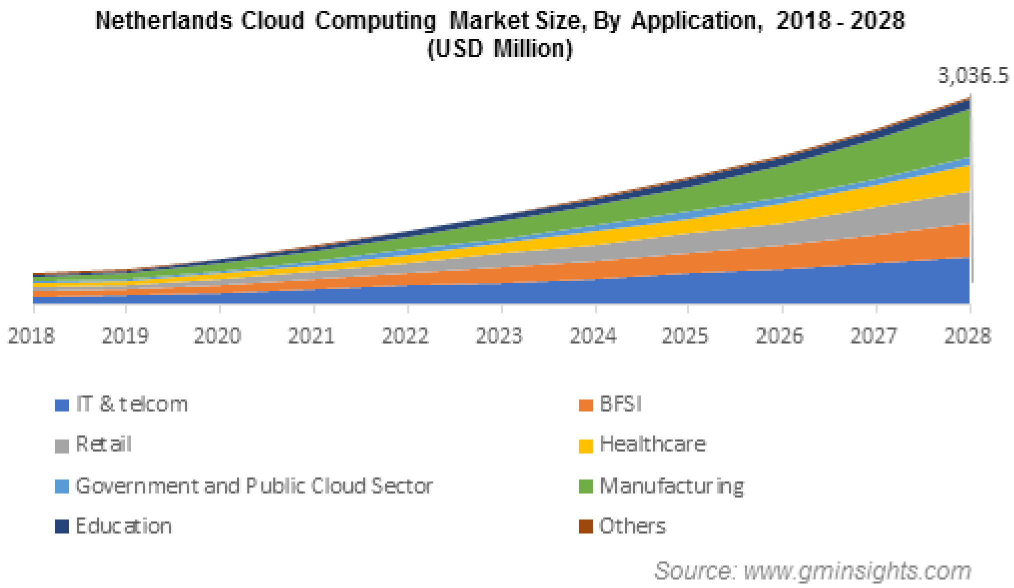



**Figure 6: Netherlands Cloud Computing Market size growth projections**

Coupled with industry-led trends, public policy adoption at the European level will also set the adoptions trends soon. Initiatives such as Gaia-X [27], promising to set up a next-generation data infrastructure in Europe, are also shaping public opinion on cloud benefits. There is also an increasing trend among European HPC operators, including cloud services in their portfolio services (e.g., Jülich Supercomputing Centre [28]). European Commission is actively pushing for a common strategy for improving Europe's data sovereignty [29]. EC has launched European Alliance on Industrial Data, Edge, and cloud [30] which is actively working on key EU policy goals such as:

- Joint investment in cross border cloud infrastructures,
- EC cloud rulebook,
- European marketplace for cloud services.

## 3.5 CONSEQUENCES ON LEXIS PLATFORM DEVELOPMENT STRATEGY

The increasing popularity of workload containerisation (or even "serverless" execution) has been considered in the co-design of LEXIS, where - after the first year of the project - the containerisation of the Pilot application and the pervasive handling of workloads as containers have been a major focus. Container orchestration platforms can be integrated into the LEXIS Platform as compute backends in the future or can also serve to run parts of the LEXIS services themselves.

While future work remains to be done (to move from near to TRL8 to TRL9), LEXIS has proven adaptable and one step ahead of current IT in industry and academia, in the sense that LEXIS has been a major motivation to enter the world of containerisation for our Pilot partners and LEXIS Open-Call applicants. Thus, LEXIS developments - up to the preparation of, e.g., workflow templates for function-as-a-service execution - will continue to follow top-notch Cloud (and Cloud-Native) standards and integrate them with the HPC and Big Data world, where the LEXIS Platform sees its focus.

# 4 IMPACT OF EMERGING SECTORS ON CONVERGENCE TRENDS

Advances in space technologies, hardware miniaturisation, and further commoditisation of computing services have led to new market opportunities in traditional sectors such as agriculture, insurance, health, and finance. Last-mile connectivity is on the verge of being solved, thanks to LEO constellations such as Starlink, OneWeb, Project Kuiper, and several European start-ups, including SatRevolution, actively democratising space. Low-cost computing services from European cloud operators enable many innovative concepts to reach full market potential. Such emerging sectors further drive technology convergence trends. The following subsections track a few notable emerging markets in Europe.

## 4.1 EARTH OBSERVATION AND REMOTE SENSING APPLICATIONS

In the last decades, a new generation of Earth Observation (EO) satellites, because of technological advances and open data policies, has provided a huge amount of remote sensing (RS) data openly available. For instance, an exponential increase in the availability of open geospatial data has been observed with the Copernicus Earth Observation and monitoring programme of the European Union [31], which delivers new satellite data complemented by in-situ observation.

This scenario has been a great challenge for traditional spatial data infrastructures (SDI) to properly store, process and disseminate a large amount of data. Novel technologies based on cloud computing and distributed systems to access and process big Earth Observation data have been proposed and developed to address these requirements.

Due to an increasing offer of high quality for Earth Observation data, enhanced by recent data collection and storage achievements, new actors attracted by the emerging potentials are entering the EO market to create new competition and opportunities. The global recognition of EO leads the dynamic of this market as a fundamental tool to address the main challenges of the 21st century, such as climate change, natural resources, and disaster management.

The space market provides valuable information regarding societal challenges and industry activities in different sectors such as meteorology, climate change, agriculture, natural resources, etc. This market is divided into three different sectors:

- The ***EO upstream* market** includes EO data acquisition and collection (manufacturing of satellites, ground systems, launchers, ground operations). Alongside the already consolidated space data providers, in this market, a new generation of private space companies manufacturing smaller and cheaper satellites are becoming more prominent in the last years.
- The ***EO midstream market*** includes sales or distribution of EO data to customers. The market for very high spatial resolution satellite imagery distribution has historically been dominated by large international commercial actors (Astrium, DigitalGlobe, etc.). On the other hand, in recent years, the development of the Copernicus EO program has given a boost to the exploitation of free and openly accessible datasets.
- The ***EO downstream market*** includes exploiting EO data, providing EO-related value-added products and services to end-users (institutional and private customers). Currently, this market offers the most interesting potential for European companies.

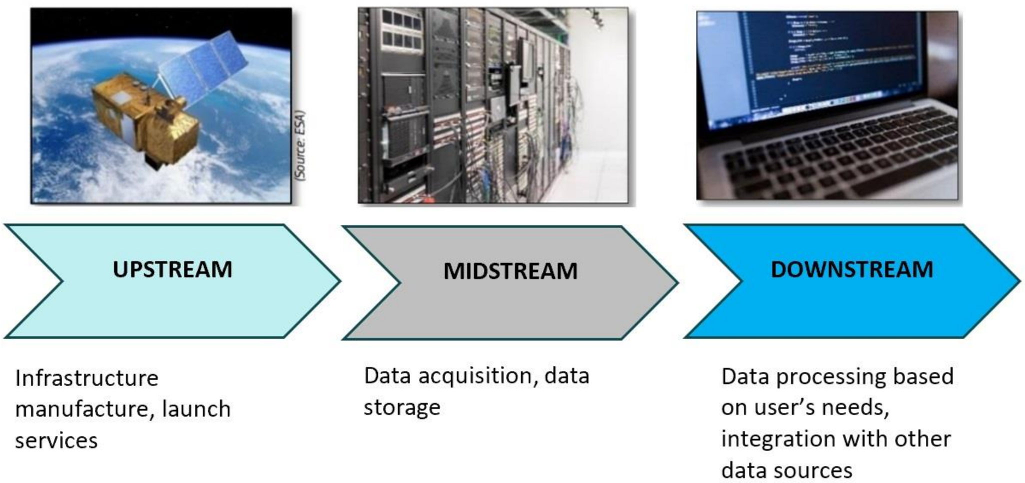



**Figure 7: The EO market**

In 2017 the European EO market (see Figure 7) was valued at between EUR 2.7 and 3.1 billion, divided between EO satellite operations (the upstream part of the supply chain), EO data acquisition and storage (the midstream part), and EO data processing (downstream part) [31].

The main emerging trends in the EO market are:

- **EO 2.0 players**: Space start-ups are emerging in the upstream market. This is correlated with the birth of new constellations of small satellites, which differ from traditional large EO satellites in terms of cost for access to space and delivery of near-real-time images. They are targeting high spatial resolution imagery (mostly optical) with a high tasking capacity compared to traditional players. The growth of EO 2.0 actors should promote the development of a mass market for high-resolution imagery in near real-time in the future.
- **Unmanned Aircraft Systems (UAS):** data provided by drones are useful for small and local area surveys, providing very high-resolution imagery that is complementary to satellite-derived datasets.
- **Cloud computing**: Cloud computing is a new way to access data that facilitates large-volume storage. Users do not need to download and store the data on their own hardware, reducing the cost of access. Because of the evolution of the industry structure caused by new commercial operators who extend their services to new applications, new actors such as Amazon Web Services have reached the top of the market in a few years. AWS provides an internet cloud-based platform, making available Landsat (the open-data US Earth Observation system) data since mid-March 2015. There is strong competition among cloud providers such as AWS, Google, Microsoft, IBM, and this is helping to bring down the costs of storage. Nevertheless, considerable effort and technical skills are required for users to take advantage of these cloud computing environments. Therefore, an increased need for simple solutions that provide high-level analytical tools to EO users, avoiding the technical issues related to these cloud computing environments, has been recently observed, and on this one has been invested. The Sentinel Hub platform9 is an example of this kind of solution. This platform uses cloud computing services to access and process the Copernicus EO datasets and provide to users proper Application Programming Interfaces (API) to deal with data easily. Similar solutions provide functionalities for EO big data management, storage and access, the processing on the server-side without downloading huge amounts of datasets, finally supporting on-demand analysis and the exploitation of synergies between multiple data sources. Further examples of similar platforms are Google Earth Engine[10], Open Data Cube (ODC)[11], ESA's Earth Observation Thematic Exploitation Platform (TEP) platforms, and NASA LP DAAC Application for Extracting and Exploring Analysis Ready Samples (AppEEARS)[12].
- **GIS market**: GIS is defined as a “computer information system that can input, store, manipulate, analyse, and display geographically referenced (spatial) data to support decision-making processes”. It allows spatial data to be combined with other sources (in-situ data, navigation signals, social media information, etc.), creating very high-value-added products for end-users. For instance, in the field of Oil & Gas, the leader in the GIS platforms market is the ArcGIS platform, operated by the US company Esri. The company has captured between 80-90% of GIS platform sales to the Oil and Gas industry

## 4.2 SMART AGRICULTURE

The history between agriculture and digital technologies dates to the 1970s and 1980s. In the early 1970s, earth observation satellite programs (ERTS and then LANDSAT in the United States) used satellites designed to meet the needs of the Department of Agriculture. In 1983, the first software programs designed for agriculture appeared (agricultural accounting and plot management), which initiated the transition to digital.

The birth of **precision farming** (also called "intra-plot management"), in the years 85-90, accelerated the use of IT tools with the first yield maps (1980). Precision farming is made possible by the rise of digital sensors. Their cost has also become more affordable (observation is the first phase). Yield is the first unit measured. One of the first

[9] The Sentinel Hub platform: https://www.sentinel-hub.com/
[10] Google Earth Engine: GEE, https://earthengine.google.com/
[11] Open Data Cube: ODC, https://www.opendatacube.org
[12] NASA LP DAAC Application for Extracting and Exploring Analysis Ready Samples: https://lpdaac.usgs.gov/tools/appeears

applications of precision farming in crop production was the integration of harvested quantity sensors (weighing, volume) in a combine harvester, to derive a geo-referenced yield.

Beyond precision farming, **digital farming** is a concept that appeared in the mid-2010s [32].

Digital farming goes beyond precision farming, focused on the operational phase of production and intra-plot or intra-herd management, and this in two ways. On the one hand, due to the proliferation of technologies for acquiring and exchanging data, on the other hand, because of new digital networking services, which farmers are using to free themselves from the intermediaries of the market (marketing, training, exchange of knowledge and equipment, rentals between peers, etc.).

Thus, in digital farming, **HPC technologies, as well as Big Data,** are implemented at all scales of agricultural production and its ecosystem:

- At the farm level (optimisation of cultivation operations, herd management, etc.),
- In support services (new agricultural advisory services based on automatically collected data),
- At larger scales such as in a territory (water management) or in a value chain (traceability, improvement of inputs such as seeds, better match between production and the market, etc.).

The challenges of adopting HPC and Big Data technologies in agriculture are numerous, with a very wide range of possibilities. They are, in fact, intimately linked to the more global issues of the adoption of digital tools, in the broad sense, by Agriculture [32].

#### Agronomic challenges:

Through the various technologies implemented, high-performance computing enables agriculture to gain efficiency and transform it in depth.

The amount of data produced by observation equipment and sensors installed in agricultural plots, within herds or in buildings allow better characterisation of agricultural systems. Their use through powerful decision support systems makes it possible to optimize the management of current production systems better. These data also contribute to the development of new production systems necessary for the agroecological transition, particularly the diversification of crops, the transformation of cropping practices and the emergence of new work organisations, both at the level of farmers and decision-makers.

The development of new algorithms using state-of-the-art digital processing improves knowledge of the functioning of plants and animals and consequently improves models for making forecasts, anticipating risks, improving agricultural management decision-makers' policy, or strengthening early warning systems for food security. The current computing power makes it possible to lead to overall predictions to improve this accuracy.

#### Economic challenges:

In this context, the main contribution of high-performance computing technologies (CFD coupled with data analysis) is a reduction in production costs and in the quantity of inputs (water, energy, fertilisers, pesticides, etc.), helping to improve the competitiveness of the entire production chain. The decision-making tools built from the data collected make it possible to control and optimize the quantity of inputs, in accordance with recent legislative and environmental guidelines for the reduction of phytosanitary products.

Once again, the costs of these inputs are constantly increasing, the use of high-performance computing and Big Data technologies play and will play an increasingly crucial role in the economic balance between agricultural practices (and their costs) and the market.

#### Environmental challenges:

The main challenge in using high-performance computing and Big Data technologies is to optimize the performance of different agricultural processes using the least possible energy and inputs, thus reducing their ecological footprint.

To this end, digital farming joins the approach of precision farming. The use of technologies (e.g., mathematical models, learning methods, etc.) makes it possible to obtain precise and regular indicators on a farm, such as wind speed, rainfall, or the nature of the soils. This in-depth knowledge of the environment aims to adapt agricultural practices to the specific nature of the farm environment, from plot to intra-plot scale.

### A colossal market in which Europe is starting ... far behind the United States

To better assess how to support this new paradigm in agriculture, it is important to understand who the players are and who was the driving force behind these innovations. If large American companies have taken the lead and today, across the Atlantic, the so-called “Ag-tech” market is booming, France and the European Union are beginning to seize the stakes of this sector.

Traditional American industrials in the agricultural sector provide farmers with their equipment and inputs (seeds, chemicals, etc.). Today, the major industrials in the sector are beginning to understand that the digital transition of agriculture is creating a new source of values: those of farmers' data. Therefore, the latter are repositioning themselves as a result by developing their business model to collect data from farms, add value to them, and equipping themselves technically to process them and build new services for farmers.

"$ 1 billion is the amount Monsanto bought Climate Corporation a few years ago, it is also the number of Ag-Tech investments made in 2014 in the United States!"

The American industrial **John Deere** developed very early a real fleet of connected machines (harvesters, planters, binders, etc.) filled with sensors, which can work independently: they know how to spread fertilisers on their own, at the right time and at the right depth, and measure harvest data in real-time. At the same time, John Deere has developed its *MyJohnDeere.com* platform on which farmers can view weather forecasts, commodity prices, and all the brand's service applications. The "On the go Big Data" app provides real-time access to all past and present data from your farm. **High-performance computing and big data processing** are the foundations of all these services!

**Monsanto is** a famous player in the agricultural industry under the Bayer banner, specialising in optimising seeds to improve crop productivity. The company quickly realised that if half of the improved productivity came from new genetic practices, the other half was more related to improved agricultural practices.

Monsanto has therefore developed in this segment, buying The Climate Corporation for a billion dollars. This company specialising in agricultural data science transforms data into advice for farmers, climatic hazards being the primary source of risk in agriculture. It then conquered all the links in the value chain by acquiring Solum (soil measurements), PrecisionPlanting (data on seedlings) and 640 Labs (data analysis).

Crossing more and more databases allows it to enrich its services. Now, Monsanto is deploying the *FieldScripts* system in the United States, which collects two years of data from farmers' machines and develops a program to optimise sowing. The service is billed at **$ 20** per hectare and promises an increase of around **5%** yields.

**Bayer**, which has become the world's largest pesticides and seeds company, says its application, that is already in use on farms covering **more than 24 million hectares** in the United States, Canada, Brazil, Europe, and Argentina. It announces that “data science” could be a **$ 20 billion revenue** opportunity beyond its core business of seeds and chemicals.

In 2019, **Syngenta** purchased Cropio, adding the leading digital agriculture company in Eastern Europe to its growing digital platform *CropWise*. With the acquisition of Cropbio, Syngenta prided itself on being "the only agricultural company to have access to leading management platforms in the four main agricultural markets: in the United States with *Land.db*, in Brazil with *Strider*, in China with the *Modern Agricultural Platform* and now Eastern Europe with *Cropio*. In total, **more than 40 million hectares worldwide** will be managed using a Syngenta digital tool, with plans to double by the end of 2020.

These agribusiness companies must rent the digital infrastructure they need to run their applications from big tech companies that control global cloud services, such as Amazon Web Services.

**Amazon**, which is developing its own digital agriculture platform, can leverage the data collected by Bayer and the many other companies that use its cloud services. Therefore, it has a huge advantage over these companies, not only in terms of the amount of data it can access but also in terms of analysing that data and profit from it in the longer term.

**Microsoft** is rolling out a digital farming platform called *Azure FarmBeats* that runs on the company's massive and global cloud computing technology, Azure. The platform is intended to provide farmers with real-time data and analysis on the condition of their soils and water, crop growth, the pest and disease situation and impending weather and climate changes that they may face.

The value of this information and advice depends on the volumes and quality of data that Microsoft can collect and analyse with algorithms. Therefore, Microsoft joins forces with the main companies developing agricultural drones and sensor systems and companies developing technologies that can receive and act on the information transmitted by *FarmBeats*: high-tech tractors, drones of spraying pesticides and other machines connected to Azure's cloud.

Agribusiness companies, especially those selling seeds, pesticides, and fertilisers, are ahead of the Big Tech. The biggest players in the Agri-industry all have apps, now spanning **millions of hectares** of farms, which get farmers to provide them with data in exchange for advice and discounts on the application of their products.

The logic that is already emerging is towards integration between companies that supply products to farmers (pesticides, tractors, drones, etc.) and those that control the flow of data.

**A digital divide?** All of this may seem quite out of touch with the realities and needs of the roughly **500 million smallholder family farms** around the world, which produce much of the world's food. High-tech applications like driver-less tractors and currently developed pesticide spray drones are not intended for them.

Above all, the data collected makes the quality of the information that digital platforms provide to farmers. Thus, for farms located in areas with significant data collection and for farms that can afford new data acquisition technologies (such as new tractors, drones, or field sensors), technology companies can collect large volumes of high-quality, real-time data. They have developed algorithms to process and analyse the data and provide these farmers with advice on fertiliser application, pesticide use and harvest times that are quite specific and useful to their farms.

Small farms, however, tend to be in areas where there is little or no extension services and virtually no centralised field data collection. Small farms also cannot afford the high-priced data collection technologies that large farms can use to push information to the cloud. As a result, the data that tech companies collect on small farms will inevitably be of poor quality.

There is a major stake here to evolve at a similar speed. **High-performance computing and Big Data technologies**, through the processing of different kinds of data (satellite, field data, etc.) can solve this divide.

Over the past two decades, Microsoft co-founder **Bill Gates** has spent much of his fortune trying to get smallholder farmers in the South to adopt what he describes as "seeds, pesticides and the most advanced fertilisers", sold and developed by the world's largest food companies.

B. Gates believes that digital agriculture can make a difference. In September 2020, Microsoft and AGRA (Alliance for a Green Revolution in Africa) formalised a partnership to help Microsoft roll out its *Azure FarmBeats* platform across the continent and deepen their joint efforts to deploy the virtual assistant application ("chatbot") Microsoft's *Kuzabot*, which provides advice to small farmers via WhatsApp and SMS.

## 4.3 SMART BANKING, FINTECH SOLUTIONS

Although the banking sector has been slow in adopting cloud solutions fuelled by competition from fintech start-ups, recent years have shown steady adoption of cloud technologies. A recent report [33] compiling data from

Blomberg and Pernewswire puts 22% of banking applications running on the cloud now. McKinsey report [34] suggests that for banks to remain competitive, aggressive digitisation is needed (see Figure 8). The same report also makes a case for digital banking services as it allows for lower Opex and Capex requirements (see Figure 9).

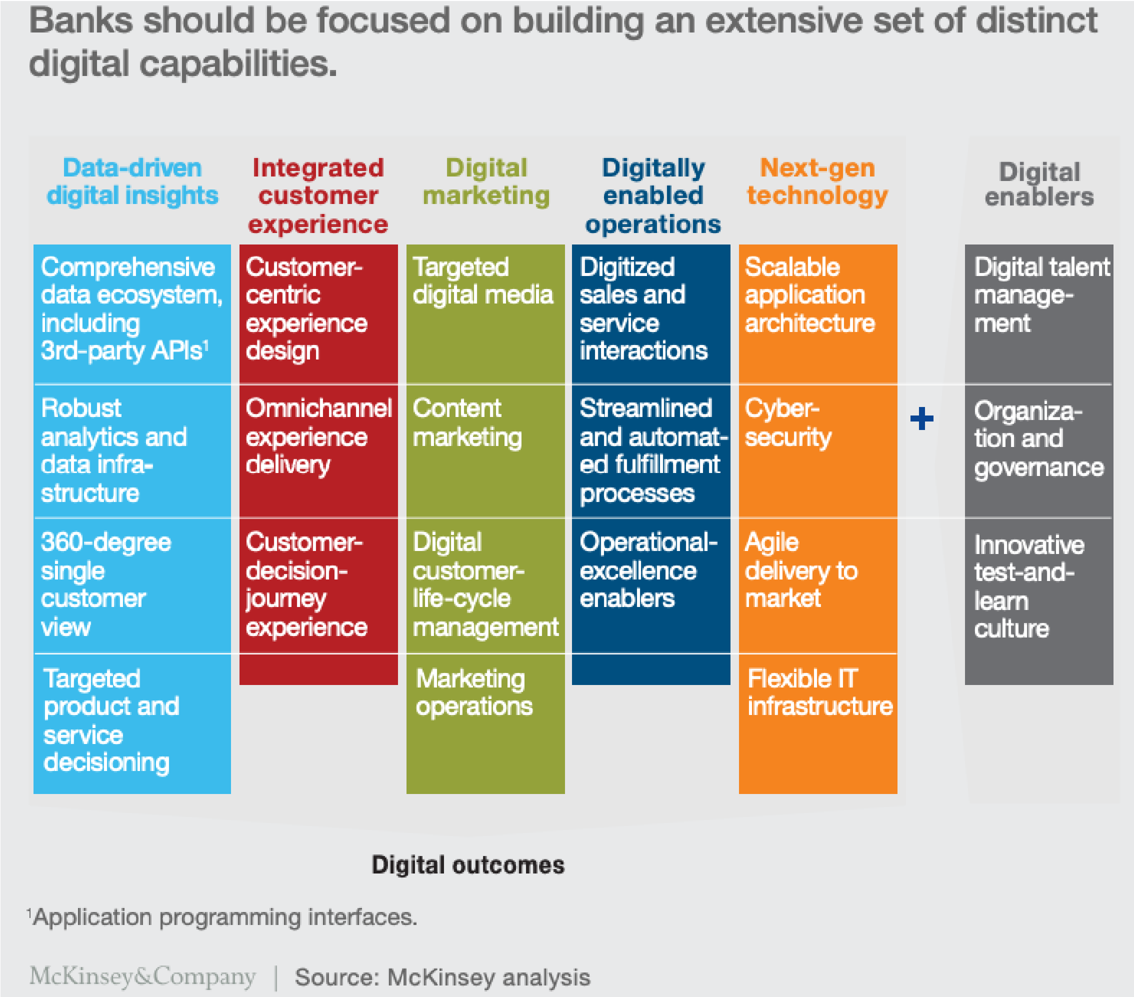



Figure 8: McKinsey report recommendation for banking transformation

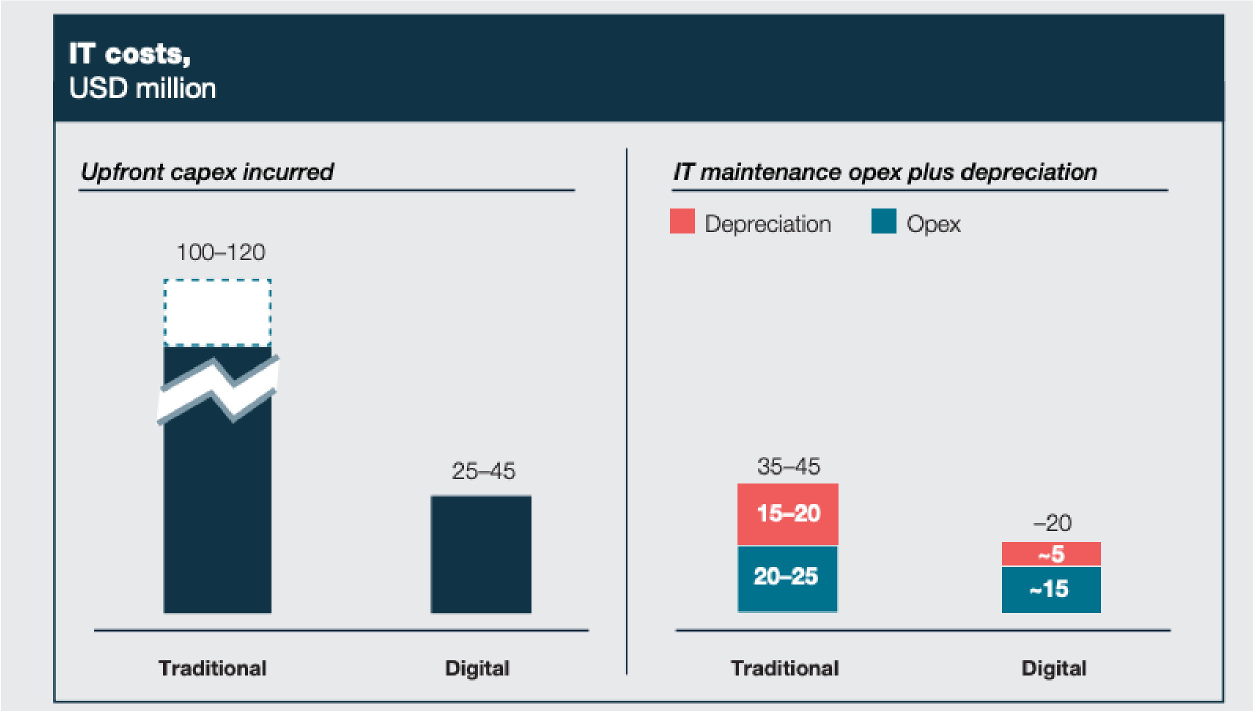



Figure 9: Digital advantage for banking services over the traditional setup

Frost & Sullivan recent report [35] suggests increased uptake of hybrid cloud technologies by Financial Service Industry (FSI). Banks and FSIs are migrating to the cloud at a record pace. About 50% already use the cloud in some form, and the adoption is expected to hit 90% by 2023.

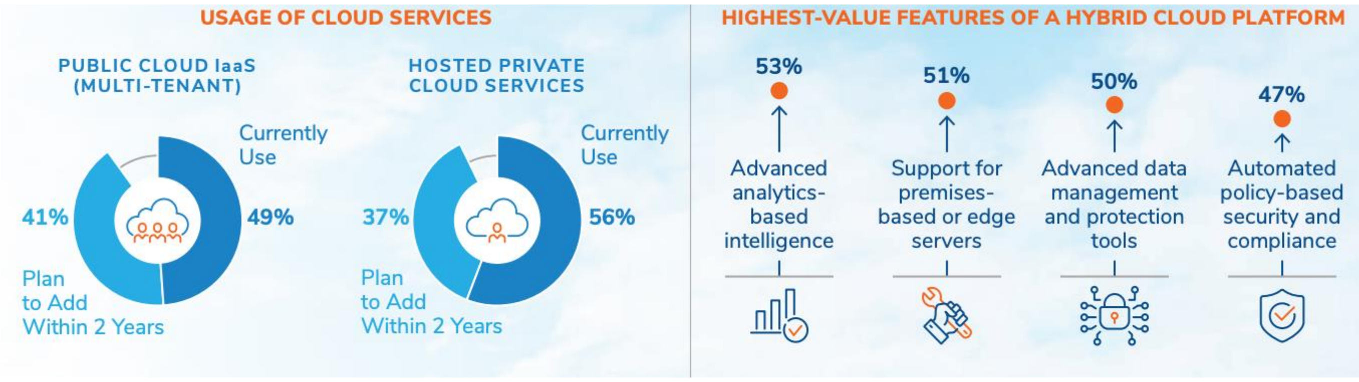


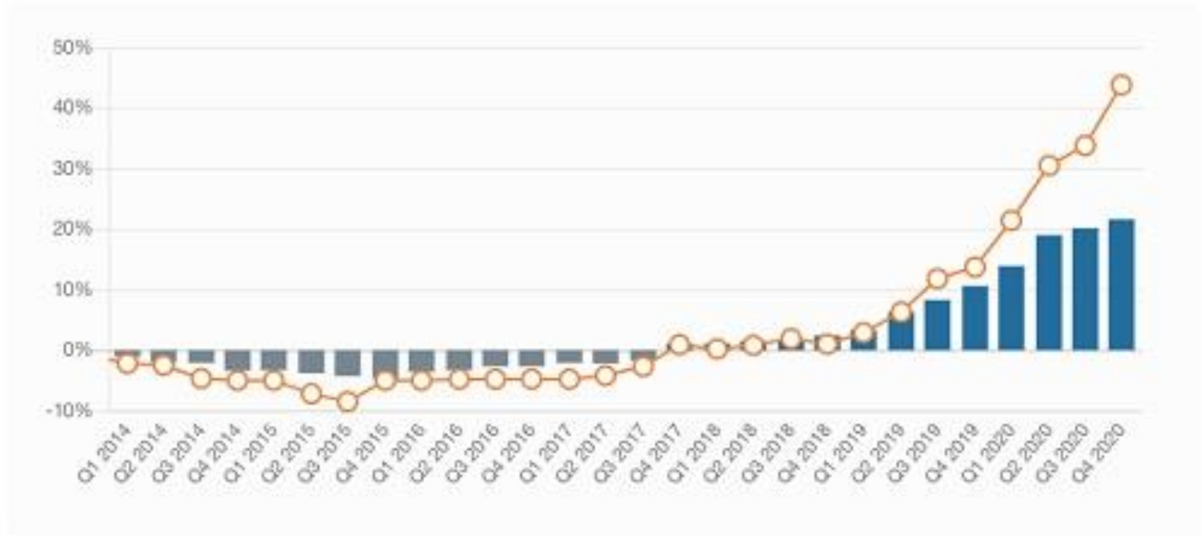

Figure 10: Banks and FSI adoption trends and top sought features (Frost & Sullivan)

Figure 10 shows an improved appetite for cloud services in FSIs. Interestingly one of the main drivers is improved security compliance offered by a move to the cloud.

## 4.4 SMART PARAMETRIC INSURANCE

One of the downsides of climate change is an increased frequency of adverse weather events such as flash flooding, cyclones, hurricanes and deep freeze and extreme heat waves. All such events are disastrous for SMEs. A study in 2019 by US Federal Emergency Management Agency (FEMA) found that "90% of smaller companies fail within a year unless they can resume operations within five days" [36, 37]. The Covid-19 pandemic also has made businesses aware of proactive risk assessments and management. The need of the current times is claims settlement within a few days, whereas months are the norm with traditional insurance claim assessment workflows.

Covid-19 has made the cost of raising capital go high. Capital and capacity are hard to come by. This reflects in the increase in the cost of insuring assets too [38]. A recent Marsh Market Index highlights this trend (Figure 11).




*Global insurance Composite Pricing Change (blue bar = global prices, orange line represented UK prices) – source Marsh*

**Figure 11: Global insurance composite pricing change index**

Parametric insurance in such a scenario becomes beneficial to both parties. It reduces the uncertainty to the insurers and thereby results in lowering of premiums benefiting customers. Customers can often also adjust the trigger conditions to suit their budget. But such a capability requires a large investment in new-age technology such as smart contracts, large scale data analytics', and cloud-native deployments by the insurance providers.

Because of the mass deployment of IoT sensors globally, increased compute capacities being built across our globe, parametric insurance has finally become a reality. Insurance players are also becoming aware of changing times. They are aware that consumers increasingly demand highly tailored coverage plans, automated claim triggers and settlements. This is only possible with increased use of serious computing power, large scale data processing and time-based urgent computing paradigms.

Parametric insurance is increasingly covering outages by large scale IT service providers too. On April 01, 2021, Azure had a major downtime in two of their data centres in the USA for more than two hours, triggering parametric insurance [39] claims.

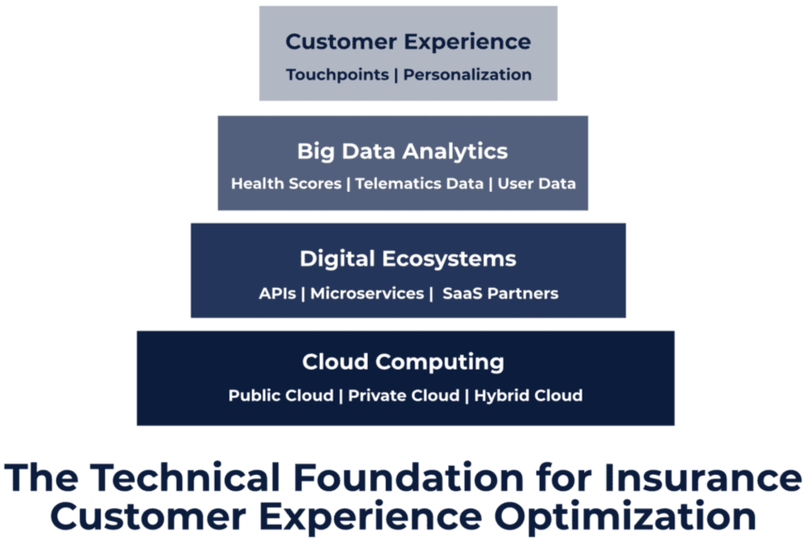



**Figure 12: Insurance customer experience optimisation technology roadmap**

A recent consumer report from Salesforce (for 2020) [40] found a general trend of increased technology adoption by insurance providers globally. That report found that Covid-19 may be an accelerator, but consumers primarily drive the cloud adoption in the insurance sector (see Figure 12).

Parametric insurance workflow [41] inherently is data-intensive, uses data provisioning, modelling, and automated trigger-driven pay-out decisions and works with large public datasets and exploits blockchain contracts and on-demand compute power from cloud providers.

## 4.5 DIGITISATION OF HEALTH MANAGEMENT

Digitisation of health management processes recently has seen a massive uptake. Covid-19 pandemic has highlighted the fact that many providers were not ready for the transition to digital platforms and/or were lacking the necessary technical capabilities altogether [42]. Due to Covid-19, several organisations have been forced to quicken their digital transformation. Figure 13 below shows the strong adoption trends within the healthcare sector for cloud computing technologies. By 2026, the cloud computing market for healthcare is likely to grow at a CAGR of 28.5% [43].

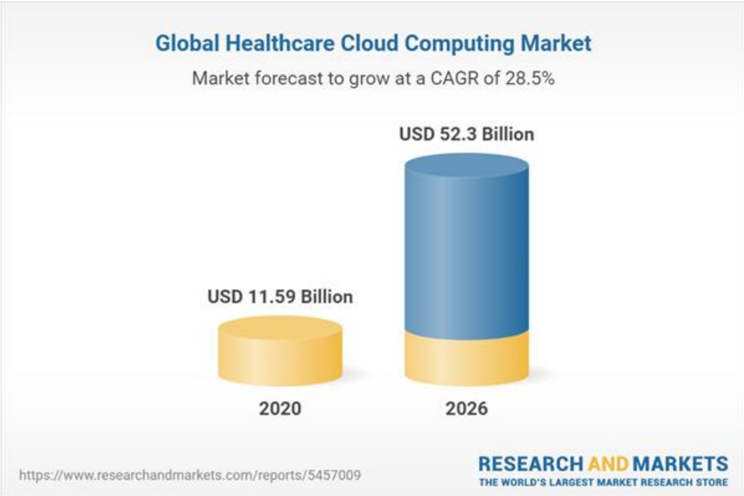



**Figure 13: Global healthcare cloud computing trends**

The main revenue growth segments till 2026 are likely to be from SaaS segment (63.7% market share) followed by IaaS segment (26.0%). The major cloud providers have the biggest market share: AWS (40%), Azure (18%), IBM (13%), Google compute engine (12%) and then followed by Alibaba Cloud. Other notable providers include Oracle, RackSpace, TenCent etc. The key driver for digital adoption has been improving the patient experience through virtual consultations, remote video meetings tools, and so on.

Figure 14 highlights some of the factors driving growth in cloud adoption in the health sector. The highest amongst them have been efforts to improve the patients' experience, including video consultations with specialists, RoI (Return On Investment) considerations, and being more innovative than competition.


**Figure 14: Convergence and growth drivers in global healthcare cloud adoption trends**

Figure 15 shows which digital health care tools have been more prominent in a patient's care workflow during the Covid-19 pandemic. The collection of modern tools being employed include not just wearable, but also increasingly biometric sensors are being used, increased use of smartphone cameras, telemedicine, and virtual patient consultations have been on the rise.

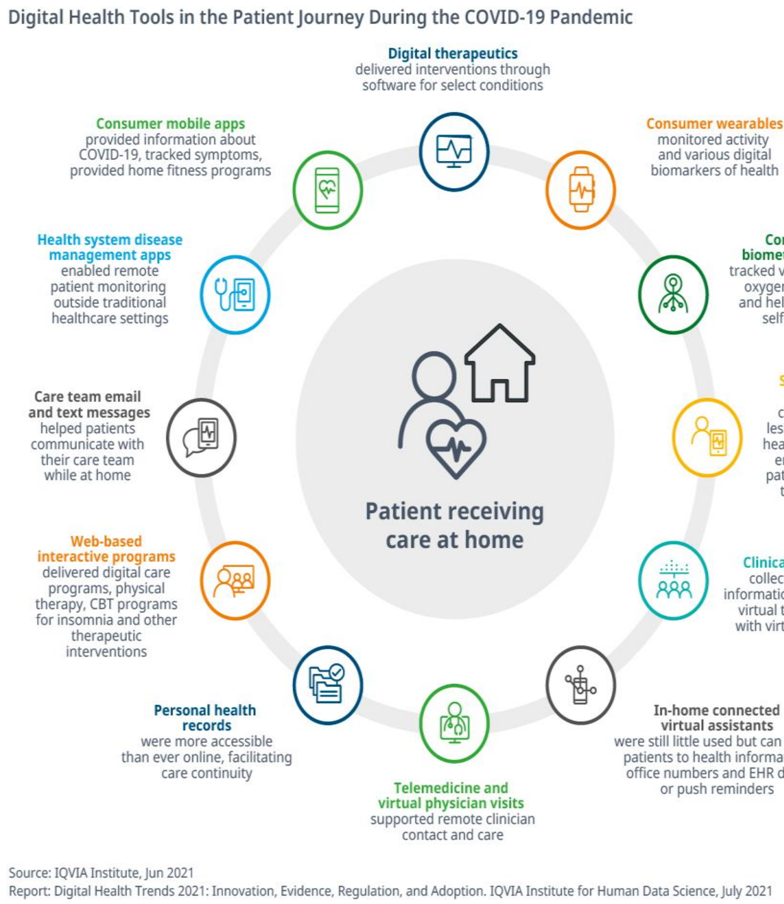



**Figure 15: IQVIA Institute digital health trends 2021 [44]**

# 5 COVID-19 PANDEMIC AND ITS IMPACT ON TECHNOLOGY ADOPTION

The trend of accelerated cloud adoption was being seen in the last few pre-pandemic years, but without any doubt, Covid-19 has further accelerated the trend of digitalisation across a broad spectrum of industries. In a recent article by InfoWorld [45], 9 out of 10 companies among 750 surveyed have increased Cloud adoption and spend as seen in Figure 16 below.

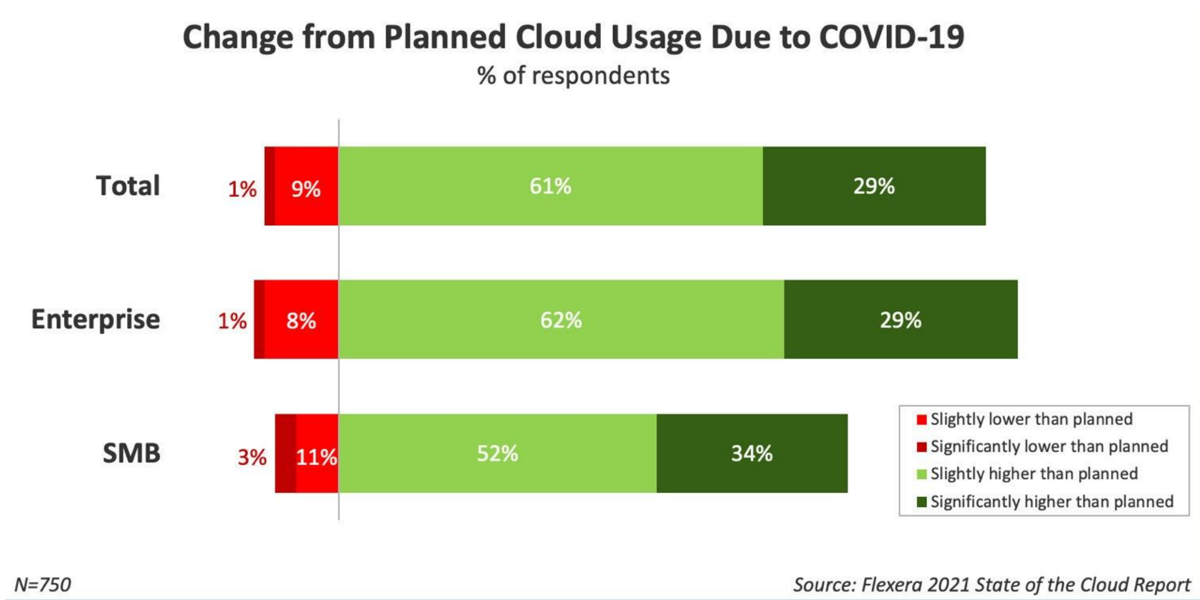



**Figure 16: COVID-19 impact on cloud usage change**

Due to workplace restrictions, several companies also saw the migration from in-house data centres to the public cloud as a more cost-effective and practical way of operating essential services in a pandemic. Another study conducted by database company MariaDB [46] confirmed the sentiment for increased appetite for cloud migration as shown the Figure 17 below.

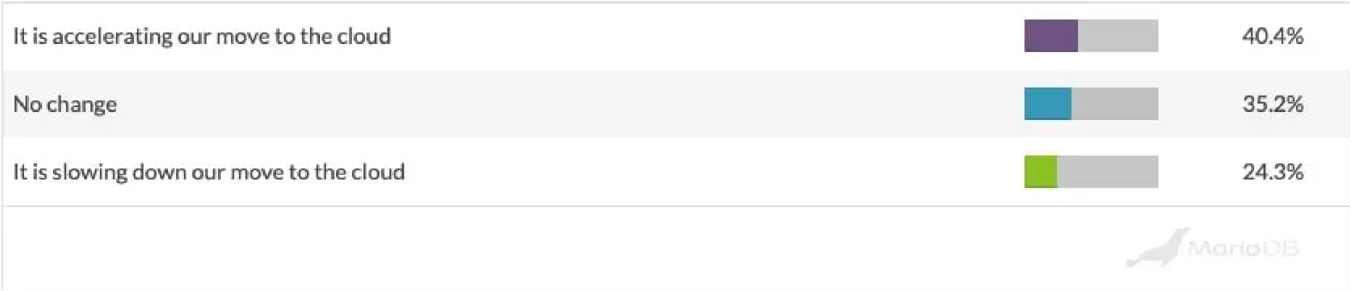



**Figure 17: A survey on the COVID-19 impact on adoption**

According to study [47] by Gartner, due to Covid-19, global spending on cloud service is targeted to increase by 18.4%. Some of the reasons behind this accelerated adoption are business resilience, the evolution of business operations, remote working, healthcare investments, online education, accelerated investment from the public sector, and a renewed focus on environmental sustainability. As per another report from Mckinsey [48], consumer and digital business adoption have leapt forward to the level estimated in the coming five years in just eight weeks. Even in the post-pandemic recovery, some digitalisation trends will remain strong, partly due to consumer demand to conduct many business dealings remotely using digital technology (see Figure 18).

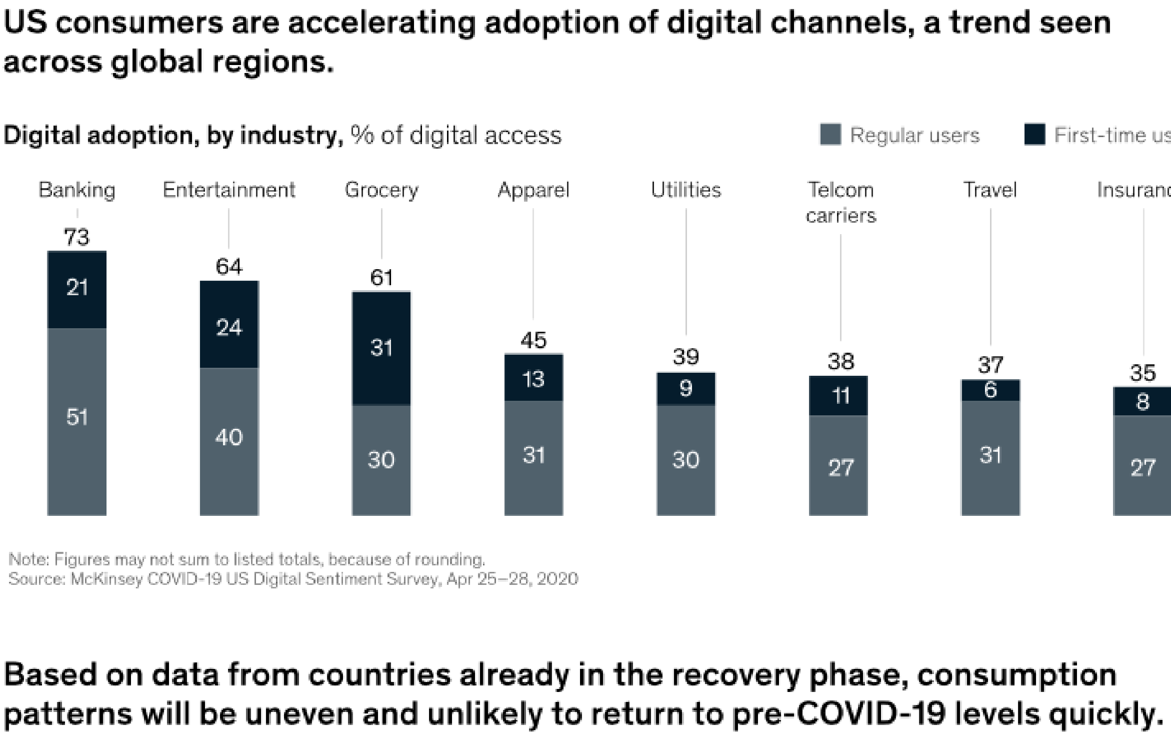



**Figure 18: Digital adoption trends by industry**

Figure 19 below shows how increased remote working, which is predicted to remain high in the post-pandemic recovery phase, contributes to digital technology adoption.

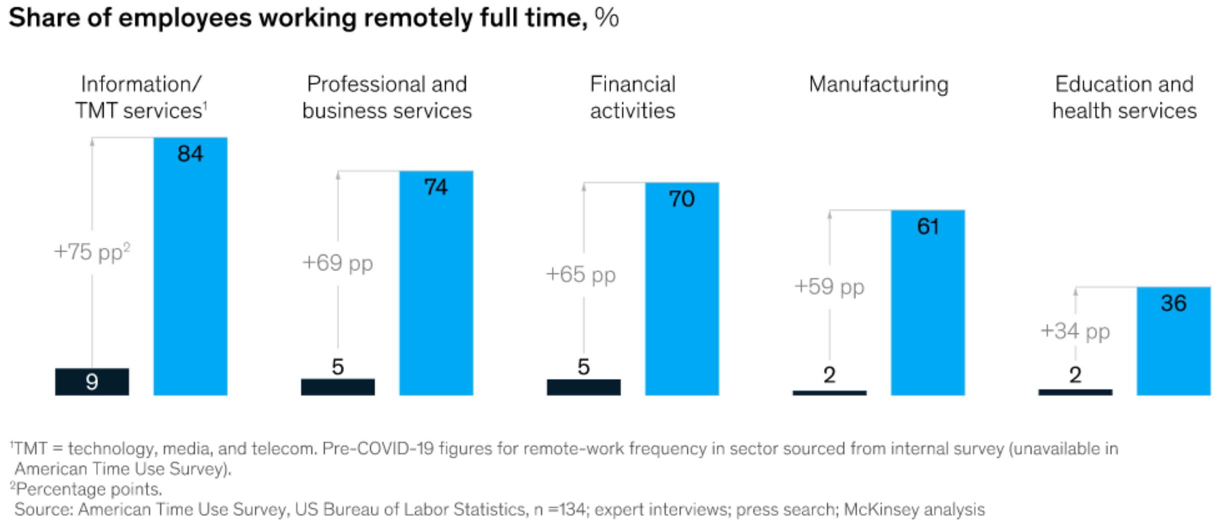



**Figure 19: Remote working trends across industry sectors**

Highly conservative and largely paper-driven sectors such as banks have also increasingly digitalised themselves to adapt to the pandemic, as reported by Forbes [49].

# 6 REVISED LEXIS MARKET POSITIONING

## 6.1 POSITIONING IN D9.5 & UPDATES

In our previous Deliverable D9.5 [2], we have detailed the key factors of the LEXIS project positioning on the global market. As a transverse approach designed to change the paradigm for industry and research, LEXIS has been architect and developed from a technical perspective to allow an unprecedented integration and enhancement of computing capabilities, software stack, orchestration, data management and flexibility looking toward the future, including the next to come exascale era. From the practical point of view, LEXIS aims to dramatically lower the barriers to entry for research, for European industries of all kinds and sizes.

Eighteen months ago, we did expect to see evolutions in the ecosystem and the market.

As a matter of fact, and as demonstrated in previous sections of the present deliverable, these evolutions have just confirmed the relevancy of all orientations taken by the LEXIS Team to develop and release an operational platform (near to TRL 8) aligned with today's and tomorrow's trends. Latest SC 2021 in St Louis, USA, just confirmed the strategic orientation of the development of the LEXIS Platform.

Due to its nature, LEXIS is cumulating two challenges in the process of defining its future positioning:

- Like any player in the market, LEXIS must define how to position itself toward market needs, existing market players, market offers (now and tomorrow), market trends.
- As a player whose origin and existence are deeply linked to public funding at various levels, LEXIS must consider various structural factors and challenges from its birth's ecosystem.

We will use in next sections "LEXIS" to refer to the present project ending the 31st of December 2021, and we will use "LEXIS Platform" to refer to what will become the project after its official end.

The extended version of the LEXIS market positioning is available as an internal LEXIS consortium document due to confidentiality reasons.

## 6.2 LEXIS ECOSYSTEM: STRUCTURAL FACTORS, CHALLENGES & THEIR IMPACT

The central point about LEXIS lies in its nature. It is a temporary consortium realising a federation of infrastructures, funded by public or local finance, or from the EU. Therefore, “infrastructure” and public funding are de-facto referring to a specific “ecosystem” where structural factors and challenges are deeply influencing the potential positioning of LEXIS after its end as an EU funded project.

Such structural factors are:

- Legal factor,
- Governance factor,
- LEXIS legal status factor,
- Complexity factor,
- Diversity of objectives factor,
- Diversity of needs from LEXIS users as a factor, and
- European strategy factor.

**Structural challenges** result from these structural factors. LEXIS and LEXIS Platform must face the following ones:

- Servicing diverse needs and users,
- Re-conciliating divergent objectives from diverse stakeholders,
- Building compatibility between various legal frameworks and their constraints,
- Being market compatible without breaching fair competition rules,
- Fully integrating the guidance (and later regulations) for digital sovereignty of Europe, keeping the LEXIS Platform aligned with the objectives of international cooperation.

Exploitation schemes for the LEXIS Platform shall follow the spirit of the LEXIS project, and thus not only allow for academic usage, but clearly warrant legal and functional compatibility with the private sector and Industry’s as well as SME needs. Thus, LEXIS platform operation models are desirable in which Industrial exploitation also in an operational/production phase and commercial for-profit scheme is possible. In Section 6.4, several exploitation schemes are discussed, and these requirements are met particularly well by one scheme (“D”, cf. Section 6.4).

## 6.3 LEXIS AS A PLATFORM

The LEXIS project delivers a platform characterised by the capabilities provided and the ability to be aligned with various practical objectives.

### 6.3.1 Technical Power & Relevance

LEXIS, as a federation of infrastructures with added-value services for its users, is demonstrating by its technical characteristics being completely aligned with market trends and ready for future evolutions:

- Being powerful by federating the computing power of multiple clusters, despite the heterogeneity of their architectures (CPU, GPU, FPGA, etc.) with best-in-class data management solutions covering the needs for all sizes of datasets, including huge ones. This allows large scale executions, taking advantage of top of the range workflow management solutions. LEXIS powerfully covers all computing needs for various research or industry projects. In addition, the possibility to scale up by adding to the federation additional clusters and data solutions without specific limits. Today composed of clusters from ICHEC, LRZ and IT4I (petascale part of the EuroHPC programme), LEXIS can later federate additional computing platforms, and also with commercial cloud providers. It is technically open to both public and private computing centres.
- Being relevant by dramatically increasing the possibility of maximising the Return on Investment (ROI) of the federated infrastructures by giving more opportunities to deal with more projects and projects of all sizes, including huge ones. Very large executions have been at the centre of the LEXIS design to face the growing needs of researchers and those needing to mix Big Data with intense computations, with or without Artificial Intelligence applications, as requested by the Digital & Computing Continuum. Additionally, LEXIS is designed to face present and future needs, engineered for scalability in the future, and on-boarding all technology trends adapted to cloud-based architectures and the portability linked to containers and Kubernetes. Simplicity is another outstanding feature of LEXIS. However, should problems arise, the user has access to various services via the portal and the single point of access. These are scientific support with the partners involved, technical assistance and support, proposed training opportunities and on-boarding processes.

LEXIS is ready to face the years to come, with an unprecedented ability to permanently evolve, at service levels, in scale and on-boarded technologies relevant to the foreseeable future of the digital continuum.

### 6.3.2 Openness for partnering with various types of operators

LEXIS is scalable but is also open to future partnerships and collaboration by nature. On top of being designed for federating additional clusters and data solutions, LEXIS is natively designed to be open technically to partnering, in terms of operations, with other players, public or private. LEXIS can be easily interconnected via APIs to data centres, cloud providers, data providers, other computing centres (not part of the federation) and more. Discussions have already started about a potential collaboration with some of them, including other EU funded projects.

Another type of partnership is to support players who want to adopt the LEXIS Platform to create their own federation, independently from the existing one created during the LEXIS project. In addition, LEXIS can partner with existing service providers, public or private for developing the software stack to be used on the platform.

Designed and engineered for natural openness, LEXIS has no specific technical limit in building operational partnerships of all kinds to improve its impact on research, economy, and society. LEXIS and LEXIS Platform are by nature open and flexible.

### 6.3.3 Alignment with the EU Digital Sovereignty ambitions

The LEXIS project was initially designed and started before the emergence of a strong initiative from the EU toward Digital Sovereignty. This move from the EU did emerge just after the start of LEXIS. It has allowed the LEXIS Consortium the opportunity to immediately consider this new parameter and include it in the design of the LEXIS Platform.

Recognising its importance for the future, the consortium had to assume that the Digital Sovereignty initiative will transform itself into recommendations and rules, meaning a need for compliance.

The expression of Digital Sovereignty is mostly developed along three axes as of today:

- **Data sovereignty:** the most visible expression is the **GAIA-X initiative** [27] that LEXIS is monitoring. The technical framework, as known today, is still a work-in-progress, but the outcomes, as known today, have been taken into consideration in the technical characteristics of the LEXIS Platform. It means that LEXIS and LEXIS Platform can be integrated into a digital sovereignty continuum, where all operators can efficiently manage compliance without disruption in this continuum.
- **Security, Cyber-Defence:** by integrating the best-of-breathe security solutions and practices from its initial design, LEXIS and LEXIS Platform are naturally aligned with the requirements in terms of security ambitions. It is to be noted that members of the existing LEXIS Federation have a long practice of security, being by nature very sensitive assets at the service of their respective governments, including sometimes for national security purposes. Hence high security is a normal practice, already well-honed by LEXIS members.
- **Data and privacy:** the existing EU norms, the **GDPR** rules, are already implemented for some years and are well-practised. They have been fully implemented in the LEXIS Platform from the very beginning to ensure total compliance. Some additional and more restrictive regulations are already implemented within LEXIS, with some federation members, due to some specific national requirements from governments (i.e., Germany and the LRZ) regarding data protection. LEXIS is ready to develop and improve all along with the evolution of regulations and can stay compliant.

LEXIS and LEXIS Platform are today compliant and have the natural possibility to stay compliant with future regulations and recommendations to come in terms of Digital Sovereignty.

### 6.3.4 One-stop service experience to cover all needs of users

For many potential users, multiple barriers of entry are paving the way. A major goal of LEXIS is to remove two major ones: ease of access and access to support services for potential users. From its inception, the design of the LEXIS project includes not only the technical platform LEXIS but also a set of services.

- The **LEXIS Portal** is the single point of entry for end-users. It brings simplicity and the needed tools in one place and facilitates the handling and implementation of application experiments, the associated datasets, and the outputs, including visualisation. The LEXIS Portal is the most visible illustration of a one-stop experience, removing one of the biggest barriers of entry for non-experienced HPC users and bringing simplicity for the experienced ones, saving time and costs (see Deliverable D8.3 [50]).
- The **service approach** of LEXIS is the second way to illustrate the one-stop experience and demonstrate the ability to cover all the needs of users. Assisting from the preparation of application experiments, data sets, workflows and computation outputs, LEXIS can deliver a simple and straightforward user experience. The highly visible part of this service approach is the concept of appointing a single **Project Manager** on the LEXIS side as a single point of contact to assist the users and help them coordinate and prepare the implementation and delivery phases. This has been tested and validated during the LEXIS Open Call.

## 6.4 SCENARIOS FOR LEXIS PLATFORM EXPLOITATION

Four main scenarios are confirmed after three years of developing and testing LEXIS as the potential choices for future LEXIS Platform exploitation (See Table XY). These scenarios all are based on the operations model allowed by the platform.

| LEXIS SCENARIO | TITLE | DESCRIPTION |
|---|---|---|
| **SCENARIO A** | LEXIS Platform at the sole service of its founders | Represents a kind of status-quo at the end of the official project in December 2021. Therefore, existing consortium members will continue to use the LEXIS Platform for their own needs, taking advantage of the numerous improvements brought to end-users, from academic/public research or private in the case of one-off pure research projects. |

| | | |
|---|---|---|
| **SCENARIO B** | LEXIS Platform for European & International Cooperation | The LEXIS Platform developed mostly on top of open source technologies will be proposed to third parties internationally. These third parties, intending to create their own federations, will capitalise on the LEXIS developments and seek technical assistance from LEXIS Consortium members due to their accumulated experience. |
| **SCENARIO C** | LEXIS Platform for extending capabilities for Research in Europe | The existing federation will on-board other supercomputing infrastructures within the EU to increase the mutualisation capabilities and the computing power available for LEXIS Platform users. |
| **SCENARIO D** | LEXIS Platform for fully serving the Digital & Computing Continuum | The LEXIS Platform ambitions are to cover end-to-end the Digital & Computing Continuum for maximum impact on research, economy, and society, as requested by the EU in the Grant for the LEXIS project. This scenario allows for tackling the specific challenges linked to private sector and industry's needs. |

**Table 3 Scenarios for LEXIS Platform exploitation**

### 6.4.1 The LEXIS Operations Model

The LEXIS Operations Model is based on three components:

- The **Relationship Control**: When a computing centre starts a discussion with a potential client/user (research, public, private) about implementing and running a new project, who controls the relationship? Each computing centre has its clients. Usually, these clients are among the groups the computing centre is supposed to support, as per the definition of the mission by the stakeholders (local authorities, governments, universities, EU). Hence it is only conceivable for the computing centre to have full end-to-end control of the relationship with its clients because it is at the heart of its official mission. It cannot give up on controlling the relationship. If a computing centre does not do that, it will not make the mission.
- The **Technical and Scientific Assistance Supply**: When in the process to welcome a new client with its application experiment, the computing centre provides the infrastructure, but it is usually needed for the client to get technical and sometimes scientific assistance to develop, adapt, port the application experiment to be executable on the clusters. Services may include anything needed from training, code porting, algorithm development or optimisation, and even sometimes pure scientific support or research. The infrastructure or computing centre can provide it, and sometimes other third-party players can also be involved. This is true for all types of clients, public research, private research sector.
- The **Execution of Required Computing**: When the application experiment or project is ready to be executed, the infrastructure or computing centre provides the required computing resources.

With the federated infrastructure as designed by LEXIS, each supercomputing centre can handle and fully control relationships with many more clients /projects (public, academic or private) independently from the technical/scientific support and computing time that can be shared with the federation. Thus, they are always in the position to seriously increase the possibility to meet their objectives toward local and national stakeholders.

But suppose they are short of technical/scientific resources or short of available computing time, for whatever reason. In that case, they can still serve their clients, control their relationship, and find the missing components inside the federation, as designed in LEXIS.

This is a mutualisation/optimisation process where supercomputing centres and their respective stakeholders can only get advantages and control:

- More clients/users,
- More projects,
- Unified and simplified on-boarding,
- Better ROI on the infrastructure,
- Ability to manage large projects, even bigger than what their individual infrastructure can handle,
- Increase of the experience curve,
- Increase of attractiveness to recruit scientists and computing specialists, and
- Higher impact on the local/national/European economy.

### 6.4.2 Exploitation scenarios and comparative scoring

Table 4 shows how each exploitation scenario for the LEXIS Platform is scored in terms of impact and cover of needs.

| | SATISFYING LEXIS EXISTING MEMBERS | SATISFYING EU RESEARCH SUPERCOMPUTING ECOSYSTEM (PUBLIC & ACADEMIC) | ATTRACTING & COLLABORATING WITH EU CLOUD COMPUTING AND CLOUD BASED HPC OPERATORS – PRIVATE SECTOR (STRICTLY EUROPEAN ONES) | INTERNATIONAL AND EUROPEAN RESEARCH COOPERATION | SATISFACTION OF LOCAL & ACADEMIC INTERESTS | SATISFACTION OF NATIONAL INTERESTS | SATISFACTION OF EU INTERESTS | ABILITY TO SATISFY CLIENTS IN ACADEMIA, INDUSTRIES AND SERVICES FOR RESEARCH ONLY | ABILITY TO SATISFY CLIENTS ININDUSTRIES AND SERVICES FOR R&D AND COMMERCIAL USAGE | ABILITY TO COVER THE FULL DIGITAL & COMPUTING CONTINUUM | TOTAL SCORING |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario A** | 4 | 0 | 0 | 2 | 2 | 2 | 0 | 4 | 2 | 2 | 18 |
| **Scenario B** | 4 | 2 | 0 | 4 | 2 | 0 | 2 | 4 | 2 | 2 | 22 |
| **Scenario C** | 4 | 4 | 2 | 2 | 4 | 4 | 4 | 4 | 6 | 2 | 36 |
| **Scenario D** | 6 | 6 | 8 | 4 | 6 | 6 | 8 | 6 | 8 | 8 | 66 |

**Table 4 How each exploitation scenario for the LEXIS Platform is scored in terms of impact and cover of needs**
**SCORING: Maximum = 8, Significant = 6, Medium = 4, Low = 2, Zero or negligible = 0**

It is to be noted that **scenario B** (proposing the LEXIS Platform – open-source-based - to the international community) is always actionable aside from any of the three other scenarios, A, C or D. It should be seen as complementary to any other exploitation path. But in itself, the potential of “distribution” of the LEXIS Platform to allow third parties to build their own federation does exist but in a limited way due to the relatively few numbers of potential clients.

**Scenario A** represents a kind of status quo in which partners having developed the LEXIS Platform use it for their needs but with a positive but not significant impact.

**Scenario C** represents European infrastructures capitalising on the LEXIS Platform to increase their ability to deal with more projects and bigger ones via mutualisation. But in this case, there is still no real possibility to address the Digital & Computing Continuum, despite it being the source of significant scientific developments and major economic developments.

**Scenario D** is the only one that covers the research needs and the Digital & Computing Continuum, essential for our economic growth in Europe and for staying competitive with other geopolitical blocks like China and the USA today.

## 6.5 LEXIS FINAL POSITIONING FOR AFTER END-OF-PROJECT

The practice of high-end computing is evolving a lot. By history, supercomputing infrastructures have been used for pure research and development, first by public and academic researchers, then by some industries for the sole purpose of one-off projects, as a part of their global R&D efforts, without direct commercial purpose, at this stage. In the past, before the emergence of Big Data, Artificial Intelligence, Edge computing and the Internet of Things (IoT), it was a practice that supported research, economy, and society for decades.

The major shift we can observe today is that aside from classic research (as during the last 40 years), high-end computing is extending the scope of usages massively to integrate Big Data, AI, IoT and Edge Computing. The result is a very structuring trend for decades to come: the Digital & Computing Continuum.

In such a context, it is no more possible to ignore the real challenges for the European research, economy, and society in developing high-end computing (HPC/HPDA/AI), its practice and its adoption by not only pure classic research (public, academic, private) but also every player in the economy with a goal to improve economic performance. This includes all companies in industries and services sectors, from start-ups to large multinational ones.

The competitive position of Europe is now relying more and more on its ability to control the Digital & Computing Continuum according to its own terms and not according to the interests of other geopolitical interests (today, USA and China mainly).

Classic research is still there and needs to be supported, also by opening doors of the Digital & Computing Continuum to new kinds of research (e.g., Earth Observation, as explained in Section 5.1), but it can no longer be the focus when investing billions in high-end computing infrastructures. As described in Section 5, emerging convergence trends demonstrate a huge need in all sectors of the economy and society.

### THE LEXIS PLATFORM POSITIONING

The positioning of LEXIS must be understood according to these parameters and to the major shifts and challenges for research and the economy in the EU. Under these terms, analysing the scoring of the four potential exploitation scenarios for the LEXIS Platform will drive to a simple conclusion: LEXIS Platform must position itself according to Scenario D. To be clear, that is the ambition.

As a federation, LEXIS Platform is not proposing a merge of existing and fragmented infrastructures. Based on the very functional LEXIS Platform, the proposition is to federate, meaning to coordinate, synchronise and optimise the usage of the existing and future investments by public bodies and the European private sector by:

- Proposing an end-to-end solution for the needs of each category of users/clients,
- Removing the most significant barriers to entry (to foster high levels of adoption),
- Simplifying the access to and the usage of these infrastructures and research investments,
- Allowing the removal of the major problem of the Investment Disruption.

Adamants to the success of such a positioning are:

- A single point of entry for client users to find what they need, end-to-end,
- A legal entity to carry the legal and administrative complexity out of the users/clients, and to get the ability to contract and engage,
- An increase in the number of infrastructures (publicly owned Super-computing centres, Data centres, privately owned cloud services and computing centres) becoming members of the federation,
- Additional developments to maintain the platform, increase functionalities, facilitate the porting of projects entering the exploitation phase to infrastructures compliant with the EU Digital Sovereignty policies,

- The maintenance of the administration process defined during LEXIS Open Call (please see D9.12 [51]), including dedicated project managers for each project,
- The integration in LEXIS Platform with various scientific teams to support projects,
- Maintaining and/or developing support services, including by capitalising on existing offers from existing or next to join partners,
- Partnering with existing centres of competencies, public or private.

In the end, LEXIS Platform will become a new kind of player in the EU Landscape. It will have a **hybrid positioning**, focusing on optimising the usage of existing assets of all kinds to generate a massive increase of various types of ROIs, at the service of research, economy, society and ultimately all public stakeholders, locally, nationally and at the EU level.

In addition, by incorporating Scenario B and C, LEXIS Platform intends to foster traditional research development and the development of international collaborations. Having a legal entity to port these activities will be a major facilitator to engage in international collaborations, with a good level of control and a high level of efficiency.

# 7 SUMMARY AND CONCLUSIONS

This deliverable presents the findings of emerging market trends and places the LEXIS Platform in the emerging market context. Largely, digital adoption trends in HPC, Big Data and Cloud technologies have not suffered setbacks due to the global pandemic. On the contrary, digital transitions have accelerated, most significantly in Cloud technologies, and emerging sectors have only added more fuel towards convergence trends within HPC, Big Data and Cloud offerings.

This deliverable also presents various scenarios of exploitation of LEXIS results post-completion and outlines strengths and weaknesses of the proposed four possible outcomes in the context of European data sovereignty, security, and privacy tenets.

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