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to grow a sustainable and comprehensive ecosystem

D1.5: European Cloud Computing roadmap and policy recommendations Q1-2022

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Abstract

This deliverable has a threefold goal. First, it presents the methodology followed for the research roadmap. Secondly, it presents a multi-sourced context analysis and finally, the initial findings of research topics.

Keywords:

Document Revision History

Version	Date	Description of change	List of contributor(s)
V0.1	18/11/2021	TOC proposal	Enrique Areizaga (TECNALIA)
V1.0	02/08/2022	First compiled version	Enrique Areizaga (TECNALIA)
V1.1	04/08/2022	Including Revision comments from MARTEL	Enrique Areizaga (TECNALIA)
V1.2	12/08/2022	Final formatting and revision	Giovanni Rimassa (MARTEL)

Disclaimer

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Nature of the deliverable:	R	
Dissemination Level		
PU	Public, fully open, e.g. web	√
CI	Classified, information as referred to in Commission Decision 2001/844/EC	
CO	Confidential to HUB4CLOUD project and Commission Services	

** R: Document, report (excluding the periodic and final reports)*
DEM: Demonstrator, pilot, prototype, plan designs
DEC: Websites, patents filing, press & media actions, videos, etc.
OTHER: Software, technical diagram, etc

EXECUTIVE SUMMARY

This deliverable document the findings on the focus topics tackled up to M14 by HUB4CLOUD in support of ECC roadmap. This document will also indicate how HUB4CLOUD will take over road mapping activities after the end of H-CLOUD.

This document develops a scoring and a classification methodology of topics established in D1.4 and will end up with a set of recommendations and prioritizations for the European Commission to include in the upcoming work program.

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ABBREVIATIONS

B2B	Business to Business
B2C	Business to Consumer
B2G	Business to Government
BIM	Building Information modelling
CTO	Chief Technology Officer
ECC	European Cloud Computing
eIDAS	electronic IDentification, Authentication and trust Services
EU	European Union
EUCS	European Union Cloud Services Scheme
G2C	Government to Consumer
GDPR	General Data Protection Regulation
IDSA	International Data Spaces Association
IoT	Internet of Things
IP	Internet Protocol
IT	Information Technologies
MCDA	Multi Criteria Decision Analysis
MPC	Multi Party Computing
RIA	Research and Innovation Action
SME	Small and Medium Enterprise
TCP	Transmission Control Protocol
TRL	Technology Readiness Level

1 INTRODUCTION

This document is the second of a series of three documents that aims to present the proposal for a research roadmap in the domain of cloud computing continuum. HUB4CLOUD partners followed a multi-sourced methodology, gathering content from relevant stakeholders such as existing RIA projects, interviews, surveys, analysis of the current context and running initiatives but also adopting more formal methods inspired by systematic literature reviews. The main goal is to come up with a list of research challenges and topics that can later be classified, scored, and prioritized.

The document is structured as follows.

Section 2 presents the approach and methodology followed for the elucidation of the research roadmap.

Section 3 presents the methodology followed for the analysis of the research venues which is the last input for the findings of the research challenges and topics, which are presented in a structured way in this part of the document.

Section 4 contains the conclusions and future work.

2 ROADMAPPING APPROACH AND METHODOLOGY

2.1 Introduction

This report is the second outcome of task *"T1.3 Road mapping and policy recommendation"* with the main objective to contribute to the ECC research roadmap and policy recommendations aligninig the view from different stakeholders (research, industry, users). In order to achieve this objective Task 1.3 proposes a multi-source analysis (see Figure 1) considering different sources to gather the input form the different types of stakeholders academia, practiotioners, industry and users. The result of this analysis started in D1.4 (M9), and is covered in the present deliverable. It will be further developed in D1.6 (M21).

Figure 1. Multi source analysis in Task 1.3.

2.2 Methodology

The proposed methodology stands over 3 main pillars (Figure 2). The methodology is similar to the one already presented in D3.5 but tailored for the domain at hand. This demonstrates the repeatability and the scientific soundness of the approach:

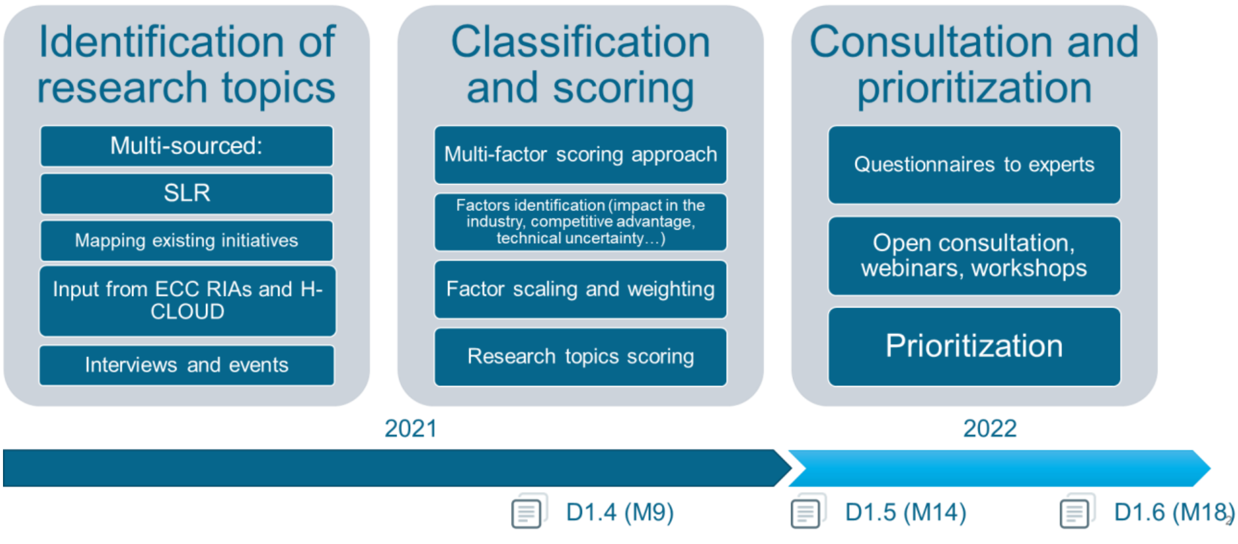

Figure 2. Methodology followed in Task 1.3

1. Identification of research topics from diverse sources: Included in D1.4
2. Classification and scoring (Figure 3): Once the inputs are gathered an initial list of research topics will be created. This list will be classified and scored using a set of factors (i.e.

impact in the industry, competitive advantage, technical uncertainty, etc).

3. Consultation and prioritization: The initial classification performed by HUB4CLOUD will be shared with the community through different channels (workshops, interviews) and as a result the final prioritization of the topics will be performed.

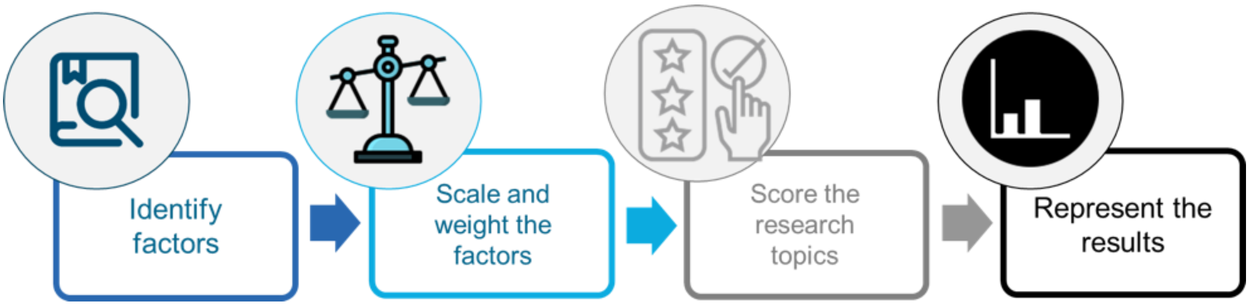

Figure 3. Multi-factor scoring methodology phases

This deliverable (D1.5) reports the work done for the second pillar in Figure 2.

3 CLOUD COMPUTING RESEARCH TOPICS AND CHALLENGES

According to the 2030 Digital Compass: the **European way for the Digital Decade,** chapter 3.2 "Secure and performant sustainable digital infrastructures[1]" EU-based cloud providers have only a small share of the cloud market (more precisely, 86% of the European Cloud market is dominated by non-EU players- Amazon, Microsoft and Google currently account for 69% of the regional market and their share continues to steadily rise.)[2], which leaves the EU exposed to such risks and limits the investment potential for the European digital industry in the data processing market. It also implies a challenge to achieve the "Digital Autonomy".

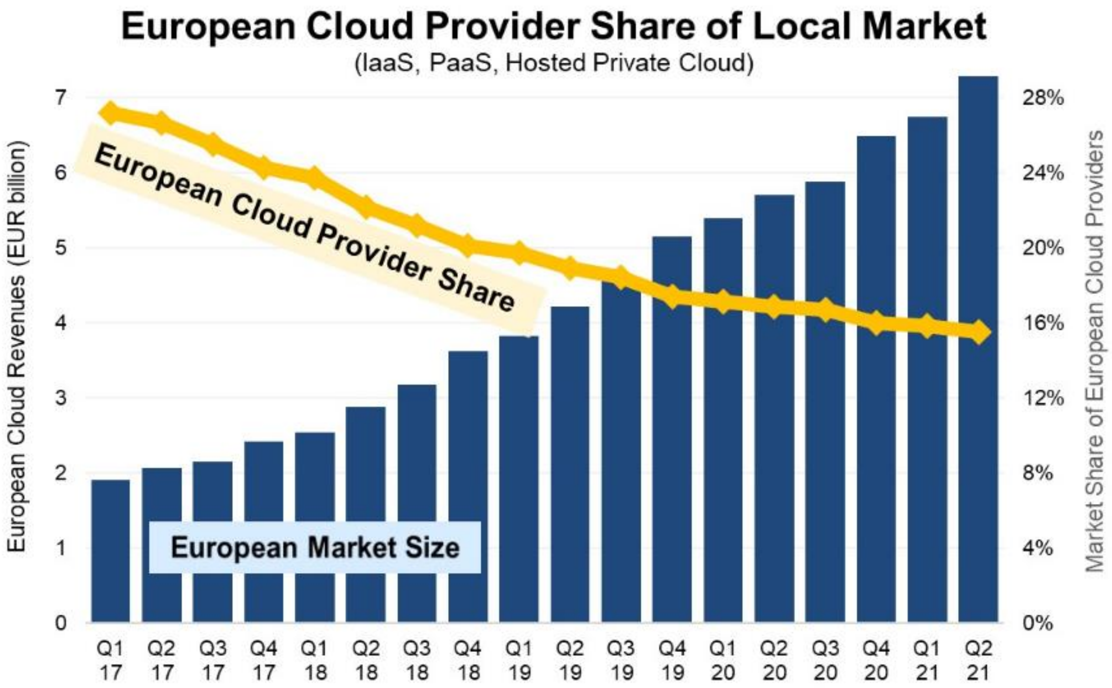

Figure 4 European Cloud Provider Share of local market (Sgrresearch)

Moreover, the strength of European companies lies in their expertise and market share in sectors such as: Mobility, Energy, Home, Agriculture, Manufacturing and Logistics. Therefore, there is a unique opportunity for Europe to bring its players back to play a significant role in the IT market by **2025** and make a quantum leap towards "Digital Autonomy for Europe".

To achieve this goal, Europe needs to strengthen its supply and value chains in cloud-to-edge computing by integrating computing, connectivity, IoT, AI and cybersecurity, building open platforms and a next generation of IoT and edge computing ecosystems integrated in a continuum from cloud to edge to IoT. There is a need to move from the current situation where 80% of data processing and analysis is done in data centres and centralised computing facilities (see Figure 4), to 80% or more being processed at the edge by 2025[3].

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[1] Europe's Digital Decade: digital targets for 2030 | European Commission (europa.eu)

[2] European Cloud Providers Double in Size but Lose Market Share | Synergy Research Group (srgresearch.com)

[3] In-depth reviews of strategic areas for Europe's interests | European Commission (europa.eu)

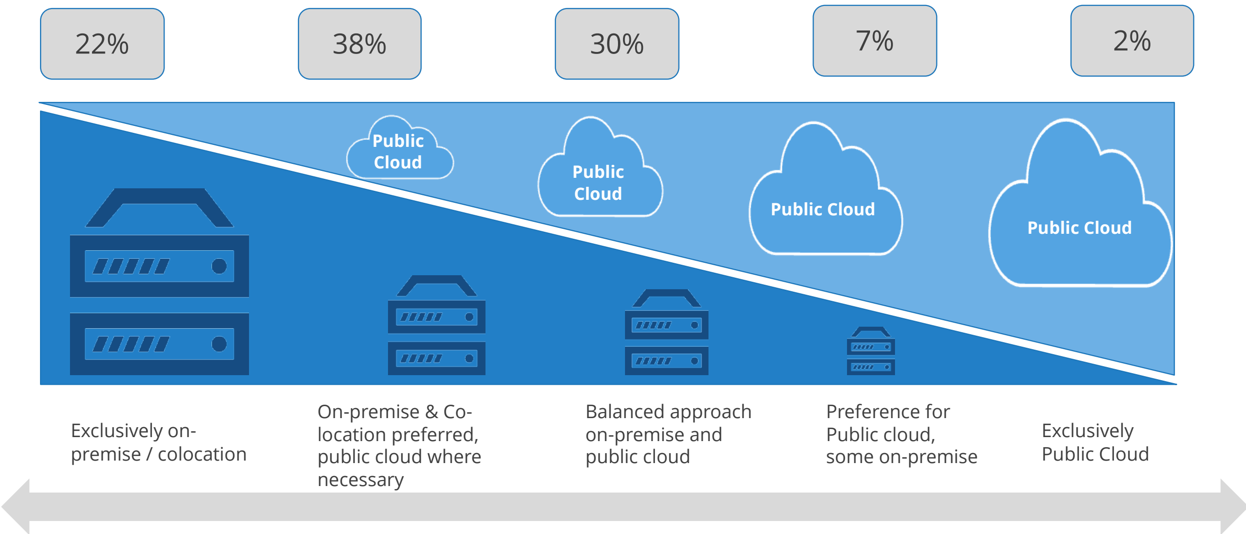

Figure 5 Cloud Adoption by companies. IDC EMEA, 2021

Therefore, it is important to consider during the classification a vision where billions of intelligent, AI-driven sensors and actuators collect, process, and analyse data in real time, individually or as a swarm (collective behaviour or decentralised self-organised systems).

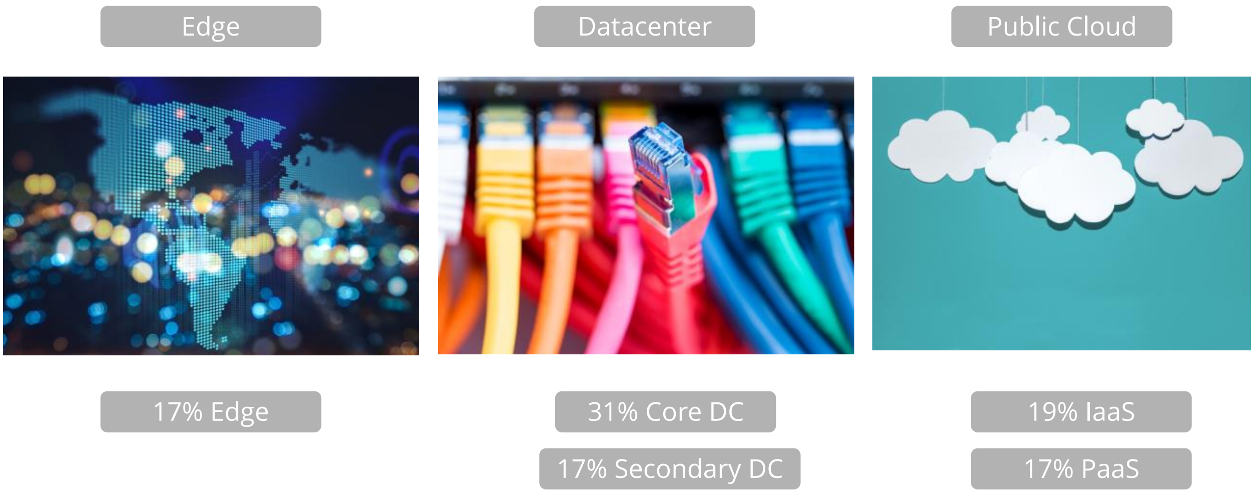

Figure 6 IT infrastructure budgets split between different locations[4]

The Green Deal is also of paramount importance. The transition to the Edge will have an impact on the green effect in two main ways. Firstly, by reducing the growth of data centers (and thus the energy footprint), as huge amounts of data will now be processed locally. Secondly, as "enablers", by facilitating home automation, control of energy consumption, electric mobility, etc.

[4] IDC EMEA, 2021 Annual Multicloud Survey N=925

3.1 Multi-criteria Decision Analysis for ranking Cloud Computing R&D topics

Considering the objectives for the digital decade already shared by the European Commission and in order to rank the different research themes and challenges, the main objective is to establish a "Roadmap for research to drive the acceleration towards European digital autonomy". To achieve the objective, Multicriteria Decision Analysis, or MCDA, will be used.

Three dimensions will be explored: Technical, Business and Sectoral. Each of these, with their corresponding factors, is based on the criteria guiding the European Commission in the pursuit of "a Europe fit for the digital age" in which digital technologies and solutions are strongly rooted in core European values, ranging from fundamental individual rights to market openness and environmental sustainability.

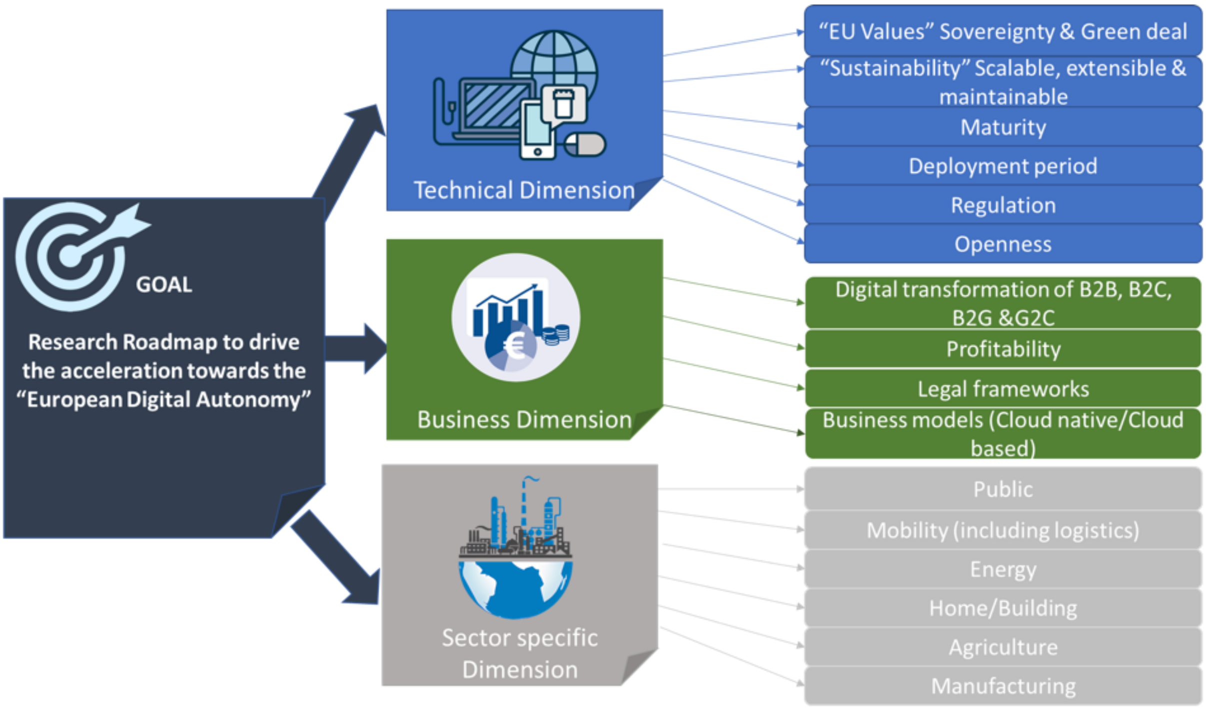

Figure 7 HUB4CLOUD multi-factor scoring methodology

Once the dimensions were chosen, the factors were selected in such a way that they could respond to how the different research activities contribute to addressing the main challenges of European cloud computing.

Within the **Technical dimension** the factors selected are:

1. **EU Values:** "Sovereignty & Green Deal"
   - How will they help to reduce the Greenhouse gas emissions with the target of 50% by 2030 in comparison with 1990?
   - How will they contribute to Data Governance: Data protection, Data Sovereignty, efficient Data sharing and Security?
2. **Sustainability:** "Scalable, extensible & maintainable"
   - How can the different solutions scale from their basic version?
   - Can their solutions be applied to other alternatives?
   - Are there any constraints that could hamper their support and upgrade after the life of the project?

3. **Maturity:**
    - How far is to move to High TRLs?
4. When will they be available?
    - What is their deployment time range (1-3 years/3-5 years/5-8 years)?
5. **Regulation:**
    - Do research activities contribute to the standardisation of European cloud computing in different fora?
    - Do they reinforce the use of European standards in the field of cloud computing?
6. **Openness**:
    - Openness can be measured with the license but also the copyright owner and the technical capability for a - open-source or closed-source - service to export personal and non-personal data out of the service - to prevent artificial data-gravity.
    - Are there any limitations that will restrain other potential users or developers from using them?

Business dimension:

1. **Digital transformation** of Business to Business (B2B), Business to Consumer (B2C), Business to Government (B2G) and Government to Consumer (G2C)
    - What are the acceleration options proposed to boost uptake of CC technologies and solutions?
    - What timeframe would be acceptable for Research and innovation outcomes to become market ready?
    - How should a cloud infrastructure be exploited to facilitate the creation of cloud-enabled ventures?
2. **Profitability:**
    - What is their Economic Viability?
    - Which metrics are analysing to understand whether the business model/pricing strategy is adequate or not?
    - What business models are likely to engage SMEs and Entrepreneurs
3. **Legal Frameworks:**
    - What are their contributions to enable certified services to be widely adopted within Europe?
    - How can they preserve the GDPR while not been a big burden to SMEs and entrepreneurs?
    - How could Cloud Service providers move the services within different countries in Europe while complying with one regulation that will be accepted by all?.
4. **Business models:** Cloud native/Cloud based
    - How are Cloud Computing based business opportunities commercialised?
    - What type of actors are interacting with CC business opportunities?
    - How are potential business opportunities in CC identified?
    - What are they looking for in a business opportunity?

Sector Specific dimension

The 6 sectors considered are the ones identified as the most important within Europe's economy:

1. **Public Sector:**
    - Digitalisation of public services by 2030,
        - key public services: 100% online,
        - e-Health: 100% of citizens having access to medical records,
        - Digital identity: 80% citizens using digital ID
2. **Mobility** (including logistics):
    - contribution to the autonomous mobility
    - Reduction of emissions and immissions
    - Simple, fast, and affordable mobility services
    - Seamless, convenient, and integrated traffic flows
    - Traffic safety
3. **Energy:**
    - Data-driven solutions should result in the energy data room coping with the transition to decarbonized energy and carbon neutrality
    - Enabling energy efficiency and sector coupling (e.g. green energy fluids), as well as more flexible and renewable energy integration into the European electric system
4. **Home/Building:**
    - Data acquisitions technologies (sensors, IoT, 3D scanning)
    - Automating Processes (robotics, 3D printing and drones)
    - Digital information and analysis (Building Information modelling (BIM), Virtual/augmented reality, Artificial intelligence, Digital twins)
    - Digitalisation of the Building Permits Systems
5. **Agriculture:**
    - Building a climate of trust between business operators and farmers to foster the collaboration among multinationals, SMEs, one-man businesses, and family farms.
    - Ensuring data interoperability and portability within the entire chain from farm to fork to guarantee the access to the digital single market.
    - "Smart Farming" where the deployment of edge capacity connected to machinery in farms will allow to collect agriculture data in real time, provide advanced services to farmers like harvest prediction or farm management, and optimize food supply chains.
6. **Manufacturing:**
    - Manufacturing-as-a-service enabling manufacturing companies – notably SMEs – to have local access to cloud based innovative industrial services platforms, and marketplaces to boost the visibility of their production capacities.

Roadmap	Technical (35%)	EU Values (20%)
		Sustainability (15%)
		Maturity (15%)
		Deployment time (15%)
		Regulation (15%)
		Openness (20%)
	Business (30%)	Digital transformation (30%)
		Profitability (25%)
		Legal (20%)
		Business models (25%)
	Sectors (35%)	Public (25%)
		Mobility (15%)
		Energy (15%)
		Home/Building (15%)
		Agriculture (15%)
		Manufacturing (15%)

Table 1. Weight assignment

From the weight allocation table, the ranking score is established.

The score will be calculated according to the centre of gravity of each research topic. Thus, if a research topic focuses on technical regulation, legal impact on business and applies mainly to the energy sector, the score will be ((35*15) + (30*20) + (35*15))/100 =5.25+6+5.25=16.5). The maximum score a research topic can obtain is "100".

3.2 Overview of identified Cloud Computing Continuum research topics

The following image shows an overview of the identified research topics, initially classified by time horizon and potential business impact. Although many of these challenges may have several of these business impacts, only the most relevant one has been selected for visibility purposes.

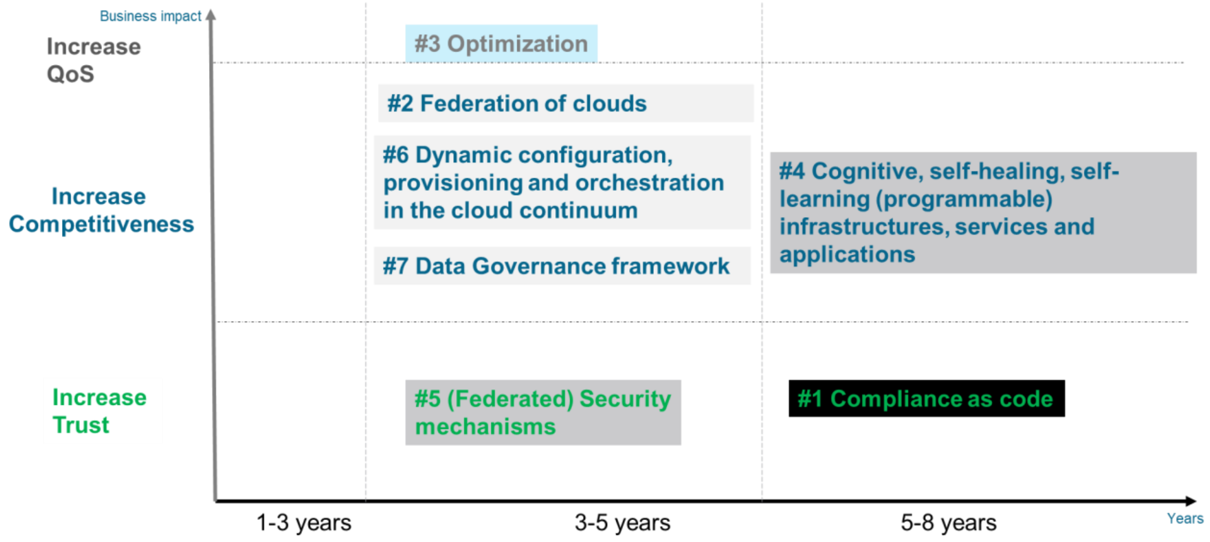

Figure 8. Overview of identified cloud computing continuum research topics (source: editors' own contribution)

3.3 Description of Cloud Computing research topics and challenges

The initial set of research themes and challenges are described below. While the main source of the research challenges is the analysis of research sites, it has been complemented by inputs from the previous sections, namely context analysis, surveys, interviews, and research projects.

All research challenges are presented following the same structure:

- **Description:** brief description of the challenge.
- **Expected timeframe:** time in which this challenge is expected to be developed.
- **Social impact:** expected impact on society as a whole.
- **Technological impact:** main technological outcome.
- **Business impact:** expected impact on the business environment.
- **Source:** indicate where this research challenge comes from, such as research site analysis, interviews, context analysis, surveys, etc.

3.3.1 Compliance as code in cloud security certification

Description: Compliance as code ensures that all compliance requirements are met through tools that automatically configure requirements and then gather evidence and evaluate that evidence against a set of pre-defined metrics/requirements. Compliance as code allows preventing, detecting, and remediating non-compliance, especially when high levels of security assurance are sought. Compliance as code in technical measures, such as protocol version checking, vulnerability management and vulnerability handling, although challenging, can be achieved. However, compliance as code for organisational measures (e.g., policies and procedures), which involve natural language processing and the need for machine-readable language and a large corpus of data, is a difficult task. Finally, the characteristics and complexity of the cloud supply chain make the task of compliance-as-code even more complex, as certifications will also need to be composed.

Expected time: Due to its level of maturity, it is expected to be ready within 5 to 8 years. However, the recent statement by GAIA-X CTO Pierre Gronlier (Cloud Expo Europe-Frankfurt 2022) that code compliance modification is the most important action for GAIA-X to succeed could accelerate its readiness by 3 to 5 years.

Societal Impact: Increased trust on cloud services, which is one of the main pillars of Gaia-X.

Technological Impact: Natural Language Processing (NLP), need to create a corpus of data, catalogue metrics, cloud security certification

Business Impact: increased reliance on cloud services, higher degree of automation, reduced effort in complying with regulatory requirements.

Source: EUCS [8], Gaia-X [2].

Compliance as Code **Score 7,5325**	Technical (35%) **Score 8,2**	Contribution to Data Privacy and Data Sovereignty (20%) (**Score 10**)
		Main enabler to make the cloud federation scalable (15%) (**Score 10**)
		Still not mature enough (15%) (**Score 5**)
		Evolving from long term to Mid-term (15%) (**Score 5**)
		Enforcement of the Regulations (15%) (**Score 8**)
		Specially for Gaia-X it will be highly recommended to be Open (20%) (**Score 10**)
	Business (30%) **Score 8,25**	Main role in Cloud computing federation (30%) (**Score 10**)
		Increase SMEs Digital offer profitability (25%) (**Score 7**)
		Compliance with EU regulation (20%) (**Score 10**)
		Fostering integrated CC offers (25%) (**Score 6**)
	Sectors (35%) **Score 6,25**	A must for public services (25%) (**Score 10**)
		Relatively important for Mobility (15%) (**Score 5**)
		Relatively important for Energy (15%) (**Score 5**)
		Relatively important for Home/Building (15%) (**Score 5**)
		Relatively important for Agriculture (15%) (**Score 5**)
		Relatively important for Manufacturing (15%) (**Score 5**)

Table 2. Compliance as Code Scoring

3.3.2 Federation of clouds

Description: Cloud federation presents several challenges not only from a technical but also from an operational point of view that ultimately also affect the technical solution adopted. In the context of this research challenge, cloud federation also encompasses edge nodes, IoT and other infrastructural resources with sufficient computing power.

The main challenges in this respect are:

- Common model to describe all resources and their (non)functional characteristics in all different layers (infrastructure, platform, service).
- Common model to describe services and (non)functional characteristics of resources in the different lifecycle phases: on-boarding and creation
- Mechanisms and protocols to enable verification of service and instance credentials in their lifecycle: configuration, provisioning, orchestration, operation, deprovisioning and post-mortem
- Mechanisms for stateful and stateless dynamic portability of data and applications
- Mechanisms for dynamic and automatic contracting and de-contracting of cloud and edge services
- Tools and mechanisms for dynamic service selection and composition based on user needs (see 3.3.3)
- Tools and mechanisms for dynamic configuration, provisioning, and orchestration (see 3.3.6) of programmable infrastructures
- Federated security mechanisms such as identity and access management, authentication and authorisation, confidentiality and integrity, multiple access, privacy
- Task scheduling and workload optimisation (see 3.3.3).

Expected time: 3-5 years

Societal Impact: Europe will be able to regain its digital sovereignty, enjoying cloud services that comply with European regulations.

Technological Impact: Driving innovation in the field of cloud, edge, and software development.

Business Impact: Creating new business models and increasing Europe's competitiveness.

Source: Gaia-X [2], IPCEI-CIS, Future Cloud Cluster Roadmap [10], Future Cloud Cluster Reference Architecture [11], [38], [39], [40], [41], [42], [43], [44], [45], [46], [47]–[49], [51], [52], [53], [69], [73].

Federation of Clouds **Score 7,72**	Technical (35%) **Score 8,05**	Contribution to Data Privacy and Data Sovereignty (20%) (**Score 10**)
		Main enabler to make the cloud federation scalable (15%) (**Score 10**)
		mature enough (15%) (**Score 8**)
		Mid-term (15%) (**Score 8**)
		EU approach for CC (15%) (**Score 8**)
		Open solutions gaining relevance (20%) (**Score 7**)
	Business (30%) **Score 9,4**	High influence in business digital transformation (30%) (**Score 10**)
		Increase SMEs competitiveness (25%) (**Score 10**)
		Compliance with EU regulation (20%) (**Score 7**)
		Fostering integrated CC offers (25%) (**Score 10**)
	Sectors (35%) **Score 5,95**	Mild influence in public services (25%) (**Score 4**)
		High important for Mobility (15%) (**Score 10**)
		Relatively important for Energy (15%) (**Score 5**)
		Relatively important for Home/Building (15%) (**Score 5**)
		High important for Agriculture (15%) (**Score 10**)
		High important for Manufacturing (15%) (**Score 8**)

Table 3. Federation of Clouds Scoring

3.3.3 Optimization techniques for non-functional characteristics of the cloud continuum such as energy consumption, resource selection, reliability, performance, latency minimization, …

Description: The use of heuristics and evolutionary algorithms has great potential to improve the non-functional characteristics of various domains of the cloud continuum.

Some of these include:

- Energy consumption: Minimise the power consumption of the data centre and edge nodes. Analyse the energy consumed by the workloads of services and virtual machines and be able to predict, tune and optimise the energy consumed by the workloads, as well as offload computation.
- (Dynamic) resource allocation: For resource allocation, the challenge is to apply heuristics and use as input not only "static" characteristics such as service location, CPU, etc., but also dynamic characteristics such as flow data from monitored (and potentially) unmonitored metrics such as throughput, mean time between failures in a given time period, which can also help to select an optimised mix of resources for an application.
- Latency minimisation: optimising latency by finding a balance between latency and reliability, for example.
- Data transmission minimisation.

Expected time: 3-5 years

Societal Impact: in the case of energy consumption, reduce the carbon footprint of data centres. In other cases, consumers will enjoy better quality of service.

Technological Impact: novel algorithms

Business Impact: Improve the quality of services provided. Reduce barriers to entry into the cloud market for new edge infrastructure/service providers (e.g. resource allocation mechanisms will be needed to create an abstraction layer over cloud/edge service providers, helping users to deal with the increasingly heterogeneous edge computing market and avoiding vendor lock-in).

Source: Future Cloud Cluster Roadmap [10], Future Cloud Cluster Reference Architecture [11], [40], [43], [44], [45], [46], [47]–[49], [57], [59], [61], [63], [64], [66], [69], [70], [72]

Optimization Techniques **Score 6,335**	Technical (35%) **Score 6,35**	EU Values Contribution to decrease the IT food print (20%) (**Score 8**).
		Sustainability Fully scalable and enhances scalability of the systems (15%) (**Score 10**)
		Not mature enough (15%) (**Score 5**)
		Mid-term (15%) (**Score 8**)
		Not directly related to regulations (15%) (**Score 2**)
		It depends on the underlying technology (20%) (**Score 5**)
	Business (30%) **Score 7,4**	It highly contributes to the digital transformation of the organizations (30%) (**Score 10**)
		Increase competitiveness of IT intensive organizations (25%) (**Score 8**)
		No directly affected (20%) (**Score 2**)
		Fostering new collaboration opportunities IA+Cloud (25%) (**Score 8**)
	Sectors (35%) **Score 5,4**	Low influence in public services (25%) (**Score 2**)
		High importance for Mobility (15%) (**Score 10**)
		High important for Energy (15%) (**Score 8**)
		Relatively important for Home/Building (15%) (**Score 5**)
		High important for Agriculture (15%) (**Score 10**)
		High important for Manufacturing (15%) (**Score 8**)

Table 4. Optimization techniques Scoring

3.3.4 Cognitive, self-healing, self-learning (programmable) infrastructures, services and applications

Description: The goal of cognitive computing in the cloud is to mimic the decision making that a DevOps team member would perform in a given situation and execute that decision automatically. For this, artificial intelligence techniques and algorithms have great potential. Example scenarios include better decision making in the dynamic composition of resources and services and better prediction of errors and anomalies of resources, applications, and services, learning from past failure situations by launching automatic self-configuring mechanisms.

Cognitive computing in the cloud therefore needs to classify and analyse large amounts of data (structured and unstructured) and from various sources, refine them, create and improve algorithms and their execution time, detect and recognise patterns, process natural language, and finally self-learn from data and situations.

Some research attempts have been made to develop self-healing tools and mechanisms and self-adaptive distributed applications. Self-healing strategies have ranged from not porting the application or part of the application to another resource, but simply scaling the resource or remotely restarting/reconfiguring the virtual machine automatically to finding another optimal configuration of the resource, provisioning it, configuring it and porting the application. The main challenge of the latter strategy is to port stateful components on the fly while maintaining data integrity and doing so securely.

For a cloud to be truly cognitive there must be a clear understanding of the metrics to be collected, the sources, frequency, and purpose of those metrics, but not only that. There must also be an understanding of cause-effect and what-ifs to create the right self-healing strategies for each possible situation, although the model must also learn from past situations (self-learning).

In the case of programmable infrastructure or infrastructure as code, this is a challenge that is not yet being fully addressed.

Expected time: 5-8 years

Societal Impact: Better quality of service

Technological Impact: novel algorithms

Business Impact: Increasing the competitiveness of European industry, greater automation and higher efficiency

Source: Surveys, HUB4CloudSCB, Future Cloud Cluster Roadmap [10], Future Cloud Cluster Reference Architecture [11], [54]

Cognitive, self-healing, self-learning (programmable) infrastructures, services and applications **Score 5,9225**	Technical (35%) **Score 6,95**	Indirect contribution to decrease the IT food print (20%) (**Score 6**)
		Scalable (15%) (**Score 8**)
		Not mature enough (15%) (**Score 3**)
		Long/mid-term (15%) (**Score 5**)
		Affected by the regulation (20%) (**Score 8**)
		It depends on the underlying technology (20%) (**Score 5**)
	Business (30%) **Score 6,85**	It contributes to the digital transformation in a substantial way (30%) (**Score 8**)
		Increase competitiveness of IT intensive organizations (25%) (**Score 6**)
		Directly affected (data governance) (20%) (**Score 6**)
		Innovative business models (25%) (**Score 7**)
	Sectors (35%) **Score 4,1**	Medium impact in Public Services (25%) (**Score 5**).
		Medium impact for Mobility (15%) (**Score 5**)
		Useful in Energy (15%) (Sc**ore 6**)
		Low influence in home/building (15%) (**Score 2**)
		Low influence in home/building (15%) (**Score 2**)
		High important for Manufacturing (15%) (**Score 8**)

Table 5. Cognitive Cloud Scoring

3.3.5 (Federated) Security mechanisms

Description: Security in federated clouds, which include multiple clouds but also cloud, edge, and fog, presents several challenges. These will be divided into the following:

- Identity management: how to ensure segregation of duties: managing, approving, and assigning user accounts
- Access management in a multi-layer context
- Authorisation: authorisation management not only for user accounts, but also for technical accounts, i.e., accounts that are assigned to machines for compliance or automatic checks, for example.
- Confidentiality, integrity, and availability

In the current context, digital identities are stored in centralised databases that carry several risks, as users, in most cases, expose their data voluntarily even if they are not aware of it. OpenID is an effort to create a universal solution, but it also presents problems. The European Commission has developed eIDAS, the European digital identity, which has many advantages (e.g. cross-border interoperability), but the citizen must also provide all his or her data containing his or her digital identifier, which in many cases is excessive.

The federated identity model allows single sign-on and avoids sharing unnecessary data with third parties. In this context, the user must trust the identity provider to transfer only the information he/she really wants to share, and the service provider must trust the attributes of the digital identity he/she receives from the intermediary (identity provider). Hence the need for a model that puts the user back in control of his or her own information and identity and breaks down the information silos that are attractive to wicked actors. In this way, it is the user himself who has full custody and control over his data, sharing only what he wants and when he wants it. One such model is the Sovereign Identity Model (SSI), where the user is the exclusive owner, manager, and custodian of his or her data and identity. As a complement, there is the option to self-manage personal identity through Decentralised Identity (DID). In the case of the cloud continuum, as stated above, the accounts that manage the services are technical accounts. Solutions such as those mentioned above have not yet been investigated in such technical and impersonalised contexts.

Expected time: 3-5 years

Societal Impact: trustworthiness

Technological Impact: mechanisms, protocols, policies

Business Impact: trust in all layers of the cloud federation, ability to prevent and react quickly to intruders and malicious attacks, integrity and confidentiality.

Source: Gaia-X [2], EUCS [8], Future Cloud Cluster Roadmap [10], Future Cloud Cluster Reference Architecture [11], [38], [39], [57], [58], [62], [65], [68], [73].

Security Mechanisms **Score 7,555**	Technical (35%) **Score 7,75**	SSI and DDI are key for EU values on privacy (20%) (**Score 10**)
		DID linked to the success of Cloud Federation (15%) (**Score 10**)
		Work in progress (15%) (**Score 4**)
		Midterm (15%) (**Score 5**)
		Wallet concept been regulated (15%) (**Score 6**)
		Openness from EU support (20%) (**Score 10**)
	Business (30%) **Score 6,75**	Trust will facilitate Digital transformation (30%) (**Score 8**)
		It might impact in profitability by engaging more customers due to trust (25%) (**Score 4**)
		Adoption will facilitate cross border services (20%) (**Score 8**)
		More integrated services offer (25%) (**Score 7**)
	Sectors (35%) **Score 8,05**	Trust is a must for Public sector (25%) (**Score 10**)
		Security is essential in taking decision on mobility (15%) (**Score 9**)
		It might help to share Energy data (15%) (**Score 7**)
		It might help to share Home/Building data (15%) (**Score 6**)
		It might help to share Agriculture data (15%) (**Score 6**)
		Manufacturing requires securing all processes and data (15%) (**Score 9**)

Table 6. Security mechanisms Scoring

3.3.6 Dynamic configuration, provisioning, and orchestration in the cloud continuum

Description: application developers and operators in the cloud continuum today face the challenge of adopting new paradigms such as DevOps or MLOps, but often lack the right languages, tools and mechanisms to configure, plan, prepare and execute tasks in heterogeneous computing environments. Moreover, they are faced with the tasks of continuous optimisation and autonomous (re)deployment of complex, context-aware and stateless/stateful applications and data in a federated environment (including edge, cloud and network services) ensuring service continuity and anticipating possible failures in the underlying infrastructure, especially in critical systems that need to be resilient and whose response time becomes vital.

In the case of (infrastructural) languages, the plethora of existing languages covering the infrastructure lifecycle (configuration, provisioning, deployment and orchestration) and their limited focus on some of the activities to be automated, leads to several problems: long selection of tools, difficulties to hire developers specialised in all selected tools, lack of integration between the different activities, need of time to learn and experiment with new tools, much effort to integrate the selected tools for the different activities, lack of multilingual support, thus generating potential errors in the chain. In addition, most of these languages and tools are currently not compatible with edge or other infrastructural computational resources.

Now that data processing at the edge is becoming increasingly important to reduce data transmission and avoid network latency, the automatic deployment of analytical pipelines together with dynamic provisioning and workload configuration at the edge node is an unsolved challenge.

Expected time: 3-5 years

Societal Impact: improved quality of services

Technological Impact: service composition: ability to compose/assemble services based on a common domain-specific language to express requirements, characteristics, and constraints.

Business Impact: increased competitiveness, increased automation, increased productivity, increased added value.

Source: Gaia-X [2], Future Cloud Cluster Roadmap [10], Future Cloud Cluster Reference Architecture [11], [40], [41], [42], [45], [46], [47]–[49], [51], [53], [54], [57], [67].

Orchestration in the Cloud continuum **Score 6,3575**	Technical (35%) **Score 5,75**	Mild impact on energy consumption (20%) (**Score 5**)
		Orchestration will provide scalability (15%) (**Score 10**)
		Work in progress (15%) (**Score 4**)
		Midterm (15%) (**Score 5**)
		Will contribute to EU regulations (15%) (**Score 6**)
		Many private solutions (20%) (**Score 5**)
	Business (30%) **Score 7,25**	Orchestration will facilitate Digital transformation (30%) (**Score 8**)
		Adoption will increase productivity (25%) (**Score 8**)
		Cloud Services within different countries while complying with one regulation (20%) (**Score 8**)
		More value to services (25%) (**Score 9**)
	Sectors (35%) **Score 6,2**	Mild influence for Public sector (25%) (**Score 5**)
		Important impact on mobility (15%) (**Score 9**)
		Mild influence for Energy (15%) (**Score 5**)
		Mild influence for Home/Building (15%) (**Score 5**)
		Mild influence for Agriculture (15%) (**Score 5**)
		Important impact on Manufacturing (15%) (**Score 9**)

Table 7. Orchestration in the Cloud Continuum Scoring

3.3.7 Data Governance frameworks

Description: Data is becoming the new asset of organisations. The creation of sectoral and cross-sectoral data spaces is expected to become a reality. However, challenges remain:

- Implementation of data usage policies: while usage-related requirements are often expressed informally and by non-technical people, usage policies must be expressed formally, so that they can be read by machines and consumed by them. Such usage policies often require prior provider-consumer negotiation.
- Enforcement of data usage policies: data access is usually done only once, but data usage is done several times in one session. Therefore, enforcement of policies is very important.
- Traceability: keep track, especially in distributed and federated systems, of policy enforcement by consumers. In this way, the provider can always verify correct compliance with usage requirements.
- Monetisation and revenue models for data exchange
- Data sharing mechanisms
- Privacy preserving technologies, multiparty computing (MPC), homomorphic encryption, differential privacy, obfuscation, privacy risk assessment.
- Interoperability: technical and semantic interoperability; need for data connectors, curators and sanitisers.

Expected time: 3-5 years

Societal Impact: improved services, processes, and products

Technological Impact: connectors, policies, mechanisms, tools.

Business Impact: better decision-making, greater competitiveness.

Source: IDSA [4], Gaia-X [2].

Data Governance Frameworks **Score 8,0525**	Technical (35%) **Score 8,8**	Contribution to Data Privacy and Data Sovereignty (20%) (**Score 10**)
		Main enabler to make the cloud federation scalable (15%) (**Score 10**)
		Still to mature (15%) (**Score 8**)
		Mid-term (15%) (**Score 8**)
		Data Governance Act (15%) (**Score 10**)
		Open solutions available (20%) (**Score 7**)
	Business (30%) **Score 8,35**	Digital transformation in B2G/G2B (30%) (**Score 7**)
		New revenue models (25%) (**Score 10**)
		Linked to GDPR (20%) (**Score 10**)
		New business models on data sharing (25%) (**Score 7**)
	Sectors (35%) **Score 7,05**	High influence in public services (25%) (**Score 10**)
		High important for Mobility (15%) (**Score 10**)
		Relatively important for Energy (15%) (**Score 5**)
		Relatively important for Home/Building (15%) (**Score 5**)
		High important for Agriculture (15%) (**Score 10**)
		High important for Manufacturing (15%) (**Score 7**)

Table 8. Data Governance Frameworks Scoring

4 CONCLUSIONS

This document has identified the main research and innovation challenges and priorities to provide the HUB4CLOUD roadmap and focus for policy recommendations to guide future European investments in cloud computing.

Once the context is understood, research topics have been extracted following a systematic and replicable approach. From these sites, and from the input of the context analysis, seven major themes related to cloud computing have been identified and are described in chapter 3.

The method selected to establish a ranking and prioritisation of the seven research challenges was based on Multi-Criteria Decision Analysis, or MCDA. The three main factors are technical, business, and sectoral. Each of the factors is composed of different criteria that include a set of questions to facilitate their individual scoring. This method, as well as the weight assigned to each factor, was agreed within the HUB4CLOUD consortium.

This methodology was shared with selected stakeholders to obtain a first ranking of cloud computing challenges. Several key representatives of European RIAs, as well as European CEOs, government representatives, GAIA-X CTO, CTOs of digital hubs and technical advisors have been consulted on the seven broad themes.

The results are summarised in the Figure 8 and show the scores obtained per challenge and factor.

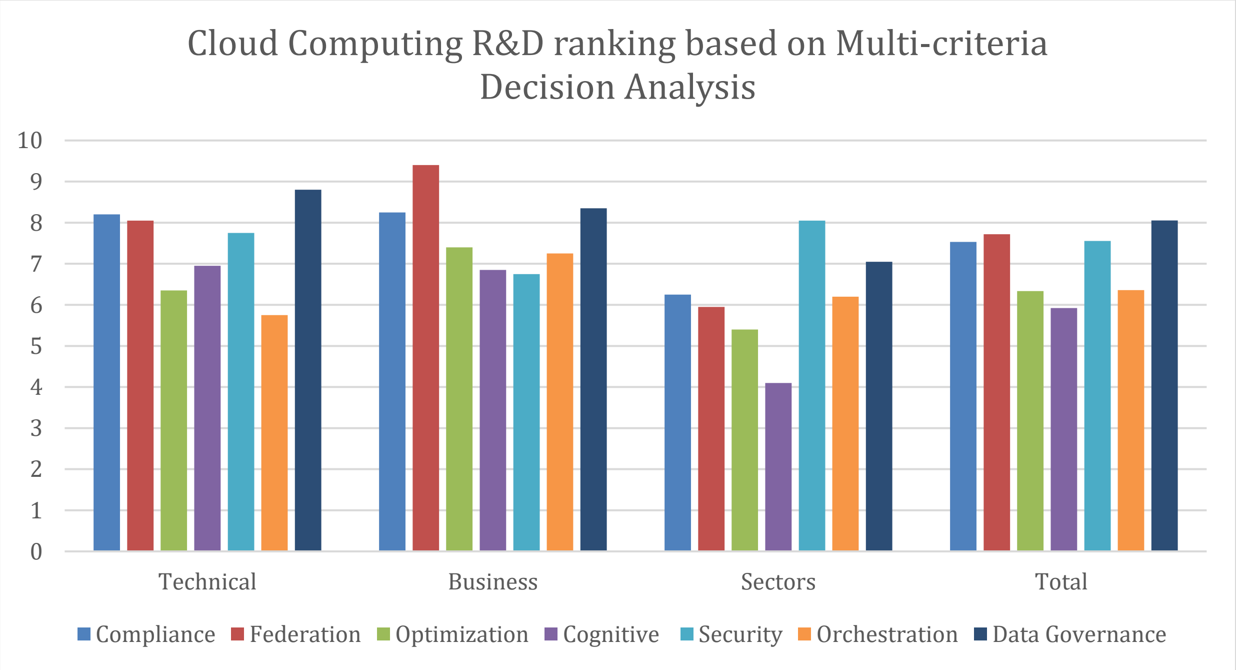

Figure 9 Cloud computing R&D ranking

From the **technical perspective,** the most supported R&D challenge is Data Governance, followed by Compliance as Code and Cloud Federation.

When looking at the **business perspective**, the same three R&D challenges remain at the top, albeit in a different order. Cloud Federation is the most likely to contribute to the acceleration of Cloud Computing business in Europe.

However, when analysing the challenges from the point of view of relevance to the different **sectors**, the one that stands out by far is Security. This is followed by Data Governance, which shows that the industry is very sensitive to privacy and security.

Finally, taking into account the scores obtained in all the factors, the four challenges shown above once again stand out, with Data Governance as the highest priority, followed by Federation of Cloud, Compliance as Code and Security, with very little difference between them.

The next step will be to conduct public consultations to confront the results obtained with the different sensitivities in the cloud computing ecosystem with the intention of achieving a consolidated roadmap that will be useful for the European Commission in defining policy recommendations.

The last version of this document, due towards the end of the project, would contain the final recommendations to the European Commission for the upcoming research work programmes.

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