HORIZON CLOUD

THE EUROPEAN
CLOUD COMPUTING HUB

Towards a vibrant European Cloud Computing ecosystem

Strategy Position Paper

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ABSTRACT

This document elaborates on the topic of selecting some strategic objectives that are relevant for the European Cloud Computing ecosystem and presents how and to what extent ensuring alignment towards such objectives across the initiatives of the ECC ecosystems is a beneficial factor. Moreover, several recommendations and measures are proposed to help ensure an overall strategic alignment across the ECC ecosystem. Some of these measures are of general applicability, whereas some others are more narrowly tailored, as they rely on peculiar traits and conditions that apply of specific topics or objectives.

EXECUTIVE SUMMARY

The HUB4CLOUD Coordination and Support Action has been actively engaged on several fronts within the European Cloud Computing (ECC) ecosystem interacting and engaging with several relevant ongoing Horizon 2020 projects, but also with representatives of the European Commission and many organisations and experts across various research and innovation fields in Europe and beyond. This to help grow and diversify the community around the ECC ecosystem, while helping all its participants in reaching out to a broader audience and maximise the impact of their research and innovation efforts and results. This is a challenging job as it requires to understand and harmonise visions, objectives, and activities across different communities that are indeed gathering around the so-called computing continuum at the convergence of Cloud, Edge and IoT.

Therefore, one of the very central aspects to ensure the growth of a cohesive and vibrant ECC ecosystem is the capability to identify, analyse and share common strategic objectives across the community, despite its diversity and partial fragmentation. Only by aligning on a commonly shared strategic agenda it will be possible to guarantee growth, impact, and sustainability of the European Cloud Computing ecosystem.

This document elaborates on the strategic objectives around the themes identified as the most relevant to the community and presents how and to what extent ensuring alignment towards such objectives across the initiatives of the ECC ecosystems is beneficial. Recommendations and measures are proposed to help ensure a well-suited strategic alignment across the ECC ecosystem. Some of these measures are of general applicability, whereas others are more narrowly tailored, as they rely on peculiar traits and conditions of specific topics or objectives.

For each identified strategic objective, some structural analysis has suggested appropriate levels of alignment, and where they apply. Measures proposed to support the indicated alignment in the appropriate contexts distinguish between measures that can be adopted by individual research initiatives or groups, and more systemic ones that can work best when picked up by coordination projects, institutions, or communities as a whole.

The purpose of this paper, without any ambition of completeness, is to gather the views of the ECC project portfolio about what themes and objectives are strategically important, and to serve as a informational guideline for multiple stakeholders that can influence the intended and achieved alignment level around specific ECC objectives. The analysis and recommendations contained herein can guide the debate and action planning of suitable policymaking, associative, and communication institutions, as well as research and innovation actors.

A complementary purpose, which could gain more and more importance in the near future, is to be an informative communication asset to introduce new members of the ECC community to the general landscape and themes of interest. This is particularly relevant in light of the various convergence and interconnection trends occurring between ECC and, e.g., IoT, AI, and Big Data communities, as well as the evolving and increasingly integrated European policy context.

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ABBREVIATIONS

CSA	Coordination and Support Action
CSP	Cloud Service Provider
EC	European Commission
ECC	European Cloud Computing
FaaS	Functions as a Service
GDPR	General Data Protection Regulation
HLEG	High-Level Expert Group
IaaS	Infrastructure as a Service
ICT	Information and Communication Technology
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Things
NIST	National Institute of Standards and Technology
PaaS	Platform as a Service
R&I	Research and Innovation
RIA	Research and Innovation Action
SaaS	Software as a Service

1 INTRODUCTION

The HUB4CLOUD Coordination and Support Action has been actively engaged on several fronts within the European Cloud Computing (ECC) ecosystem interacting and engaging with several relevant ongoing Horizon 2020 projects, but also with representatives of the European Commission and many organisations and experts across various research and innovation fields in Europe and beyond. This to help grow and diversify the community around the ECC ecosystem, while helping all its participants in reaching out to a broader audience and maximise the impact of their R&I efforts and results. This is a challenging job, requiring to understand and harmonise visions, objectives, and activities across different communities gathering around the so-called computing continuum at the convergence of Cloud, Edge and IoT.

Therefore, one of the very central aspects to ensure the growth of a cohesive and vibrant ECC ecosystem is the capability to identify, analyse and share common strategic objectives across the community, despite its diversity and partial fragmentation. Only by aligning on a commonly shared strategic agenda it will be possible to guarantee growth, impact, and sustainability of the European Cloud Computing ecosystem.

This document, which was initially planned for May 2022, but that has been delayed (in agreement with the HUB4CLOUD Project Officer) to the end of the project, elaborates on the choice of strategic objectives around the themes identified as the most relevant to the community, and presents how and to what extent ensuring alignment towards such objectives across the initiatives of the ECC ecosystems is beneficial. Moreover, several recommendations and measures are proposed to help ensure an overall strategic alignment across the ECC ecosystem. Some of these measures are of general applicability, whereas some others are more narrowly tailored, as they rely on peculiar traits and conditions that apply of specific topics or objectives.

The remaining of this document is organised as follows:

- Section 2 first presents and discusses a list of topics, related to Cloud Computing that all have the potential of playing a strategic role with respect to the evolution and success of the European Cloud Computing community. Then, it zooms on a subset of those topics that have emerged as the most relevant ones within the overall Horizon Europe Work Programme also in a forward-looking perspective.
- Section 3 elaborates on the findings discussed in Section 2, to identify the main strategic objectives and alignment factors that are key for the growth and development of an open ecosystem for European Cloud Computing. The focus is first on some factors concurring to determine the alignment level for a given strategic goal, then on discussing the strategic objectives per selected theme and the corresponding alignment measures.
- Section 4 concludes this deliverable providing summarising the main findings presented in the previous sections and providing and overview of aspects that will require more work in the future.

2 EUROPEAN CLOUD COMPUTING STRATEGIC THEMES

This Section presents and discusses a list of topics, related to Cloud Computing in various ways, that all have the potential of playing a strategic role with respect to the evolution and success of the European Cloud Computing community, whether from a scientific and technological perspective, from an economic one, or because of the social and policy impact that is foreseen as associated to further development in these areas. In the remainder of this document, the word **theme** and **themes** are used exclusively to refer to the areas of investigation considered for strategic alignment analysis, either individually or in a group. Words with similar meaning like *topic*, *domain*, *area* are instead to be understood in their generic, everyday meaning and can refer to one of the themes or not, as it will be clear from the context.

After the presentation of a long list of options for the themes in the next subsection, a shortlisting process is described, which has been carried out following a consultation with the Horizon 2020 projects in the Cloud Computing arena (topics ICT-15-2019 and ICT-40-2020) and the subsequent development during HUB4CLOUD further engagement activities, as well as the policy and research directions that have so far emerged from the first two years of the Horizon Europe Work Programme.

2.1 Candidate Themes for Strategic Alignment

The initial long list of themes deemed relevant for the purpose of evaluating the optimal level of strategic alignment for European Cloud Computing included **eight themes**.

1. Compositional Cloud Certification
2. Open Source
3. Skill Development
4. Software Engineering for the Cloud
5. Green Cloud
6. Cloud Federation
7. Cloud-Edge-IoT Continuum
8. AI for the Cloud

Each one of these was analysed first, and then presented to a group of representatives of H2020 Cloud Computing projects for assessment and selection. For each of these themes, the following points were addressed:

- Overall description of the theme.
- Reasons for its significance for European Cloud Computing strategy.
- Current state of the research and innovation work around the theme in Europe.
- Examples of projects, initiatives, and alliances with an interest in the theme.

These eight themes are described in the following subsections

2.1.1 Compositional Cloud Certification

Previous analysis of the state and trends of Cloud Computing adoption has highlighted how agreed and **standardised certification schemes** can play a key role in Europe. For example, in [1], Page 4, it is pointed out that to "*Promote standard certification and auditing instruments that make it easier for cloud providers to comply with existing regulation and help cloud buyers to gain more transparent understanding of contractual conditions*" is an important measure to

address **the major challenge of compliance, trust, and fairness between supply and demand**. Further work from the Horizon Cloud initiative (e.g., as shown in [2], Page 51) recognises the contribution of ENISA and their [3] certification scheme for EU Cloud Services (EUCS); this is particularly connected to the cybersecurity risks and trust aspects that are another major challenge identified for European Cloud Computing.

In Cloud Computing, both the technical architecture and the business and cost models conspire to create **a service-oriented delivery environment at all levels, IaaS, PaaS, and SaaS**. In such a landscape, offered services may and will depend on other services so that a trustworthy end-to-end certification scheme must rely on compositionality to be able to certify the whole on the basis of its parts. **Compositional Cloud Certification** is in fact the approach adopted by ENISA EUCS, and means combining risk assessments, security controls and implementation measures, conformity assessment methods, evidence, and other factors.

Beyond helping with cybersecurity and trust, cloud certification could help with interoperability and market clarity and consolidation; as Figure 1 shows, there are several security certifications that are adopted by relevant CSPs, but the overall market is still fragmented. Moreover, most of such certifications are not yet specific to Cloud Computing. An initiative such as the ENISA EUCS, which is currently available in a draft version and underwent a public consultation towards the production and release of a final version, is therefore particularly well suited to the current situation of European Cloud Computing.

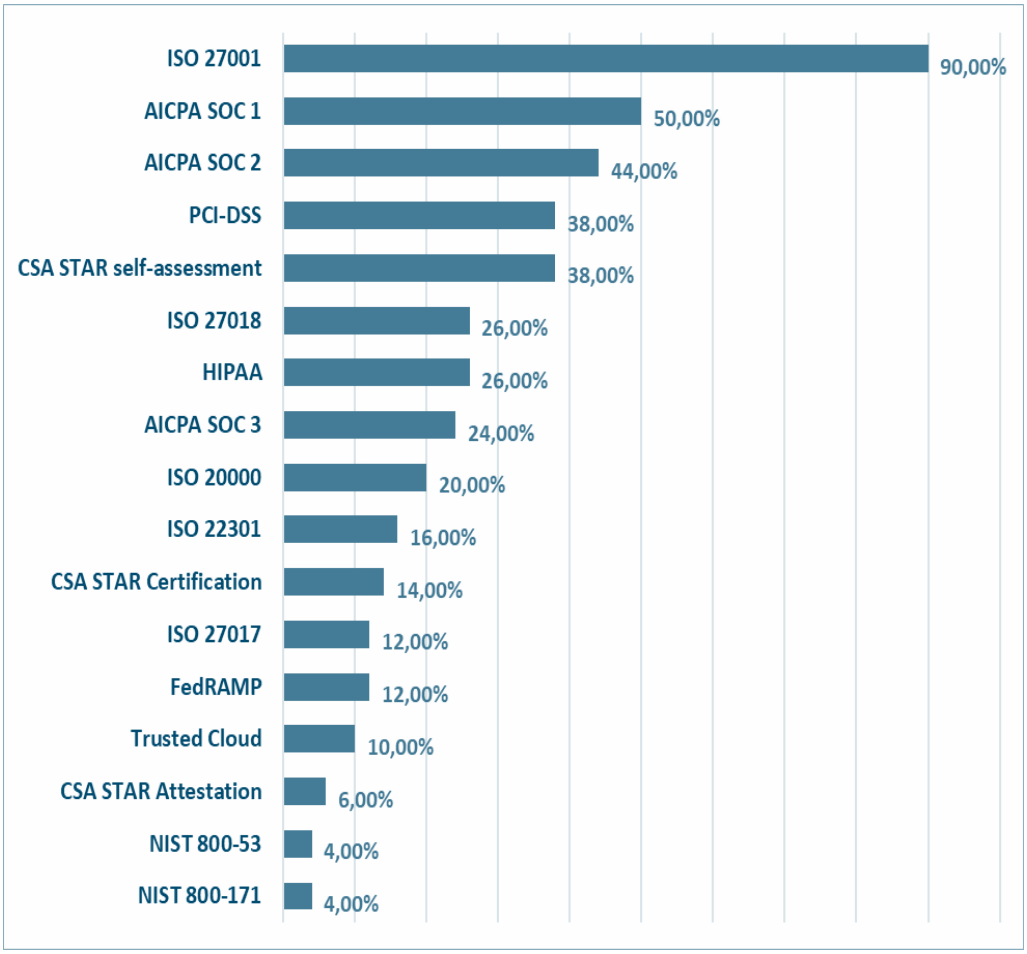

Figure 1 - Accredited certifications from top 50 CSPs

Compositional and cybersecurity certifications are also a hot topic for the European research ecosystem, with several Horizon 2020 research and innovation projects either completed[1] or currently active[2], and new ones to come as part of the Horizon Europe programme. Moreover, due to the increasingly heterogeneous nature and system-of-systems approach implied by the Cloud-IoT convergence towards a Cloud Computing Continuum, a dynamic and extendable compositional approach is needed, possibly relying on the latest certification schemes for Cloud and IoT, such as the one promoted by EUCS, and paying due consideration to the key relevant legal aspects, such as GDPR [4], the European Data Governance Act [5], and the Data Act [6].

2.1.2 Open Source

From its inception decades ago, Open Source is now a global movement and among the major forces shaping the ICT industry and environment in all sectors. From technical solutions to business models, from social impact to geopolitical landscape, everything related to computers and software must consider the principles, practice, and effects of Open Source.

From a European perspective, there is an overall **Open Source Software Strategy** from the European Commission [7], as well as more specific actions and innovation topics related to Cloud Computing. Here the general importance of Open Source (software, but also hardware in some key areas) for **European digital autonomy** combines with the ongoing convergence towards Cloud-Edge-IoT continuum (discussed in Section 2.1.7) and the goal of increased Cloud Computing adoption in Europe.

Open Source is also a vector for market impact as it can be an extremely effective adoption enabler and accelerator, and it has been identified as a public good with significant impact on technological independence, competitiveness, and innovation [8]. **A strong European presence and lead on open-source projects for the computing continuum will both promote EU technologies and optimally position European organisations** to provide skills, products, and services around these technologies and projects.

The obvious strong connection of Open Source with Software Engineering at large also applies when considering more specifically Cloud Computing and its evolution; the project and activities mentioned in Section 2.1.4 are also relevant to this topic, with an additional mention for the *CL4-2022-DIGITAL-EMERGING-01-26 – Open source for cloud-based services* Horizon Europe topic. The Horizon Cloud initiative and HUB4CLOUD have Open Source for Cloud Computing as one of the core landscaping and investigation areas, also considering its relation to standardisation activities [9]. Moving on to consider the role of Open Source for European research and innovation projects, it must be recognised that, in the domains of Cloud Computing and IoT, more work is needed to achieve an adequate impact (e.g., measured by the number of European companies and projects that are top contributors to globally leading Open Source projects such as OpenStack or Kubernetes).

2.1.3 Skill Development

Europe needs digitally empowered and capable citizens, a digitally skilled workforce and way more digital experts than today. Basic digital skills for all citizens and the opportunity to acquire specialized skills in information and communications technology (ICT) for the workforce are a prerequisite to participate actively in the Digital Decade. Within the Digital Compass [10],

[1] DECIDE project (see https://www.decide-h2020.eu/), CERTMils project (see https://certmils.eu/)

[2] MEDINA project (see https://medina-project.eu/)

there is a proposed level of ambition that by 2030, 80% of all adults have basic digital skills, and at least 20 million are employed ICT specialists in the EU, with convergence between men and women. It is important to note that in the modern economy, digital skills are the shared language (including everything from social media to cybersecurity), so all workers need to be proficient in this language, but they do not necessarily need to have software coding skills.

The COVID-19 crisis further highlighted how digitalisation is crucial to ensure our society and economy can still function also in extreme emergency cases and how **cloud technologies play an essential role to ensure private and public service resiliency**. A major obstacle to overcome though is the capability for organizations and citizens to quickly take up on those digital skills that are needed to understand, adopt and use such technologies. The role European Cloud Computing projects and the outcomes they generate can play in skills development/upskilling and education, especially when it comes to advanced cloud technologies, is fundamental for the future of Europe and for the realization of its data and industrial strategy.

This theme belongs to HUB4CLOUD core focus, and the project gathered data from experts in the European cloud computing domain who are confronted by finding appropriate talent on a day-to-day basis. HUB4CLOUD conducted interviews, performed desk research and organized webinars and panels to gain insights from the market, discussing and learning from different actors (industries, SMEs and Startups, academia, online courses platforms and individuals) about the European cloud computing skills' gap and ways to bridge them. Further activity has focused on exploring the needs for Cloud Computing skills, training needs and opportunities in the next years [11], feeding these insights into work on roadmap and policy recommendations.

2.1.4 Software Engineering for the Cloud

Cloud Computing acted as a transformative force throughout ICT, changing the infrastructure and deployment needs for computer systems, as well as the dominant business models and value chains. From the CAP Theorem [12] to microservices architectures [13], to elastic resource management and orchestration [14], there are several important theoretical and practical software engineering innovations brought about or arisen because of Cloud Computing. These foundational steps have led in turn to new challenges and needs for further software engineering investigation and development targeting the Cloud Computing specifics.

The increasing system complexity and ongoing integration and convergence of Cloud Computing and IoT are two key reasons why Software Engineering for the Cloud emerged as a candidate theme for an analysis of the importance of strategic alignment. **Application developers and operators are invited to embrace Cloud Continuum adopting a DevOps perspective**, focusing on the whole Lifecycle of the Software, from the design and the development to the operation, as a whole and maintaining suitably coherent methodologies and tool chains. Increasing ubiquity and pervasiveness of computing capabilities and data availability resulted in the proliferation of complex applications, which effectively process data from heterogenous digital sources in a timely manner and bridge Cloud Computing, Edge Computing, and IoT.

The current European landscape faces several technical challenges and includes solution approaches related to Software Engineering for the Cloud: on DevOps, often the automation and the tool chain are partial and context-specific, and some work still needs to be done on skill development and talent retention; even in the more specific fields of system monitoring and benchmarking there is a lack of holistic approaches with the reliance on some more traditional methods that are not always suited to cloud-native, online environments. On more advanced topics, such as self-healing and the transition to a full Cloud-Edge-IoT computing continuum, progress is being made but there are few, if any, comprehensive and mature approaches that could be designated as best practice to follow.

Given the importance of this theme and the still insufficient level of maturity in some key areas, it is not surprising that several European research and innovation initiatives are active in this

domain. From a coordination and synergy point of view, HUB4CLOUD has set up and is leveraging a liaison with the ongoing CSA project SWForum[3] that manages the RIA projects and community around European software engineering. Both projects from the Cloud Computing[4] (ICT-06-2016, ICT-15-2019 and ICT-40-2020) and Software Technologies[5] (ICT-50-2020) topics are engaged in Software Engineering for the Cloud, tackling for example modelling of infrastructural elements, DevOps for Cloud-Edge-IoT Continuum native applications, performance optimisation in Edge Computing, or Self-healing applications.

2.1.5 Green Cloud

Considering the sustainability, environmental impact, and in **particular the carbon footprint of Cloud Computing has by now become paramount**, given the growth and relevance of the sector and the overall strategic European objectives indicated by the EC for the European Green Deal and the Digital Decade [15]. This theme, as the two subsequent ones described in Section 2.1.6 and Section 2.1.7, is one of the major areas that has been covered by the H-CLOUD CSA project that recently finished; **Green Cloud challenges and requirements are therefore included in the Green Paper** [1] **and in a dedicated Briefing Paper** [16]. Technologies, standards, policies, and operating approaches needed to reduce the energy and environmental footprint of Cloud Computing and of related networking and distributed information systems such as edge computing include requirements and challenges at multiple levels: on application architecture, end-to-end carbon emissions associated to the whole product life cycle of ICT hardware, design and operation of data centres, connection to and usage of renewable and sustainably generated electrical power including heat reuse and reduced water supply consumption, and synergy with communication network infrastructures.

This theme is strategically important for two different but related reasons: on the one hand, the cloud-to-edge computing continuum must be energy-, and more importantly, environmentally-, efficient as a contribution to the general carbon neutrality and sustainability objectives. On the other hand, **energy efficient computing is required across the EU as well as globally**, so that EU leadership can support EU competitiveness. This entails providing EU organizations and consumers the information and possibly the means they need to make environmentally-aware decisions about their cloud computing resources, though an holistic approach which empowers market participants to optimize the systems of which they are only a part.

EU Data centre power consumption was estimated [17] at almost 77 TWh in 2018 (2.7% of total EU electricity consumption), projected to grow by 21%, to 93 TWh, in 2025, including edge data centres; additional increases are expected from data transmission, particularly 5G. **Work is currently needed to tackle multiple knowledge gaps that still remain, in order to picture a clear landscape for European Green ICT and strategically plan at the business and policy levels**. R&D challenges remain in the technology stack, especially when the Computing Continuum and the manifold nature of Edge Computing enter the picture, as well as next generation mobile networks; policymakers and authorities possess however some levers in this

[3] European forum of the software research community. Available at https://swforum.eu/

[4] DITAS project (see https://www.ditas-project.eu/), ACCORDION project (see https://www.accordion-project.eu/), MORPHEMIC project (see http://morphemic.cloud/), PLEDGER project (see https://www.pledger-project.eu/), RAINBOW project (see http://rainbow-h2020.eu/), SMARTCLIDE project (see https://www.smartclide.eu/), PHYSICS project (see https://physics-faas.eu/), SERRANO project (see https://ict-serrano.eu/)

[5] PIACERE project (see https://www.piacere-project.eu/)

respect, such as policy tools to incentivise environmentally efficient behaviour, or public procurement guidelines.

2.1.6 Cloud Federation

Cloud federation [18] extends cloud interoperation beyond hybrid cloud and multi-cloud concepts **to cover a multilateral, distributed alliance of multiple providers of cloud services, and more generally information services**. The topic should be expanded to include data federation, since this is a way of managing distributed, decentralized data and data sources. Federations coordinate activities of their members/partners to collectively achieve a common, possibly higher, purpose. **Cloud federation** typically entails some specific loss of autonomy by the engaged participants in the service of an agreed higher purpose, but it remains a **loosely coupled**, **multi-authority agreement** that largely preserves the independence and operating freedom of its participants.

In the European context, cloud federation is often seen as an effective response to the higher market fragmentation and smaller average CSP size when compared to the United States or China [19]. Moreover, initiatives like **Gaia-X** [20] combine the political will, technical discussion forum, and widespread industry impact and consensus necessary **to achieve a true European common platform for secure cloud federation**. Beyond its economic significance and suitability to the specific context of European cloud market, cloud federation is relevant because offers insights into the technical challenges of ecosystems and multi-organizational coordination: business ecosystems are growing in importance across the economy worldwide, and understanding the technical foundations for these ecosystems can allow them to focus on their business purpose. This is particularly relevant in connection with the **Data Economy and specifically the common European Data Spaces** that are being worked on for several industry sectors such as agriculture and mobility [21]. GAIA-X and the European Open Science Cloud (EOSC) [22] are significant federation initiatives in Europe planned to serve the public and private sectors, and the research sector, respectively; in the United States, both NIST and IEEE are engaged in work to specify architectures and standards for interoperable cloud federation.

2.1.7 Cloud-Edge-IoT Continuum

Edge Computing [23] **locates data processing and storage capabilities close to end user devices, internet of things (IoT) devices, sensors, and other devices at the "network edge**", to reduce latency and network usage, and increase data security and governance. Edge computing allows data to be processed close to its source and avoid transmission to core data facilities and to the cloud. Edge computing follows a general paradigm of local data reduction and data processing to improve performance and responsiveness.

This theme was already a core focus of the H-CLOUD project and is widely covered in [1] and [2]. However, its definition varies, depending on the perspective of each specific community (e.g., core cloud providers, telecommunication operators, IoT manufacturers), and the ongoing Cloud-Edge-IoT convergence into a computing continuum means that Edge Computing is also a moving target, though its significance is not waning in any significant way.

The strongest reason for the strategic importance of Edge Computing in Europe is not just technical but rather systemic. **The EC has identified edge as both an essential enabler for a digital Europe and an important market that should be defended against non-EU domination**. Given the current market situation, especially in the IaaS segment where large hyperscalers dominate, as well as the normative path started with GDPR [4] and now including the Data Governance Act [5] and Data Act [6], there is an increased sensitivity in Europe to the issue of *digital autonomy* (sometimes referred to as digital sovereignty). However, this is not an isolationist trend. The intention is to actively participate in the global digital community by injecting into it a European vision. **Digital autonomy means the possibility for Europe to act independently according to its values**. Resilient digital supply chains need to be established

while driving digital innovation across all sectors of the economy, being assertive on what are the European values, safeguarding Europe's strategic interests and cooperating with the confidence of knowing that Europe has the means to follow its own path if necessary.

From a more technical perspective, **Edge computing encompasses a diverse range of technologies, architectures and standards** ranging from cloud computing, to embedded device technologies and architectures, to operating and technical models optimized for the telecommunications market. There are also a range of possible, yet still uncertain, business operating models that might feasibly arise in the edge computing market.

2.1.8 AI for the Cloud

This topic is not in the agenda of either CSA (H-CLOUD and HUB4CLOUD) from the Horizon Cloud initiative, but Artificial Intelligence is extremely widespread across the RIA projects that compose the currently active Cloud Computing project portfolio[6]. Above and beyond the specific projects, **AI is certainly an enormously important topic for Europe in general**, with the continued efforts [24] from the European Commission and the European Parliament to shape and define a "third way" for AI, usually branded with the *trustworthy AI* label.

This vision started with the first deliverables from the *Artificial Intelligence High-Level Expert Group*[7] (AI HLEG), namely the AI Definition [25] and the Ethics Guidelines [26]. Looking at these two documents, as well as to the draft legislation on AI [27], it appears clear that the European Commission has taken an academically sound approach in defining AI and characterising what an AI system is and does. When comparing the AI HLEG definition for Artificial Intelligence and some core principles of cloud-native systems such as the ones published by the Cloud Native Computing Foundation (CNCF) in [28], some interesting architectural challenges emerge.

In [25], the AI HLEG refers to several system properties (perceiving the environment through sensors, being capable to affect the environment through actuators, being goal-oriented, possessing an internal control and reasoning loop) as fundamental traits for AI. On the other hand, cloud-native systems are usually realised through mostly stateless components, loosely coupled interactions and data pipelines rather than control loops. This is an architectural mismatch between Big Data and Intelligent Agent models, which need be addressed and somehow solved to produce effective software infrastructure for intelligent computing continuum applications. The current landscape is still very open and no general agreement seems close: Michael Wooldridge wrote about "Big AI" in [29] to refer to the Big Data inspired approaches to Artificial Intelligence, and pointed out both their success and fundamental limitations and even systemic threats of the kind that the European trustworthy AI vision tries to counter.

Despite the challenges outlined above, **the interdependence of Cloud Computing and Artificial Intelligence is a clear and significant trend**: the emergence of Edge Computing and the Cloud-Edge-IoT continuum is mirrored by **AI topics such as federated learning, edge intelligence, or AI at the edge**. More specifically, the "AI for the Cloud" focus (i.e., how to use AI to improve Cloud Computing infrastructure), already present in Horizon 2020 projects from the ICT-15 and ICT-40 topics and part of the Horizon Cloud portfolio, became a fundamental pillar of the Cloud-Edge-IoT strategy within the Cluster 4 of Horizon Europe.

The *CL4-2022-DATA-01-02 – Cognitive Cloud: AI-enabled computing continuum from Cloud to*

[6] MORPHEMIC project (see http://morphemic.cloud/), SMARTCLIDE project (see https://www.smartclide.eu/), DATACLOUD project (see https://datacloudproject.eu/), AI-SPRINT project (see https://www.ai-sprint-project.eu/)

[7] . European Commission. High-*level expert group on artificial intelligence*. June 2022. Available at https://digital-strategy.ec.europa.eu/en/policies/expert-group-ai

Edge topic in the current call of the Work Programme 2021-2022 was defined thanks to the different inputs from independent experts and the cloud research community. The topic envisions that AI will transform current clouds into cognitive clouds, thus leading to a higher automation on different aspects of the Computing Continuum by dynamically adapting applications and infrastructure to data and computing variability demands. This topic puts AI centre stage as key enabler of next-generation Cloud and computing continuum infrastructure, but the interplay between AI and Cloud Computing is also significant in the *CL4-2021-DATA-01-05 – Future European platforms for the Edge: Meta Operating Systems* topic, where intelligent and dynamic resource management is an essential ingredient, and *CL4-2022-DATA-01-03 – Programming tools for decentralised intelligence and swarms*, where visions and approaches from the area of distributed AI and multi-agent systems combine with IoT and Edge scenarios.

2.2 Theme Selection Process

The list of topics in Section 2.1 was presented and discussed with representatives of the relevant RIAs and of the European Commission during a dedicated online workshop organised by the HUB4CLOUD project in April 2021. Some immediate feedback was gathered directly during the event, where the attendees were asked to comment on the perceived importance of each theme, both in general for the European Cloud Computing ecosystem and more specifically for their own project and interests. An initial poll for relevant strategic objectives and the most suitable level of alignment for each of them was also informally conducted, to gauge the immediate reaction of the project representatives attending the event.

2.2.1 Immediate Feedback Discussion

Software infrastructure and software development aspects were highlighted, pointing out that there are several vertical stacks (e.g., optimised for AI, or using the FaaS paradigm) and some form of enablement of these multiple stacks across the computing continuum is needed, for **increased interoperability** (without necessarily resorting to a fully unified standard or APIs, for example by providing common and open design environments). **Software Engineering**, especially geared towards Cloud Computing and the Cloud-Edge-IoT continuum, **is certainly paramount for many strategic objectives and has strong synergies with Open Source from a methodological, community, and economical point of view**.

The ***AI for Cloud*** theme also gathered immediate interest during the feedback session of the event, as its importance and priority now and in the foreseeable future was recognised, and the same was true for the ***Edge Computing*** theme, especially when situated within the wider landscape of Cloud-Edge-IoT continuum. Both themes had a strong presence across the RIA projects, as underlined by the introduction presentation that each project gave during the opening session of the workshop.

A special situation occurred for the ***Green Cloud*** theme: while its importance was recognised with awareness and even concern about the magnitude and risks of the challenges associated with this theme, as highlighted by the general climate and energy crises that Europe has to face at present and in the future, the RIA project themselves were unsure about how much they could really contribute to this theme. This might be attributed to the specialised focus of the H2020 projects belonging to the HUB4CLOUD portfolio (see Table 1), mostly taking a strongly ICT focused stance; the hope remains that with the new Horizon Europe programme, which should promote the multi-actor approach even more and has a presence of Cloud-Edge-IoT topics also beyond the core ICT Cluster 4 (e.g., the *Sustainable, secure and competitive energy supply* and *Clean and competitive solutions for all transport modes* destinations in Cluster 5), this situation will improve and wider **synergies between ICT partners and environment or sustainability specialists can be established**.

2.2.2 Survey on Themes and Strategic Objectives

After the initial workshop, the relevant RIA projects were invited to express their selection of topics more systematically considering the most important ones (up to four per project), and to optionally suggest some related strategic objectives. This section reports on the polled results: each project could answer the question "*Is this theme, in your opinion, strategically important for the European Cloud Computing community?"* for each theme, with the choices of *Yes*, *No*, and *Indifferent* and the request was not to express more than four *Yes*.

Additionally, as reported in Table 1, the RIA projects have been mapped to the themes according to their own areas of research, to provide some context for each project's choices and feedback. More information on all projects can be found on [30] and [31].

Table 1 - Mapping between projects and themes

RIA / Themes	Cloud Cert.	Open Source	Skill development	Software Engineering	Cloud Federation	Cloud/Edge Continuum	Green Cloud	AI for Cloud
ICT-15								
Morphemic		X	X	X				X
Pledger						X		
FogProtect						X		
SmartCLIDE		X		X				X
Rainbow		X		X		X		X
Accordion				X		X		
ICT-40								
Physics				X		X		
DataCloud				X		X		X
Charity			X			X		
AI-Sprint				X		X		X
Serrano					X	X	X	X

In the following, the responses from the RIA projects are shown and briefly discussed, for each theme in the original long list.

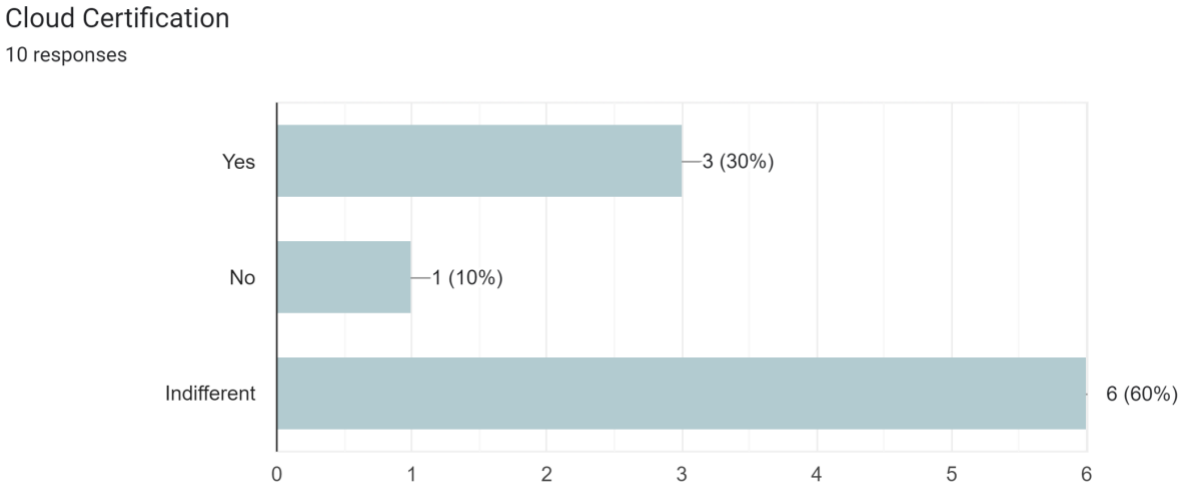

Figure 2 - Responses for the Cloud Certification theme

As Figure 2 shows, the *Cloud Certification* theme obtained a certain level of recognition by the respondents, but most of them expressed indifferent to it. This may be related to the eminently research and technical focus of the project representatives and not invalidate the overall importance of certification schemes for business stakeholders, but suggest that, for this audience, other themes might possibly be more suited for selection.

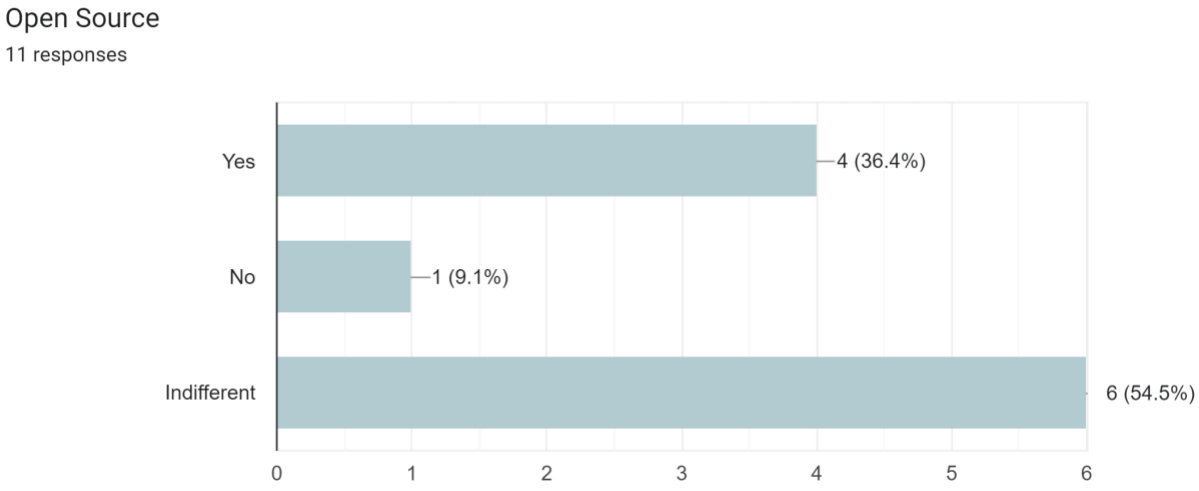

Figure 3 - Responses for the Open Source theme

The *Open Source* theme, illustrated in Figure 3, obtained a better approval than *Cloud Certification* did, but still had more than half of the responses expressing indifference. This can also be due to the request of limiting the *Yes* to no more than four, so that for some respondents Open Source was perhaps relevant, but not a high-priority theme.

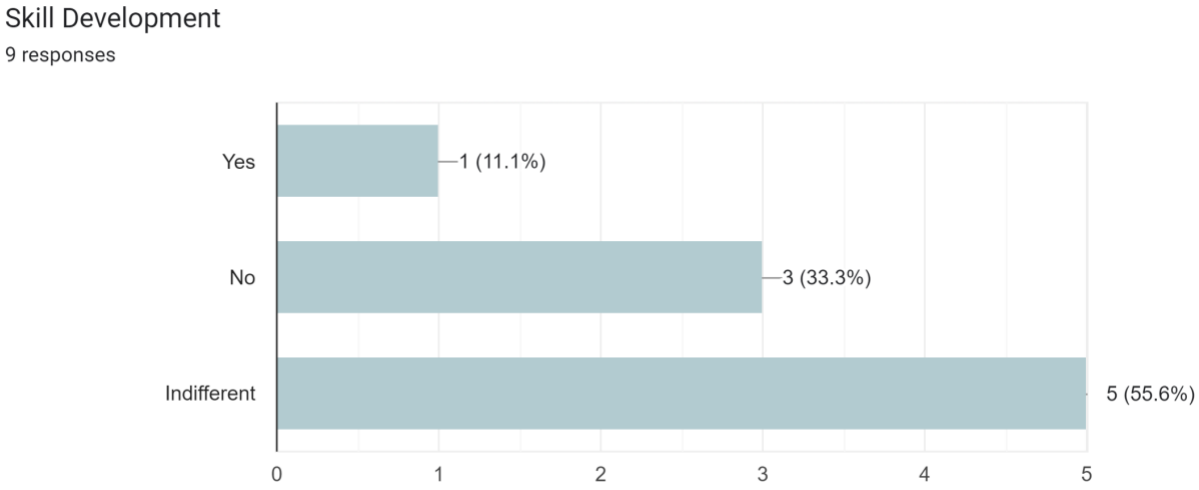

Figure 4 - Responses for the Skill Development theme

The chart in Figure 4 shows that the *Skill Development* theme gained very little traction with the project representatives, and it even scores the highest amount of *No* answers across all the themes. While this topic remains extremely important for the European Cloud Computing community at large and belongs to the core agenda of HUB4CLOUD (see [32]), it seems clear that for this specific audience the theme is not at all a priority.

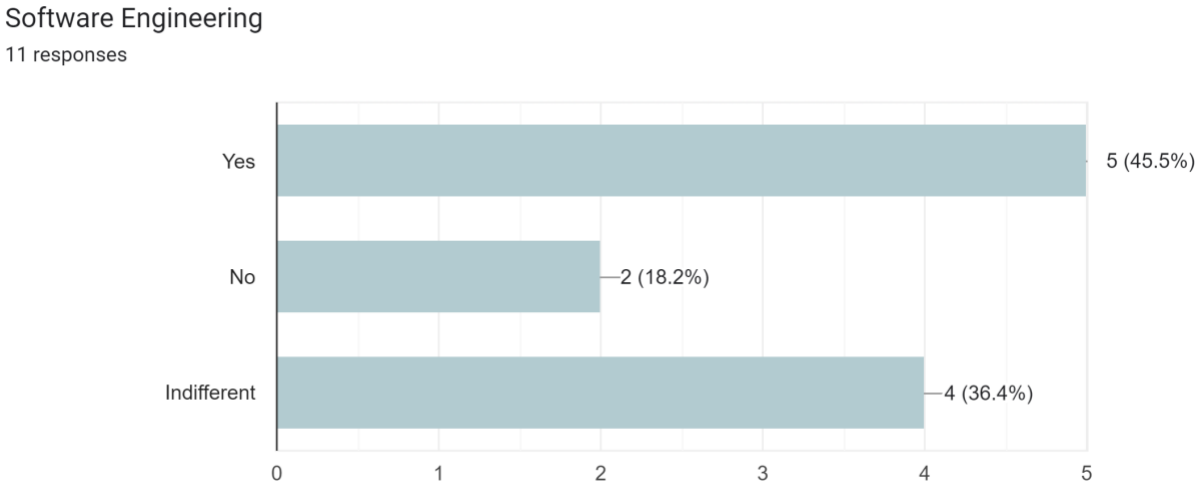

Figure 5 - Responses for the Software Engineering for the Cloud theme

As depicted in Figure 5, the *Software Engineering for the Cloud* theme has a strong appeal for the project representatives, rather unsurprisingly given their deep engagement in advanced cloud-native system research and development. The results of the poll reinforce the immediate feedback from the workshop and the project to theme mapping of Table 1.

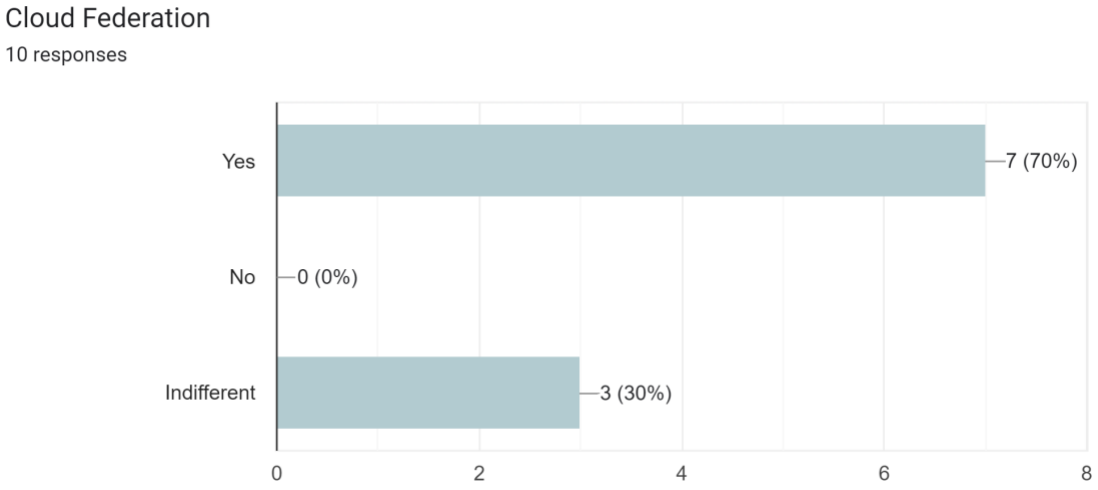

Figure 6 - Responses for the Cloud Federation theme

There is a strong recognition that the *Cloud Federation* theme is strategically very relevant, with Figure 6 showing a 70% of *Yes* answers. This result is well aligned with both the previous work by the Horizon Cloud initiative (the H-CLOUD project had cloud federation as one of its core domains of investigation) and the European landscape at large, not only the GAIA-X initiative but also the movement towards European Data Spaces.

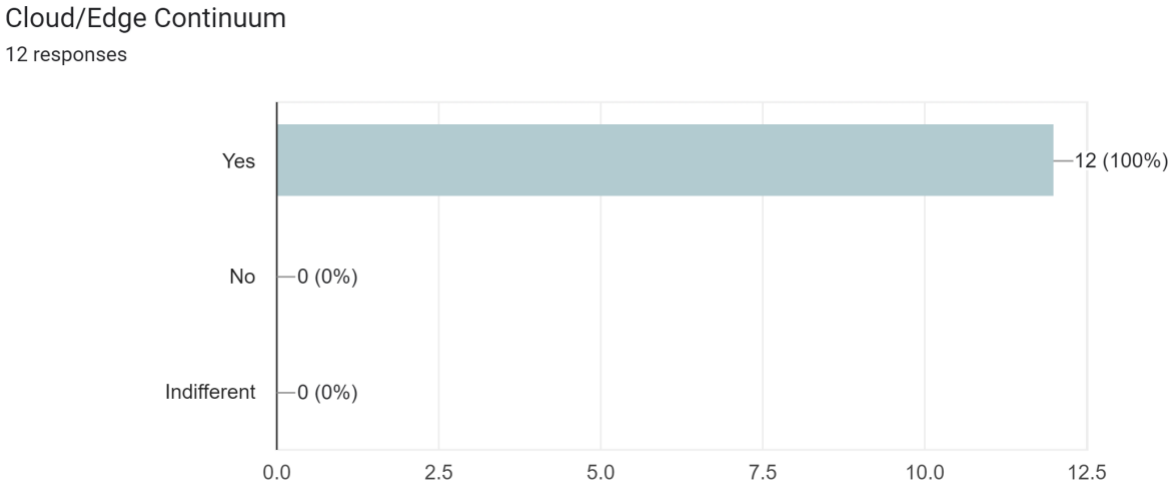

Figure 7 - Responses for the Cloud/Edge Continuum theme

It would be difficult to overestimate the strategic importance of Edge Computing and the Cloud-Edge-IoT convergence for European innovation and economy, but the unanimously positive response for the *Cloud/Edge Continuum* topic, shown in Figure 7, certainly removes any possible doubt. Edge Computing was already a Horizon Cloud focus, and material such as [1] and [23] already contains a wealth of information and analysis. However, in the current situation, Edge Computing is still a moving target, and its strategic relevance is certainly not going to decrease, also in light of the first Horizon Europe activities and the larger EC roadmap.

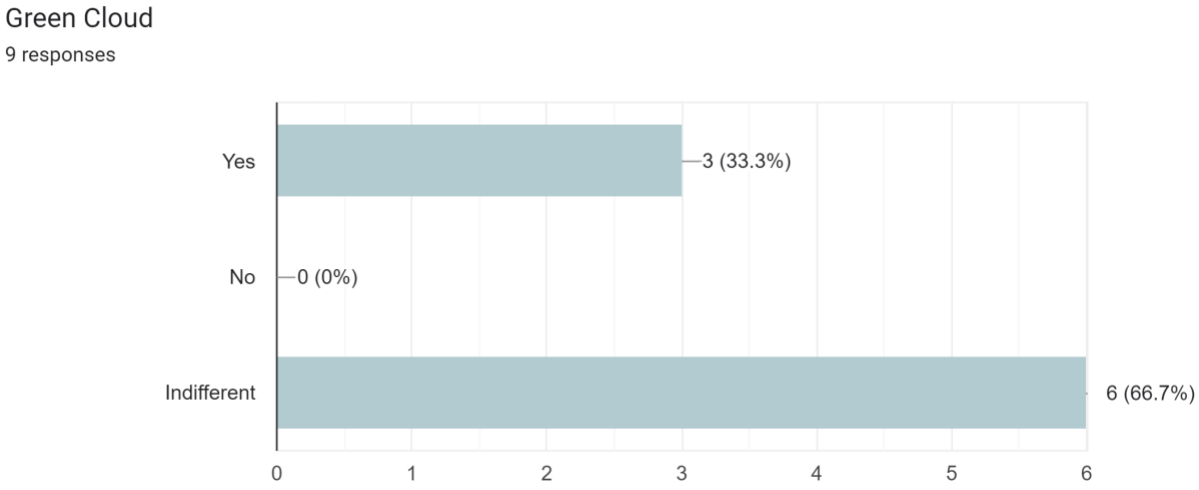

Figure 8 - Responses for the Green Cloud theme

Responses for the *Green Cloud* theme, shown in Figure 8, confirmed the somewhat unsatisfactory impression of the workshop: everybody acknowledges the critical importance of green and sustainable ICT (there are zero *No* answers), but two thirds of the project representatives declared their indifference to the topic as a key strategic factor for European Cloud Computing.

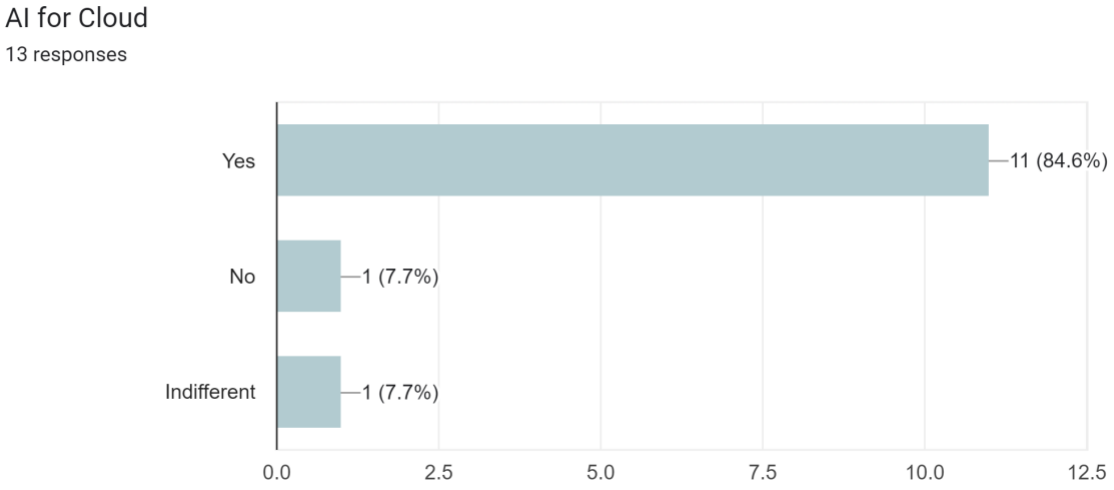

Figure 9 - Responses for the AI for Cloud theme

The polled responses for the *AI for Cloud* theme, reported in Figure 9, confirm the strong interest of the project representatives: an overwhelming majority of the respondents considered the relationship between Artificial Intelligence and Cloud Computing as strategically important for Europe.

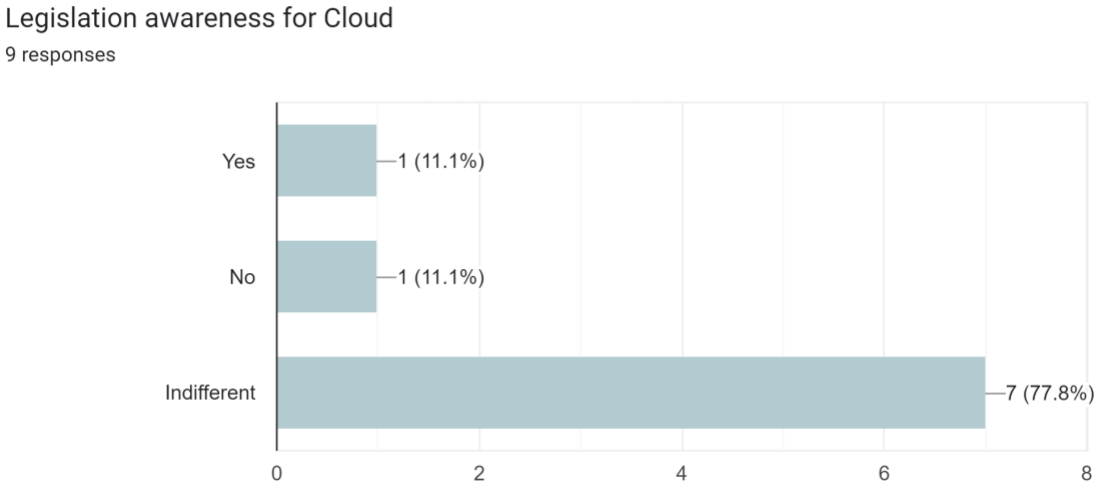

Figure 10 - Responses for the Legislation Awareness for the Cloud theme

The *Legislation Awareness for Cloud* topic was not discussed at the workshop, but was nevertheless added to the poll list because of some findings of [1], where demand-side challenges and obstacles to Cloud adoption in multiple verticals and for SME clients were to be found in obscure or unfavourable service contract conditions, particularly when dealing with the largest hyperscalers and CSPs. Despite the importance of this theme from a market development perspective, Figure 10 shows that these legislative and contractual issues do not seem to raise great interest among the RIA project representatives. Like for other more business-centred themes in the list, this result probably reflects the research-oriented and technical focus of the current HUB4CLOUD project portfolio (see Table 1).

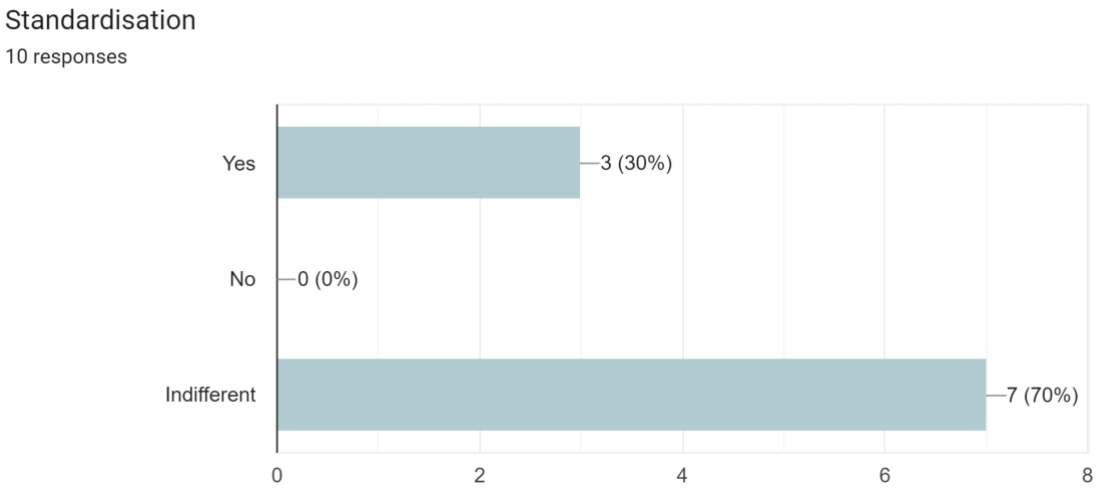

Figure 11 - Responses for the Cloud Standardisation theme

Like the previous theme, this *Cloud Standardisation* option was not present at the workshop but became part of the poll later. The reasons for its addition were on the one hand to complement the *Compositional Cloud Certification* theme with another normative aspect of Cloud interoperability, and on the other hand the connection of Open Source and Open Standards, which was already recognised at the workshop and is present as part of the analysis in [33]. The resulting responses from the project representatives, shown in Figure 11, report a good level of interest but still confronted with a large indifferent majority.

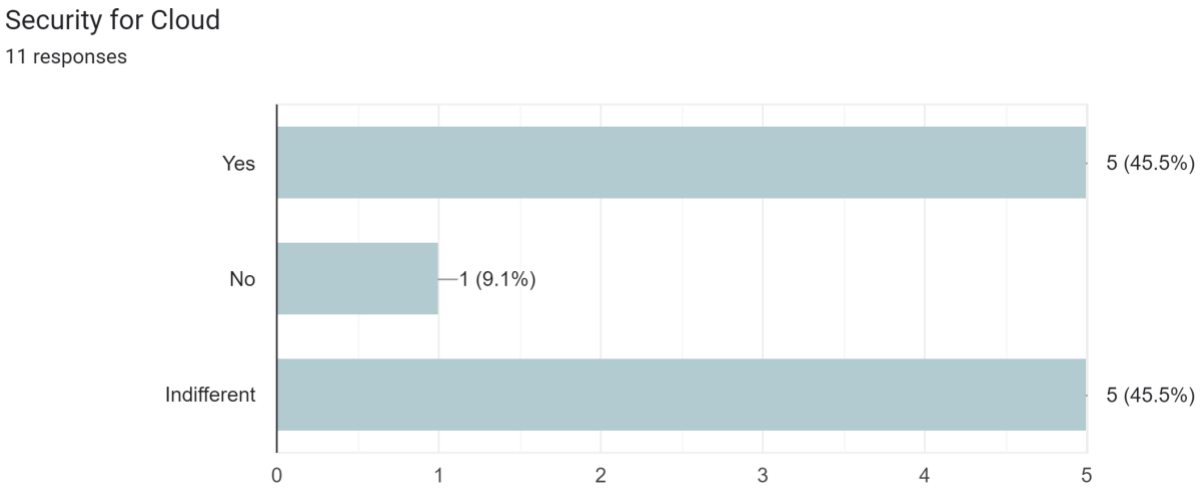

Figure 12 - Responses for the Security for Cloud theme

Last but not least, the *Security for Cloud* theme was added for its ubiquitous presence and importance in previous Horizon Cloud work as [1] and [2], where it is recognised as one of the foundational elements critical to the Digital Transition, as well as its importance throughout European ICT research and innovation programmes and policy goals like digital sovereignty and data protection. Figure 12 shows the polled results, with a halfway split between interest and indifference, not completely surprising given the difficulty of keeping a casual focus on cybersecurity: either a project is strongly engaged in it, with competent and dedicated partners, or it declares it out of the core research scope and settles on applying best security practices to the fullest possible extent, without adding cybersecurity to the project's innovation agenda.

2.2.3 Additional Discussion Forum: Digital Autonomy in the Computing Continuum

On 11 November 2021, the European Commission, with support of the H-CLOUD, EU-IoT and HUB4CLOUD CSAs, organised a virtual event titled "*Digital Autonomy in the Computing Continuum*". The meeting gathered researchers, innovators, industrial stakeholders, SMEs/start-ups, policy makers, standardisation experts, regulators, from relevant initiatives and related projects. The purpose was to discuss the current situation of the Cloud and IoT domains, the main trends for the near future, connections and influences with the Horizon Europe research and innovation programme and relevance to the Digital Europe Programme. As mentioned above, the Horizon Cloud CSAs and EU-IoT one co-organised the event, and the full video recording of it is available, along with the slide decks for all the speakers[8]. Two written reports were produced, a shorter summary [34] and a more comprehensive extended report [35].

This event was organised similarly to the online workshop described in Section 2.1, albeit on a larger scale and wider scope, with speakers from multiple areas and organisations tackling several aspects relevant to European Cloud Computing, Edge Computing, and IoT. The programme touched base on the wider research and innovation spaces, emerging challenges and directions in the Cloud and IoT areas, linked but not limited to subjects under the Horizon Europe Cloud/Edge/IoT topic. Experts and attendees have then been able to discuss topics in

[8] European Commission. Digital Autonomy in the Computing Continuum – Agenda, Speakers, Recording, Presentations. Available at https://app.swapcard.com/event/digital-autonomy-in-the-computing-continuum

three different sessions on programming tools for decentralised intelligence and swarm computing, Cognitive Cloud for an AI-enabled Computing Continuum, and the role of open-source software and hardware in a Computing Continuum supporting Europe's digital autonomy.

Furthermore, the industrial perspective was addressed, represented through various industrial initiatives, alliances, and public-private partnerships engaged in topics linked to the Continuum Computing and Next-Generation IoT. Position statements and future perspectives were presented as input for a medium-term, future-looking perspective to complement Europe's initiatives on common data spaces and federated cloud infrastructures under the Digital Europe Programme.

While the details can be found and analysed directly within the event recordings, slide decks, and event reports, the significance of the *Digital Autonomy in the Computing Continuum* virtual workshop for this position paper lies in providing a related but independent counterpoint to the project portfolio poll described in Section 2.2.2, emphasising the relevance and traction of some themes included in the long list, such as *Edge Computing*, *Open Source* and *AI for the Cloud*.

2.2.4 Additional Discussion Fora: Cloud Summit 2021 and Cloud Summit 2022

A major part of the mission of HUB4CLOUD and the Horizon Cloud initiative revolves around communication and community building, which entails the organisation and promotion of many events dedicated to the various relevant topics of interest [36]. In particular, a yearly *Horizon Cloud Summit* flagship event was planned: the 2021 edition happened as a fully online event due to COVID-19 restrictions, whereas the 2022 edition took place in Frankfurt within the Cloud Expo Europe[9]. Both editions of the flagship event contained sessions related to some of the themes presented in the long list of Section 2.1, thus providing additional input and advance validation of the relevance of each theme for the European Cloud Computing community and the variety of opinions and insights provided by the prominent experts in the area.

The 2021 edition[10] featured two sessions that are connected to the *Open Source* theme: a first panel focussed on *European Digital Autonomy in the Computing Continuum*, thereby touching on the theme in Section 2.1.7 but with recurrent mentions of the Open Source role in this endeavour, similarly to what happened in the EC event mentioned in Section 2.2.3. A second panel was then explicitly dedicated to *Cloud Standardisation and Open-Source for a Robust Digital Cloud Landscape* and was more detailed and analytic in examining the many diverse facets of how Open Source, and its relation with standardisation, can be a powerful enabler for European Cloud Computing progress along the path towards an integrated computing continuum.

The 2022 edition[11] furthered the discussion by hosting dedicated panels on *Cloud-Edge-IoT convergence – challenges and way ahead* (again hitting on the theme of Section 2.1.7), *AI for the cloud – how to improve the cloud using AI* (thereby targeting the theme of Section 2.1.8), and *Cloud computing skill training needs and opportunities in Europe* (clearly related to the theme of Section 2.1.3). In summary, the two Horizon Cloud Summit events provided analysis and insight not only on several themes in the Section 2.1 long list, but also on the more specific challenges and strategic objectives associated to these themes that need to be addressed.

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[9] Cloud Expo Europe. Available at https://www.cloudexpoeurope.com/

[10] Horizon Cloud. *Highlights of the Horizon Cloud Summit 2021*. Available at https://www.h-cloud.eu/news/highlights-of-the-horizon-cloud-summit-2021/

[11] Horizon Cloud. *Recap Horizon Cloud Summit 2022*. Available at https://www.h-cloud.eu/news/recap-horizon-cloud-summit-2022/

2.3 Selection Results and Chosen Themes

From the results of the discussion and poll among the Cloud Computing RIA projects, as well as from the additional engagement described in Section 2.2.3 and Section 2.2.4, three themes were selected for the remaining steps of the analysis presented in this document. The criteria for the choice were first and foremost the level of interest expressed by the Horizon Cloud RIA project portfolio, with the additional contribution of the overall European Cloud Computing landscape and the next focus areas in the Horizon Europe programme; finally, an aspect of coverage was considered, looking at HUB4CLOUD's own scope and the one of the other currently active H2020 CSA projects.

The resulting three themes are listed in the following:

- **Cloud-Edge-IoT Continuum**
- **AI for the Cloud**
- **Open Source**

The next sub-sections detail the reasons and intent underlying the choice of each of the three themes.

2.3.1 Theme 1: Cloud-Edge-IoT Continuum

The completely unanimous, perfect response of the RIA project representatives to the theme from Section 2.1.7 makes the inclusion of *Cloud-Edge-IoT Continuum* compelling. However, it must be noticed that **Edge Computing** is already one of the focus areas of the Horizon Cloud initiative, through the now completed H-CLOUD project: the [1], [2], and [23] already cited, provide a comprehensive coverage of the subject. To progress further from what has already been done, and taking into consideration the additional input received from the events described in Section 2.2.3 and Section 2.2.4, the strategic analysis will broaden to go beyond Edge Computing and consider the whole emerging Cloud-Edge-IoT continuum, also in light of the direction taken in the first year of the Horizon Europe Programme, with the *CL4-2021-DATA-01-05* "Meta-OS" topic, where six research and innovation projects have been funded and are starting their operation end of Q3 2022, firmly against a full computing continuum backdrop.

2.3.2 Theme 2: AI for the Cloud

This theme came a close second to the *Cloud-Edge-IoT Continuum* in the poll of Section 2.2.2, with 11 *Yes*, 1 *No* and 1 *Indifferent* answers. Artificial Intelligence is not among the focus areas of either Horizon Cloud CSA project, or it is currently handled by the VISION[12] CSA project, part of the H2020 ICT-48 topic. However, as highlighted by the very positive poll response, by the project-theme mapping depicted in Table 1, and the further interactions in the two most recent Horizon Cloud Summit events reported in Section 2.2.4, the interest and involvement from the current H2020 Cloud Computing research and innovation community is and remains quite high. Moreover, as shown in [35] and in the event on European Digital Autonomy described in Section 2.2.3, the specific use case of leveraging AI methods and architectures to improve the automation, resilience, and effectiveness of next-generation Cloud Computing systems is a key topic within the Horizon Europe Programme.

A set of RIA projects for the *CL4-2022-DATA-01-02* "Cognitive Cloud" topic has been funded

[12] Value and Impact through Synergy, Interaction & coOperation of Networks of AI Excellence Centres. Available at https://www.vision4ai.eu/

and will start soon, as well as the RIAs for the *CL4-2022-DATA-01-03* "Swarm Intelligence" topic. This new, nascent ecosystem will blend with the various RIAs from the Horizon Cloud community which will run into the year 2023, as well as the corresponding projects from the IoT space. It is with this awareness that the AI for the Cloud topic has been selected to be further analysed in Section 3.3.

2.3.3 Theme 3: Open Source

While the first two themes followed readily from the results of the Section 2.2.2 poll, the selection of the third theme required some further thought and decision making. Proceeding along the list of themes from the poll among the RIA project representatives, the next highest number of *Yes* (seven) is given to the *Cloud Federation* topic. Its importance notwithstanding, this theme has already been thoroughly covered within the Horizon Cloud initiative by the H-CLOUD project (see [1], [2], and [19]); differently from the *Cloud-Edge-IoT Continuum* theme chosen in Section 2.3.1, there is no transformation of Cloud federation into something wider and particularly targeted by the next RIA projects. Rather, it's the Gaia-X initiative [20] that is now acting as a nexus for European Cloud federation efforts. A related topic is European Data Spaces, which certainly make use of federation, but are not to be seen as the evolution of Cloud Federation at large.

Discounting the *Cloud Federation* theme, there are two further topics that scored five *Yes* answers, namely *Software Engineering for the Cloud* (see Section 2.1.4) and *Security for Cloud* (not presented at the initial workshop, but added later, see Figure 12). The former theme is currently covered by the SWForum[3] CSA project, with which HUB4CLOUD liaised from the beginning; the latter theme, dealing with cybersecurity, is even farther from HUB4CLOUD core topics and there are no immediate links with the Horizon Cloud outcomes.

Next in the interest list emerged from the RIA project poll is *Open Source*, with four *Yes* answers, but also present in the project to theme mapping of Table 1, the events described in Section 2.2.3 and Section 2.2.4, and actually still related to the *Software Engineering for the Cloud* theme, given the influence and relevance of Open Source for modern software development practices and Cloud software infrastructure.

The *Open Source* theme is in fact one of the focus areas for HUB4CLOUD in terms of mapping of relevant initiatives [37], and is therefore a good candidate to be selected as the third and last strategic theme covered in this position paper, as detailed in the following Section 3.4.

3 ECC STRATEGIC OBJECTIVES AND ALIGNMENT

The overarching goal of the strategic analysis presented in this position paper is to foster the growth and development of an open ecosystem for **European Cloud Computing** (ECC). Each of the three selected themes includes important enablers for this objective, which need to be made explicit as a set of strategic objectives that can be achieved together in an integrated way. Such objectives should be sufficiently *important*, *desirable*, and *achievable* for European Cloud Computing so as to justify the application of effort towards them.

Once suitable strategic objectives are defined, the related question of *strategic alignment* enters the picture; it is however important to acknowledge that the determination of the suitable alignment level is not a trivial task, and it depends on the specific objective and associated context. Strategic alignment can be a good indicator of the strength and health of a socio-technical ecosystem, but the reality is more complex and multi-faceted than simply a problem of maximising alignment in the ECC community. The following Section 3.1 presents and discusses some factors concurring to determine the alignment level for a given strategic goal, whereas the subsequent Sections (3.2, 3.3, and 3.4) will discuss the issue for each chosen theme.

3.1 Objectives and Alignment Affinity

The strategic relevance of an objective within European Cloud Computing does not mean that a high alignment is the right approach. The best alignment level depends on multiple factors and contextual conditions, but the core issue is the trade-off between **efficiency** and **resilience**.

The *United in Diversity* EU motto [38] could be seen as expressing such a trade-off: tighter and strongly aligned union yields higher efficiency, which is however often obtained at the price of reduced resilience. In interconnected complex systems there is a link between the number of alternative interaction paths and its resilience or fragility [39]. Two guiding patterns are:

- The **best path** to a strategic objective **is known and clear**, and **high efficiency** is at a premium. Then, **stronger alignment** will usually be the effective strategy.
- A strategic objective can be pursued by **multiple approaches**, **individual failure** is more likely, and there is an **uncertain or challenging context**. Then, a **weaker, loosely coupled alignment** level will likely be the winning choice with an emphasis on redundancy and resilience, despite lower global or average efficiency.

Further insight can be gathered by considering the internal structure of the European Cloud Computing network of actors. Innovation-based communities, being often a hybrid composition of academic and business institutions, usually operate under a regime of so-called *coopetition*[13], where members work together or compete in variable combinations depending on the situation. This enriches alignment with new traits: is high alignment stifling competition and differentiation, or is it helping frictionless cooperation? The answer is related to coopetition levels.

Alignment (or lack thereof) can also have different impact in different areas of a value network, depending on the number and size of actors in a given segment, the balance of power between suppliers and customers, and the dominant business models. A remarkable case is two-sided markets [40], or more generally multi-sided [41], which play a critical role in the formation and maintenance of innovation and business ecosystems (as both an opportunity and as a threat). In a multi-sided market, the simple *network effect*[14] rule that value increases with the number of

[13] Investopedia. *Coopetition*. March 2022. Available at https://www.investopedia.com/terms/c/coopetition.asp

[14] Investopedia. *Network Effect*. June 2022. Available at https://www.investopedia.com/terms/n/network-effect.asp

participating actors becomes more structured: the size of a certain side of the market increases the value that some other side or sides can extract from it. In such a context, questions about finding the best alignment level must be accordingly qualified (alignment of which sides? To the benefit of which other sides?).

The following Sections, taking into account the three selected themes, will present strategic objectives for each and discuss the associated alignment levels and possible measures.

3.2 Theme 1: Cloud-Edge-IoT Continuum

3.2.1 Strategic Objectives for Theme 1

From the engagement of the RIA project representatives described in Section 2.2.2, as well as the events discussed in Section 2.2.3 and Section 2.2.4, three objectives related to the *Cloud-Edge-IoT Continuum* theme emerged as common topics:

SO-1.1. Privacy-preservation as a key for Edge Computing to enable digital autonomy, at the European and individual/user level

SO-1.2. A reference architecture for Cloud-Edge-IoT Continuum systems, supporting decentralisation and interoperability

SO-1.3. Dynamic orchestration approaches to handle the complexity and heterogeneity of Cloud-Edge-IoT Continuum infrastructure and applications

The alignment level to be associated to *SO-1.1* has probably to be high; in terms of privacy, recent history has shown that under a deregulated regime the economical (and at times even political) incentives to monetise or otherwise exploit user data are simply too strong to be resisted by most operators. The EU has already taken important steps to define and regulate the Data Economy trying to enable its healthy development while avoiding unfair and exploitative practices. Privacy-preservation, in its connection to Edge Computing, has two distinct facets: at the ***Europe/group/institution level***, it becomes about digital autonomy of European companies, associations, and institutions that may have sensitive edge-produced data that they want to use without jeopardising its security (e.g., in a federated machine learning scenario); at the ***individual level***, it naturally extends the original idea of privacy protecting the individual from other actors, including governments. In both case high alignment and strong data- and edge-awareness appear to be the way forward.

The *SO-1.2* has a very canonical nature: the desire for a reference architecture is common, when new technological system approaches start to mature, and that such an architecture should be decentralised and support interoperability follows rather directly from the nature of Cloud-Edge-IoT. The remarks made in Section 3.1 apply however in multiple ways. Firstly, Edge Computing, as the middle ground between Cloud and IoT (and even telecommunication networks), often lacks even terminological agreement; secondly, it covers a large set of heterogeneous systems, domains, and use cases. These two points alone suggest an “uncertain or challenging context”, but there is also the efficiency-resilience trade-off: it is already widely agreed that Edge Computing systems will have to be much more resilient (and less efficient) than traditional Cloud data-centres, due to their much greater variability and lower environmental control. All this points towards a low level of alignment around this strategic objective. From a business perspective, likewise, the complex structure of the IoT and Edge markets when applied to different verticals and use cases reinforces the need for low alignment, or at least a low global alignment with clusters of more highly aligned sub-communities.

For the last strategic objective of this theme, *SO-1.3*, there is a similar situation as for *SO-1.2*, but with the high, multi-decade efforts in research and development on topics such as service oriented architectures, autonomic computing, and dynamic application orchestration. This

amount of knowledge and tools represents an extremely valuable starting point, even though the full challenge posed by completely arbitrary, heterogeneous Computing Continuum systems is yet to be tackled. The resulting alignment level is somewhat in the middle, certainly low enough to foster research, exploration, and free-form coopetition, but without ignoring accepted baselines, components, and infrastructure, especially when they are open and widely available.

3.2.2 Measures to Ensure Alignment within Theme 1

Section 3.2.1 made the case for *SO-1.1* to have a high level of alignment, given the importance of privacy for European Data Economy, but such an alignment can be enforced through a combination of measures with different normative strength. At the legislation level, beyond the GDPR [4], further European norms such as the Data Governance Act [5] and the Data Act [6] have already taken significant steps, but there are other additional pathways:

- **Technical Innovations**. There are many research and innovation activities (e.g., the RIA projects funded on the *2021-DATA-01-05* "Meta-OS" topic) working on data sovereignty and privacy preservation approaches in Edge Computing settings, and several software offers are available at various levels of maturity. Converging on some of these efforts or systems would contribute to strategic alignment.
- **Standards**. Activities on consensus and standardisation in privacy-relevant areas of both Edge Computing and Cybersecurity can significantly contribute to a high alignment around privacy preservation, even before formal ratification by fostering awareness and coalescing support and consensus around a sound set of solutions.
- **Ecosystem Rules of Engagement**. Without either legislative or standardised status, effective enablers for high alignment are to be found in high-profile initiatives (e.g., European Common Data Spaces [21] or GAIA-X [20]) and leading reference implementations, especially when open and with a good community governance. The policies and practices on privacy preservation accepted on these ecosystems have the momentum and practical, large scale testing to act as alignment attractors for Europe.

Considering the current and future projects in the Cloud Computing and Computing Continuum spaces, it can be seen how both RIA- and CSA-type of projects can engage in the above pathways, where research and innovation efforts will connect to technical innovation, standards, and reference implementation while coordination and support work will focus on ecosystems, alliances, knowledge brokering, community growth and harmonisation.

The SO-1.2 objective, dealing with intermediate software artifacts such as architectures in a still not very mature area, was deemed in Section 3.2.1 to need a low alignment level. This needs to be refined by applying the structured analysis outlined in Section 3.1. In particular, considering the two *desiderata* of decentralisation and interoperability and proceeding along the software stack dimension (bottom to top), a suitable structure is:

- **Mechanisms**. These architectural building blocks would benefit from a higher alignment and convergence than a reference architecture as a whole; at this lower abstraction layer, reuse of open and already available mechanisms (e.g., protocols, data models, abstract processes) would be effective and would build a common toolkit for the definition and description of Cloud-Edge-IoT systems. It might even happen that some mechanisms are more valuable in or even exclusive of specific market or technological segments (e.g., far-edge with low-power devices and narrow-band connectivity).
- **Policies**. Based on the (mostly) common vocabulary provided by mechanisms, a Cloud-Edge-IoT policy level should be the place for maximum innovation, coopetition, and resilience. Exploration here is at a premium, and a reference architecture for the policy level should focus on context and external interactions, trying not to mandate too much in how low-level mechanisms are combined and leveraged for higher purposes. Here the alignment level should be at its lowest throughout the architecture.

- **Market Applications**. At this level very concrete needs and constraints must be met, which are specific of a certain vertical domain, market segment, or value network structure. This would in turn suggest high per-segment alignment and interoperability to benefit the demand side, within a multitude of segments that keep a lower alignment and interoperability levels with one another.

The consequences on the research and innovation side are to try to *embrace and extend* existing architectural mechanisms, while fostering originality and invention at the policy level (e.g., through specification languages or tools). For vertical applications, care should be taken to separate the cross-domain properties of the reference architecture from its specific elements or extensions that are tailored to particular segments of the Cloud-Edge-IoT Continuum. On the coordination and support, community building side, the emphasis should be on facilitating ***divergent thinking*** (getting people together so that, when they leave, they have **more options** in their heads than when they arrived) for low-alignment architectural layers and ***convergent thinking*** (getting people together so that, when they leave, they have **less options** in their heads than when they arrived) for high-alignment ones.

As outlined in Section 3.2.1, the objective *SO-1.3* is in a similar situation as the previous *SO-1.2* on reference architecture, but with a higher degree of concreteness and therefore a higher desired alignment level. The same split between high-alignment mechanisms and low-alignment policies applies here as well: convergence should be achieved around service orchestration engines that are reliable, open, have a large community, and do not try to be too sophisticated but rather leave configuration and policy definition open to their users (e.g., Kubernetes[15] and its various extensions). One additional area of high alignment that is critical for this strategic objective are ***metrics***. Dynamic service orchestration in an heterogeneous Edge Computing environment is a difficult task, but it is also very performance-oriented, and performance can be defined, measured, and compared in a quantitative way that is simply not possible for software architectures. It is then very important that good agreement is reached on how to define and measure a successful, high-performance dynamic orchestration; in this way, even in the face of a very low alignment with a multitude of approaches and very strong originality and resilience, it will always be possible to compare results and use them to orient incremental community preferences and choices. A last remark, connecting this theme to the next *AI for the Cloud* one of Section 3.3, is that most if not all dynamic service orchestration approaches make use of some Artificial Intelligence techniques, and these techniques must comply with the European ethical approach to trustworthy AI that is found in the AI regulation proposal [27]. The fact that AI is applied to internal system management, where no personal data from human users is generally relevant, puts *AI for the Cloud* systems outside the jurisdiction of GDPR, but does not exempt them from the need to operate fair, explainable, human-centric intelligent systems.

3.3 Theme 2: AI for the Cloud

3.3.1 Strategic Objectives for Theme 2

From the engagement of the RIA project representatives described in Section 2.2.2, as well as the events discussed in Section 2.2.3 and Section 2.2.4, three objectives related to the *AI for the Cloud* theme emerged as common topics:

SO-2.1. Increased automation for multiple benefits: scalability, complexity management, lower operation cost, higher productivity

[15] Kubernetes. *Production-Grade Container Orchestration*. Available at https://kubernetes.io/

SO-2.2. Much more dynamic and sophisticated Cloud-Edge-IoT system self-management

SO-2.3. Predictable, explainable behaviour in compliance of human-centric, trustworthy AI

The need to further the trend towards ever-increasing automation in Cloud Computing is already well established, but the mention of *SO-2.1* points to a raising importance of, and possibly concern about, this theme. Multiple factors (the increasing complexity and heterogeneity of systems, the raising importance of Edge Computing and the computing continuum, the end-to-end, holistic approach necessary to tackle sustainable evolution of ICT, among others) concur to suggest that only a strong increase in automation capabilities for Cloud systems will enable an environmentally sustainable and economically feasible growth in scale, complexity, variety and effectiveness. To determine the desirable level of alignment, a certain similarity with *SO-1.3* can be recognised: high alignment would be desirable on the more commoditised reusable mechanisms (telemetry, representation of capabilities and resources, time series management and data processing), with a broader freedom to explore awarded to a higher, policy level through a lower expected alignment.

Such a convergence is also visible in the current and immediately upcoming projects in the European research and innovation space: in theory, the brief for the *CL4-2021-DATA-01-05* "Meta-OS" projects is to focus on Cloud-Edge-IoT systems management, without necessarily using AI, whereas the brief for the *CL4-2022-DATA-01-02* “Cognitive Cloud” projects is to use AI to improve Cloud systems management, without necessarily including Edge Computing. In practice, however, it is to be expected that both pools of projects will tackle the issue of how to define architectures, approaches, and policies to effectively apply Artificial Intelligence to improve Cloud-Edge-IoT systems management. The sensible choice for *SO-2.1* is therefore to strive for high alignment on metrics and a common set of reliable and open core services and components. Such metrics, in particular, should heed the vision [15] and targets of the Digital Compass related to sustainability and the twin transitions.

The situation is almost exactly the same for objective *SO-2.2*, which in a sense extends *SO-2.1* to the full spectrum of the Autonomic Computing *self-** properties. While automation can be considered first and foremost a matter of deployment and IT systems operations, injecting self-management and intelligence into Cloud-Edge-IoT continuum systems, running on extremely heterogeneous, highly distributed networks where all non-functional properties of interest (performance, reliability, scalability, composability, extendibility, etc.) wildly vary from node to node, requires a stronger focus on the earlier phases of the software life cycle, from novel architectures (see objective *SO-1.2*) to different and enhanced programming models (see the expected outcomes for the *CL4-2022-DATA-01-03* “Swarm Intelligence” topic).

Among the objectives associated to this theme, it is *SO-2.3* the one where a stronger, higher alignment is needed and expected. Such a high alignment follows from the European values and normative frameworks that privilege data and privacy protection, and adopt principles of caution, transparency, and preservation of human agency for all AI applications. Given the fast-paced and widespread innovation currently occurring within the Artificial Intelligence, it is clear that high alignment cannot be achieved through normative system specification, but rather has to define the compliant observable behaviour and interactions with human stakeholders.

This results in the need of not only metrics, but also test suites, checklists, and in general validation processes that can be applied to all AI artifacts (software, training sets, data sets, complete systems) and throughout the system life cycle. Not only after implementation, but also at conceptualisation and design time. An early but important example of this approach is given by the ALTAI list [42], allowing early self-assessment of AI systems and available also as a Web-based online tool.

3.3.2 Measures to Ensure Alignment within Theme 2

The suggested measures to support the most appropriate alignment level for each of the three

strategic objectives associated with this theme take into account the similarity in the alignment structure between *SO-2.1* and *SO-2.2*: high alignment on comparable metrics and reusable components, and low alignment on technical choices and integration policies. The involved research and innovation community should initially concentrate on low-alignment activities such as conceptualisation, architecture design, or technological and algorithmic exploration. Only in a second moment, as a check point along their own way, should the work start to consider examples of concrete industries, use cases, and full-fledged pilot scenarios for validation of the chosen approaches. At this point, partially switching from horizontal, platform-like development to a more domain-specific analysis and system design, clusters of higher alignment can be identified and built by collaborating with external groups that are active in similar sectors, exchanging ideas at a minimum, but hopefully finding concrete components and services that can be jointly adopted and maintained, to start a more open and stable community around them. On the coordination and support side, just like Section 3.2 mentioned for *SO-1.2* and *SO-1.3*, the communication and community building actions should be aware of the ongoing discussions and cooperations in the innovation space and foster the suitable kind of interaction (divergent/exploratory debate or convergent/agreement decision) for the different parts associated to each of the two strategic objectives.

The high alignment needed for *SO-2.3* is very important, but also external to the European Cloud Computing community; it comes either from EU policy and legislation, or from research and innovation in general AI rather than Artificial Intelligence specifically applied to improving Cloud or Cloud-Edge-IoT systems. Therefore, from the research and innovation side the most important action is to liaise with other projects and communities operating in the European applied AI space, such as the AI-on-Demand Platform [43]. Likewise, at the coordination and support level, initiatives focussed on Cloud Computing or Cloud-Edge-IoT continuum will have to extend their outreach to include communities and associations dedicated to Artificial Intelligence (with their own leading initiatives and projects), and possibly act as communication and engagement gateways for the ECC community. The reason is that the public discourse around trustworthy AI, its policy aspects, future legislation, and strategic geopolitical landscape have become too important and exhibit an end-to-end, holistic nature that requires direct engagement, which cannot really be replicated in a “AI, yes, but only for the Cloud” mirror community outside the main European Artificial Intelligence discussion stream.

3.4 Theme 3: Open Source

3.4.1 Strategic Objectives for Theme 3

From the engagement of the RIA project representatives described in Section 2.2.2, as well as the events discussed in Section 2.2.3 and Section 2.2.4, three objectives related to the *Open Source* theme emerged as common topics:

SO-3.1. Expand the presence and importance of European actors throughout the Open Source ecosystem for Cloud-Edge-IoT software, in terms of contributors, leadership, and governance

SO-3.2. Manage and contain fragmentation in Open Source projects and effort for future Cloud Computing work

SO-3.3. Contribute to a European strategy for Open Source unfolding within a larger agenda for digital autonomy, level playing field, and safeguarding European values

The SO-3.1 is a broad and ambitious goal, which encompasses much more than the core actors in European Cloud Computing research and innovation, but for the purpose of this analysis it will be appropriate to consider three aspects of Open Source strategic alignment:

- **Content**. This is the scope of the open-source output from a project or initiative: creating new open-source components, contributing to existing ones, interfacing to external open-source systems and infrastructure, and many other examples. It is clear that very low alignment is key in this aspect, to maximise each initiative and sub-community freedom to shape their Open Source strategy to fit the specific technical and business context. Some general constraints will be there in terms of agreed architectures, commodity components, and conceptual models for Cloud Computing (or Cloud-Edge-IoT continuum), but by and large each actor or group will be able to walk their own path.
- **Process**. This is an aspect where high alignment and overall guidance would benefit greatly the European Cloud Computing community. While content is and should remain specific, aligning on Open Source processes, both to understand and practice them, will yield widespread payoff in terms of impact, productivity, and clarity of communication. From detailed technical procedures such as how to submit a code change proposal and how to accept it into an open-source project, up to larger scale, release-wide operations, many processes would be covered by a comprehensive process map such as the EFDP [44] and EFSP [45] from the Eclipse Foundation.
- **Governance**. Aligning on processes without considering governance would probably improve efficiency and productivity, but would not help Europe progress toward higher impact and leadership in the worldwide Open Source ecosystem related to Cloud Computing. A possibly abstract but high alignment on Open Source governance will be paramount for Europe, not only for the same reasons mentioned with respect to process alignment, but even more importantly for the critical connection to European values and legislation. A complete set of governance[16] documents includes key processes, but goes well beyond them to also cover normative and policy areas, which are the best points to connect to the foundational and most general European values.

The objective *SO-3.2* is itself about controlling Open Source fragmentation so the first reaction would be to push for a very high alignment. This intention must however be tempered by those resilience and freedom of exploration needs outlined in Section 3.1. Fragmentation must be managed, not eliminated outright, so a *divergent/convergent thought* pattern must be applied in dependence of the maturity level of a specific Open Source project or contribution.

Lastly, alignment on objective *SO-3.3* is really a matter of normative common rules, EU-scale policies and agendas, as well as community and consensus building on a multi-national scale that goes well beyond the reach of individual projects or initiatives contributing to Open Source. By its very definition, this objective requires a high alignment across its participating actors.

3.4.2 Measures to Ensure Alignment within Theme 3

Measures to support alignment on *SO-3.1* must consider the aspects listed in the previous Section 3.4.1. From a content point of view, freedom is key and low alignment is sufficient, but some care can be placed, especially by coordination and support actors, into avoiding duplication of effort: the vision here is to increase efficiency and impact by bringing projects working in the same topics together so that more relevant open-source projects can be set up or contributed to. At the process and governance levels, where a higher alignment is desired, the needed measures on the side of research and innovation initiatives will be to learn and master processes to engage effectively with Open Source and commit skills and resources to that, in addition to their core research and development work. On the coordination side, the appropriate

[16] The Eclipse Foundation. *Eclipse Foundation Governance Documents*. Available at https://www.eclipse.org/org/documents/

measures revolve around offering information and training related to Open Source processes, foster communication and understanding across research and innovation actors, and help select the most suitable Open Source targets and build momentum towards them, leveraging communication channels and actions specifically suited to Open Source culture and practice.

The objective *SO-3.2* is overwhelmingly a coordination concern: it is not realistic to expect that single research and innovation efforts can detect, filter, and possibly consolidate fragmentation while tending to their own, often challenging, technical agenda. The best positioned actors for this task are coordination and support initiatives, but also larger, established associations and alliances that can leverage their membership numbers. In all cases, effective measures would include assessment (but not necessarily ranking) of open-source projects in terms of activity, maturity, impact, community strength and openness, and governance. Such assessments, combined with facilitating communication, understanding, and cross-fertilisation among projects in a similar manner as previously indicated for objective *SO-3.1*, can strike the right balance between reducing project fragmentation and allowing adequate freedom of exploration of original, innovative and alternative approaches. It should be noticed that, perhaps, the most effective tool against fragmentation is prevention: this would be achieved indirectly by the training and education effort in service of *SO-3.1*. When well versed in the landscape, processes, and governance of Open Source, research and innovation actors will most likely avoid creating new, redundant open-source projects when viable ones already exist, and will lean instead towards liaising and contributing to such projects, recognising their resulting higher cost-effectiveness and overall impact.

As far as the *SO-3.3* objective is concerned, most of the alignment measures available to the European Cloud Computing community are indirect. Legislation and policy awareness, collection and organisation of feedback at an associative or industry level, organisation and participation to meetings and events where discussions are held about European strategy for Open Source, are all valid and effective measures to ensure contribution to these very wide topics that often go beyond innovation strategies to touch on wider social and geopolitical concerns. The event on *Digital Autonomy in the Computing Continuum*, described in Section 2.2.3, is a very appropriate example of these well-established measures that should be kept for the next evolutionary steps of European Cloud Computing.

4 CONCLUSIONS

This strategic position paper has considered the overall landscape of European Cloud Computing to determine a set of important themes where community awareness and cooperation are a critical success factor, and it becomes therefore key to assess for each theme the most appropriate level of alignment, striking the right balance between compliance and freedom. Such an alignment level depends not just on the examined theme, but also on the more specific strategic objective that is being pursued in relation to that theme.

This long list of themes was presented and discussed with the research and innovation projects in the current H2020 cloud computing portfolio, to gather their priorities and comments and from them produce a consolidated subset of three themes and associated strategic objectives.

For each identified strategic objective, some structural analysis has suggested an appropriate level of alignment to strive towards. Suggested measures to support and facilitate the achievement of the indicated alignment have been provided, distinguishing between research and innovation measures that can be adopted by individual research initiatives or groups, and more systemic measures that can work best when picked up by coordination projects, institutions, or communities as a whole.

The purpose of this paper, without any ambition of completeness, is to gather the views of the ECC project portfolio about what themes and objectives are strategically important, and to serve as a informational guideline for multiple stakeholders that can influence the intended and achieved alignment level around specific ECC objectives. The analysis and recommendations contained herein can guide the debate and action planning of suitable policymaking, associative, and communication institutions, as well as research and innovation actors.

A complementary purpose, which could gain more and more importance in the near future, is to be an informative communication asset to introduce new members of the ECC community to the general landscape and themes of interest. This is particularly relevant in light of the various convergence and interconnection trends occurring between ECC and, e.g., IoT, AI, and Big Data communities, as well as the evolving and increasingly integrated European policy context.

REFERENCES

[1] Horizon Cloud. *Cloud Computing in Europe: Landscape Analysis, Adoption Challenges and Future Research and Innovation Opportunities*. November 2020. Available at https://h-cloud.eu/download/green-paper/

[2] Horizon Cloud. *Cloud Computing in Europe: Landscape Analysis, Adoption Challenges and Future Research and Innovation Opportunities*. April 2022. Available at https://www.h-cloud.eu/?wpdmdl=4541&ind=1645025986562

[3] ENISA. *EUCS – Cloud Services Scheme*. December 2020. Available at https://www.enisa.europa.eu/publications/eucs-cloud-service-scheme

[4] European Commission. *General Data Protection Regulation (GDPR)*. Available at https://gdpr.eu/tag/gdpr/

[5] European Commission. *European Data Governance Act*. May 2022. Available at https://digital-strategy.ec.europa.eu/en/policies/data-governance-act

[6] European Commission. *Data Act*. July 2022. Available at https://digital-strategy.ec.europa.eu/en/policies/data-act

[7] European Commission. *Open source software strategy 2020-2023*. October 2020. Available at https://ec.europa.eu/info/departments/informatics/open-source-software-strategy_en

[8] European Commission. *Study about the impact of open source software and hardware on technological independence, competitiveness and innovation in the EU economy*. September 2021. Available at https://digital-strategy.ec.europa.eu/en/library/study-about-impact-open-source-software-and-hardware-technological-independence-competitiveness-and

[9] Horizon Cloud. *Cloud Computing Standardisation and Open Source Initiatives*. October 2021. Available at https://www.h-cloud.eu/download/d3-1-2/

[10] European Commission. *Europe's Digital Decade*. August 2022. Available at https://digital-strategy.ec.europa.eu/en/policies/europes-digital-decade

[11] Horizon Cloud. *European Cloud Computing training needs and Opportunities*. August 2022. Available at https://www.h-cloud.eu/?wpdmdl=5421&ind=1659682412171

[12] S. Gilbert and N. Lynch. *Brewer's conjecture and the feasibility of consistent, available, partition-tolerant web services*. ACM SIGACT News, Volume 33,Issue 2. June 2002. Reference available at https://dl.acm.org/doi/10.1145/564585.564601

[13] C. Richardson. *Microservice Architecture*. Available at https://microservices.io/

[14] Wikipedia. *Elasticity (cloud computing)*. Available at https://en.wikipedia.org/wiki/Elasticity_%28cloud_computing%29

[15] European Commission. *2030 Digital Compass: the European way for the Digital Decade*. March 2021. Available at https://eufordigital.eu/library/2030-digital-compass-the-european-way-for-the-digital-decade/

[16] Horizon Cloud. *Green ICT*. October 2020.Available at https://h-cloud.eu/download/hcloud_app14_greenict/

[17] Environment Agency Austria, Borderstep Institute. *Energy-efficient Cloud Computing Technologies and Policies for an Eco-friendly Cloud Market*. May 2020. Available at https://ec.europa.eu/newsroom/dae/document.cfm?doc_id=71330

[18] National Institute of Standards and Technology. *The NIST Cloud Federation Reference Architecture*. February 2020. Available at https://www.nist.gov/publications/nist-cloud-federation-reference-architecture

[19] Horizon Cloud. *The Potential of Cloud Federation*. November 2020. Available at https://h-cloud.eu/download/cloud-federation-briefing-paper/

[20] Gaia-X. *A Federated and Secure Data Infrastructure*. August 2022. Available at https://gaia-x.eu/

[21] European Commission. *Common European data spaces for agriculture and mobility*. December 2021. Available at https://digital-strategy.ec.europa.eu/en/library/common-european-data-spaces-agriculture-and-mobility

[22] European Commission. *European Open Science Cloud (EOSC)*. June 2022. Available at https://digital-strategy.ec.europa.eu/en/policies/open-science-cloud

[23] Horizon Cloud. *Edge Computing Development and Supply*. November 2020. Available at https://h-cloud.eu/download/h-cloud_app12_edge_computing_v0-7/

[24] European Commission. *Coordinated Plan on Artificial Intelligence 2021 Review*. July 2022.

Available at https://digital-strategy.ec.europa.eu/en/library/coordinated-plan-artificial-intelligence-2021-review
[25] AI HLEG. *A definition of Artificial Intelligence: main capabilities and scientific disciplines*. April 2019. Available at https://digital-strategy.ec.europa.eu/en/library/definition-artificial-intelligence-main-capabilities-and-scientific-disciplines
[26] AI HLEG. *Ethics guidelines for trustworthy AI*. April 2019. Available at https://digital-strategy.ec.europa.eu/en/library/ethics-guidelines-trustworthy-ai
[27] European Commission. *Proposal for a Regulation laying down harmonised rules on artificial intelligence*. April 2021. Available at https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021PC0206
[28] Cloud Native Computing Foundation. *CNCF Cloud Native Definition v1.0*. June 2018. Available at https://github.com/cncf/toc/blob/main/DEFINITION.md
[29] Michael Wooldridge. *Welcome to Big AI*. in IEEE Intelligent Systems, vol. 37, no. 3, pp. 24-26, 1 May-June 2022. Available at https://ieeexplore.ieee.org/document/9839451
[30] Horizon Cloud. *Projects – Research and Innovation*. Available at https://www.h-cloud.eu/projects/research-innovation/
[31] Horizon Cloud. *Cloud Catalogue*. Available at https://catalogue.h-cloud.eu/
[32] Horizon Cloud. *European Cloud Computing Training Needs and Opportunities*. August 2022. Available at https://www.h-cloud.eu/?wpdmdl=5421&ind=1659682412171
[33] Horizon Cloud. *Cloud Computing Standardisation and Open Source Initiatives*. October 2021. Available at https://www.h-cloud.eu/download/d3-1-2/
[34] Horizon Cloud. *Event report: Digital Autonomy in the Computing Continuum*. November 2021. Available at https://www.h-cloud.eu/?wpdmdl=1858&ind=1642066887979
[35] Horizon Cloud. *Extended Event report: Digital Autonomy in the Computing Continuum*. November 2021. Available at https://www.h-cloud.eu/?wpdmdl=1897&ind=1643279452674
[36] Horizon Cloud. *Outreach and Engagement Report*. December 2021. Available at https://www.h-cloud.eu/download/h4c-2-4/
[37] Horizon Cloud. *Cloud Computing Standardisation and Open Source Initiatives*. October 2021. Available at https://www.h-cloud.eu/download/d3-1-2/
[38] European Union. *EU motto*. Available at https://european-union.europa.eu/principles-countries-history/symbols/eu-motto_en
[39] Horstmeyer, L., Pham, T.M., Korbel, J. *et al. Predicting collapse of adaptive networked systems without knowing the network*. Sci Rep 10, 1223 (2020). https://doi.org/10.1038/s41598-020-57751-y
[40] Grassmann, O., Frankenberger, K., Csik, M. *The Business Model Navigator. 55 models that will revolutionise your business*. 2014, Upper Saddle River, NJ: FT Press. Available at https://businessmodelnavigator.com/pattern?id=52
[41] Sanchez-Cartas, J. M., León, G. Multisided Platforms and Markets: a Survey of the Theoretical Literature. January 2021. Available at https://doi.org/10.1111/joes.12409
[42] European Commission. *Assessment List for Trustworthy Artificial Intelligence (ALTAI)*. July 2020. Available at https://digital-strategy.ec.europa.eu/en/library/assessment-list-trustworthy-artificial-intelligence-altai-self-assessment
[43] Europe's AI-on-Demand Platform. Available at https://www.ai4europe.eu/
[44] Eclipse Foundation. *Eclipse Foundation Development Process*. March 2020. Available at https://www.eclipse.org/projects/dev_process/
[45] Eclipse Foundation. *Eclipse Foundation Specification Process*. November 2021. Available at https://www.eclipse.org/projects/efsp/

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