Mapping Cloud-Edge-IoT opportunities and challenges in Europe

Market landscape, technological innovations, value chains and use cases

White paper

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1. Introduction

In today's rapidly evolving digital landscape, the concept of the computing continuum has emerged as a fundamental pillar of technological development. According to EU Commission studies,approximately 80% of data processing and analysis currently occurs within data centres and centralised computing facilities, with the remaining 20% in smart connected objects. Under this scenario, the traditional Internet of Things (IoT) infrastructure involves smart objects collecting data while most computing resources are centrally stored in the cloud.

However, predictions indicate that these percentages are shifting and will continue to do so in the coming years, with an estimated 80% of data originating from smart devices. This shift calls for a transformation of the current infrastructure, where computing processing and storage capabilities must increasingly reside at the "edge" of cloud infrastructures, in proximity to the multiple data sources represented by smart devices.

This paradigm signifies the growing convergence of the traditionally separated cloud, edge, and IoT technologies. The vision is seamless integration, where cloud computing, edge computing, and the Internet of Things (IoT) merge to form a powerful network infrastructure.

The computing continuum promises to revolutionise our interaction with technology, unlocking new possibilities across various industries and sectors.

In this dynamic context, this paper aims to offer a comprehensive overview of the computing continuum, focusing on the opportunities it presents and the levers to adjust in order to address existing challenges.

Bridging the gap between existing literature and the current digital transformation, this paper offers a fresh perspective on the evolution of Europe's computing continuum. While many publications have touched upon the theoretical aspects or technical analyses of distributed intelligence paradigms in the continuum, this work delves deeper into this paradigm's practical implications and transformative potential. It not only elucidates the concept but also spotlights its real-world applications, market trends, and its pivotal role in Europe's technological trajectory.

The paper is structured as follows:

- **Chapter 2** introduces the concept of the computing continuum and discusses its significance, particularly in the context of Europe's technological future.
- **Chapter 3** offers an overview of current market trends and key value chain drivers in the European industrial landscape, specifically focusing on five promising sectors: manufacturing, healthcare, energy, agriculture, and transportation. This chapter also delves into the dynamics of each industry's value chain, including data, revenue flows and service requirements.
- **Chapter 4** provides a detailed exploration of the opportunities and challenges related to Cloud-Edge-IoT (CEI) adoption. It also examines a set of use cases from industry and research that actively address identified barriers and leverage drivers to exploit business opportunities.
- Finally, **Chapter 5** summarises key considerations regarding the readiness of identified use cases and the way forward.

From a methodological perspective, the insights collected here rely on a mixed quantitative and qualitative research method, including surveys, secondary sources analysis, and interviews. This approach also involves the analysis of the interactions between Cloud-Edge-IoT (CEI) stakeholders along the value chains in the agricultural, manufacturing, transportation, healthcare and energy sectors. This observation was possible thanks to the organisation of value chain adopter (VCA) groups for each sector and invited CEI tech adopters – end users, infrastructure providers (cloud & telcos), resellers, service providers, tech integrators, Standards Development Organisations

(SDOs), public bodies, Public-Private Partnerships (PPPs), industry associations, and data spaces. With each group, a series of interactive workshops was organised. Additionally, in-depth interviews were conducted to discuss potential data-driven revenue streams, regulatory or technological barriers, market gaps and business opportunities that will leverage the adoption of CEI technologies on the European market.

2. Concept of computing continuum

2.1. Definition

In this discussion, it is essential to clarify that the definition of the Cloud-Edge-IoT (CEI) Continuum can exist on various levels, and there's ongoing work to establish a comprehensive taxonomy of its components. A prominent example is the "European Cloud, Edge, and IoT Continuum", also known as the EUCloudEdgeIoT (EUCEI) initiative, launched in the latter half of 2022 with funding from the European Commission. EUCEI aims to guide the convergence of cloud, edge, and IoT domains, fostering collaboration to shape the future CEI market.

This paper refers to the emergence of the computing continuum as a result of the convergence between two previously separate domains: Cloud and IoT. The Computing Continuum constitutes a coordinated ecosystem comprising diverse devices, systems, platforms, and resources. It introduces a new paradigm of services and solutions offering enhanced privacy, wider deployment of low-power devices, context-specific models for improved intelligence, increased reliability, reduced latency, and lower costs and energy consumption. It facilitates the seamless orchestration of applications and intelligence across multiple environments, autonomously managed to enforce policies and compliance.

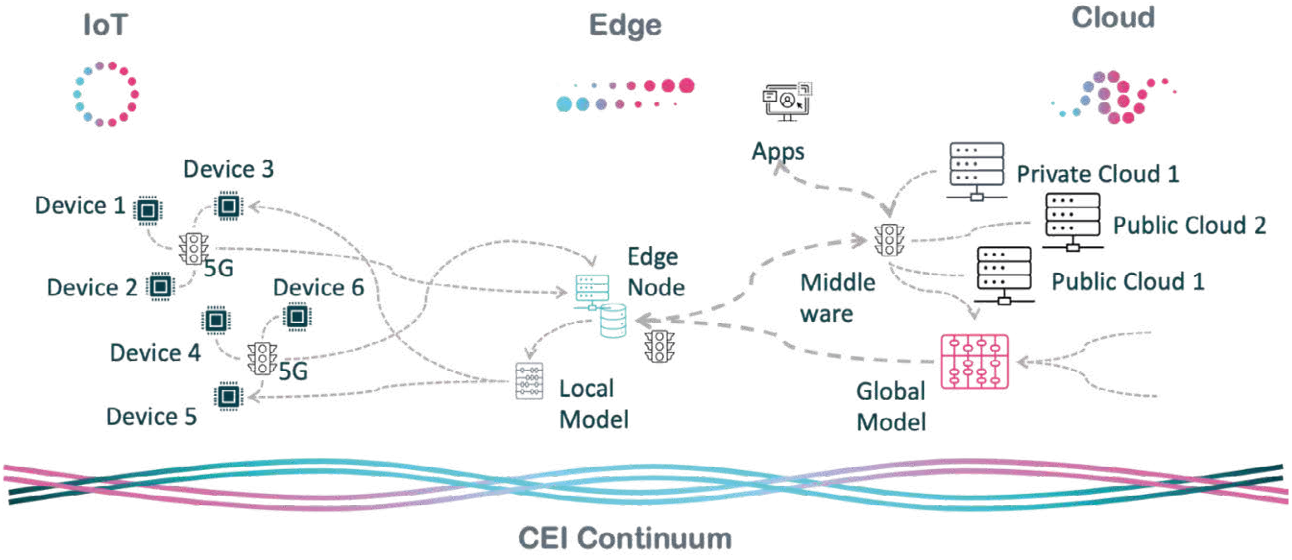

Figure 1. Illustration of the Cloud-Edge-IoT Continuum (Source: UNLOCK-CEI, D4.1 Technology Scoping Paper)

2.2. The foundation of tech development

Building on the foundational understanding established in the previous section, it is essential to delve deeper into the intricacies of the Cloud-Edge-IoT Continuum. As highlighted earlier, the definition of the CEI Continuum is multifaceted, with ongoing efforts to develop a comprehensive taxonomy of its components.

Central to this discourse is the need to provide an overview of the current state of tech development. Delving deeper into the computing continuum characteristics, the following elements can be highlighted:

- **Composition** : The CEI is a mosaic of multiple heterogeneous devices and computing resources. Each component within this continuum is identified and grouped based on its specific functions, capacities, and parameters.
- **Coordination and Distribution** : The CEI excels in coordinating and distributing tasks. It oversees data collection, processing, and the implementation of artificial intelligence across all connected devices and resources.
- **Proximity Processing** : One of the standout features of the CEI is its ability to process data as close as possible to the event source. While it leverages cloud computing for high-performance applications, it reserves localised processing for scenarios where centralised cloud architecture might not be ideal due to constraints like latency, bandwidth, cost, or privacy. In such cases, data is processed in a distributed manner across edge or device clusters.
- **Autonomous Management** : The CEI is not just a passive system; it's a dynamic entity. It manages itself autonomously, ensuring high availability and scalability without compromising business security and control.

Furthermore, the 'edge' within the CEI can manifest in various locations, each with its unique characteristics:

- **Device Edge** : This refers to devices with the capacity to run processes and deliver outputs independently. It encompasses powerful devices like cars and tractors, which have substantial power sources and robust connectivity. It also includes constrained devices that, while limited in individual capacity, can participate in distributed processing in tandem with larger devices.
- **Telco Edge** : With the advent of 5G, Mobile Edge Computing (MEC) has come to the forefront. It provides processing capacity at the network's edge, bringing it closer to users or devices, ensuring faster data processing and reduced latency.
- **Operational Edge** : This is the integration of Edge-IoT within the Operational Technology (OT) systems of a business. Located on-premises, it is similar in capacity and structure to MEC, ensuring seamless data processing and management within a business's operational framework.
- **Enterprise Edge** : Often referred to as Cloud-edge, this is a centralised resource within an organisation. It manages, filters and routes data flows between remote sites and data centres, offering cloud-like capacity to entire enterprise operations.

Considering these characteristics, the integration of Cloud, Edge, and IoT technologies within the CEI Continuum demands a sophisticated approach to manage and optimise these interconnected systems effectively. This is where Meta-Operating Systems (MetaOS, a specific cluster of projects funded by the EC) come into play. Meta Operating Systems are advanced software frameworks designed to orchestrate and streamline the operation of diverse computing elements within the CEI Continuum. Several categories have been identified as primary areas where research and innovation projects within the Meta-Operating Systems cluster can advance the convergence of Cloud and Edge technologies:

- **Integration:** This is the cornerstone for ensuring the seamless functioning of various devices, especially those at the far edge. Automating this integration and the subsequent onboarding process is pivotal for successfully deploying a Cloud-Edge computing solution.
- **Brokering**: This mechanism plays a crucial role in the broader technological ecosystem, facilitating interactions and transactions between different entities.
- **Application**: These are the tangible software solutions that end-users interact with, providing them with the tools and platforms they need to achieve their objectives.
- **Orchestration**: This element ensures the harmonious operation of various components within the continuum, allowing for streamlined processes and efficient workflows.
- **Trust and Performance:** In an age where data breaches and cyber threats are ever-present, the importance of trust cannot be overstated. Coupled with performance, these two pillars ensure that technological solutions are reliable and uphold the highest standards of data protection and operational efficiency.

2.3. Position of computing continuum as the backbone of future digital Europe

The computing continuum's significance extends beyond mere technological convergence. CEI technologies, encompassing Edge Computing, IoT, and Cloud infrastructure, are set to be a transformative force for the EU's digital empowerment goals. They will enhance digital connectivity, accessibility, and inclusivity across member states, fostering a harmonious and widespread digital ecosystem. These technologies will catalyse innovation in sectors like healthcare and manufacturing, enabling real-time data analytics and AI-driven insights. Furthermore, they aim to ensure universal access to digital benefits and contribute to economic growth, improved quality of life, and global competitiveness, positioning the EU as a digital pioneer with boundless potential for positive changes.[1] By championing the integration of edge computing nodes with cloud infrastructures, the EU envisions a harmonised and distributed digital ecosystem. This ecosystem is poised to revolutionise how businesses operate, governments work, and citizens interact in a digital realm.

This new paradigm and context is emerging through the maturing of key fundamental technologies, especially the advent of 5G and its capacity to provide adaptive, programmable and cognitive infrastructure, the effective means for containerisation and orchestration of applications across mixed resources and the virtualisation of devices in addition to cloud assets. These devices are equipped with more adaptive and intelligent chips and capacities. All of which underpins the role of edge computing as the link between high-power, high-capacity resources and low-power, more constrained devices.

Many use cases are already taking advantage of the opportunities technologically provided by the Computing Continuum, from harnessing renewable energies to optimising data processing and reducing carbon footprints. However, organisations adopting the Computing Continuum face challenges. Implementing a Computing Continuum requires new business processes, coordination between Operational Technology (OT) and Information Technology (IT), and investment in future-ready infrastructure. While the computing continuum's technological advancements and their implications for business processes are evident, understanding their impact on the broader market landscape is crucial to predict future adoption trends and challenges. As we transition from the theoretical underpinnings to the practical applications of the computing continuum, the next chapter delves into the prevailing market trends in the Cloud-Edge-IoT domain, offering insights into how these innovations shape the commercial ecosystem and influence strategic decision-making.

1 European Commission, "Shaping Europe's Digital Future", 2020.

3. Market landscape of computing continuum

3.1. Market trends and insights

Despite the unpredictable environment in Europe, firstly due to the pandemic and then to the Russia-Ukraine War, inflation, high energy prices, and supply chain disruption, the Cloud-Edge-IoT market proved resilient and continued its evolution in 2022, though at a lower growth rate.

With €172bn in spending in 2022, the IoT market already accounts for a significant investment in Europe and it is forecast to continue growing strongly at a compound annual growth rate of 10.8% to 2026. Across the computing continuum, edge and cloud will shape the infrastructure market with a total spending of €143.1bn. With increasing computing and processing needs, the edge computing market will develop rapidly. In Europe, Edge computing spending is expected to grow from nearly €36bn in 2022 to €75bn in 2026 with a compound annual growth rate (CAGR) of 14.6%.[2] According to a recent survey conducted in the UNLOCK-CEI project, 35% of European respondents plan to start using edge by 2025.[3]

European Cloud, Edge and IoT Markets

Cloud	Edge	IoT
Spending in 2022 EUR 109.6 bn	Spending in 2022 EUR 33.5 bn	Spending in 2022 EUR 172.3 bn
CAGR to 2026 20.8%	CAGR to 2026 14.1%	CAGR to 2026 10.8%

Figure 2. European Cloud, Edge and IoT Market Size (Source: IDC Spending Guides and Trackers, May 2023)

Overall, despite still being an emerging technology segment, the rapidly maturing edge computing ecosystem represents one of the most attractive technology areas for investment, having tremendous applications for IoT and other underlying technologies (such as AI, AR/VR, robotics, etc.) by bringing computation closer to the data source, significantly reducing the response time, improving bandwidth utilisation, and reducing the overall operational costs. In a world where massive amounts of data are being generated every second, it will be critical for organisations to be able to act upon the data as fast as possible.

While numerous sectors leverage cloud, edge, and IoT technologies, five sectors stand out due to their strategic significance in market adoption and future prospects. These sectors are manufacturing, energy and utilities, transportation (encompassing logistics and mobility), healthcare, and agriculture. Several criteria underscore their prominence in the Cloud-Edge-IoT market within Europe:

2 UNLOCK-CEI Deliverable1.2, Cloud-Edge-IoT Demand Landscape (second version), May 2023.
3 UNLOCK-CEI Survey (Feb 2023), n=700.

- **Industry Investment:** The magnitude of the industry's expenditure on Cloud-Edge-IoT (CEI).
- **Current Use Cases:** Robust examples of present-day CEI applications.
- **Future Use Cases:** Compelling instances of prospective CEI applications.
- **Sector Diversity:** An intent to explore a wide range of sectors.
- **Economic Significance:** The critical role these sectors play in Europe's economy, such as employment rates, GDP contribution, and other metrics.
- **Security Relevance**: Their importance to European security, highlighting the need for self-reliance and technological leadership in pivotal areas.
- **Sustainability Relevance:** Their contribution to sustainable development and renewable energy goals, like carbon emission reduction and the introduction of novel energy sources, aligning with Europe's Fit for 55 climate plan." climate initiative
- **Societal Impact:** Their influence on European society in areas like healthcare, employment, and cultural heritage.
- **Diverse Representation:** These sectors offer varied insights into distinct facets of the European economy.

The transition to edge computing is unfolding across various European industries. While edge adoption currently trails behind cloud and IoT, its uptake varies notably among industries. The healthcare sector stands at the forefront of this adoption, with manufacturing closely following. In contrast, agriculture trails behind the others. However, a substantial portion of all five industries foresees a growing need for edge deployment in the upcoming future.

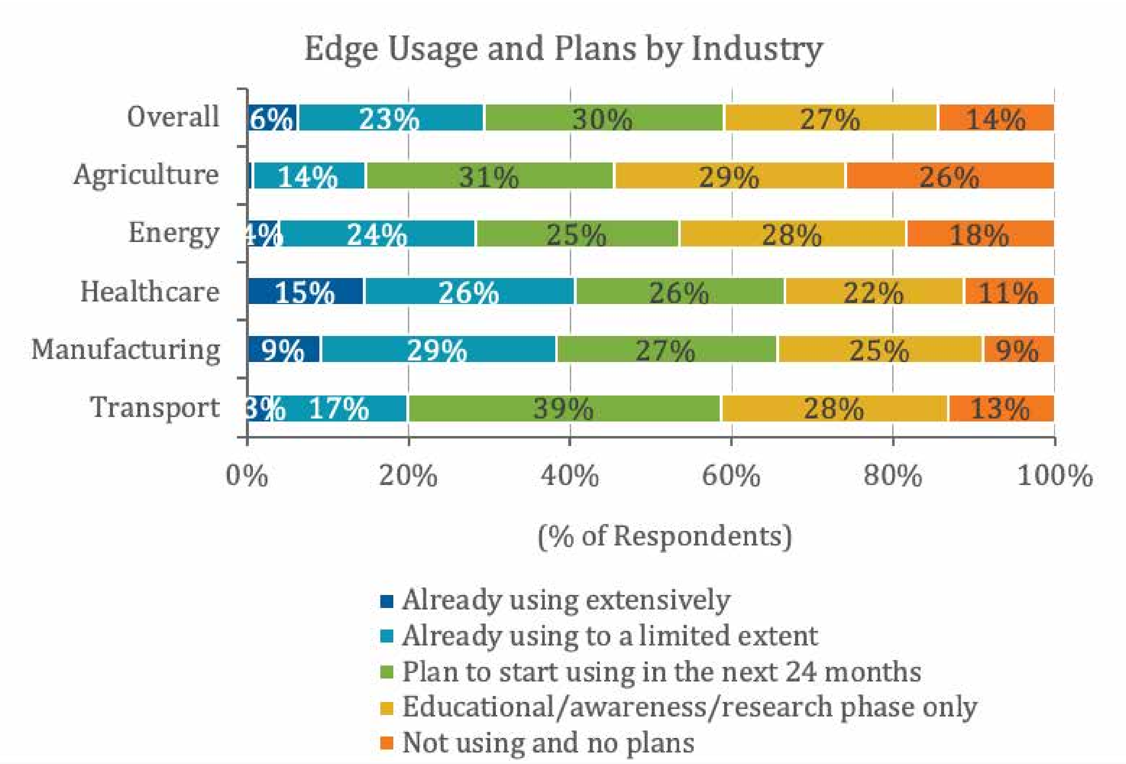

Figure 3. Edge Usage and Plans by Industry (Source: UNLOCK-CEI Survey, March 2023)

Question: Is your organisation using or planning to use edge computing in the next 24 months?

N=700 (Base: All respondents)

3.2. A deep dive into promising industries

In the subsequent section, we delve deeper into analyses of the five chosen industrial sectors.

Manufacturing: The manufacturing industry is the largest segment of the overall European CEI market. In 2022, spending is estimated to be EUR 49.6 billion, more than twice that of the second-largest industry.[4] According to the World Bank, manufacturing is the largest employer in Europe, accounting for 15% of GDP in 2021.[5] Manufacturers are embracing a wide range of CEI use cases, ranging from energy management and asset monitoring to autonomous vehicles and production automation. With such a large significance to the economy and society, widespread usage of CEI, and diverse use cases, the manufacturing sector is a top sector for CEI adoption. This is not only limited to the production phase but also extends to the after-sale phase of manufacturing, where the importance of data sharing and data analytics acts as a driving factor for the adoption of CEI solutions in this sector.

Energy and Utilities: The European energy sector, vulnerable to geopolitical threats, is undergoing a profound transformation marked by diversification and digitalisation. This sector is swiftly adapting to challenges like energy insecurity and the pressing need for decarbonisation. Given its vast geographical spread, the industry encompasses numerous remote assets, including offshore oil platforms, wind farms, pipelines, and expansive power lines. The industry is ambitiously adopting automation and remote management using IoT. Its strategic nature, rapid transformation and distributed assets make it a strong sector in CEI. One of the most promising avenues for CEI integration within the energy sector lies in flexible energy and grid management systems. To address overarching challenges such as flexibility (incorporating adaptable energy sources), stability/resilience (enhancing network observability, automation, and controllability), and efficiency (maximising energy use), it is imperative to adjust consumption/generation timings and/or locations. This adjustment can primarily be realised through market flexibility, technical flexibility and active network management. Efficient and stable integration of flexibility sources into the energy system necessitates active grid management, heightened observability, automation, and controllability across the grid, energy generation, consumption, and storage. This must be achieved with varying degrees of temporal and spatial granularity. As we strive for this flexibility, the roles of existing stakeholders in the energy system must evolve. Concurrently, this transformation paves the way for a plethora of new market opportunities and demands, reshaping the energy landscape. The incorporation of CEI solutions can streamline the seamless and stable integration of flexible energy sources into the overarching system.

Transportation: The passenger transport industry is migrating from manually controlled vehicles with internal combustion engines toward electric vehicles that are connected, intelligent, and increasingly autonomous. This shift is complemented by the development of upgraded smart infrastructure and charging stations. Meanwhile, on the logistics side, transport vehicles are also becoming smart and eventually autonomous, while fleets are tracked and optimised, freight conditions are monitored, and assets are tracked continuously across borders and oceans. These use cases are developing rapidly. The combination of mobility, remote connectivity, simple existing use cases (like fleet tracking) that are widely deployed now, highly advanced future use cases (such as autonomous vehicles) that will drive strong investment in the future, and distributed computational needs position this sector at the forefront of Cloud-Edge-IoT (CEI) adoption. As the functional scope of the transportation sector is very diverse considering transport modes in passenger and freight transport, the field of IT solutions and, thus, conceivable CEI applications is very large. The CEI applications may concern transport networks, vehicles, traffic management, mobility services, data platforms, logistics applications, fleet management, planning applications,

4 *UNLOCK-CEI D1.1, Cloud-Edge-IoT Demand Landscape (First version), Nov 2022*

5 World Bank national accounts data, and OECD National Accounts data files. Manufacturing, value added (% of GDP). Available at *https://data.worldbank.org/indicator/NV.IND.MANF.ZS?locations=EU*.

and also CEI solutions for traffic management, autonomous driving, especially software-defined vehicles and smart cities as future scenarios in the transportation sector.

Healthcare: The healthcare industry is very different from the other industries. This sector has a large public-sector presence throughout Europe. It features significant regulatory guidance and intervention. It is critical for European society's well-being. The industry has many large and small healthcare facilities, with data-sharing needs among them, as well as unique privacy concerns. It also has a large amount of mobility of staff, patients, medications, dangerous materials, and valuable hospital assets that need tracking, coordination, and control. This sector is making extensive use of connected devices, asset tracking, patient monitoring and analytics. With the integration of AI-based diagnostics, healthcare facilities are emerging as prime contenders for local edge computing resources, emphasising security, privacy, and efficiency. In sum, healthcare is critical for society, a strong candidate for diverse CEI use cases, a subject of significant regulation and policy attention, and a very different example than the other industries discussed, all of which make it an important sector in the context of CEI.

Agriculture: The agriculture industry is far smaller than the others in terms of employment, but it is strategically critical for European society's well-being, and it accounts for the largest share of land use in Europe, amounting to 39.1% of total EU land in 2018, according to Eurostat. The distributed geographical nature and low density of workers in the agriculture industry are key reasons this industry needs to make use of CEI solutions. This sector extensively uses animal tagging and increasingly uses field monitoring to optimise yields. Agricultural machinery is connected and smart, and it is moving toward autonomous operations. However, much of the agricultural land has limited cellular network coverage. As a result, this industry is continuing to develop IoT use cases, making use of edge computing (such as systems on-board farm machinery) for automation and local analytics to implement precision farming, as well as connecting to cloud resources for analysis across territories and asset fleets. The unique nature of the industry and strong adoption of CEI solutions make agriculture a strategic sector in the context of CEI.

In conclusion, the current market status of the European computing continuum is characterised by a dynamic landscape of diverse devices, edge computing adoption, heightened security and privacy concerns, and a growing emphasis on digital transformation through hybrid cloud solutions. As the European market continues to evolve, numerous opportunities are on the horizon waiting to be addressed. Businesses and innovators have the chance to further harness the potential of the computing continuum, offering more seamless, efficient, and secure experiences for consumers and enterprises alike. With advancements in technology, regulatory frameworks, and evolving customer expectations, the future of the computing continuum in Europe holds great promise, encouraging continued exploration and innovation in this transformative field.

Therefore, an analysis of computing continuum value chains is needed to provide insights into the intricate web of stakeholder relationships, processes, and innovations that drive this transformative domain. This exploration will shed light on the pivotal role of value chains in shaping the trajectory of the computing continuum in Europe, offering a comprehensive understanding of its dynamics, drivers and opportunities. Such an overview is offered in the next chapters.

3.3. Computing continuum actors and value chain drivers

The value chain of the computing continuum is diverse and multifaceted, involving cloud service providers, edge infrastructure vendors, IoT device manufacturers, and data analytics companies. To further accelerate the adoption of the computing continuum, the EUCEI community has been established (discover more at www.eucloudedgeiot.eu), acting as a collaborative platform for stakeholders to share knowledge, resources, and best practices.

3.3.1. Stakeholder dynamics in the CEI landscape

CEI technologies represent a paradigm shift in processing, storing, and communicating data. As these technologies evolve, the involvement of various stakeholders becomes crucial to ensure their effective implementation and adoption. Here is a more detailed look at the role of stakeholders in the context of CEI technologies.

Primary Stakeholders:

- **Business Users**: These enterprises and organisations adopt CEI technologies to enhance their operations. They drive demand for new features and improvements, ensuring that the technology aligns with real-world business needs. Their feedback is invaluable in refining and optimising CEI solutions.
- **Tech Providers and Developers** : These stakeholders are at the forefront of designing, developing, and deploying CEI technologies. They innovate and create solutions that cater to the market's evolving needs. Their expertise ensures that the technology is robust, scalable, and secure.
- **Industrial and Technology Associations:** These bodies often set standards and best practices for CEI technologies. They play a role in ensuring interoperability, security, and compliance across different CEI solutions.
- **Academic and Research Institutions:** These stakeholders contribute by conducting research, developing new algorithms, and training the next generation of CEI professionals. Their involvement ensures that CEI technologies remain at the cutting edge.

Secondary Stakeholders:

- **Citizens and General Public:** As end-users, they interact with CEI technologies, often without realising it. For instance, when using smart home devices or accessing services powered by edge computing. Their feedback can highlight usability and accessibility issues, driving more user-centric innovations.
- **Regulatory Bodies:** As CEI technologies become more integrated into daily life, regulatory bodies will play a role in setting guidelines and policies to ensure data privacy, security, and ethical use of the technology.

In the context of CEI technologies, stakeholders' involvement is multifaceted. While primary stakeholders drive the development and direct application of the technology, secondary stakeholders ensure its broader acceptance, ethical use, and societal impact. Engaging with all these stakeholders is essential to harness the full potential of CEI technologies and ensure they bring value to society at large. The interplay between primary and secondary stakeholders is a matter of innovation and adaptation. Their collective actions and demands form the basis for the value chain drivers.

3.3.2. Value Chain evolution and drivers in the CEI Ecosystem

With its intricate value chains across sectors, the CEI ecosystem is being shaped by a myriad of technological drivers and market demands.

In the following, we will highlight the key points of the strategic research and innovation agendas of the leading cross-sector industry associations that belong to the TransContinuum Initiative[6] and Key Digital Technologies Joint Undertaking and sector-specific industry associations, focusing on potential "demand pull" drivers. The key points outline mutual dependencies, requirements, and technological demands to make interactions between stakeholders along data-driven value chains more efficient.

The cross-sector key insights and findings regarding "demand pull" drivers, observed opportunities and challenges in the upcoming years are the following:

- Digital twins, immersive communication, holographic telepresence, ubiquitous support for AI, augmented/virtual reality applications as well as a trustworthy and secure edge-clouding computing connectivity infrastructure for safe and secure personal mobile robotics are major "demand pull" drivers for CEI technologies.
- Real-time capabilities, low-latency performance on the edge, optimisation and complex problem-solving and reasoning in the cloud are the main required features of the future Cloud-Edge-IoT Continuum. Seamless integration of application workflows digital twins, including physics-based simulations and AI/ML, will be crucial.
- Due to climate change and the recent shortage of energy sources, energy and resource efficiency will become crucial for the competitive advantage of European companies. Therefore, new efficient hardware for data management and processing is needed to achieve the ambitious plans of BDVA regarding energy savings of 10% per year. 6G IA calls for AI-based optimisation of network management functions and more efficient radio technologies to return to energy consumption like 4G networks.
- The semiconductor industry, represented by Key Digital Technologies, strives for flexible and open hardware interfaces and architectures in combination with efficient and light weighted AI/ML algorithms for embedded software and neuromorphic computing to meet these ambitious energy efficiency demands.
- The integration costs of existing heterogeneous tools and frameworks from different communities and vendors are very high. Europe faces fierce competition with Asian and American vendors who already announced their own IoT and Edge Computing strategies. Single-vendor solutions require fewer integration efforts and lead to lock-in for the ICT providers and the end users. Open hardware and software communities as well as frameworks at the infrastructure level, will allow for new business opportunities, enable growth for SMEs and start-ups, and prevent the formation of oligopolies on the market.
- Current government actions such as the infrastructure investment programmes European Alliance for Industrial Data, Edge and Cloud and IPCEI CIS enforce a strong "technology push" for CEI infrastructures in Europe. The newly updated computing und connectivity infrastructures will raise the "demand pull" for new service offerings and individual hardware and software solutions in the upcoming years.
- The identified demand-pull topic areas such as digital twins, AI and IoT have been part of the standardisation landscape for many years. The standardisation bodies need to focus their current attention on open APIs and standards for CEI infrastructures. The main GAIA-X objective is to provide an open, cloud-agnostic infrastructure for the European economy and prevent vendor lock-in effects. GAIA-X is a promising initiative that pursues the standardisation of cloud-, edge- and AI services at the infrastructure level.

6 Big Data Value Association (BDVA), 6G Industry Association, Alliance of Internet of Things and Edge Computing Innovation (AIOTI), European Cyber Security Organisation (ECSO), European Technology Platform on Smart Systems Integration (EPoSS), European Service Network of Mathematics for Industry and Innovation (EU-Maths-In), Association for European NanoElectronics ActivitieS (AENEAS), INSIDE Industry Association

3.4. Value chains, revenue streams and service requirements

This section delves into the value chains, revenue streams, and service requirements across various sectors to understand how Cloud-Edge-IoT (CEI) technologies impact different industries.

3.4.1. Manufacturing

The diagram below illustrates the complex value chain involving a manufacturing SME and its tech providers. Revenue streams flow from the SME to various CEI solution providers. While OEMs (Original Equipment Manufacturers) don't directly influence these internal CEI cases, their evolving requirements can impact CEI technology adoption. Implementing internal CEI solutions in manufacturing is complex, demanding tailored solutions for specific production setups and integration into existing IT systems. This involves components from various suppliers, including Cloud-Edge-IoT tech and cloud providers.

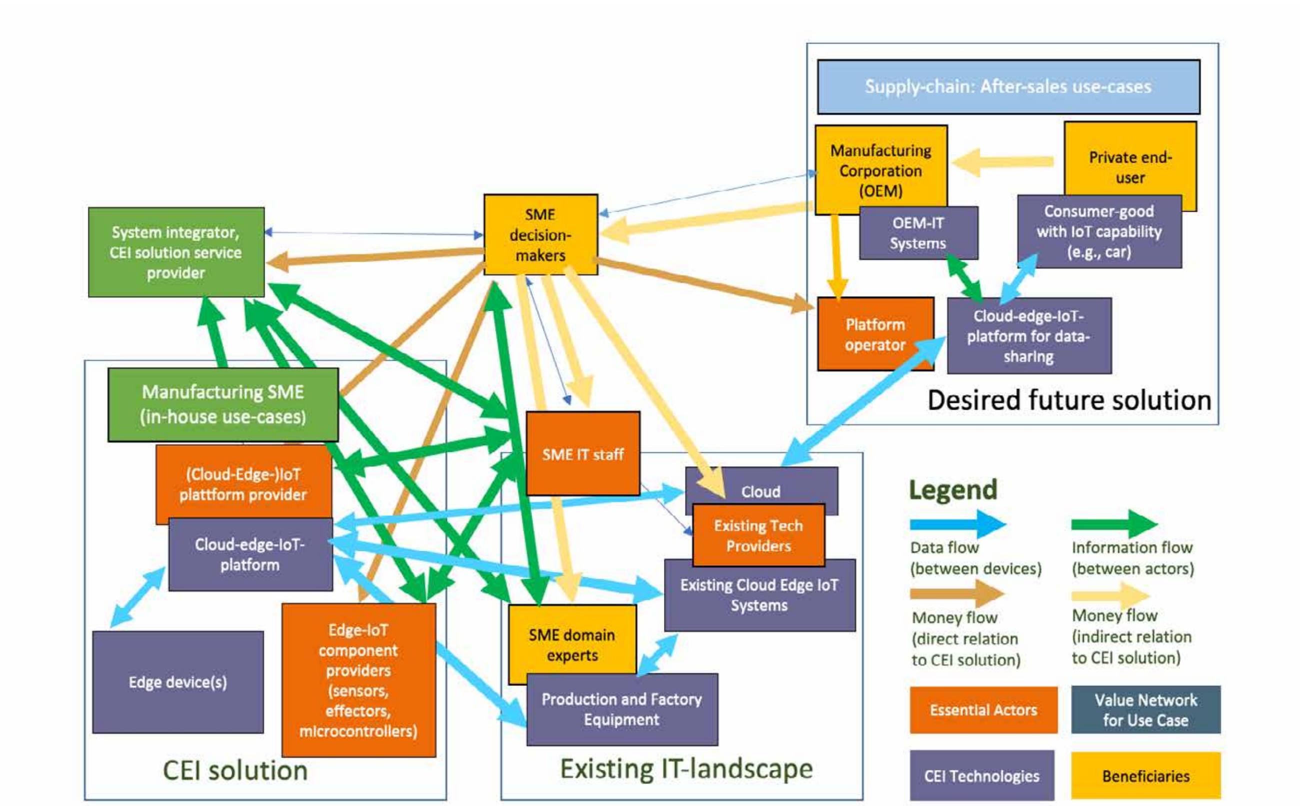

Figure 4 – Manufacturing Value Chain (Source: UNLOCK-CEI D3.2 "Sector-specific service requirements, data flows and revenue streams in Cloud-Edge-IoT value networks")

For internal CEI solutions, key decision-makers include the manufacturing expert affected by the CEI system, company leaders, and IT staff overseeing integration and operation.

In terms of service requirements, manufacturing companies prioritise workplace safety, addressing skilled labour shortages through automation, preparing for market shifts (including CEI-readiness, resilience, OEM demands, and sustainability), marketing benefits, and gaining a competitive edge by offering superior products or services. Several aspects of system implementation and operation need to be considered to address these priorities effectively.

- **Design**: Solutions should be customised to on-site processes, offering tangible benefits.
- **Installation**: Cost-effectiveness is key, with system integration and customisation being major cost factors. Standardising data formats and interfaces can reduce these costs.
- **Operation**: The system must operate in near-real-time, even with internet disruptions,

relegating only offline processes like AI-model-learning to the cloud. A user-friendly interface is essential for non-engineers, ensuring seamless integration with end-user workflows.

- **Value-added Supplements**: Data can enable external monetisation strategies, like enhancing OEM customer service or aiding compliance with regulations like the German Supply Chain Act[7].
- **Maintenance**: Considering SMEs' limited on-site staff, the system should require minimal maintenance. Non-engineers should handle basic maintenance tasks, and customer service should be reliable with a dedicated contact.
- **Disposal/Upgrade**: The system should be long-lasting, with upgrades causing no interruptions. Major upgrades should come with staff training options.

3.4.2. Transportation

The following simplified, generic data model presented for the transportation sector in a Smart City provides insights into the intricate relationships between various stakeholders involved in urban traffic management.

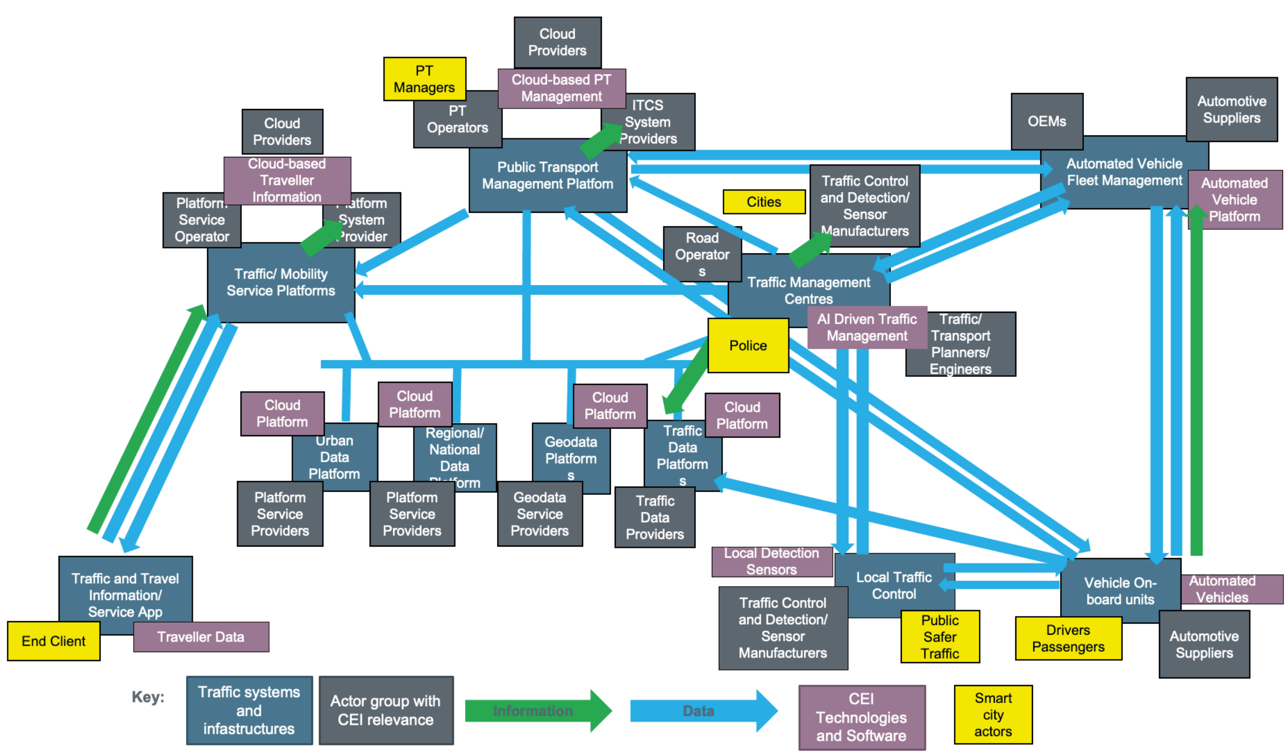

Figure 5. Transportation Value Chain (Source: UNLOCK-CEI D3.2 "Sector-specific service requirements, data flows and revenue streams in Cloud-Edge-IoT value networks")

This model highlights the importance of seamless data sharing and communication among road operators, traffic control/management/information system providers, traffic police, public transport companies, and other actors. These stakeholders collaborate to ensure efficient traffic flow, reduce congestion, and enhance cities' overall quality of life.

Value streams (money flows) in transportation management are influenced by public sector involvement. Since traffic management is vital to urban infrastructure, a significant portion of data exchange is not charged. However, specific value streams were identified:

- Traffic data flows from private data providers like INRIX, Google, and TomTom to public traffic managers and planners. Private companies have increasingly gained access to relevant data from navigation systems and mobile phones, enabling them to offer better traffic data than

7 https://www.bundesregierung.de/breg-en/service/archive/supply-chain-act-1872076

public authorities in some cases.

- Road operators often pay service fees when their traffic management software is hosted in the cloud.
- Road operators purchase systems and services from private companies specialising in traffic control systems.
- Traveller information services, such as mobility as a Service (MaaS), may charge end users, generating service fees.
- As automated driving becomes more prevalent, there is likely to be a commercial relationship between OEMs and cloud service providers, particularly for vehicle edge platforms in automated driving.

Key service requirements for effective traffic management include:

- **Design**: Solutions must be customised to fit urban traffic management's specific processes and needs. They should offer tangible benefits by improving traffic flow, reducing congestion, and enhancing safety.
- **Installation**: Cost-effectiveness is crucial during installation, with a focus on seamless system integration and customisation. Standardising data formats and interfaces can help reduce installation costs. Future solutions that provide post-sales consumer data should ensure that the derived value justifies the service cost.
- **Operation**: Traffic management systems must operate in near-real-time, even in the presence of unreliable internet connectivity. Key operations like real-time traffic monitoring and incident detection should be handled at the edge to minimise latency. User-friendly interfaces are essential to enable non-technical staff to use these systems effectively.
- **Value-added Supplements**: Leveraging data for external monetisation strategies can include enhancing OEM customer service or aiding compliance with regulations related to traffic data.
- **Maintenance**: Traffic management systems should be designed for minimal maintenance, considering that public sector organisations often have limited on-site technical staff. Basic maintenance tasks should be manageable by non-engineers, and reliable customer service with dedicated contacts is essential.
- **Disposal/Upgrade**: Systems should be designed for longevity, with major upgrades that do not disrupt traffic management operations. Staff training options should accompany significant upgrades to ensure smooth transitions.

3.4.3. Energy

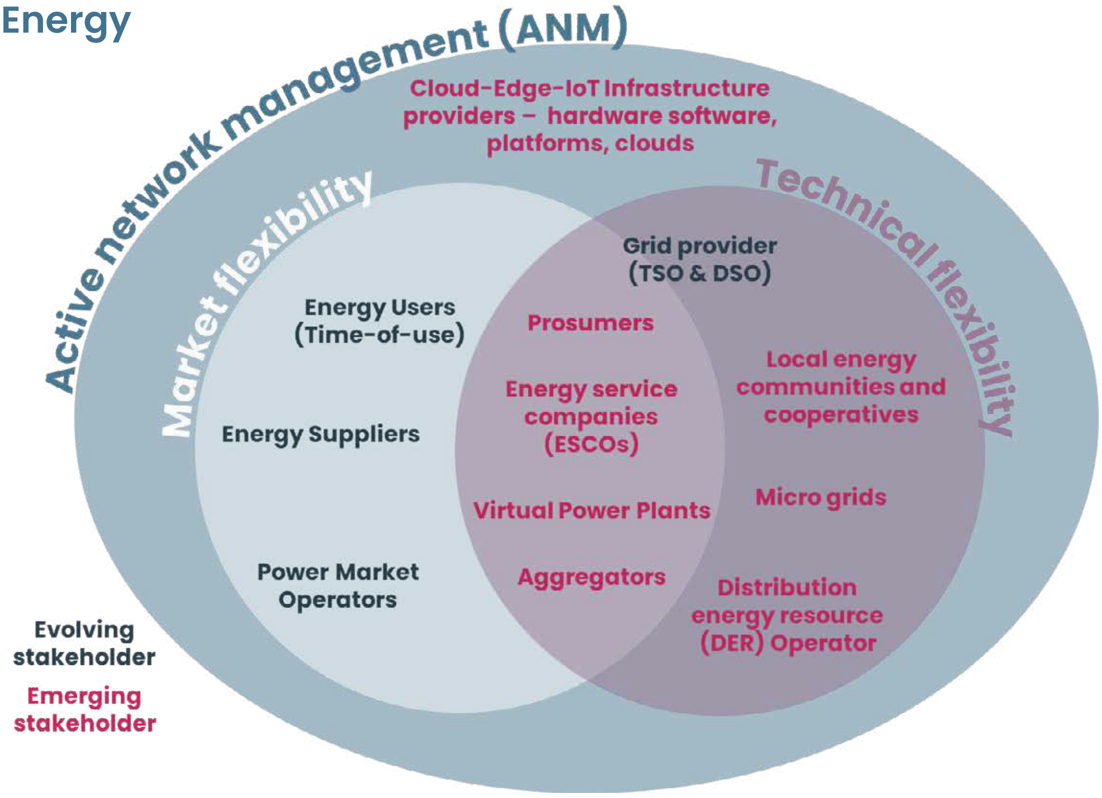

Figure 6. Energy sector value network
(Source: UNLOCK-CEI D3.2 "Sector-specific service requirements, data flows and revenue streams in Cloud-Edge-IoT value networks")

The figure above illustrates the non-linear value network within the energy sector, emphasising the evolution of roles among existing stakeholders and the emergence of new players. This dynamic landscape presents both challenges and opportunities for grid providers and participants in the energy market.

Traditional stakeholders in the energy sector, such as grid providers and utilities, are undergoing transformations in their roles and responsibilities. For example, prosumers who generate and consume energy are playing a more significant role in the energy ecosystem. Energy aggregators have also emerged as intermediaries that collect energy from various sources, aggregate it, and sell it in larger quantities to wholesale buyers or grid operators.

Key service requirements in the energy sector encompass various aspects:

- **Design**: The energy sector operates in a highly regulated environment, requiring alignment and harmonisation of processes and standards at local, national, and European levels. Collaboration along the value chain and the implementation of EU regulations are essential. The interoperability of infrastructure and platforms is crucial, along with the standardisation of sensors, data formats, communication standards, and grid signals.
- **Regulatory Framework**: Regulatory compliance and adherence to data protection, security, and ethical standards are paramount, given the sensitive nature of energy data.
- **IT Infrastructure** for Active Network Management (ANM): Open-source IoT platforms are needed to serve as the control room architecture for future grids. These platforms should overcome traditional Supervisory Control and Data Acquisition (SCADA) systems and handle large volumes of data. ANM should enable observability, controllability, and automation of the grid, depending on location and time.
- **Installation**: Effective installation requires careful planning and coordination, considering the deployment of sensors, communication networks, and data management systems. Integration with existing energy infrastructure is essential.

Operation: The operation of an Active Network Management (ANM) system should ensure high granularity in monitoring and controlling the grid. It must address connectivity issues and manage grid stability in real-time.

Maintenance: Remote monitoring features are essential for the efficient maintenance of CEI infrastructures in the energy sector. Data privacy and cybersecurity measures must be in place to protect critical infrastructure.

Upgrade: Upgrades should guarantee continuity of service while accommodating evolving grid requirements and regulations.

3.4.4. Healthcare

The healthcare sector features a diverse network of stakeholders, each with its own interests and roles in the data-driven value chain. This network diagram illustrates the complex dependencies and interactions among healthcare actors, including care providers, MedTech companies, telco infrastructure providers, and more.

In the healthcare industry, many different actors are interacting with each other, collaborating or competing in complex data-driven value chain networks.

The following network shows the different dependencies between the identified stakeholders, especially concerning money and data flow and gives better insight into the interconnectedness of different actors in the health sector. It highlights the key role of MedTech companies as they are at the centre of the network and at the interface of both money and data flows. Normally, care providers are the owners of the data and medical technology stakeholder act as the main stakeholder. Basic requirement for all interactions are the services provided by telco infrastructure providers. The network shows a possibility of how the different actors might interact. For specific use cases the interaction of actors might differ.

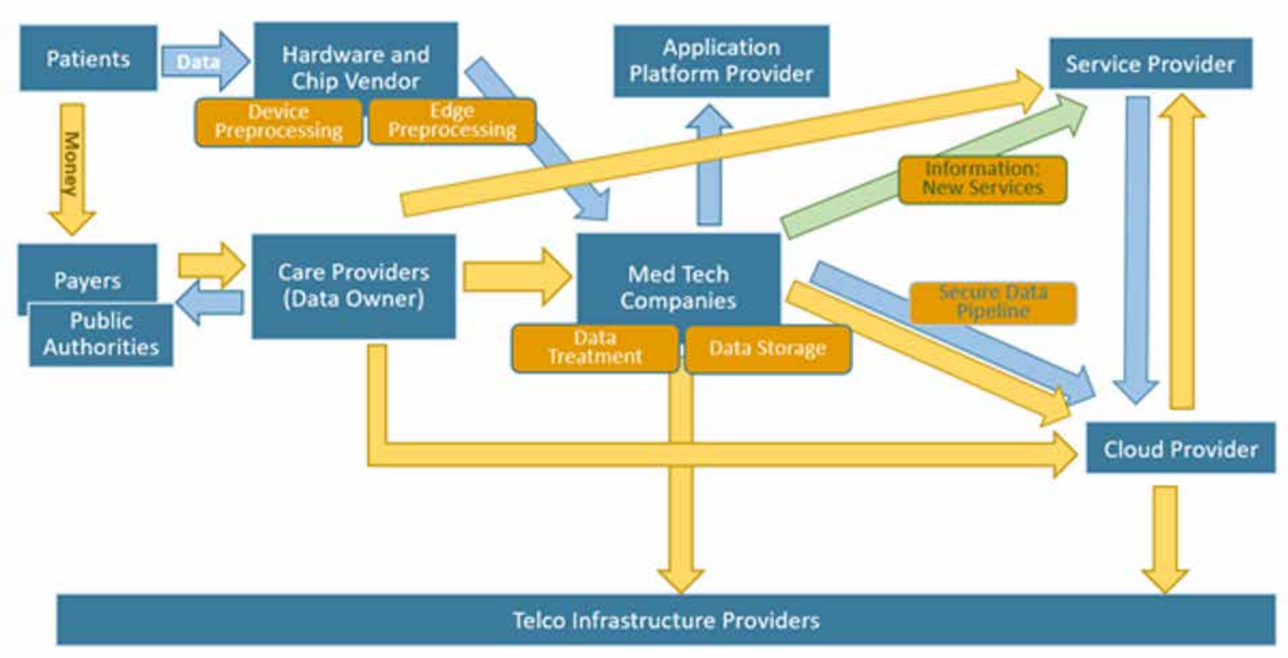

Figure 7 – Healthcare Value Chain (Source: UNLOCK-CEI D3.2 "Sector-specific service requirements, data flows and revenue streams in Cloud-Edge-IoT value networks")

Key service requirements in the healthcare sector encompass several critical considerations:

- **Design**: Healthcare CEI applications need to adhere to stringent regulatory frameworks and ethical constraints. Usability is paramount, as these applications often involve the participation of medical professionals and patients.
- **Installation**: Implementing CEI solutions in healthcare settings can be particularly challenging due to complex governance structures, privacy concerns, and the critical nature of healthcare data.
- **Operation**: Healthcare systems must handle high granularity in data processing and analysis. They must also address connectivity issues, ensuring that healthcare professionals have access to vital information when needed.
- **Maintenance**: Efficient maintenance of CEI infrastructures in healthcare requires remote monitoring features. Data privacy and cybersecurity are of utmost importance to protect sensitive patient information.
- **Upgrade**: Upgrades must be carefully planned to ensure continuity of service in healthcare settings, where even brief interruptions can have severe consequences.

3.4.5. Agriculture

The agricultural value chain diagram centralises farmers and equipment manufacturers, illustrating how CEI solutions are integrated into farm equipment to enhance productivity, sustainability, and profitability.

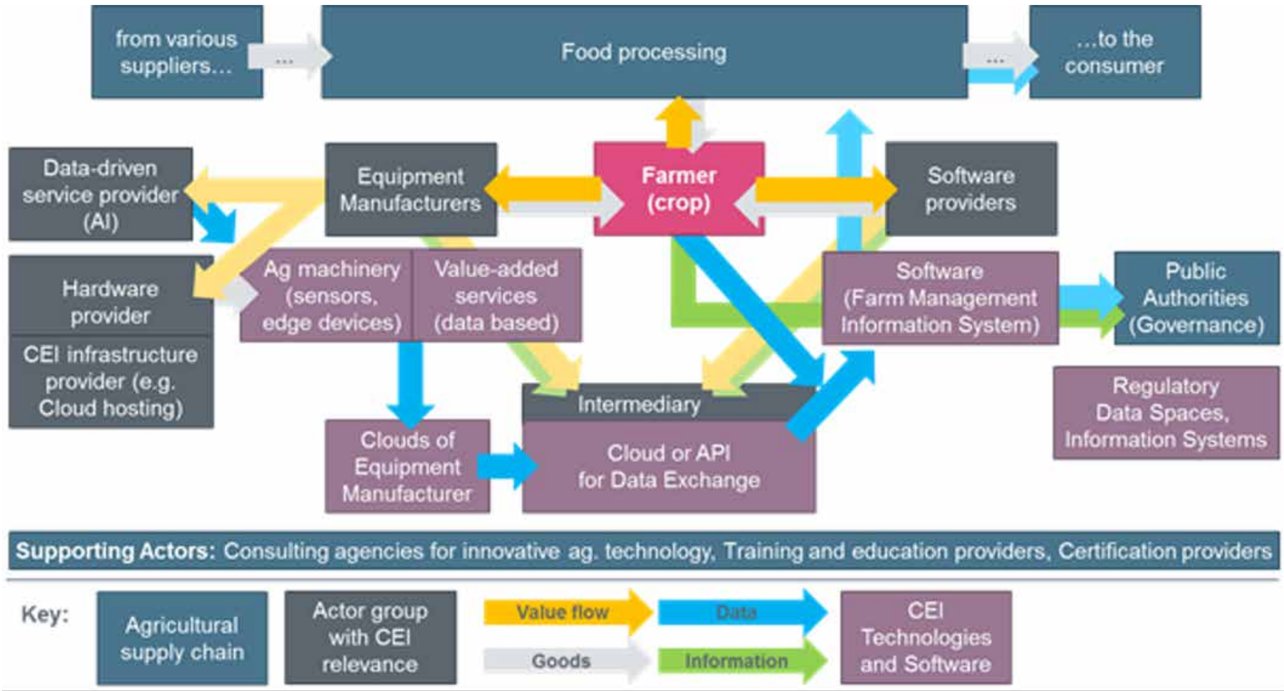

Figure 8 – Agricultural Value Chain (Source: UNLOCK-CEI D3.2 "Sector-specific service requirements, data flows and revenue streams in Cloud-Edge-IoT value networks")

Key service requirements for CEI applications in agriculture encompass various factors:

- **Cost-effectiveness**: Agricultural CEI solutions must offer a clear return on investment, considering the often narrow profit margins in farming. Solutions should be designed to reduce operational costs and increase crop yields.
- **International Applicability**: Agriculture is a global industry, and CEI solutions should be adaptable to different farming practices and climates worldwide.

- **24/7 Availability**: Farmers rely on CEI systems around the clock, particularly during critical planting and harvesting seasons. Systems must be highly reliable and available.
- **Robustness Against Environmental Influences**: Farming is conducted in diverse environmental conditions. CEI equipment must be rugged and capable of withstanding various weather conditions and environmental factors.
- **Offline Applicability**: CEI systems should still function effectively in remote or rural areas with limited internet connectivity, storing and forwarding data when connectivity is restored.
- **Updateability**: Agriculture is subject to rapid technological advancements. CEI solutions should be designed with upgradability in mind, ensuring farmers can benefit from the latest innovations.
- **Interoperability**: CEI solutions should prioritise interoperability and easy integration to accommodate diverse equipment and technologies used in agriculture.
- **Customisation**: Every farm has unique needs. CEI solutions should be customisable to suit specific farming practices and goals.
- **AI Support**: The integration of artificial intelligence (AI) can provide valuable insights for farmers, helping them make data-driven decisions.

4. Opportunities and challenges in the CEI ecosystem

The Value Chain drivers, characteristics, and flows previously discussed are instrumental in guiding the progression and speed of innovations in the CEI Ecosystem. Every sector, from health to manufacturing, is experiencing transformative changes fuelled by their distinct value propositions. These drivers, integral to each sector's value chain, influence the emerging opportunities and challenges. For a comprehensive view, we've outlined the opportunities and challenges encountered by various sectors and cross-domain areas.

Sectors	Opportunities	Challenges
Health	Smart medical devices offer less invasive and more comfortable treatments. Edge devices ensure patient data privacy, especially in the health sector. In critical settings like operating rooms, these devices offer real-time decision support, crucial for saving lives.	Accessing high-quality health data is challenging due to strict regulations and ethical concerns, especially for at-home monitoring. Ensuring security in wearables, edge devices, and cloud services is vital. Cloud providers must adhere to data protection standards. Many clinics lack interoperable systems. AI diagnostic tools face rigorous, costly certification processes, posing risks for tech companies. The health sector's value chains are intricate, with stakeholders both collaborating and competing.
Agriculture	CEI technologies bolster eco-friendly and efficient agricultural production through automated machinery and real-time data-driven decisions. Smart farming solutions cater to individual plant and animal needs, with potential in automation and retrofitting machinery. Data Spaces provide modern storage, ensuring farmer data sovereignty and simplifying regulatory reporting. Given many farmers' outdated IT systems, CEI adoption presents vast opportunities, especially with high demand for weather and yield information. Local edge-operated multi-sensor systems address unstable internet connections, optimising data transfer and processing.	The agriculture sector is traditionally slow to adopt new technologies. Limited network coverage hinders CEI adoption, making reliable solutions like edge computing vital. Without seamless data collection, implementing AI-driven optimisation and data sharing becomes challenging and expensive.

Sectors	Opportunities	Challenges
Transportation	Edge platforms locally process critical data for latency, privacy, and efficiency. Clouds handle strategic operations, from planning to AI calculations. CEI technologies foster new transportation services like shared platforms and automated vehicles. As centralised functions evolve, European entities should expand cloud capacities and edge presence. Key European players like T-Systems, Bosch, and Siemens should be fortified against global hyperscalers.	CEI technologies rely on cloud providers, often introduced by major international companies like AWS and Google. In Europe's transport sector, there's a risk of vendor lock-in due to limited cloud provider options. Public transport users express concerns over data sovereignty and protection when data is stored on international servers. The debate continues on data ownership between public authorities and private providers, with a growing trend towards public-controlled data servers.
Energy	CEI technologies offer real-time analysis to address growing network and energy complexities, enhancing efficiency and transforming consumers into active energy contributors. Blockchain aids in local energy trading, while real-time regulation ensures balanced power distribution. Digitalisation empowers consumers to actively participate in energy operations.	For CEI technologies to reach their potential, policy and regulatory reforms are essential to maximise digital electricity benefits and minimise risks. Emphasising data ownership, privacy, and cybersecurity is vital, and evolving business models and standardisation are crucial in this dynamic energy ecosystem.
Manufacturing	CEI technologies in manufacturing align with the Industry 4.0 vision, transitioning factories to smart spaces using IIoT. Manufacturers value production data for optimisation, processing it near sensors on edge devices. This supports real-time applications and efficient data management, with cloud applications essential for strategic operations and deep analytics.	Collaboration with global hyperscalers raises data sovereignty concerns, prompting a need for European entities to enhance cloud and edge tech capacities. Many business models lack clarity, especially in predictive maintenance, leading to uncertain market potential. Data exchange is pivotal; while automotive OEMs can set standards, other sectors face complex inter-company coordination. Ensuring data consistency and quality remains a universal challenge across digital solutions.

Sectors	Opportunities	Challenges
Cross-domain	Industry associations and initiatives are shaping the CEI technological landscape, with a focus on digital twins, immersive communication, holographic telepresence, and AI support. The push for real-time, low-latency performance and seamless integration of workflows signifies the industry's direction. Climate change and energy shortages amplify the demand for energy-efficient solutions, with initiatives like 6G IA emphasising AI-based optimisation. European funding programs and standardisation efforts, such as GAIA-X, aim to provide an open infrastructure, promoting transparency and efficiency. The UNLOCK-CEI survey indicates a growing interest in Edge technologies, with transportation, agriculture, and manufacturing sectors leading the way. Key opportunities for European organisations include the development of AI and 5G technologies, security solutions, mastering next-gen component technologies, and leveraging cost and energy reduction for impactful solutions.	While various tools and frameworks are available for hardware/software development, high integration costs pose challenges. Asian and American competitors have already launched their IoT and Edge Computing strategies, leading to potential vendor lock-ins for ICT providers. Open hardware and software communities are seen as alternatives to mitigate these dependencies. The push for CEI infrastructures in Europe is strong, but the adoption rate of edge is currently limited. Challenges include high costs, unclear ROI, security concerns, inadequate IT infrastructure, deployment complexities, and the need for complete end-to-end solutions.

Table 1. Overview of opportunities and challenges of CEI in Europe

In the table above, we've delved into the myriad opportunities and challenges presented by CEI technologies, providing a preliminary overview of the current landscape.

4.1. CEI adoption challenges

The complexity of edge adoption means that there are deeper layers of challenges that merit specific attention. In the following chapter, we will take a closer look at these specific challenges, detailing their implications for the future of CEI in various sectors.

4.1.1. Clear business case

One of the main barriers to adopting CEI is high cost. Companies need a clear business case to understand the tangible return on investment of CEI solutions. Without a solid business case, decision-makers find it challenging to justify the upfront costs, integration complexities, and potential disruption associated with implementing Cloud-Edge-IoT solutions. Moreover, the lack of standardised frameworks and proven success stories further exacerbates the uncertainty surrounding the potential value proposition. As a result, companies may be hesitant to invest in IoT-edge solutions, hindering the broader adoption and realisation of their transformative potential.

Addressing this barrier necessitates a comprehensive evaluation of costs, benefits, and potential risks specific to each organisation. A robust business case for Cloud-edge-IoT solutions must articulate the tangible value proposition in financial terms, demonstrating how the technology will generate measurable returns and impact key performance indicators. This requires a thorough analysis of current processes, identifying pain points and areas of improvement that CEI solutions can address. By quantifying the potential cost savings, productivity gains, and competitive advantages, decision-makers can make informed judgments and overcome the lack of a business case obstacle. Furthermore, organisations can leverage industry-specific use cases, benchmarking data, and success stories to build confidence and establish a persuasive argument for the adoption of IoT-edge solutions.

4.1.2. Interoperability and Standardisation

The complexity and heterogeneity of CEI applications, where different devices and systems interact and operate together, makes the search for common requirements essential to shape a normative and technical roadmap able to incorporate and regulate potential game-changing applications and use cases. Moreover, several technical challenges arise from such heterogeneity, such as resource allocation and service orchestration. This is where standardisation efforts can help and enable the commercialisation network technologies, providing the interoperability and scalability required to fully realise the potential of the cloud-edge-IoT computing continuum and better manage its intrinsic heterogeneity (Zhang et al., 2020). Standards will play a crucial role in addressing challenges related to data management, security, and privacy and will be essential for facilitating the integration of a largely heterogeneous number of IoT devices with different power and existing technologies. Thus, the development of high-quality ICT standards resulting from the cross-sectoral collaboration between policymakers, industrial players and researchers will be essential to develop new and innovative digital services and enable the capillary transformation of business, industry, and society in general (Toche et al. 2021).

Another core topic linked to the successful implementation of standards linked to cloud, edge, and IoT technologies relates to the formulation of standards for the implementation of a successful data strategy supporting physical infrastructures to store information across terminals. Moreover, the massive storage of data and the need to create relevant data services need appropriate management practices to accommodate different stakeholder groups' needs. In this context, the successful deployment of AI applications is essential to properly handle datasets and ensure gatekeeping, compliance and transparency across the board (European Commission, 2023).

Despite the standardisation challenges, various activities have already been performed. As an example, the StandICT.eu initiative, backed by the European Commission, has unveiled comprehensive reports on the intricate landscapes of the Internet of Things (IoT) and edge computing. Originating over two decades ago, the IoT has become a cornerstone in various industries, from healthcare to finance, reshaping how businesses operate both locally and globally. Similarly, edge computing, defined by the Alliance for Internet of Things Innovation (AIOTI) as a shift from centralised to decentralised architectures, is gaining traction across multiple sectors. Both domains underscore the paramount importance of standardisation. Collaborative efforts among Standards Development Organizations (SDOs), Alliances, and Open-Source Software (OSS) initiatives have been instrumental in this standardisation journey. The reports aim to simplify these complex and dynamic landscapes by creating an open-access database of related specifications, documents, and more. This endeavour makes the vast amount of information more digestible and sets the stage for future extensions and comparisons.

In sync with these efforts, The EUCEI task force on architecture is actively delving into several pivotal areas. They focus on defining taxonomies, facilitating the sharing of components between Research and Innovation Actions (RIAs), and ensuring rigorous peer review and testing. One of their primary objectives is to enable in-depth architectural discussions among projects in the IoT/Edge and Cloud domain, aiming to create a seamless continuum. They are also dedicated to identifying the key thematic areas and the essential building blocks within them. Furthermore, the task force is committed to understanding and highlighting the unique contribution of each project to these thematic areas, ensuring a holistic and comprehensive approach to the challenges and opportunities in the realm of IoT, Edge, and Cloud technologies.

4.1.3. Organisational and value chain capacity

The lack of organisational and value chain capacity presents a significant barrier to the widespread adoption of CEI solutions. Organisations often find themselves unprepared to handle the complexities associated with implementing and managing these technologies. These solutions require a shift in organisational structure, processes, and skills. Adopters should go through a change management of their legacy technologies and existing knowledge.

Additionally, the adoption of CEI solutions involves multiple stakeholders and partners across the value chain. This brings up several challenges, such as security concerns, reliance on external parties for infrastructure and risk of potential disruptions. Collaboration and coordination among these entities are critical for successful implementation. However, differing levels of technological capabilities, varying investments, and conflicting priorities can hinder the adoption process. Without proper alignment and engagement across the value chain, organisations face difficulties seamlessly integrating CEI technologies, hindering the realisation of their potential benefits.

Overcoming the lack of organisational and value chain capacity requires a proactive approach to building the necessary capabilities. Organisations need to invest in training programs, reskilling initiatives, and talent acquisition to ensure their workforce possesses as well as proper change management processes. Collaborative efforts should be made to foster strong partnerships and communication channels across the value chain, addressing misalignment and promoting a shared understanding of CEI solutions' benefits and implementation strategies.

4.1.4. Skills

The topic of digital skills and access to the necessary talent within both industry and research organisations is one of the principal barriers identified towards both technology adoption and development, especially within the Cloud-Edge-IoT context. It is estimated that by 2027, there will be a 4-fold increase in the demand for skills related to AI application development AI implementation and 3-fold for Cloud Infrastructure, IoT Analytics and Cloud Integration and APIs compared to 2020.[7] Across both Cloud and IoT an average of 39.5% of companies plan to hire staff with these skills over the coming two years, this is combined with a similar proportion who plan to reskill and upskill existing staff to meet the new demands in these fields. The convergence of the technologies contained with the CEI, which also includes cybersecurity, data and AI, is taking effect on the skills required for the deployment of the wider selection of technologies in each solution and use case. Initial indicators from leading use cases indicate a reduced demand for IoT skills, with Cloud skills providing the extension into the edge while IoT becomes more niche. Within the roles primarily in the cloud, a strong co-capacity is required for Cybersecurity and Data, while in IoT, it is Data and Cloud. The spread of skills required within CEI use cases also varies within domains, highlighting the contextual nature of the future needs within the CEI. While the markets for the CEI in Europe are forecast to grow, without significant efforts to continuously upskill existing IoT and Cloud professionals, there will be a limit on how well the European industry can adjust to the CEI paradigm. This will translate into a lower appetite for new platforms and systems, reduced investment in infrastructure and continued cloud-centric deployment where the potential business outcomes or current pains are not sufficiently strong enough as the organisation will lack the talent to support implementation. The CEI must address both the changes that it will cause within the skills demands and roles and the supply of the talent pipeline within the domains and key value chains must be a key focus for the scaling up of the use cases within the RIAs and as the progress moves towards Large Scale Pilot actions.

4.2. Addressing CEI Challenges: Insights from Industry and Research and Innovation Use Cases

The challenges faced by the EU and detailed in previous sections can be partially addressed via specific use cases from the industrial world and the cluster of research and innovation projects that the EC has specifically funded to bring the CEI continuum forward. As detailed above, the challenges span economic, environmental, and technical domains. The following section provides some key examples of how industry and research use cases can be used to address and mitigate some of the challenges described.

4.2.1. Industry spotlight use case examples

The CEI opportunities are mainly found at the level of use-cases. The computing continuum opens up a plethora of innovative use cases across various industries. The seamless integration of cloud, edge, and IoT technologies enables faster decision-making, enhanced user experiences, and reduced operational costs. The spotlight use-cases of each sector help address some specific challenges, as detailed in the examples below.

Manufacturing

Example 1

Use case: Asset Monitoring and Maintenance

Description: CEI solutions in asset monitoring and maintenance provide manufacturers with real-time insights into the condition and performance of machinery. Manufacturers can install asset monitoring systems to detect such conditions as temperature, vibration, moisture, chemical exposure, pressure, and others, to provide rea-time visibility into their asset conditions. These systems can then identify changes or problems, and initiate maintenance. By doing so, this solution reduces costs, extends the life of equipment, reduces errors, increases productivity and reduces downtime. Such systems can also be integrated into digital twins and integrated with other operations and IT systems for easier management, increased efficiency and moves toward automation. It is the most widely used use case in manufacturing, used by 64% of respondents in the industry. it is highly accessible and often one of the first use cases to be adopted. It can also be a foundation for larger CEI/digitalization initiatives that bring large gains to the industry.

Example 2

Use case: Automated Guided Vehicles

Description: CEI solutions in automated guided vehicles are among the use cases in manufacturing with the highest future potential . Factories, warehouses and logistics centres feature many moving parts and inventory. Forklifts, and production lines tend to require employees navigating facilities amidst large equipment, creating safety risks. AGVs and robots enable automation of many of these processes. Items can be transported throughout the facilities without requiring a worker's attention and without putting workers at risk. As such, these solutions can increase efficiency and safety while reducing accidents.

Energy and Utilities

Example 3

Use case: Smart Grid

Description: Smart grid is a use case category in which utilities use field devices to control and optimize (e.g.) power flow, respond to variable demand, manage renewable energy production from consumers and independent producers, shift peak demand through variable pricing, and detect and respond to faults. It increases the reliability of the infrastructure, increases efficiency and reduces energy usage. With the more comprehensive modernization of energy grids toward smart grids, Europe will gain more reliable and resilient energy supply, incorporate renewables, manage the transition to electric vehicles, reduce carbon emissions, and shift peaks in demand to reduce overall infrastructure needs. Smart grids include smart meters, which are also critical enablers for consumers to monitor and manage energy usage at a granular level and to respond to price signals to reduce peaks in demand.

Example 4

Use case: EV Chargers

Description: With the move toward decarbonization, European economies are shifting toward electric vehicles. To power these vehicles, home chargers increase consumer power demand and change consumption patterns, requiring adaptability from the smart grid. They also can act as batteries to supply the home during peak hours, and to recharge during off-peak periods. Moreover, public charging stations require additional management capabilities supported by CEI technologies. CEI solutions are needed to remotely manage EV charging stations. They can be used to identify users and their vehicles and to manage payments. The chargers also must communicate with the network to report availability, so that users can be directed to available chargers. EV chargers utilize on-device computing resources and sensors, connectivity to the vehicle, as well as connectivity to the cloud for analytics, network management and additional functionality.

Transportation

Example 5

Use case: Employee Safety Monitoring

Description: CEI solutions for employee safety monitoring are among the most adopted use cases in the transportation sector. These solutions focus on enhancing device compatibility to prevent dysfunctional systems. They ensure seamless communication among various safety devices and systems used in transportation. By standardising protocols and interfaces, these solutions improve safety and operational efficiency, addressing the challenge of device compatibility.

Example 6

Use case: Asset Command and Control

Description: CEI solutions for asset command and control are among the highest potential future use cases in the transportation sector. These solutions optimise processing needs and leverage unused edge capacities. They enable real-time tracking and management of assets, such as vehicles and cargo. By efficiently utilising edge computing resources, transportation companies reduce processing costs and improve asset management, addressing the challenge of optimising processing needs and unused capacities.

Healthcare

Example 7

Use case: Remote Health Monitoring

Description: CEI solutions for remote health monitoring are among the most adopted use cases in the healthcare sector. These solutions facilitate collaboration among healthcare providers, researchers, and institutions. They enable real-time monitoring of patients' health data, promoting better healthcare outcomes. CEI technologies support seamless data sharing and coordination among stakeholders, addressing the challenge of fostering collaboration in healthcare.

Example 8

Use case: AI-Enabled Diagnosis and Treatment

Description: CEI solutions for AI-enabled diagnosis and treatment are among the healthcare sector's highest potential future use cases. These solutions address the need for a highly skilled workforce by automating certain healthcare tasks. They assist healthcare professionals in diagnosing and treating patients, reducing the burden on specialised medical staff. By leveraging AI and edge computing, healthcare organisations can provide timely and accurate diagnoses, improving patient care and addressing labour shortages effectively.

Agriculture

Example 9

Use case: Asset Monitoring and Maintenance

Description: CEI solutions for asset monitoring and maintenance are among the most adopted use cases in the agriculture sector. These solutions provide real-time insights into the condition and performance of agricultural machinery and infrastructure. By leveraging CEI, agricultural businesses can reduce their dependency on traditional cloud solutions and minimise the risk of vendor lock-in. Predictive maintenance based on real-time data ensures cost savings, enhances productivity, and minimises downtime in agriculture.

Example 10

Use case: Precision Farming

Description: CEI solutions for precision farming are among the highest potential future use cases in agriculture. These solutions address incompatible systems and protocol vulnerabilities by providing standardised interfaces and communication methods. They ensure compatibility among various precision farming devices and systems, reducing operational complexities and enhancing efficiency. Standardisation fosters interoperability, improving overall agricultural practices.

Beyond the provided examples, a series of spotlight use cases are available in the following publication: **Updated report of CEI demand landscape**

4.2.2. Research and Innovation use case examples

Similarly to the previous chapter, a series of positive innovations and contributions to the challenges faced come from the research world. Indeed, Europe has started to support the work of Research and Innovation Actions (RIAs) to develop innovative use cases.

Agriculture

Within the agriculture domain, use cases are being explored that will improve productivity and the automation of activities by integrating various technologies, from soil sensors to unmanned tractors. Examples include:

- Smart Tractors: The pilot developed by aerOS in Germany showcases precision farming with John Deere tractors. It serves as an integration tool connecting tractors to the continuum, and zero-touch orchestration allows for data autonomy of vehicle swarms, leading to precision farming. The interoperability between farming-related information systems and increased productivity based on data processing using high-performance computing connected to the cloud achieves CO2-neutral intelligent farming.
- Precision Bio-Spraying: This use case is part of the NEMO project. It uses federated learning models (FL) from data collected by sensors and drones to trigger spraying. The connection of IoT devices to ML and FL models allows data analysis, while connection to edge nodes provides low latency and allows for a fast response. Spraying can accurately and quickly adapt to changes in data measured by sensors. It can, therefore, reduce the spread of pests or disease and increase harvest quantities.

Manufacturing

Manufacturing has been constantly automated over the past decades. Industry 4.0 and 5.0 bring new technology solutions that increase manufacturing plants' productivity with AI, Big Data, IoT and others. Some examples of integration of new solutions include:

- Robotics Optimisation: The use of robots in factories requires high energy use, whereas some functionalities of robots require high power regardless of the robot's size. It must address the challenge of inefficient energy use for the movement of robots with devices by using energy-aware distributed computing. The orchestration of systems and connection to CEI networks distributes computing and resource requirements based on the capacity availability of connected nodes. The data sharing and resource distribution allow for the computing of energy efficient processing and consequently optimise battery life for continuous operations. This use case is being developed by FLUIDOS
- Human-Centred Indoor Factory Environment Safety: The collaboration between robots, AGVs, and humans is he target of this use case. The human-centred indoor factory environment safety pilot addresses worker safety in Industry 4.0 factories by creating a safety shell for workers. Real-time data collected from IoT devices (sensors, cameras, etc.) using high-precision layers creates a collaborative environment by integrating all devices in the network. To ensure the safety of workers, the data needs to be instantly analysed and processed, requiring low latency and high processing power for precise localisation and fast response in case of unexpected events. The architecture relies on the distribution of resources along the continuum by orchestrating devices and computing power efficiently and accurately, resulting in a factory 4.0. This use case is being developed by NEMO.

Energy and Utilities

The current energy crisis and vulnerability of power network requires new solutions to the traditional energy and utilities sector. New technologies provide solutions which optimise the production of renewable energy, predictive maintenance of the power grid, additional security of the network and many more. Some of the examples are showcased in the portfolio project pilots:

- Energy Grid Resilience: The pilot addresses the challenge of orchestration of extensive systems of electric grids across the country. The single-domain orchestration along the grid and integration of sensors, cameras, and drones assures increased cyberattack protection as it identifies potential vulnerabilities and uses self-healing to cover them. Additionally, based on processing needs, the sensors can detect issues that require maintenance within outliers from data collected and analysed along the network. This use case is being developed by FLUIDOS.

- Managing Renewable Energy Production Centres: This use case builds on sector-specific federated nodes within Gaia-X. It leverages renewable energy sources to implement edge services in green energy centres and power development sites (wind turbines) linked to cloud computing centres. Monitoring energy consumption and real-time analytics to adjust activity within energy production and distribution results in improved quality of energy services. This use case is being developed by aerOS.

Healthcare

New technologies speed up innovation in the healthcare industry, from new life-saving medicines to AI and ML remote diagnostics or remote patient monitoring. Some use cases looking at these challenges include:

- Medical Diagnostics: The Real-time medical diagnostics pilot carried out in remote areas of Italy in collaboration with ESAOTE and CNIT uses various IoT devices and wearables to perform basic medical tasks without a doctor. The use of sensors and interfaces allows for accurate patient evaluation without the physical presence of doctors, simultaneously addressing the sectoral challenge of shortage of medical staff. Based on processing needs, the operating system uses virtual objects to integrate data from various devices and process it along the continuum. AI and ML models can analyse the data collected from a patient, perform patient diagnostics and increase doctors' productivity, resulting in remote patient diagnostics at any time.
- Health-Safe Smart Building: It uses sensors and data collected on utilities used in smart homes, which allow for remote monitoring of the elderly or vulnerable people. It reuses and scales IoT platforms and technologies, integrates new interfaces, and enables interoperability across systems to provide solutions for independent elderly and vulnerable people. Caregivers and first responders can monitor activities in smart homes without disrupting the privacy of inhabitants by collecting and analysing data on, for example, the use of water or electricity. The integration and self-orchestration of devices along the network is essential to provide accurate response to potential risks and grant adequate care.

Transportation and Logistics

Self-driving cars, unmanned vehicles, and automated logistics chains are some of the technological advancements of the recent era that are becoming an integral part of the sector. Automatisation and integration of new technologies increase the efficiency of systems, from shipping half across the world to the last mile delivery. Examples of use cases include:

- Predictive Delivery: The pilot targets the last-mile distribution of fresh food in Spanish cities. Market predictive analysis for logistics optimises the supply of fresh food, thus reducing waste. The deployment of a smart edge-cloud platform that acts as a digital twin collects, analyses and shares data collected from sensors and systems along the supply chain and accurately indicates current product needs.
- Smart Port: This pilot aims to create a smart port in Limassol, Cyprus. The integration of all members of the logistics chain into one network will allow for effective communication and increase the effectiveness of systems and services. It will eliminate data and resource sharing barriers and smoothen all processes, from ship docking to delivery truck management. Another essential aspect of the project showcasing the application solution is the implementation of distributed ledger technologies for smart contracts. The port-wide solution will increase security with advanced authentication and identification tools, creating a more efficient and reliable process. This use case is being developed by aerOS.

Beyond the provided examples, a series of spotlight use cases are available in the report **Catalogue of MetaOS use cases**

5. Concluding remarks and future directions

As detailed in the paper, the CEI ecosystem is at the forefront of a transformative landscape. Sectors ranging from health to manufacturing are on the cusp of leveraging the vast opportunities presented by CEI technologies, such as enhanced real-time data processing and the realisation of Industry 4.0. However, they simultaneously grapple with challenges like data privacy, technological adoption rates, and the imperative for clear business cases. A unique contribution of this paper lies in its comprehensive exploration of the CEI landscape, detailing both its vast opportunities and inherent challenges. It provides a granular analysis of sectors like health, agriculture, transportation, energy, and manufacturing, offering insights into their specific opportunities and challenges within the CEI framework.

The true potential of these innovations is not solely anchored in technological advancements but also hinges on the comprehensive readiness of organisations to adopt, integrate, and evolve with them. This readiness is a multifaceted concept, spanning organisational structure, value chain capacity, interoperability, standardisation, and the availability of requisite skills. Recognising this intricate landscape, the UNLOCK-CEI project, represented by the authors of this paper, has started to work on a CEI Adoption Readiness Framework. Drawing inspiration from relevant frameworks like PESTEL, Porter's 5 Forces, and Blue Ocean Strategy, this tool offers companies a roadmap to assess their preparedness across a spectrum of dimensions, from economic and technological facets to legal, regulatory, and risk compliance.

Looking ahead, the future of the CEI landscape is poised for further evolution. This paper concludes by suggesting that the next pivotal step is to delve into potential future scenarios, understanding the dynamic interplay of market forces, technological innovations, and organisational strategies. This will guide informed decisions and shape the trajectory of CEI integration.

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