EUCloudEdgeIoT.eu
UNLOCK-CEI

Technology scoping paper

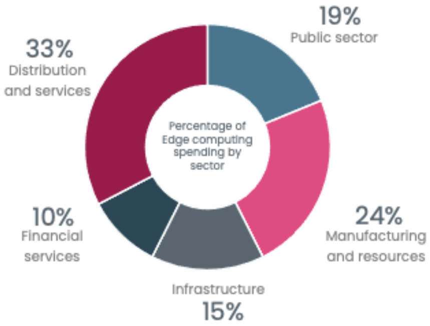
Brendan Rowan , José Enrique Álvarez , Zuzana Kušíková
BluSpecs
30/11/2022

EUCloudEdgeIoT.eu
Unlock CEI

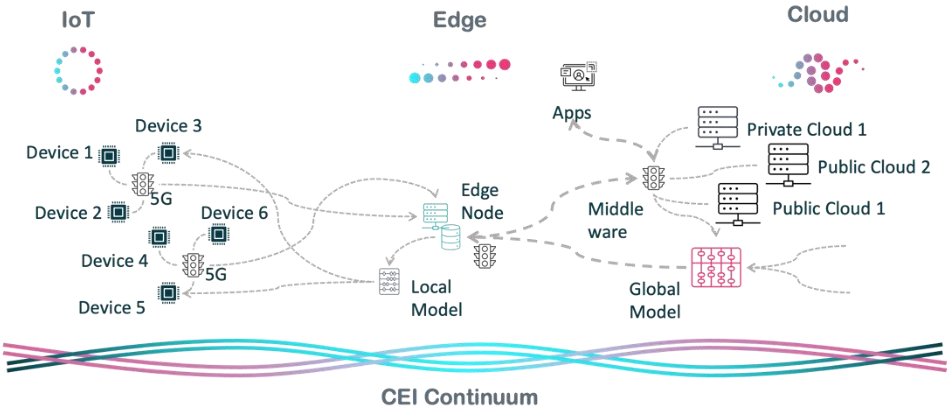
Executive Summary

Definition of the Cloud Edge IoT Continuum

With increasing computing and processing needs, edge computing will join cloud computing as the next important part of digital infrastructures and the convergence of Cloud and Edge will serve as an enabler of future developments. The growing need for edge computing solutions and building CEI networks is reflected in the analysis of expected spending on enterprise edge, estimated to double, from €18bn to €39.6bn, between 2020 and 2025 and outpace the average growth within the ICT market[1].



In Europe, Edge computing is expected to increase at an annual growth rate of 26,5%, from €815m in 2020 to €2.6bn in 2025[2]. Also, Edge is expanding across industries as it allows advances in many forms, from simplifying production and automatizing equipment, increased safety, and reliability, to full digital integration of all resources enabled by the developments in IoT (*see left*). The developments in IIoT and AIoT are especially crucial in distribution and services, and manufacturing and resources which show the highest spending per sector, according to IDC's report.



This convergence of the Cloud and IoT within a computing continuum results from the changing technological landscape. Recent advances have seen the development of more intelligence devices, capable of applying on-device processing combined with the production of federated AI architectures across devices. This is combined with intelligent and programmable networks, development of cognitive cloud systems and advances in orchestration across different cloud environments which has resulted in the device to cloud continuum.

Among the characteristics of the CEI are principally the following:

- It is comprised of multiple heterogenous and mixed devices and computing resources which are identified and grouped by their individual functions, capacities, and parameters.
- It coordinates and distributes data collection, processing, and artificial intelligence across the available connected devices and resources
- It processes data as close as possible to the event and reserves cloud computing for targeted high-performance applications when the applied business case allows. E.g., in those circumstances in which the centralised architecture of cloud computing is not suitable for the

[1] Europe Edge Computing Market 2020-2030 (2021) GMD Research
[2] Worldwide Edge Spending Guide (2021) IDC

UNLOCK-CEI - Unlocking the Cloud Edge IoT demand potential in Europe, has received funding from the European Union's Horizon Europe Framework Programme (HORIZON) under Grant Agreement no. 101070571.

constraints of the necessity in terms of latency, bandwidth, cost, or privacy, it is processed in a distributed fashion across edge or device clusters.

- It is itself managed autonomously with dynamic distribution to ensure high availability and expansion without risking business security and control.

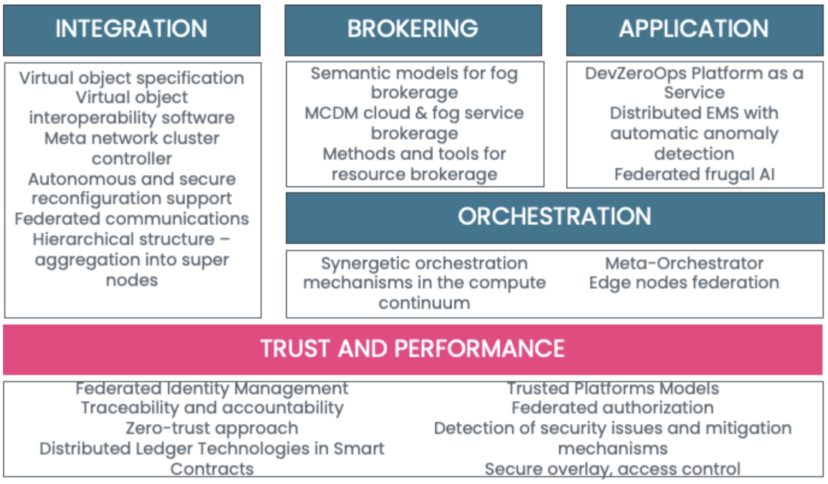
The edge within the continuum can take place in various locations which includes:

- Device edge –defined by the capacity for the device itself to run processes and deliver outputs. It can include significant processing power within devices such as cars and tractors with relatively large power sources and strong connectivity or may also refer to constrained devices which participate in distributed processing in combination with larger devices such as those mentioned above.
- Telco Edge – 5G MEC provides the processing capacity at the mast/network edge bringing it closer to the user or devices.
- Operational Edge – Edge-IoT integrated within the OT systems of a particular business' operations and is physically located on premises. Similar in capacity and structure to MEC.
- Enterprise Edge – Cloud-edge; a centralised resource within a company that manages, filters and routes the dataflows between remote sites and data centres, providing cloud like capacity to whole enterprise operations.

European Cloud Edge IoT Initiative

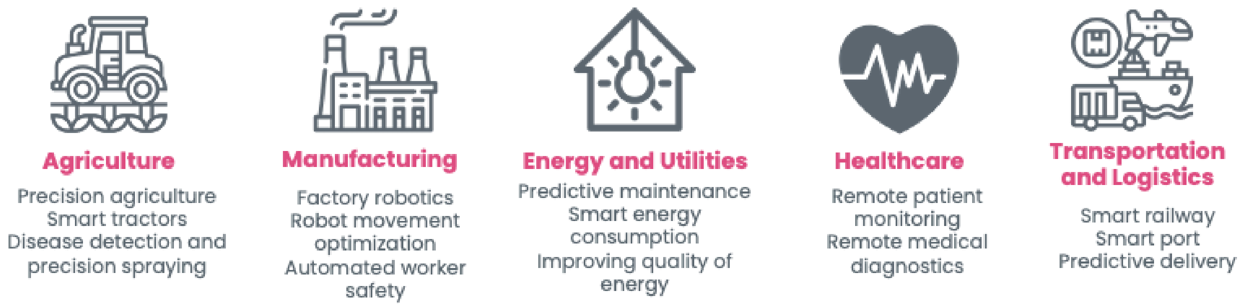
The EU CEI will link tech developers with markets and provide market forecasting, service-level requirements, go to market strategies, open-source community engagement, common architectures, and interoperability standards. It achieves this through close activation of all the key stakeholders from RD&I and industry coordinating the coming together of the IoT, Edge and Cloud communities.

The EU CEI will coordinate across clusters of Research and Innovation Actions (RIAs) which will provide the tech development and demonstration of the missing pieces that will reach a market maturity over a period of 3-5 years. Within the existing cluster of metaOS the projects will provide advances in:



- Methodology and standardisation of architecture across systems.
- Orchestration across the continuum
- Integration of heterogeneous devices and systems
- Brokering within the integrated assets and services
- Security, privacy, and data protection along the continuum
- Green computing

These technologies and systems will be proven in specific use cases which will engage diverse stakeholders across the following sectors and domains:



Glossary of terms

Item	Description
CEI	Cloud-Edge-IoT
5G	Fifth-generation technology standard for broadband cellular networks
AGV	Autonomous Guided Vehicles
AI	Artificial Intelligence
AIaaS	AI as a Service
App	Application
ARM	Advanced RISC Machine
CEI	Cloud-Edge-IoT
CO2	Carbon dioxide
CoAP	Constrained Application Protocol
CPU	Central Processing Unit
DLT	Distributed Ledger Technologies
EC	European Commission
EU	European Union
EUCloudEdgeIoT	European Cloud, Edge and IoT Continuum
GDP	Gross Domestic Product
GPU	Graphics Processing Unit
HE	Horizon Europe
HPC	High Performance Computing
HTTP	Hypertext Transfer Protocol
HVAC	Heating, ventilation, and air conditioning
IaaS	Infrastructure as a Service
ICT	Information and Communications Technology
IoT	Internet of Things
IT	Information Technology
KPI	Key Performance Indicator
LPI	Logistics Performance Index
LPP	Low power processor
LSPs	Large Scale Pilots
MEC	Multi-access Edge Computing
MetaOS	Meta-Operating Systems for the Next Generation IoT and Edge Computing Cluster
ML	Machine Learning
MQTT	MQ Telemetry Transport
NGIoT	Next Generation Internet of Things
OEM	Original equipment manufacturer

OS	Operating System
OT	Operational Technology
Paas	Platform as a Service
QoS	Quality of Service
R&D	Research and Development
R&DI	Research and Development and Innovation
RIA	Research and Innovation Action
RISC	Reduced instruction set computer
SaaS	Software as a Service
SG	Stakeholder Group
SME	Small and medium-sised enterprises
Telco	Telephone Company
TF	Task Force
TSN	Time-sensitive networking
VCA	Value Chain Adopter
VP	Value Proposition
WP	Work Package
YoY	Year-on-year

Keywords

Cloud-Edge-IoT; Computing; Continuum; Demand-Supply Dialogue; Communication; Engagement

Disclaimer

Table of Contents

List of Figures

List of Tables

1. Introduction

1.1 Purpose of this deliverable

This deliverable is part of to the UNLOCK-CEI project Work Package 4: Tech Developer Engagement, specifically Task 4.1: Portfolio supply coordination. The deliverable aims to provide an overview of the European Cloud-Edge-IoT continuum initiative and the project portfolio of *Meta-Operating Systems for the Next Generation IoT and Edge Computing Cluster*. To provide context for future development, this publication analyses existing technologies and previous initiatives that serve as a base for the EU CEI initiative.

Outlining the framework for CEI, technologies' categories addressing the main challenges and solutions will be presented. The sectorial and market challenges are the basis for market needs which will be used throughout the UNLOCK-CEI project. Lastly, Understanding the current project cluster is the first essential step towards connecting the supply and demand sides of the continuum and market-ready technology developments which will benefit the ecosystem. The deliverable provides a table of use cases from the project portfolio to show the possible solutions to industry-related challenges

Overall, the deliverable is the starting point of creating the interface between demand and supply actors and successfully delivering valued projects.

1.2 Target audience

The content of this deliverable provides valuable insights for all members of the CEI ecosystem as it maps the current status of technologies developed and the challenges faced. The demand side- European SMEs, start-ups and corporations will receive insights into technology trends and ongoing developments. This information can be then incorporated into their business plan and lead to market advantage and add value.

On the supply side, European researchers, developers, and tech innovators receive an overview of current efforts and develop a better understanding of what is meant by the CEI Continuum and MetaOS.

Lastly, policymakers can use this deliverable to understand the current status and prepare future initiatives and efforts based on identified needs.

This document is complemented by further deliverables which address the market potential and value chain members respectively:

- Deliverable 1.1 Cloud-Edge-IoT Demand Landscape
- Deliverable 3.1 CEI ecosystems overview with the value chain adopter groups.

1.3 Document Structure

Section 2 of this deliverable defines the CEI continuum and maps key technologies that enable its development. These technologies are essential for further advances as they connect existing technologies and guide innovation. Furthermore, the section looks at the main stakeholders and value chains within the ecosystem, as well as the leading players, and identifies gaps in the value chain.

Section 3 reviews the previous and future technological advancements within other EU initiatives. It identifies the main technical challenges currently faced and shows solutions being developed by the MetaOS project cluster. The technology solution framework created within this section will serve as the main framework used throughout the project, combining challenges and solution areas with project cluster developments.

Section 4 attempts to map of initial key market challenges overall and within the key sectors identified.

2. The Cloud-Edge-IoT Technology Landscape

2.1 Definition of the CEI

The Cloud-Edge-IoT paradigm is not a discrete grouping of technologies but rather a reflection of the convergence across the whole digital spectrum driven by the advancement of certain technologies that enable such integration of data processing and services from device to cloud and in-between. It is the realisation of the opportunity presented by the advancement of distributed and edge intelligence with a strategic shift to how cloud computing resources are employed, and a decentralised approach taken.

The convergence between the two domains of Cloud and IoT results from the changing landscape surrounding edge computing. Recent advances have seen the development of more intelligence devices, capable of applying on-device processing combined with the production of federated AI architectures across devices. This is combined with intelligent and programmable networks, development of cognitive cloud systems and advances in orchestration across different cloud environments which has resulted in the device to cloud continuum.

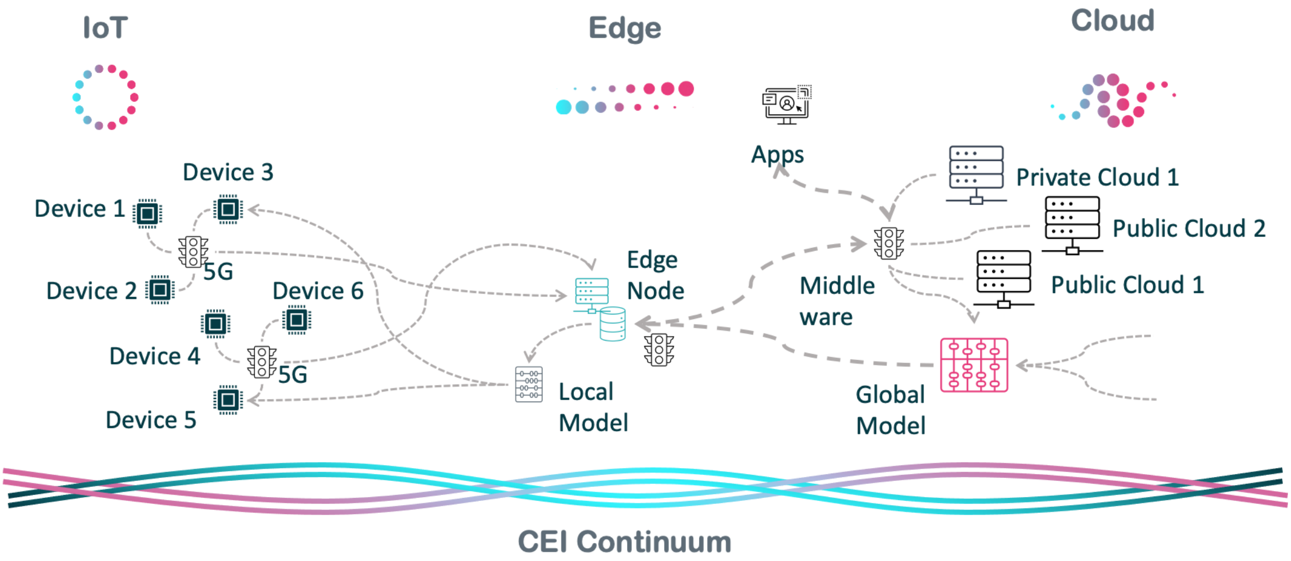


Figure 1: Illustration of the Cloud-Edge-IoT Continuum

Source: UNLOCK-CEI

Among the characteristics of the CEI are principally the following:

- It is comprised of multiple heterogenous and mixed devices and computing resources which are identified and grouped by their individual functions, capacities, and parameters.
- It coordinates and distributes data collection, processing, and artificial intelligence across the available connected devices and resources
- It processes data as close as possible to the event and reserves cloud computing for targeted high-performance applications when the applied business case allows. E.g., in those circumstances in which the centralised architecture of cloud computing is not suitable for the constraints of the necessity in terms of latency, bandwidth, cost, or privacy, it is processed in a distributed fashion across edge or device clusters.
- It is itself managed autonomously with dynamic distribution to ensure high availability and expansion without risking business security and control.

Through this approach, it is expected to overcome some of the limiting factors that have to date prevented specific applications being achieved: these can be technological such as low latency requirements, power availability, legacy devices, and processing capacity; more human related to trust in adoption of data intensive and AI based solutions; or even risk-based related to redundancy and resilience to attacks. Such applications which highlight these include robotic telesurgery, flexibility and automation of the electricity grid with self-healing systems or the management of autonomous guided vehicles (AGVs) on factory shop floors.

In general, through the achievement of a successful, dynamic, and trusted cloud-edge-IoT continuum and network of actors a massive digitalisation across all areas and application of advanced AI can be accomplished which provides flexible, adaptive, efficient and scalable applications of many advanced technologies that will fundamentally shift established models and behaviours far above what has already been achieved in IoT and Cloud Computing environments respectively.

2.2 Principal contexts for edge intelligence

Within the context of defining key ‘edges’, there has been a proposed view of four principal contexts; Device, Telco, Operational and Enterprise. Below is provided an initial definition of such contexts which may serve as a starting point for discussion within the activities of the European Cloud Edge IoT Continuum.

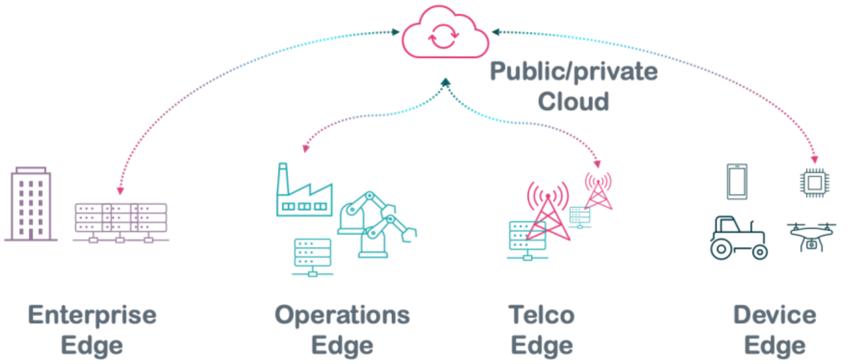


Figure 2: Representation of key edge computing contexts[3]

Device edge – intelligence on device

Enabled by the greater availability and more processing ability of devices and systems on a chip, the device edge is defined by the capacity for the device itself to run processes and deliver outputs. It can include significant processing power within devices such as cars and tractors with relatively large power sources and strong connectivity or may also refer to constrained devices which participate in distributed processing in combination with larger devices such as those seen in Figure 2.

The device edge is limited by the overall capacity of the device CPUs, GPUs, energy source and connectivity either of the single device or the edge cluster. It has almost zero latency and lower processing capacity.

Telco Edge – 5G MEC

Telco Edge Cloud is a global platform for operators to showcase and market edge computing and network resources and capabilities. In many cases it is also named as Multi-access Edge Computing (MEC). A standard and open platform provided by ETSI, stands for Multi-access Edge Computing (sometimes referred to as Mobile edge computing). The 5G MEC or Telco Edge provides the processing capacity at the mast/network edge bringing it closer to the user or devices.

As a carrier provided service, it is led by the telcos who may enter into vertical applications and offerings to developers who wish to develop their applications and benefit from hyper localisation of solutions but without complete control. It provides ultra-low latency and high bandwidth, with the potential to stimulate new types of applications and business cases.

[3] Adapted from EC

Operational Edge – Edge-IoT

Often likely to be a private edge node integrated within the OT systems of a particular business' operations and is physically located on premises. Similar in capacity and structure to MEC, it is particularly relevant where reliability, uptime and data security are of highest priority with control retained by the business team or suppliers. It can handle the majority of processes within the location but is required to be closely linked with enterprise systems held elsewhere.

Enterprise Edge – Cloud-edge

The Enterprise Edge is a centralised resource within a company that manages, filters and routes the dataflows between remote sites and data centres, providing cloud like capacity to whole enterprise operations. The Enterprise Edge is able to control what data leaves the IT system and the judicious use of external networks and cloud computing resources, especially in the case where massive raw data sets would create a prohibitive cost. It integrates IT, OT and CT workflows and is a foundation of the convergence of those two areas of data management. It has reduced latency and reduces the requirement for broadband, it can also provide third parties apps on top of standardised edge platforms similar to public cloud.

Table 1: Summary table of edge intelligence layers

Layer / Edge	Main Purpose	Applications/system example
Device	Fulfils a variety of roles depending on the kind of device but the main one is to be the entry/exit point to/from the network.	Mobile devices, sensors, gateways, routers
Operational	Handles business or manufacturing processes from a company.	Business Process Management, Data Management, Equipment Control, etc
Telco / MEC	Provides the connectivity and the processing capacity closer to the end-user or devices	5G equipment, FTTH, Zigbee, LoraWan,.. Infrastructure as a Service, etc
Enterprise	Centralised companies' system and applications resources that manage enterprise operations	Customer Relationship Management, Enterprise Resource Planning, etc

2.3 Enabling technologies

Behind the CEI Continuum is the maturing and widespread implementation of a set of enabling technologies which includes:

Table 2: Key enabling technologies of the CEI

Technology	Importance to CEI deployment
5G	Provides flexible, intelligent and programme networks that not only provide greater latency and bandwidth but also the virtualisation of functions and the orchestration of processes and data flows as well as providing network slicing for security and application specific networking.
High-Performance Computing	HPC systems typically perform at speeds more than one million times faster than the fastest commodity computer. The availability of such capacities can power the most complex of global and integrated processes and can be efficiently used for highly demanding applications when combined with edge computing and pre-processing.
Containerisation	Containerisation is the packaging of software code with just the operating system (OS) libraries and dependencies required to run the code to create a single lightweight executable- a container—that runs consistently on any infrastructure and be easily applied or transferred across different or multiple cloud environments.

Virtualisation	The virtualisation of hardware and devices allows for seamless integration which underpins the orchestration and clustering allowing for resource distribution and computing on the continuum. It enables the extension of functionalities across clusters of devices, integration of legacy systems and continued cybersecurity.
Low power processors	The increased efficiency provided by accelerators and GPUs have increased the computing power that is present at the far edge underpinning the deployment of EdgeAI and distributed intelligence. Also included is the specialisation of processors to provide intelligence within constrained devices.
Distributed Ledger Technologies	DLT enable additional layer of security and privacy which underpin mechanisms of trust such as data integrity, accountability, and authentication. They also provide mechanisms for the control of use of resources and the automation of actions or issuing of micropayments.

The technologies chosen serve as direct enablers of the CEI continuum as they facilitate the convergence of technologies across the continuum. Technologies with high importance and impact, such as VR/AR, Data analytics, etc. are compliments in the context of the creation of the continuum.

2.4 Estimated maturity and timelines

The current speed of technological development, the array of technological innovators and market trends within industries make the assessment of maturity of particular technologies very complex. Similarly, the impact of chosen technologies drastically differs based on context, whether sectorial, geographic, or else. To provide a simple graphical representation, Figure 3 maps the impact/maturity matrix based on current technology trends with respect to the overall CEI ecosystem.

5G is one of the essential enabling technologies for the CEI, however, the deployment of 5G networks drastically differs based on country and Telco providers. While some Telco companies are building extensive 5G networks in selected locations, others might not deploy for the next decade or more resulting in low technological maturity.

Containerisation is a relatively mature technology in regarding to a wide use across sectors, however, there are ongoing developments within containerisation. Specifically, the integration of containerisation and virtualisation opens new opportunities for Infrastructure as a Service and further developments, including the ones in the CEI ecosystem.

Low power processors (LPP) are an example of a mature technology where every new generation provides incremental improvements, however, the use of LPP enables important features for the CEI. DLT are a relatively mature technology, due to its wide use across sectors. The impact of DLT on CEI is high especially for the addition of security layer and functionalities like Processing as a Service.

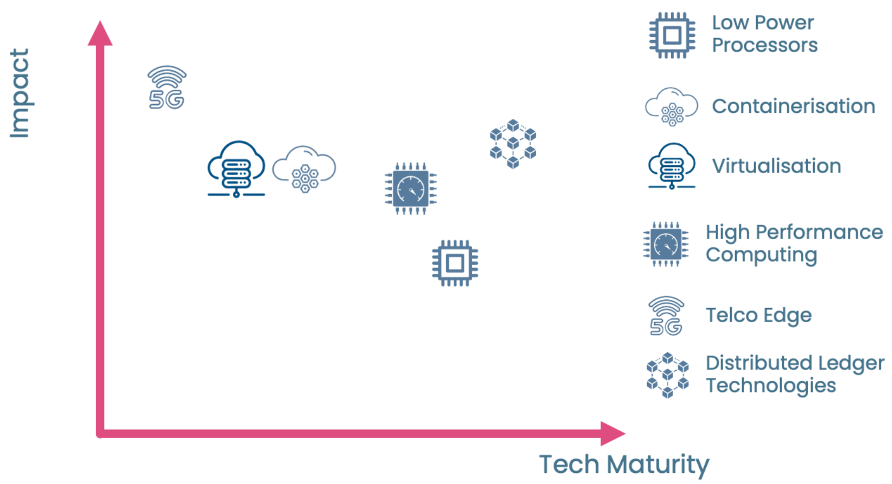


Figure 3: Impact/Maturity matrix of enabling technologies

2.5 Key stakeholders and value chain members

Outside of the RD&I communities, the value chain structure of the CEI Continuum contains many players which reflects the broad scope of the technologies included. A further overview of the value chains and respective stakeholders within key sectors is provided as part of Deliverable 3.1.[4]

Across the CEI, the principal actors include:

Hardware providers

- Chips manufacturers
- Sensor manufacturers
- Device OEMs
- Server providers
- Telco providers/carriers
- Equipment providers

Telco operators

Specialised providers

Cloud infrastructure providers

- Public cloud
- Private cloud solutions
- Cloud and Edge computing platforms

Integrators, SaaS providers and app developers

- Native apps
- Third party developers
- Open-source communities
- Users

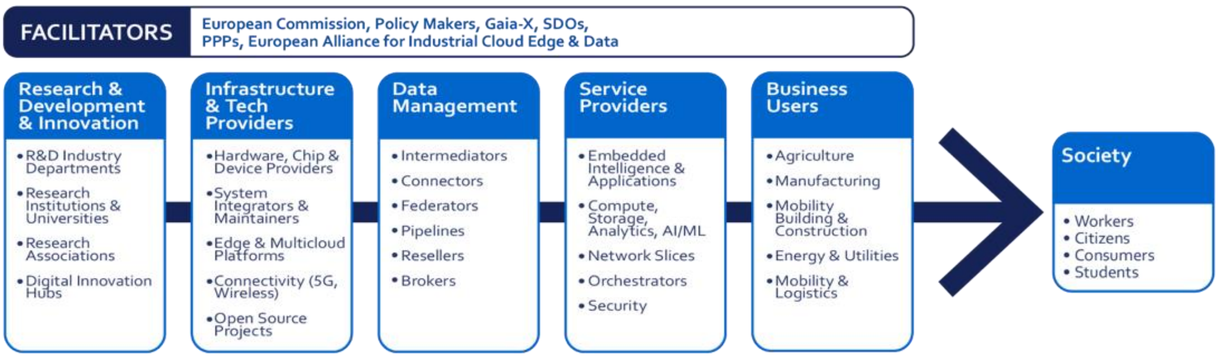


Figure 4: Initial overview of the CEI value chain

[4] D3.1 CEI ecosystem overview with the value chain adopter groups

3. The European Cloud Edge IoT development – a journey to a federated future

3.1 Overview of the initiative

the European Cloud, Edge and IoT Continuum is the umbrella initiative which provides the strategic guidance and next stage of tech development to achieve the goals of an active and dynamic European CEI ecosystem with an emphasis of developing adoption readiness among specific value chains.

The EU CEI will link tech developers with markets and provide market forecasting, service-level requirements, go to market strategies, open-source community engagement, common architectures, and interoperability standards. It achieves this through close activation of all the key stakeholders from RD&I and industry coordinating the coming together of the IoT, Edge and Cloud communities.

The EU CEI will coordinate across clusters of Research and Innovation Actions (RIAs) which will provide the tech development and demonstration of the missing pieces that will reach a market maturity over a period of 3-5 years. The first of such clusters is the **Meta-Operating Systems for the Next Generation IoT and Edge Computing Cluster** (MetaOS), a collection of six projects with a total investment of 64 million EUR with an estimated number of partners nearing a 120.

Figure 5: Projects funded under the Meta-Operating Systems for the Next Generation IoT and Edge Computing[5]

Source: EC

3.1.1 Research and Innovation Actions

The first portfolio of projects is the MetaOS which launched in September 2022 with six projects addressing the primary challenges of the convergence of Cloud to Edge. The cluster will provide initial base, references and use cases that will serve as a building block for future initiatives and shape the ecosystems. The projects included are:

- aeROS[6]

An intelligent and reliable operating system focused on delivering common virtualised services to facilitate orchestration, and virtual communication and enable the distribution of intelligence and computation –

[5] Meta-Operating Systems for the Next-Generation IoT and Edge Computing (2022) European Commission
[6] https://aeros-project.eu/

including AI, ML, and Big Data analytics, and the creation of distributed data-driven applications based on Frugal AI.

- FluiDOS[7]

A fluid, dynamic, scalable, and trustable computing continuum that spans across devices, and unifies edge and cloud in an energy-efficient manner. The MetaOS will provide a new, enriched layer enacting resource and service sharing through advertisement/agreement procedures, and hierarchical aggregation of nodes, inspired by Inter-domain routing on the networks.

- ICOS[8]

It aims to design, develop, and validate a meta-operating system by addressing the challenges of device volatility and heterogeneity, continuum infrastructure virtualisation and diverse network connectivity, optimised and scalable service execution and performance, as well as resources consumptions and costs.

- NebulOus

It will introduce advanced methods to enable secure and optimal application provisioning, resource adaptation and reconfiguration. It exploits edge and fog nodes, in conjunction with multi-cloud resources, to cope with requirements posed by low-latency applications.

- NEMO[9]

It is an open-source, modular and cyber secure meta-operating system in the AIoT-edge-cloud continuum bringing intelligence closer to the data and make AI-as-a-Service an integral part of network self-organisation and micro-services execution orchestration.

- NEPHELE[10]

It enables the efficient, reliable, and secure end-to-end orchestration of hyper-distributed applications leveraging virtual machines and objects supporting openness and interoperability aspects in a device-independent way.

All different initiatives try to focus their main functionalities in one aspect of the different layers of the CEI, but as there are many multiple interconnections and dependencies between the required features and services all of them must adapt to those multi layered services supporting the technologies and protocols used.

[7] https://www.fluidos.eu/
[8] https://www.icos-project.eu/
[9] https://meta-os.eu/
[10] https://www.nepheleproject.eu/

3.2 Previous technology advances – HCLOUD and NGIoT

Mirroring the direction of technology convergence, the European Cloud Edge IoT Continuum brings together and builds upon two previous initiatives: Next Generation IoT[11] and Horizon Cloud[12]. Each of these initiatives is a progression on prior leading initiatives like the IoT Large Scale Pilots[13]. They have addressed the foundations of the continuum through the development and active demonstration of architectures, abstraction tools and approaches, multi-cloud platforms, network virtualisation and necessary microservices which underpin privacy and trust.

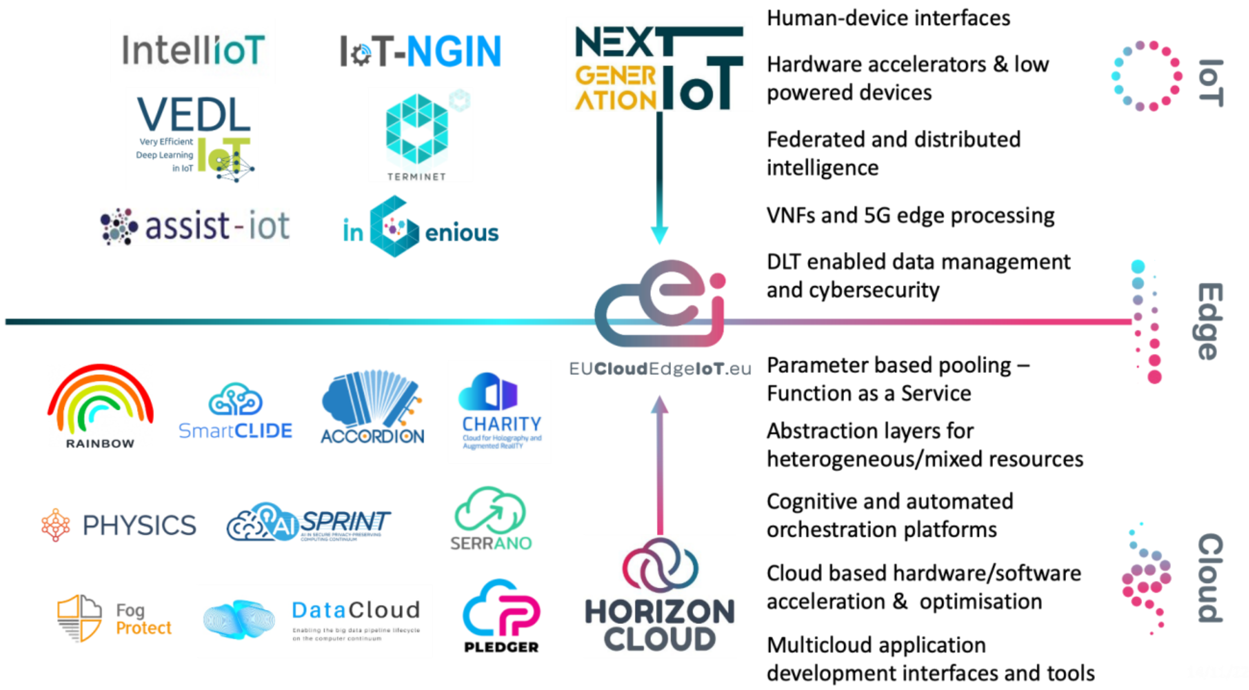


Figure 6: Overview of the progression towards the European Cloud Edge IoT referencing key projects and technology topics addressed within

The portfolios of Research and Innovation Actions (RIAs) which make up each strategic initiative drive forward technology developments and demonstrations in specific use cases spanning contexts such as manufacturing, automotive, energy, logistics and ports, financial services, agriculture, etc.

The NGIoT projects have developed federated architectures and systems which enable the integration of more intelligent devices and chipsets, implementation of federated learning and tinyML while leveraging of 5G network capacities through network functions virtualisation. The initiative serves to realise an autonomous and contextual IoT with novel and integrated human-device interactions, including tactile interfaces and local human-in-the-loop approaches.

From Horizon Cloud, the outputs and focus has been on the development of the tools, platforms and middleware to realise the effective delivery of applications across multiple, diverse and distributed cloud computing resources with a strong emphasis on orchestration. It includes the definition and implementation of abstraction layers which creates a borderless infrastructure across mixed and heterogeneous cloud resources and HPC. The projects have developed the tools and systems which allow for automated and dynamic management of resources with high availability and coordination of data processing tasks for app developers.

---

[11] https://ngiot.eu
[12] https://h-cloud.eu
[13] https://european-iot-pilot.eu

Both address the issues of trust, with its components of privacy and reliability, and security which enable the scalability of the technologies and provide end-to-end and complete management of data and risks across the whole continuum. This includes decentralised identifiers, moving target defences, Time Sensitive Networking (TSN) - enabled zero trust networks, models of models supported by 2-layer DLTs, network slicing and honeypot algorithms. To this is added proactive resource adaptation, continuous service placement middleware and automated systems and network reconfigurations.

Both initiatives have provided the foundational technologies but also importantly the mobilisation, growth and consolidation of the European actors who will realise the vision of the CEI Computing Continuum. Further detailed information can be found on the initiative portals and from individual project websites.

3.3 Driving the MetaOS forward

The joined efforts of Unlock-CEI and OpenContinuum projects will support the creation of a competitive Cloud-Edge-IoT continuum by providing market insights, future trends and supply and demand mapping to the portfolio of MetaOS projects.

Creating market-ready and user-accepted software solutions will ease the adoption of edge technologies across businesses and grow the existing ecosystem. Simultaneously, those projects will solve the main challenges of the Cloud and Edge convergence that were already identified by the EC and will foster the adoption of these technologies.

All projects are open-source, and they will be available for other developers to work on, fork and use them as a building block for further development in both business and technology solutions.

Part of the MetaOS projects include large-scale pilots aiming to demonstrate the high value of these software solutions in sectors of strategic importance in the European Union to further promote the integration of CEI solutions in the European ecosystem.

By showcasing solutions to specific business challenges including added benefits like privacy preservation or energy efficiency, will be a cornerstone of building the continuum ecosystem and enabling European digital autonomy.

3.4 Main tech areas addressed

The continuous technology developments, the increasing number of IoT devices deployed, and the shift to edge computing while 5G networks are slowly deployed contribute to increasing the number of challenges addressed by the Meta OS project. The most important that they are facing are:

- Integration and interoperability across heterogeneous devices and systems.
- Orchestration and brokering across the continuum.
- Inconsistent methods and the need for standardisation.
- Increased requirements in processing power and latency arise from a continuously bigger number of IoT devices.
- High and inefficient use of resources for example including unused processing power at the edge and excessive processing in the cloud.
- Safety, security, integrity and data privacy across systems and devices.

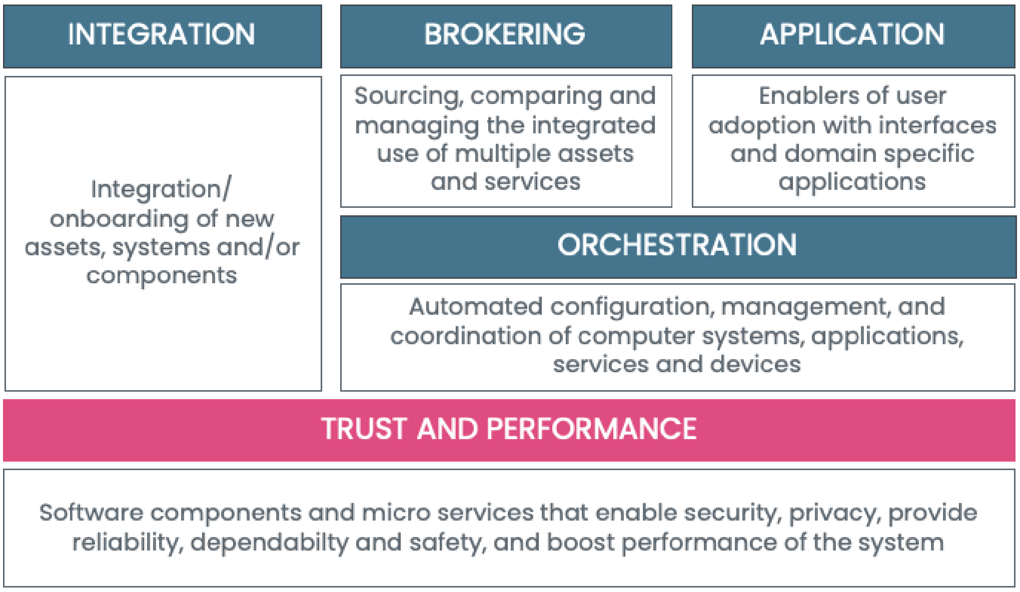


Figure 7: Framework of technology solution categories

All the appointed projects are facing these risks and issues while solving the main challenges and adding value with further benefits useful for solving lower-level challenges.

The technology solutions solve the main challenges in the convergence of Cloud and Edge technologies. Within the framework proposed, they can be divided into five main categories: integration, brokering, application, orchestration, and trust and performance.

Integration, brokering, and application look at specific solutions provided by the software, while orchestration is a key element that runs across more areas within the continuum. Trust and performance are essential to all areas, not only due to the importance of privacy and security in technology but also to provide reliable and high-performing solutions.

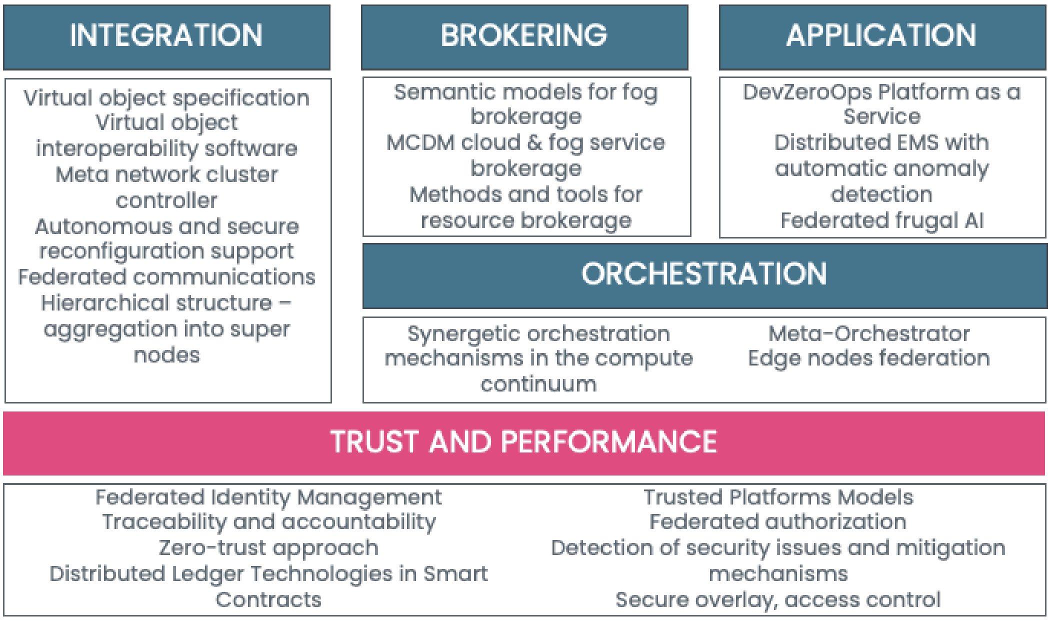


Figure 8: Summary of technology advances to be performed by the MetaOS portfolio projects

3.4.1 Integration and onboarding

Integration of devices from different manufacturers in the far edge it is a key requirement to successfully deploy a Cloud-Edge computing solution. The automation of integration and onboarding will allow for the interoperability of assets, systems, and components across the Cloud-Edge-IoT continuum. Moreover, it will overcome the barrier to the adoption of new technologies, smoothen the onboarding process and provide a single usable system across the solution architecture.

Virtualisation

Virtualisation can be defined as the software simulation of hardware platforms (Virtual Machines) and functionalities allowing one server or hardware to run multiple operating systems at the same time. Each Virtual Machine must include a full copy of an operating system, the applications, binaries, and libraries. It provides great efficiencies in terms of fewer hardware platforms or servers, but it may require more powerful equipment

3.4.2 Brokering

The concept of brokering can be described as an intermediary that, being aware of the availability of the different resources, known as subscribers, in the Edge Network, can provide access to them by creating either a virtual environment or just by redirecting the requester to those subscribers. It will be a dynamic environment that brings together smart contracts, cognitive networks and methods for ensuring high availability of resources with in-built redundancy.

3.4.3 Application

The whole purpose of Edge Computing is to bring enterprise or other applications closer to the data sources, typically IoT devices or local edge servers so they can take deliver strong business benefits with flexibility that has not been previously available. This requires new user interfaces and application tools so that a broad range of native and non-native apps are able to account for new challenges in the continuum and take real advantage of the new capacity.

3.4.4 Orchestration

Orchestration solves one of the biggest challenges in every connected platform and, specifically in distributing applications to different platforms across the layers of the continuum. Cloud-to-Edge orchestration will speed up the delivery of services, simplify optimisation, and reduce costs by delivering the required software tools regardless of the hardware or software platform. It can be visualised as having the same application on either x86 or ARM chip architectures, Linux, or Windows-based machines, etc. Thus, the orchestrator automates the management, coordination, and organisation of distributed computer systems, services, and middleware, allowing seamless orchestration.

Microservices can support flexible and dynamic provisioning of computing resources along the path by orchestrating (activating, deactivating, integrating, etc.) computing resources provided by heterogeneous computing infrastructures.

Containers

A container can be defined as a light, standalone and executable package of software that includes everything needed to run an application regardless of the hardware and software infrastructure. Containers isolate software from its environment and ensure that it works uniformly despite differing host environment.

3.4.5 Trust and performance

The complexity, heterogeneity, and high volume of components in the Cloud-Edge-IoT continuum require advanced security solutions and privacy-preserving mechanisms. Simultaneously, the increase of resources and computing power allow for advanced mechanism that ensure performance and reliability of systems. A variety of micro-services, from federated authorisation to trusted model enable increased security solutions, reliability and dependability.

3.4.6 Relationship between tech groupings and categories

The metaOS objective is to transparently manage all the layers of the cloud continuum stack as a traditional Operating system will do in a traditional computer environment.

Its main purpose is to manage all available resources to facilitate creating an adaptive application environment, driven by the processing proximity to data sources and optimised based on the data involved, the defined quality of service (QoS) requirements and the regulatory, security or privacy constraints.

But enabling all the transient fog ecosystems that exploit edge and fog nodes, in conjunction with multi-cloud resources, coping with the requirements posed by low latency applications, implies that order and coordination must be taken very seriously.

Every time a new device joins the continuum it must be integrated in a seamless way, and it must transmit data using a protocol that can be understood by the different pieces and layers of the Continuum. Assuring that each device can communicate, use the right communication network, and interact with the rest is the responsibility of the Integrator actuator.

Orchestration assures that the required software, regardless of the hardware platform, is deployed to every device that requires it. And to do so, containers are used.

Assigning the right resources or redirecting resources request to the available one is the main feature and responsibility of the Broker that gathers information regarding the application or computing resources from the Continuum.

In section 3.4.1, the different agents across the CEI layers are described and explained in how they coordinate and manage all the interactions and features of the Continuum.

3.4.7 Summary of main advances expected

The main advances expected from the first group of MetaOS projects will enable the convergence of Cloud and Edge technologies and allow for further advancements in the continuum. The technological advances included in the portfolio projects are directly solving the challenges outlined by the EC and contributing to the creation of an advanced CEI ecosystem.

Methodology and standardisation of architecture across systems

- Quality of Service assurance guide and standards
- A unified method to address security, privacy, and data protection
- Consistent use of protocols across the ecosystem allows future integration of novel technology

Orchestration across the continuum

- Systems allowing universal orchestration of software and hardware components across the continuum
- Zero-touch (fully automated) orchestration
- Synergetic orchestration mechanism

Integration of heterogeneous devices and systems

- Interoperability between different layers of the continuum
- Virtualisation development ensure coordination and cooperation across components
- Compatibility with various communication protocols (e.g., HTTP, MQTT, CoAP)

Brokering within the integrated assets and services

- Selection of technology model processes based on criteria defined
- Automation of resource/demand matching and automated prioritisation

Security, privacy, and data protection along the continuum

- Federated authentication and identification within applications
- Zero trust approach validating every stage of a digital interaction
- Inclusion of trusted platforms modules protecting hardware with cryptographic keys
- Traceability and accountability for users within and outside of organisations

Green computing

- Energy aware distribution of computing processes and power
- Using unused computing capacities increasing energy efficiency
- Analysis of CO2 production resulting in optimisation of computing processes

3.5 Demonstrators and use cases

The MetaOS projects provide demonstration of the solutions to the challenges outlined above through various pilots. Showcasing use cases and technological advancements is essential for further development of the continuum. The section below gives a brief description of project use cases representing each solution category.

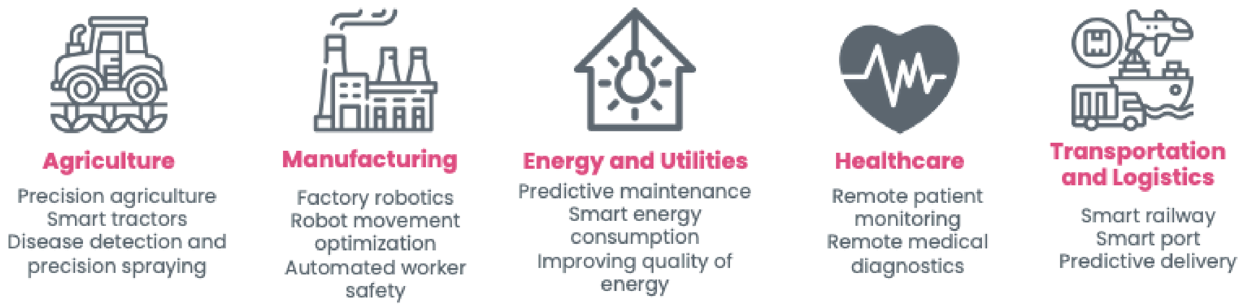


Figure 9: Use cases within key strategic sectors

3.5.1 Agriculture

Within the agriculture domain, use cases are being explored which will improve productivity and the automation of activities through the integration of various technologies from soils sensors to unmanned tractors. Examples include:

- Smart tractors (AerOS)

The pilot in Germany showcases AerOS use in 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 (NEMO)

NEMO's pilot in collaboration with Synelixis Solutions and Entersoft uses federated learning models from data collected by sensors and drones to trigger actions-spraying. The connection of IoT devices to ML and FL models analyses data and low latency due to connection to edge nodes allows for a fast response within spraying can accurately and quickly adapt to changes in data measured by sensors and avoid disease spreading and increase harvest quantities. The meta-orchestrator within NEMO's OS creates architecture within all devices in and out of the field optimizing the use of pesticides and consequently decreasing the production of CO_2.

3.5.2 Manufacturing

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

- Robotics Optimisation (Fluidos)

The use of robots in factories requires high energy use where some functionalities of robots require high power regardless of the size of a robot. Fluidos addresses the challenge of inefficient energy use for movement of robots with Robonik devices by using energy-aware distributed computing. The orchestration of systems and connection to CEI networks distributes computing and resource requirements based on capacity availability of connected nodes. The data sharing and resource distribution allows for computing of energy efficient processing and consequently optimises battery life for continuous operations.

- Human-centred indoor factory environment safety (NEMO)

The collaboration between robots, cobots, AGVs and humans is target of a pilot of NEMO in collaboration with Telefonica and Continental. 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 process requiring low latency and high processing power for precise localisation and fast response in case of unexpected event. The architecture relies on distribution of resources along the continuum by orchestrating devices and computing power efficiently and accurately, resulting in a factory 4.0.

3.5.3 Energy and Utilities

The current energy crisis and vulnerability of power network requires new solutions to the traditional sector of energy and utilities. New technologies provide solutions which optimize 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 (Fluidos)

The pilot in partnership with Ricerca sul Sistema Energetico (RSE) in Italy addresses the challenge of orchestration of extensive systems of electric grid across the country. The single-domain orchestration along the grid and integration of sensors, cameras and drones assures increased protection from cyberattacks as it identifies potential vulnerabilities and uses self-healing to cover them. Additionally, the sensors can detect issues that require maintenance within outliers from data collected and analysed along the network, based on processing needs. The use of the OS will not only increase the security of the grid and ensure reliable energy distribution network.

- Managing renewable energy production centres (AerOS)

The partnership with Electrum and CloudFerro brings an innovative pilot which builds on top of sector specific federated nodes within Gaia-X. It leverages renewable energy sources to implement edge services in green energy centres, power development sites (wind turbines) linked to cloud computing centres. The monitoring of energy consumption and real-time analytics to adjust activity within energy production and distribution resulting in improved quality of energy services.

3.5.4 Healthcare

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

- Medical diagnostics (NEPHELE)

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 the presence of a doctor. The use of sensors and interface allows for accurate patient evaluation without the physical presence of a doctors simultaneously addressing the sectoral challenge of shortage of medical staff. The operating system uses virtual objects to integrate data from various devices and process it along the continuum, based on processing needs. AI and ML models can analyse the data collected from a patient and perform patient diagnostics and increase the productivity of doctors resulting in remote patient diagnostics at any time.

- Health-safe smart building (AerOS)

The pilot in Athens uses sensors and data collected on utilities used in smart home which allow for remote monitoring of the elderly or vulnerable people. Linked with ACTIVAGE, 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.

3.5.5 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 increases the efficiency of systems, from shipping half across the world to the last mile delivery. Examples of uses cases include:

- Predictive delivery (NebulOus)

The pilot, in collaboration with Telefonica and Mercabarca, targets the last-mile distribution of fresh food in Spanish cities. Market predictive analysis for logistics optimises supply of fresh food, thus reducing waste. The deployment of 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 (AerOS)

Within the partnership with one of the biggest logistics companies in the world, Eurogate, this pilot aims to create a smart port in Limassol, Cyprus. The integration of all members of the logistics chain to one network will allow for effective communication and increase effectiveness of systems and services. It will eliminate barriers to data and resource sharing and smoothen all processes, from ship docking to delivery truck management. Another essential aspect of the project is 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.

4. Market impact

Edge, Cloud and Cloud to Edge computing have been steadily growing in recent years as companies undergo digitalisation and digital transformation changes and adopt new technological solutions to their processes.

Cloud has been to this point the main technology trend of the past decade with the steady migration of companies and resources to centralised data centres. Cloud market has been growing annually at 17% from €380 billion worldwide and €35 billion in Europe in 2020 and is expected to reach €720 billion and €75 billion in 2025, worldwide and Europe respectively[14]. Similarly, the spending on cloud computing solutions has been growing and is expected to more than double, from €76 billion in 2020 to €205 billion in 2025.

However, with increasing computing and processing needs, edge computing is going to join cloud computing as the next important part of digital infrastructures. The convergence of Cloud and Edge will serve as an enabler of future developments[15].

The growing need for edge computing solutions and building CEI networks is reflected in the analysis of expected spending on enterprise edge, estimated to double, from €18 billion to €39.6 billion, between 2020 and 2025 and outpace the average growth within the ICT market[16].

In Europe, Edge computing is expected to increase at YoY growth rate of 26,5%, from €815 millions in 2020 to €2.6 billion in 2025[17]. Also, Edge is expanding across industries as it allows advances in many forms, from simplifying production and automatizing equipment, increased safety, and reliability, to full digital integration of all resources enabled by the developments in IoT. The developments in IIoT and AIoT are especially crucial in distribution and services, and manufacturing and resources which show the highest spending per sector, according to IDC's report.

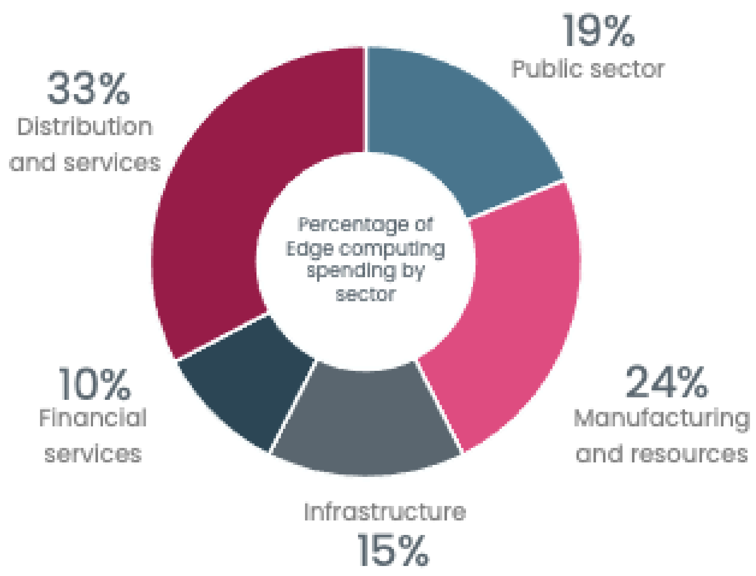


Figure 10: European Edge Spending by Sector[15]

[14] Europe Cloud Computing Market Size (2021) Global Market Insights
[15] Further information available in Deliverable 1.1 Cloud-Edge-IoT Demand Landscape
[16] Europe Edge Computing Market 2020-2030 (2021) GMD Research
[17] Worldwide Edge Spending Guide (2021) IDC

4.1 Key sectors for European competitiveness

The key sectors selected are of strategic importance for the European Union as well as sectors with existing ecosystems and potential for the use of CEI technologies. Furthermore, the large-scale pilots within the project portfolios are developing solutions primarily solving challenges of these sectors[18].

The five selected sectors are:

Manufacturing (automotive/industrial automation):

Manufacturing is the largest segment of the European CEI market, with value added to the EU GDP of 15%[19]. Manufacturing has been continuously automated in the last decades and now, with advanced IoT and IIoT, further automation efforts can be done. Cloud-Edge computing would enable the use of various technologies, including advanced predictive maintenance, robotics, and additional deployment of IIoT devices. According to Stais research, the increased operational responsiveness of the Automotive industry to Edge computing is the highest with 96%[20].

The variety of IoT devices used and high processing needs within the manufacturing process is one of the major challenges addressed by the CEI initiative and therefore, the combination of the market importance and suitability for CEI technology make it a key sector for the EU.

Agriculture

Agriculture is one of the most important sectors as it covers one of the most basic human needs. The European Union makes continuous efforts to increase the independence of EU member states for food production. Simultaneously, agriculture is a constantly challenged sector with high CO2 production, major labour shortages, and geographical distribution and distance.

Farming 4.0 brings solutions to some of the challenges by automating processes, for example predictive agriculture, advanced analytics, sustainable processes, or autonomous farming enabled by strong network coverage of Edge computing and networks. The use of CEI technologies is an essential tool to EU's achievement of farm to fork sustainable targets.

Healthcare

Healthcare is undoubtedly essential sector for the European Union as it assures the well-being and health of its citizens. At the same time, healthcare government expenditure accounts for 8% of EU's GDP[21]. Ageing population, rising shortage of healthcare workers, increase in chronic diseases or rural population are the main challenges the sector is facing today. Technological advancements have increased the life expectancy by 30 years within the last century and further innovation can achieve even more[22]. Efficient collection and use of data from IoT devices can provide information which is analysed by AI and ML models consequently accelerating medical R&D. Edge computing together with IoT can effectively address some of the biggest challenges, empower technology for at-home monitoring, telemedicine and scaled-up virtual services, along with smart systems and real-time diagnostics and aid in the shift from traditional to reactive care.

Energy and Utilities

The energy and utilities sector is especially strategically important in today's tense geopolitical situation and energy insecurity. The disperse geographic distribution of energy grid, importance in achieving Sustainable

---

[18] Description of the selection process and methodology for specific sectors is detailed in Deliverable 1.1. Cloud-Edge-IoT Demand Landscape. For further insights into market analysis, refer to Deliverable 2.1. Readiness Framework and Service Requirements.

[19] World Bank national accounts data, and OECD National Accounts data files (2022)

[20] Edge Computing Market (2021) Straits Research

[21] Government expenditure on health (2022) Eurostat

[22] 2019 Global health care outlook (2020) Deloitte

Development goals, strategic security, and potential technological improvements are important challenges that can be tackled within the CEI framework. Adding CEI technologies can improve the efficiency of energy distribution, increase the quality of energy, decrease vulnerability of networks, and provide more sustainable solutions to energy production and distribution.

Transportation

Logistics and Transportation are vital for free movement of individuals, services and goods which is the cornerstone of European integration. Transportation and logistics networks enabled international trade and move EU's economy forward. Logistics and Transportation are a crucial sector of EU's economy and strategy where eight European countries are in the top 10 of the World Bank's Logistics Performance Index (LPI)[23]. Furthermore, newest technological advancements bring improvements within different areas of the sector, from smart internal logistics network, autonomous vehicles, and robotics, to increased safety and security. The CEI framework would enable new generation of IoT as it provides network, processing and computational requirements needed. The low latency of 5G networks is necessary for the use of autonomous vehicles, which alone add estimated value of €17 trillion to the European economy by 2050[24]. In other words, the CEI computing continuum is an enabler of important advancements in logistics and transportation with impact valued at trillions of euros.

4.2 Identified use cases

The selected use cases address the main challenges within sectors by using technological solutions enabled by the convergence of Cloud and Edge computing. The selected industries can benefit from a wide range of novel technologies and their connection to the network, for example, using wearables with sensors monitoring body functions connected to hospital system that allow for remote monitoring of patients or predictive maintenance of machinery based of analysis of data collected by sensors and processed with algorithms.

Table 3: Use cases within CEI framework

Manufacturing	Agriculture	Energy and utilities	Transportation	Healthcare
Smart building (e.g., smart lighting/ HVAC for energy saving)	Asset/ equipment/ systems maintenance and repair	Smart meters	Fleet tracking, monitoring and management	Remote Health Monitoring
Asset/equipment/systems command and control	Visual inspection — quality/ integrity	Remote network management/ maintenance (e.g., fault detection)	Freight tracking, monitoring and management	Hospital Asset Tracking
Process automation and optimisation	Autonomous vehicles	Sensor-based asset diagnostics and maintenance	Passenger traffic flow	AI-enabled Diagnosis and Treatment Systems

4.3 Current challenges

The challenges the EU is facing and are addressed by the umbrella initiative are competitive(economic), environmental, and technical (discussed in Section 3.3). The creation of the CEI computing continuum will address the challenges across sectors, namely:

---

[23] Trade Logistics in the Global Economy (2018) The World Bank

[24] Autonomous Driving: The Start of a Revolution (2020) Nissan Europe

Barriers to exiting current computing solutions and dependency on gatekeeper providers

Exit strategies from cloud solutions are often complex and unless executed perfectly. Companies are at risk of losing data, increased costs and the need for completely new infrastructure in the case of vendor-lock in effect. Additionally, almost 70% of the cloud market share is captured by three big tech companies- Amazon, Google and Microsoft and only 13% of EU cloud revenues come from EU cloud service providers[25] creating a market and sovereignty risk.

Vulnerabilities caused by incompatible and varied systems and protocols

The exponential growth in use of IoT devices creates new vulnerabilities across systems and devices as hardware is often the chosen entrance for cyberattacks. The variability of devices (systems, manufacturer, age) requires different security solutions based on particular requirements which leads to complex, expensive, patchy and imperfect systems. Cyberattacks targeting IoT devices have increased by 700% since 2019 and pose a vast challenge to adoption of CEI infrastructure and IoT devices[26].

Complicated systems that require a highly skilled workforce

The addition of CEI technologies to existing infrastructures requires highly skilled workforce for the adoption, maintenance, and operation. As many of the current target sectors already use specialised systems, the requirements for worker skills will further increase with sectorial specialisation and ICT skills. Currently, only 54% of the European workforce has basic digital skills creating a gap between supply and demand[27].

Shortage of specialised labour

The EU has been facing a shortage of specialised labour over the past decades. Currently, 14 out of 19 occupations identified as high magnitude shortage are within the key sectors for the CEI continuum[28] and Europe is predicted to have a shortfall of data professionals in the millions by 2025. Although professions as *Nursing Associate Professionals* can be supported with developing technologies, others like *Applications Programmers* are critical for the continuum convergence and the digitalisation of key European sectors.

Incompatibility of devices resulting in dysfunctional systems and inability to operate across networks and divisions

Interoperability of devices is the primary challenge of the CEI convergence and has the potential economic impact of 5.5-12.6 trillion EUR from IoT use by 2030[29]. This value cannot be captured due to the barriers to adoption that incompatibility of devices creates as it creates additional risks of dysfunctionality. Furthermore, legacy systems often cannot be integrated into new infrastructures which increases waste of both budgets and devices with increased security risks.

Increased processing needs and unused capacities at the edge

The widespread use of IoT devices and advanced computing at all layers of the network creates increased requirements for computing and processing. At the same time, all these devices generate an enormous volume of new data that must be processed and stored. System capacities that are currently used cannot handle the influx of new data often leading to increased costs of storage and computing processes. Simultaneously, there are millions of devices connected to network that are not fully using their processing capacities and could be exploited at low or no cost.

---

[25] Strategic Market Intelligence for Emerging IT & Cloud (2022) Synergy Research Group
[26] 2021 Global Threat Report (2022) CrowdStrike
[27] Digital Economy and society (2021) Eurostat
[28] 2021 Labour shortages surpluses report (2022) ELA
[29] IoT value set to accelerate through 2030: Where and how to capture it (2021) McKinsey

Lack of cooperation between companies, researchers and institutions creates an information gap that prolongs and complicates development efforts

The current CEI value chain is still in the early stages of development and although there are alliances and initiatives connecting different groups, there is a lack of cooperation between them. Consequently, new developments are made that cannot be integrated across systems and reinforce the challenge of interoperability, slowing down further advances.

Addressing these challenges will reinforce the EU's digital autonomy, increase the competitiveness of European SMEs, start-ups, and corporations, and reinforce the EU's position among the technological leaders.

5. Next steps

An initial mapping of the European Cloud Edge IoT Continuum has been provided within this report. As is evident, while the EU CEI demonstrates significant potential for how businesses and industry at large employ digital technologies. This, however, requires the continued development of a set of technologies which can support the connections and management of the diverse set of tech stacks that will be required. An ongoing conversation with both tech developers and potential value chain adopters will serve to provide greater definition and detail over the coming 24 months, crystallising the CEI Continuum concept and markets.

Follow-on work includes the following:

- Continued definition of the Cloud Edge IoT Continuum from a technology position.
- Establishment of a related taxonomy of technologies that scopes the constituent technologies of the CEI Continuum.
- Crafting and development of the constituent use cases to be applied within the MetaOS projects.
- The definition of a framework for assessing the market feasibility of CEI technologies and systems.
- Tailoring of go-to-market and commercialisation strategies and approaches for tech developers.
- Definition of future technology gaps against expected demand.