Cloud Computing in Europe

Appendix 11

From core clouds to edge clouds

15th July 2020

h-cloud.eu

Title	Cloud Computing in Europe. Appendix 11: From core clouds to edge clouds
Lead Editor	Federico M. Facca
Contributors (in alphabetical order)	Massimiliano Claps, Mark Dietrich and Phil Jones
Version	0.7
Date	15th July 2020
Confidentiality Notice	**Confidential** - The information contained in this document and any attachments are confidential. It is governed according to the terms of the project consortium agreement

ABSTRACT

The European Commission is actively setting priorities for the upcoming Multiannual Financial Framework of the European Union covering the 2021-2027 period. Among the different identified priorities, "A Europe fit for the digital age" explicitly supports digitalisation. Cloud computing, as a fundamental brick of a digital Europe, will play an even stronger role in European economy and society by embracing core European values, spanning fundamental individual rights to market openness and environmental friendliness. "A European data strategy" define a strategy to digitalise Europe driven by an High Impact Project on European data spaces and federated cloud infrastructures.

In the data strategy, edge computing capacity building is highlighted as a priority. In this briefing note we explore edge computing market growth, and the implications of moving data processing balance from today's 20% data at the network edge and 80% in cloud-based infrastructure to 80% at the network edge and 20% in cloud-based infrastructure.

Following the analysis of the demand side and supply side landscape, we provide a set of key recommendations to the European Commission in relation to supporting edge computing adoption.

Important Notice: Working Document

This briefing is an annex to the Green Paper v 0.7. The Green Paper is an outcome of the H-CLOUD project, a Coordination and Support Action that has received funding from the European Union's Horizon 2020 Research and Innovation programme under grant agreement n. 871920.

CONTENTS

EXECUTIVE SUMMARY

Cloud computing is a megatrend that is a key enabler for data-driven innovation. It is expected to bring enormous benefits for citizens as stated in the recent EC Communication on Shaping Europe's digital future and the "European strategy for data, COM (2020) 66 final". It is acknowledged that coordinated efforts are necessary at European level to make sure that innovation can ultimately make a difference to industry, public administration and eventually society at large.

The European Commission is actively setting priorities for the upcoming Multiannual Financial Framework (MFF) of the European Union covering the 2021-2027 period. Among the different priorities, digitalisation is supported by the "A Europe fit for the digital age" priority. Cloud computing, as a fundamental brick of a digital Europe, will play an even stronger role in European economy and society by embracing core European values, spanning fundamental individual rights to market openness and to environmental friendliness. Nevertheless, for many organisations, "cloud adoption" is neither simple or a "one size fits all" process. It is often complex, requiring detailed planning, skilful execution and careful consideration of return on investment.

This briefing note explores, in the above context, challenges and opportunities related to edge computing.

While there are a number of key drivers for the adoption of edge computing infrastructure, there are also a number of barriers and issues slowing its adoption.

Key drivers include:

- managing the increasing amount of data generated
- supporting low-latency and realtime response; and
- increasing data security and privacy.

The demand analysis evidences that, while the potential for edge computing adoption is large:

1. Investments toward the adoption are still limited, with the exception of IoT related sectors.
2. SMEs are not ready to adopt edge computing.

The above situation is mainly motivated by:

- Complexity of adoption and lack of need skills
- Costs of investments related to adoption, including lack of public edge infrastructure offering, that would support the transition from CAPEX to OPEX cost model

In term of supply, H-CLOUD analysis highlights that:

- Large investments are ongoing the delivery of hardware and software platforms to support edge computing.
- Most of the available solutions, especially by hyperscalers, are not interoperable and aims at moving data from the edge to specific cloud infrastructures or platforms.
- While, given the demand analysis, there is a clear interest toward public edge offering, the current market offering is rather limited and not mature.

Starting from the analysis, H-CLOUD derived the following key overall recommendations toward the European Commission (as reported in the Green Paper):

S-E Challenge 1: Concern about stranded edge investments. Investing in the wrong emerging technology is a risk. The supply side should facilitate edge adoption and deployment by mitigating the risk of lock-in.

H-CLOUD analysis highlights that this challenge should be supported by: strategies helping edge technology maturation and skills development *(S-E Recommendation 2)*, creation of an ecosystem of interoperable and/or federated public edge infrastructure offering (*S-E Recommendation 3*), investing on automation and openness edge solutions (*S-E Recommendation 4*), and promoting development of common edge standards across the different industries (*S-E Recommendation 5*).

S-E Challenge 2: Edge is complex and expensive for SMEs. Help smaller organisations to improve their readiness and maturity, and reduce the complexity of edge computing adoption, while making it affordable.

This challenge should be supported by strategies helping edge technology maturation and skills development *(S-E Recommendation 2)* and investing on automation and openness edge solutions (*S-E Recommendation 4*).

S-E Challenge 3: Uncertain return on edge investments. Facilitate the widespread use of edge technology, so it reaches critical mass as a public edge capability.

This could create an opportunity for Tier 2 providers, notably those associated with mobile networks, to take a more prominent role in edge infrastructure build out, leveraging their existing footprint of distributed facilities. Research and Innovation initiatives should look into solutions, for example leveraging federation and multi-edge approaches, to allow the creation of widespread edge infrastructure across different providers (*S-E Recommendation 3)*.

S-E Challenge 4: Ensure scalability and affordability of edge computing solutions and deployments to cope with the demands of the foreseen usage scenarios, also by small players.

Research should continue to explore automation of cloud continuum from infrastructure layer up to the final application, taking into account different scenario specific demands and contributing to open source initiatives *(S-E Recommendation 4).*

S-E Challenge 5: Concerns about edge interoperability. Edge computing research and innovation solutions are coming from the telecommunications sector as well as multiple Industry 4.0 initiatives, but their approaches are diverging. This will create interoperability issues and increase the complexity of adoption and management.

The analysis highlights the relevance of promoting development of common edge standards across the different industries, and sustaining them by including them as requirements in public tenders (*S-E Recommendation 5*).

S-E Challenge 6: Limited investment on trusted data access solutions for the edge. As of today most of the solutions available for trusted access to data rely on specific hardware facilities - software based solutions are still lacking. This limits a lot the flexibility and potential adoption of public edge infrastructure offering where guarantees about trusted access to data are required.

Research should focus on open reference solution for trusted computing at the edge supporting multi tenants in isolation and compatible with the different EU privacy and security regulations [*S-E Recommendation 6*]

1 INTRODUCTION

Cloud computing assumes that the processing and storage of data take place within the boundaries of a cloud and its underlying infrastructure. While conventional cloud computing infrastructures and applications are designed to scale, and - eventually - to replicate geo-graphically, they are not meant to be geographically dispersed across an high number of point of presence and leveraging heterogeneous end points. A geographic dispersion of coordinated data processing and storage services enables low latency and data localization[1], typical requirements of some of the most recent use case scenarios in Internet of Things and Media application areas. To tackle such challenge researchers and innovators defined two interrelated paradigms: fog and edge computing. According to NIST[2], while fog computing is a computing paradigm where data processing and storage services are located between cloud data centers and end-user devices, edge computing foster the processing and storage of data at the edge of the network including smart devices and their end-users. The advantages of processing and storing data closer to their source are essentially: the reduced latency and network usage[3], the increased data security and governance[4].

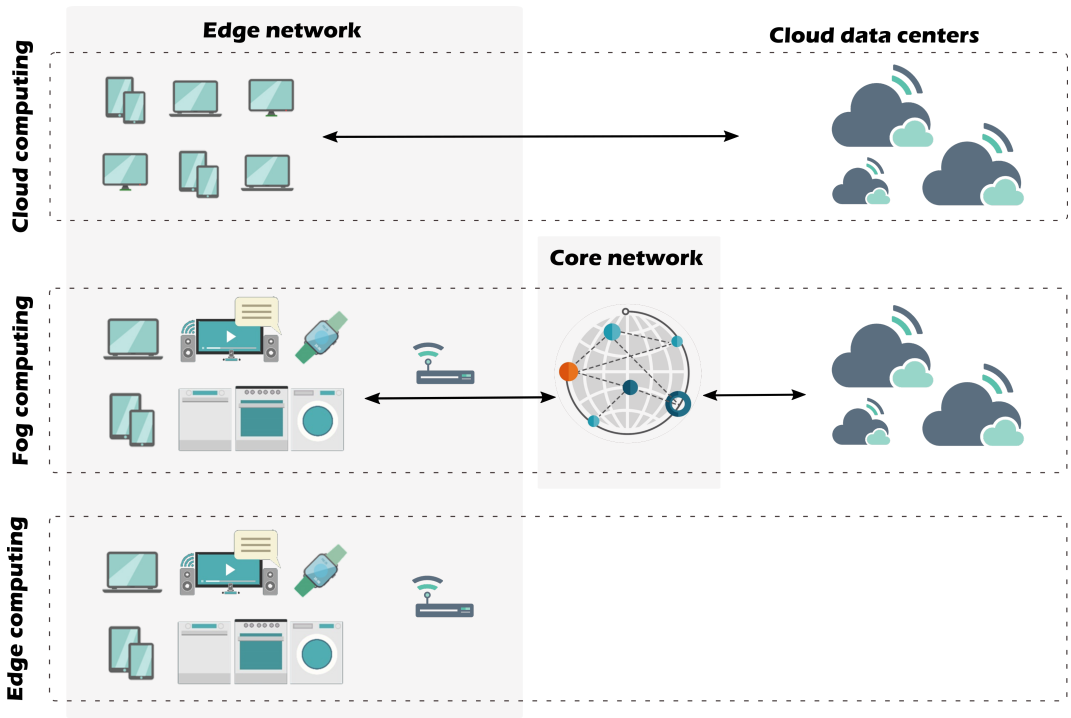

Figure 1. From Cloud computing to Edge Computing[5]

In the context of our analysis and research, in line with current market trends evidenced by IDC[6], we consider edge computing not just as the pure functionality of supporting computation at the network edge, but through the full cloud-edge continuum: i.e., from the cloud data centers, via intermediary edges, till the devices at the network edge. As rule of the thumb, the continuum from the cloud data

[1] Iorga, M.; Goren, N.; Feldman, L.; Barton, R.; Martin, M.; Mahmoudi, C. Fog Computing Conceptual Model; NIST: Gaithersburg, MD, USA, 2018.

[2] Cf. footnote 1

[3] Jain, K.; Mohapatra, S. Taxonomy of Edge Computing: Challenges, Opportunities, and Data Reduction Methods. In Edge Computing; Springer: Berlin, Germany, 2019; pp. 51–69.

[4] Industrial Internet Consortium. Introduction to Edge Computing in IIoT, 2018.

[5] Svorobej, S.; Takako Endo, P.; Bendechache, M.; Filelis-Papadopoulos, C.; Giannoutakis, K. M.; Gravvanis, G. A.; Tzovaras, D.; Byrne, J.; Lynn, T.. Simulating Fog and Edge Computing Scenarios: An Overview and Research Challenges.

[6] IDC, The Edge — Perspectives on Market Definitions and Sizing, 2019.

centers (core) to the network edge (packaged endpoint) corresponds to decreasing computational capacity, power consumption and latency. At the same time, the continuum from the cloud data centers (core) to the network edge (packaged endpoint) corresponds to an increased dispersion and distribution of the infrastructure and complexity of management of the infrastructure (also related to reduced network availability). While core and heavy edge are fixed infrastructures, light and packaged edges may be mobile.

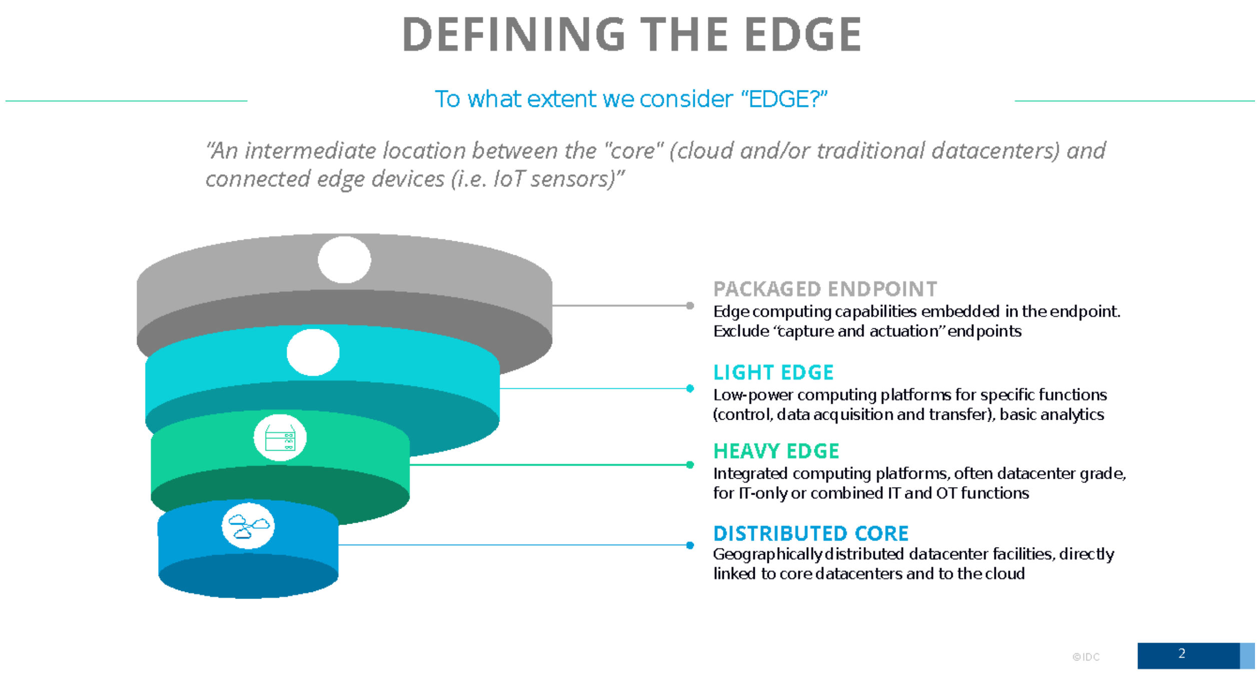

Figure 2. Defining the EDGE[7].

Naturally different type of application scenarios may leverage different "edges" in the cloud-edge continuum. e.g. Telco operators covers mostly heavy and light edges (in some cases), Industry 4.0 covers mostly light and endpoint edges.

It is worth as well to highlight, that "public", "private" and "hybrid" definitions, characteristics of cloud computing, may be applicable as well to edge computing. Nevertheless, "public edges" are still limited on the market. Thus, we can define:

- *public edge* as an edge computing services offered by third-party providers over the public Internet;
- *private edge* as an edge computing services offered either over the Internet or a private internal network and only to select users instead of the general public;
- *hybrid edge* as an aggregation of edge resources including at least 1 private edge and 1 public edge.

[7] Cf. Footnote 6.

2 CONTEXT

According to the Industrial Internet Consortium[8], the drivers for the adoption of edge computing infrastructure are:

- **Managing the increasing amount of data generated.** It is expected that by the end of 2020 there would be more than 30 billion IoT devices connected[9]. It is estimated that level 5 autonomous vehicle will generate around 3 terabyte of data per hour. Such data will require fast and reliable data processing solutions to enable real time decisions. Moving this data to the cloud for realtime processing is not going to be an option.
- **Supporting low-latency and realtime response.** Several data generated at the edge of the network, like in the case of IoT devices, requires for realtime analysis. In traditional cloud-based architectures, the processing occurs in the cloud, and thus its response time is heavily impacted by the time to transport data from the source to the processing location. In the best cases a single fragment of data needs 50 milliseconds to travel to the cloud, where it is processed, and other 50 milliseconds are required for the response/decision to reach back the edge. These 100 milliseconds could be the difference between avoiding a collision or not in the autonomous vehicle scenario.
- **Increasing data security and privacy.** Moving data from the source to the cloud, inevitability increase the surface of attack, and may imply as well moving the data across different geographies, thus infringing the different privacy regulations such as GDPR. While due to computation capacity limitations, in the past complex analysis where only possible in large infrastructure, thanks to the evolution of embedded CPUs, such as the ones of mobile phones, it is now possible to run complex AI tasks in a mobile device, thus eliminating the requirement for transferring sensible and non-sensible data.

As evidenced by IDC in its “The Technology Impacts of Edge Computing in Europe”[10] report, despite Edge computing is applied in the same set of use case as Cloud computing, they are not necessarily in competition. Rather they are complementary and interact in a smart and intelligent way. Edge may help boost cloud adoption within industries and use cases in which cloud has lagged. It is up to businesses to analyze their use cases and unique needs to determine the right balance of processing performed in the cloud and at the edge.

2.1 European Policies and Edge Computing

As discussed in “Cloud Computing in Europe: The Policy Context” briefing, the European Commission aims to launch an High Impact Project on European data spaces and federated cloud infrastructures[11] by 2022. Edge computing is considered one of the key enablers for digital transformation in Europe, and it is envisioned that the high impact project will interconnect “energy-efficient and trustworthy edge and cloud European infrastructures”.

In short, “a European strategy for data”[12] (EUSD) envisions an increasing role of edge processing (and hence edge infrastructures) in the next years and aims at stimulating the creation of an ecosystem enabling a seamless cloud-to-edge continuum of data processing capabilities.

Cloud technologies have the important role of enabling such cloud-to-edge continuum of data processing capabilities and making it widely accessible to European cloud stakeholders. Investments in this direction, connected to the 5G networks currently under deployment by network operators may also play an important role in supporting the European strategic autonomy.

---

[8] Industrial Internet Consortium. Introduction to Edge Computing in IIoT, 2018.
[9] Statista. Internet of Things - number of connected devices worldwide 2015-2025, 2016.
[10] IDC. The technology Impacts of Edge Computing in Europe, 2019
[11] EC. Communication: A European strategy for data. 2020
[12] Cf. footnote 11.

In relation to "A new Industrial Strategy for Europe"[13] (NISE), it is important to make available and accessible edge infrastructures and processing to key industrial sectors while ensuring that such new enablers embrace climate-neutrality principles. This is particularly key to ensure that digitalisation complies with the Green Deal vision, and to stimulate research and innovation in edge technologies (from hardware to software) to ensure that proliferation of edge will not negatively impact the energy bill of European digital infrastructures, compared to large data centers deployment that benefit of the "economy of scale" model to efficiently consume energy.

To support the creation and take up of energy efficient ecosystem of edge providers in Europe, several digital skills are required, for which Europe is already suffering a gap. To reduce such gap, the investments on digital education part of the new Industrial Strategy may have a central role.

[13] EC. A new Industrial Strategy for Europe. 2020

3 ANALYSIS

3.1 Demand-side analysis

The edge computing market is evolving rapidly as more number of things are getting IoT enabled. According to IDC[14], by 2023 73% of the data will be created outside the core, meaning a traditional data center or the cloud. IDC[15] highlights that this trend will be driven by IoT: "By 2022, 50% of the initial analysis of IoT data will occur at the Edge"

In line with the above forecast, according to Allied Market Research[16]: "The edge computing market size was valued at $ 1,734.8 million in 2017, and is projected to reach $ 16,556.6 million by 2025, growing at a CAGR of 32.8% from 2018 to 2025."

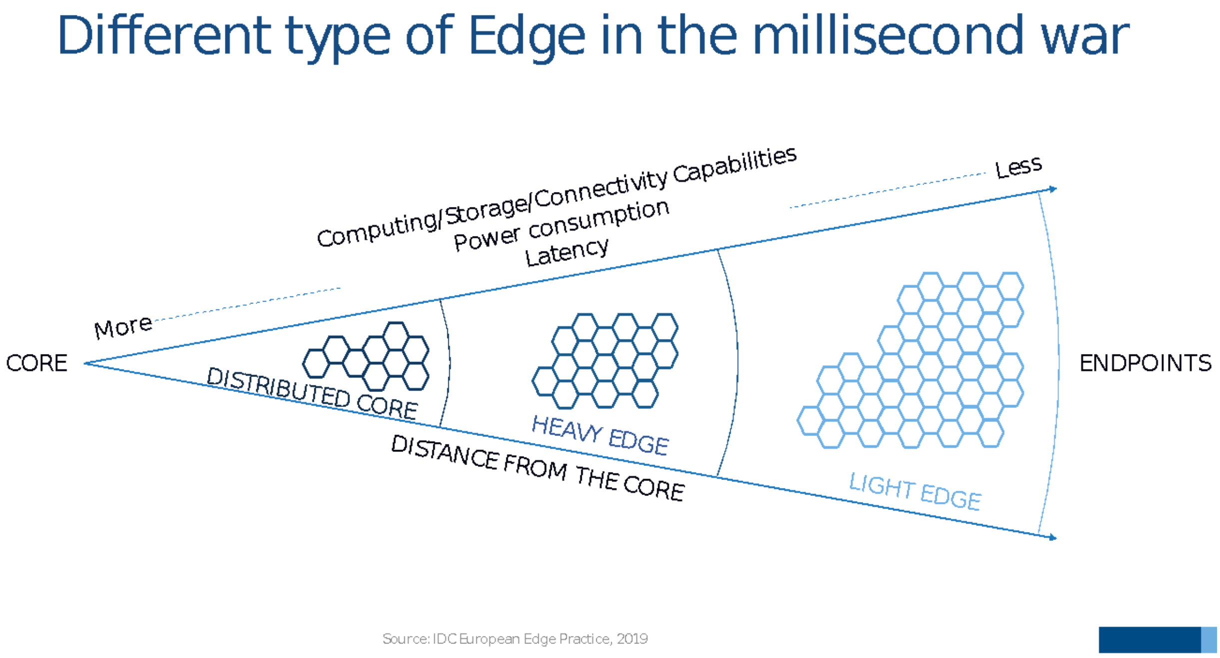

Figure 3. From Cloud (Core) to Edge

The edge computing paradigm focus on enabling localized data processing, and thus it is related to a wide number of use cases and market segments. Depending on the scenario and related demands, different level of edge may be involved in the continuum from the cloud core, to the devices at the edge of the network, including user's devices (such as mobile phones). Thus there are different type of edges in this continuum, with different computational capacity, power consumption and network latency. According to studies, the factors that stimulate the growth of edge computing adoption are the increased load of networks and cloud infrastructures connected to the rise of data-intelligence applications. This is particularly crucial in the IoT related market segments. On the other side, moving the computation to the edge may increase hardware cost and their maintenance, and such challenges may slow down the edge computing adoption growth.

A survey by Futurum Research[17] analysed the importance of Edge Computing in initiatives such as Digital Transformation, IoT, and Industry 4.0. 56 percent of the respondents, cited Edge Computing as

---

[14] IDC. Revelations in the Global DataSphere, 2020.

[15] IDC. European FutureScape, 2018

[16] Allied Market Research. Edge Computing Market Outlook – 2025, 2019.

[17] Futurum Research. EDGE COMPUTING: From the Edge to the Core to the Edge. 2018

Extremely Important. With 68 percent of enterprises in Banking & Finance citing *Extremely Important*, while Healthcare & Pharma (38 percent) and Public Sector (33 percent) trail.

The same survey by Futurum Research[18], evidences some key aspects about edge computing adoption:

- Edge Computing is being driven by operations, driven not by IT, but by the business.
- IT may not be driving the adoption of Edge Computing but ends up owning it.
- Edge Computing is more than change itself, it is enabling change – including the value – of other systems.
- Edge Computing is believed to offer increased Security, Reliability, and Performance to existing IoT and sensor-collected data.
- Edge Computing deployment is projected to increase considerably and budgets appear to match.

As evidenced by Futurum Research, the top applications targeted with Edge Computing today are Data Acquisition & Pre-processing, Security and/or Monitoring, Data Analytics, and Location Services.

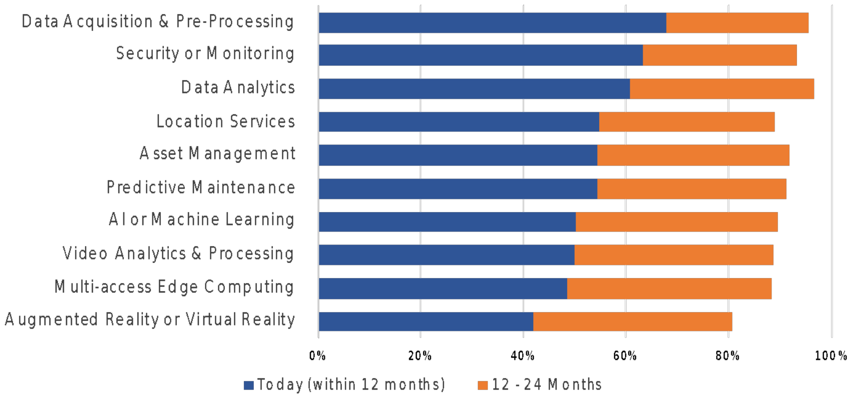

Figure 4. Most important applications targeted with Edge computing[19].

Despite the numbers by Futurum Research shows a great adoption potential for edge computing in different application areas and sectors, market research poses attention also on risks that may potentially limit such adoption. Early edge deployments show that organizations are concerned about their ability to manage assets, control costs, and ensure physical and data security. Beyond that, lack of skills is an additional barrier: one in five organizations lack the internal skills needed to support edge computing adoption. Costs are as well another potential barrier, the distributed and often remote nature of edge IT makes human intervention not affordable. As result, the investments on Edge Computing will grow only in more mature markets such as IoT, while the overall investment on Edge Computing is not likely to increase as observed by IDC[20] in the next 24 months.

[18] Futurum Research. EDGE COMPUTING: From the Edge to the Core to the Edge. 2018

[19] Futurum Research. EDGE COMPUTING: From the Edge to the Core to the Edge. 2018

[20] IDC. Multicloud Survey. 2019

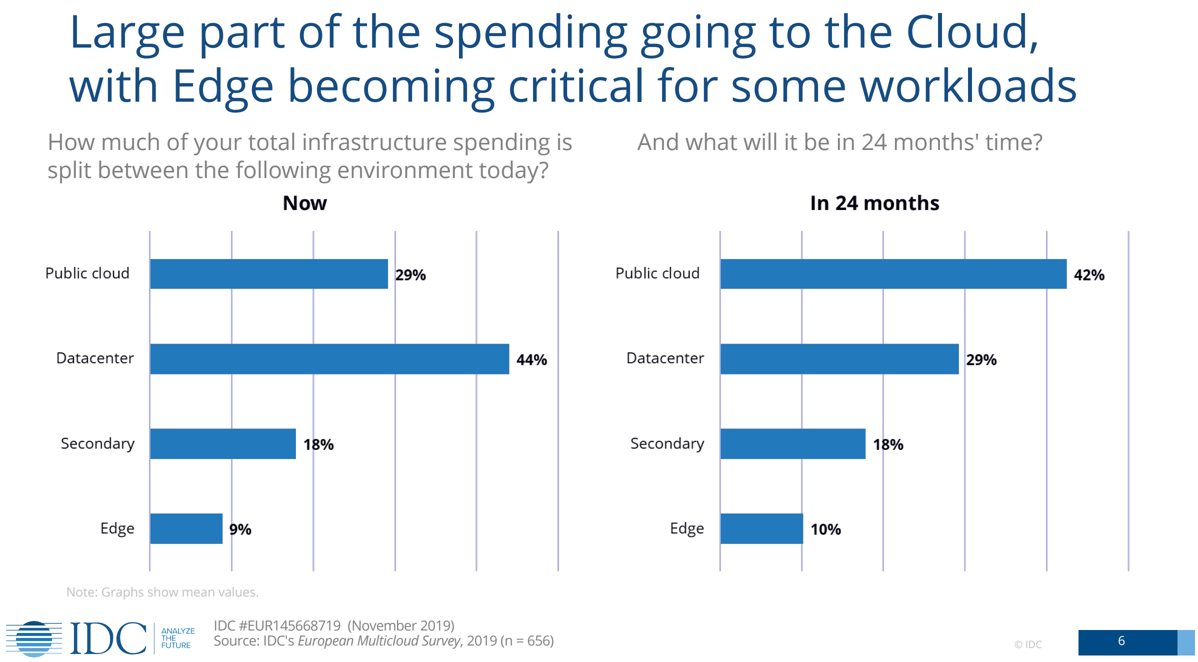

Figure 5. Share of infrastructure adoption (from cloud to edge), in 2019 and in the 2020-2021.

Looking at the size of the organizations, IDC survey[21] reveals that SMEs are not ready to adopt edge computing.

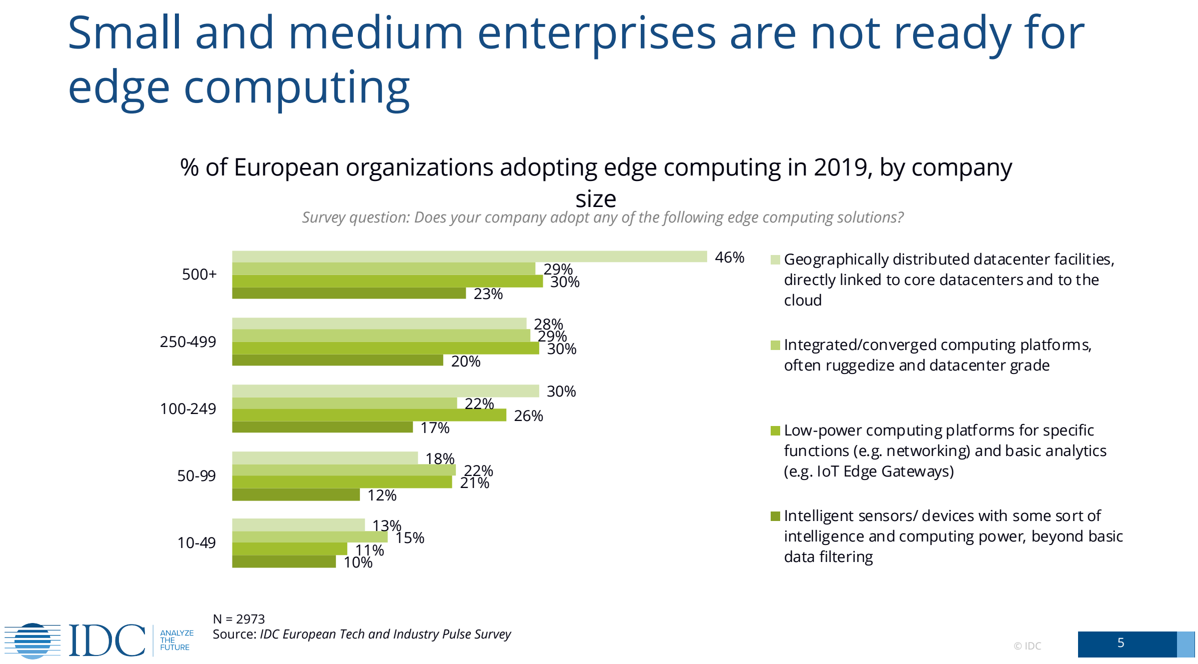

Figure 6. Share of European organizations adopting edge computing in 2019 by company size.

Currently the market adoption is driven by IoT, IDC forecast an investment of 12 billions in 2023 on IoT edge infrastructures in Europe.

---

[21] IDC, European Tech and Industry Pulse Survey 2019-2020. 2019.

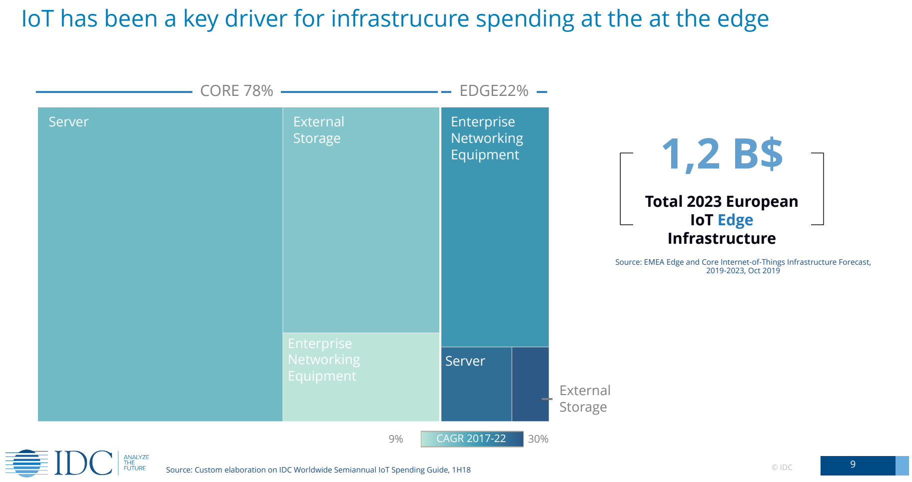

Figure 7. IoT as key driver for edge infrastructure investments.

IDC[22] identified that today in Europe, in the IoT arena, organizations are already processing 28% of their data at the edge, 32% process data both at the edge and the core, and 38% are using only core.

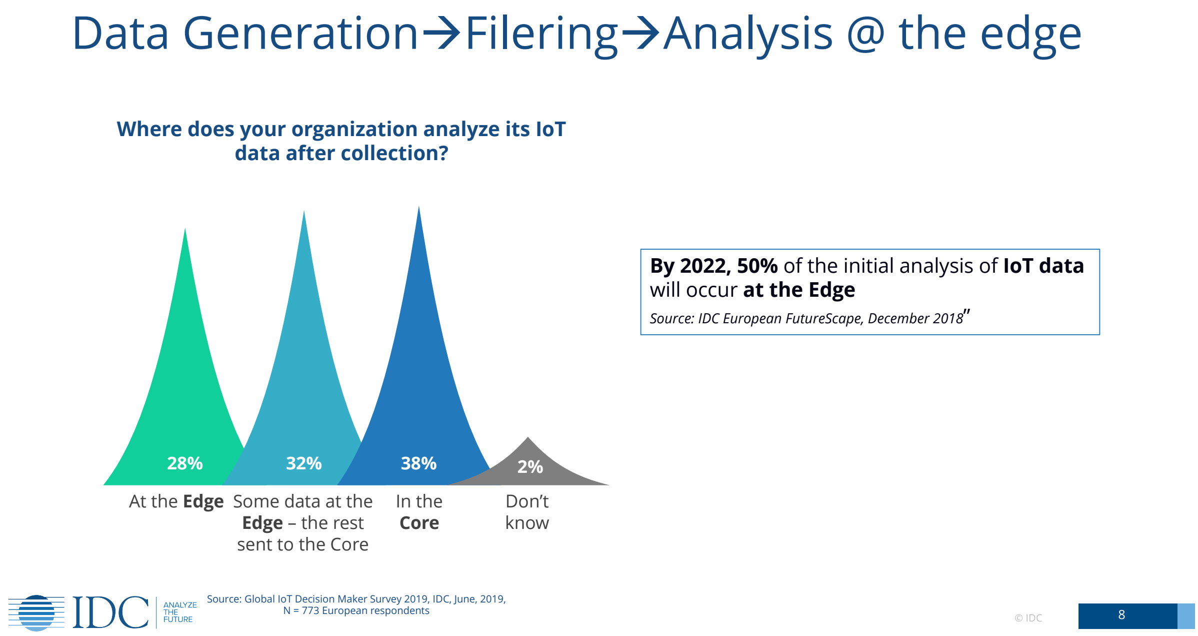

Figure 8. Share of edge and cloud processing in IoT applications[23].

The demand analysis evidences that:

- **Potential for edge computing adoption is large**.
- **Investments toward the adoption are still limited,** with the exception of IoT related sectors.
- **Most of the SMEs are not ready to adopt edge computing**, due to: investments costs, lack of skills, lack of public offers.

---

[22] IDC. Global IoT Decision Maker Survey 2019. June 2019.
[23] IDC. Global IoT Decision Maker Survey 2019. June 2019.

3.1.1 Use cases

Edge computing, while not being necessary in many scenarios, has a great potential in several scenarios where some requirements are critical to deliver a better service. These requirements, already introduced in the context discussion, include:

- Amount of data generated
- Increase of privacy and security
- Support for local interactivity
- Needs of low latency

If an application does not have such requirements, clearly there is no need for it to be implemented following the edge computing approach. On the other side, an application where such requirements are key, will benefit a lot from the adoption of edge computing.

The research from Chetan Sharma Consulting[24] investigate potential adoption in different market verticals.

- **Advertising**. In this vertical effective targeting is fundamental. In this scenario, edge computing naturally supports ability to collect and process with low latency accurate information about users and their context (location, etc.).
- **Online gaming.** It's not mystery that online games involving multiple players require quite complex coordination between users generated data that are geographically dispersed. User experience in this domain is clearly directly linked to network latency experienced by players.
- **Precision Agriculture.** Most innovative solutions for precision agriculture combines real time data from remote sources (e.g. weather forecast) and local sources (e.g. atmospheric sensors and imagery from drones). Especially local imagery sources may end up generating terabytes of data that not necessarily need to be processed in the cloud to generate valuable information. Local knowledge extraction may reduce cost and decrease latency to generate decisions and plans.
- **Manufacturing.** In the next future, automation within manufacturing will increase and include more and more IoT and robotic solutions. The fast detection of issues and their mitigation in industrial process will increase quality of products on and reduce costs of production. Low latency introduced by edge computing may also increase security (as regards human operators injuries and for data protection concerns) in highly automated industrial environments.
- **Autonomous Vehicles.** It is expected that autonomous vehicles will produce around 40 terabytes/hour that will need to be processed in almost real-time, and also when connectivity is not available, to ensure safety of such vehicles. Of course, autonomous vehicles may not be just offline but coordinate with local (e.g. streetlights, cars) and remote services (e.g. traffic central, fleet managers). Scenarios get even more complex when autonomous vehicles needs to coordinate among themselves such as in the case of vehicle fleets.
- **Smart Cities.** While not all scenarios in the smart city domain may benefit from edge computing, there are some scenarios that may be empowered by low latency and interaction localization, such as in the case of security issues detection and proactive measures related to that.
- **Energy.** Different energy sectors may benefit from edge computing. For example, oil rigs generate large amount of data and costs of transferring them to the cloud to generate insights is very expensive. Thus data can be more efficiently processed locally and only valuable insights need to be centralized. Similar issues apply to Wind farms located in disperse and wide territories.
- **Retail.** Similar to the case of contextual ads, retailers are interested into understanding consumer context and interests to propose targeted sales strategies.

[24] Chetan Sharma. The edge computing framework, 2019.

- **Sports.** Edge computing may contribute to different sports related scenarios, from the real time analytics of games to support on field strategies by the coaches, to the delivery of customized and enriched experiences to the attendees of sport events.
- **Entertainment.** As for online gaming, several entertainment services may provide better user experience thanks to edge computing. For example, in the future you may be able to see the game from the eyes of a specific players, still managing real time streaming and multicast for different devices requires high-throughput communications, such throughput may be largely reduced if processing, optimization and multicast of stream occurs at the edge.
- **Emergency.** In several emergency scenarios, IT infrastructure may be disrupted, thus requiring the need to quickly create local IT infrastructures that may serve the need of rescue teams (and local businesses) while emergency is solved.
- **Healthcare.** Novel technologies such as AI and VR are going to have an incredible impact on health care practices in the next future. Most of this solutions will anyhow require low latency and almost real-time processing capacities, thus edge computing will have a key role in enabling them.
- **Aviation.** In the aviation field, edge computing is relevant both to flight and airport management. For example, each flight produces 1-5 terabytes of data that cannot be offloaded using mobile networks. These data are often crucial to detect anomalies and hence improve maintenance procedures and increase flight safety. Enabling inflight processing through edge computing may be crucial for aviation industry future evolution and new safety standards.
- **Home automation.** More and more the number of connected devices in our homes is increasing. Today data generated are mostly sent to the cloud to derive “intelligent” actions improving our quality of life. This is raising several security concerns that may be mitigated by localized data processing provided by edge computing solutions.
- **Military.** On field operation often requires local protected mesh networks to exchange information across team members. Data collected is often crucial to elaborate strategies and intelligence insights, Military has to often setup a mesh network. In this context edge computing can provide localized analysis of data without need to offloading them in the cloud.

IDC[25] market research highlights how as off today the industries that have been largely adopting edge computing are Telco and Medias.

[25] IDC, European Tech and Industry Pulse Survey 2019-2020. 2019.

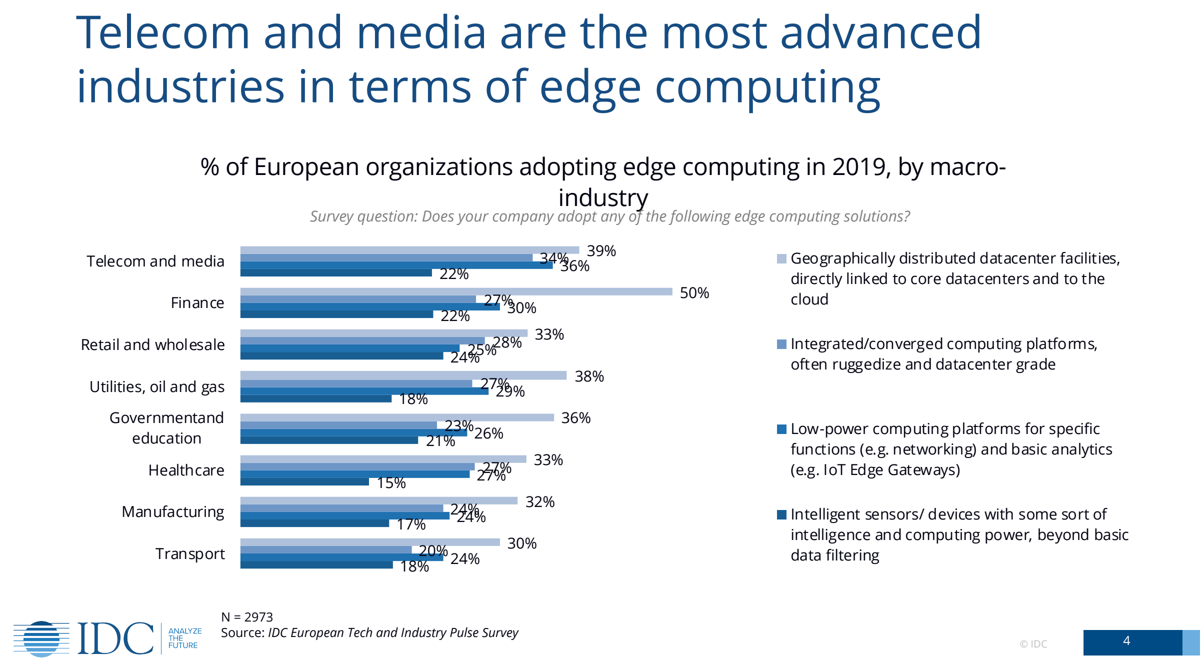

Figure 9. European Industry adoption of edge computing (with shares per type of edge).

The use case analysis evidences that today industry driving Edge Computing deployment is Telco, other industries are still beyond in the adoption despite the relevance of edge computing in their strategy. As evidenced in the demand analysis barriers for the adoption in additional sectors may include:

1. **Complexity of adoption and lack of need skills**
2. **Costs of investments related to adoption**
3. **Lack of public edge infrastructure offering, that move cost from CAPEX to OPEX**

3.2 Supplier analysis

Several edge computing suppliers are active in the platform segment aiming at delivering solutions enabling the management of data flows from the edge to the cloud. IBM Edge Computing[26] is an orchestration platform relying on Kubernetes to offer intelligent deployment and orchestration of services spanning from the cloud to edge. Cloudera launched Cloudera Edge Management[27], a solution to complements its cloud processing platform with edge capacities aiming at injecting data from local devices and processing before passing them to other cloud services. Volterra[28] provides a cloud-native solutions to manage cloud to edge workloads, including a set of edge services for processing and data injection, thus providing a complete and unified solution for edge computing management based on Kubernetes. Bosh to as part of its IoT suite offers a gateway software[29] designed for the edge that runs on different hardware and aggregate data from devices to be integrated into Bosh IoT platform.

Some of the major cloud service providers are emerging as leaders in the edge computing space as well. AWS Greengrass[30] and AWS Snowball[31] from Amazon allows to host some AWS functionalities at customer edge to run local IoT data aggregation and processing, and then transferring processing

26 https://www.ibm.com/cloud/edge-computing
27 https://www.cloudera.com/products/cdf/cem.html
28 https://www.volterra.io/
29 https://developer.bosch-iot-suite.com/service/gateway-software/
30 https://aws.amazon.com/greengrass/
31 https://aws.amazon.com/snowball

outcomes to AWS clouds for deeper analytics and reliable data storage. Azure IoT Edge[32] solution from Microsoft enables certified edge devices to host a set of IoT aggregation and processing functions at the edge and transfer they outcomes to Azure Cloud services. Azure also offers centralized way to manage the deployment of the mentioned functions at the edge. Similarly, IoT Core[33] from Google offers data processing and machine learning capabilities to edge devices.

The available offers highlight how while hyperscalers are active in the edge market, they mostly focus on solutions to integrate edges to their public cloud offering. The only exception is AWS that in January 2020 started offering in Los Angeles a new service called Local Zones[34]. Local Zones are essentially edge data centers aiming to covers location not yet covered by major AWS data centers.

Most of the large telecommunication companies that have been investing of edge in relation to virtualization of their IT/OT services, are expected to offer edge infrastructures in the next future. For example, recently TIM teamed up with Google[35] to work on the launch of a public offer for edge computing in Italy.

A number of small players aiming to offer "public" edge solutions is appearing on the market but their offer appears to be not yet mature enough. Mutable[36] is a US company leveraging a range of local data centers from different providers in US to provide a wide network of "edge" endpoints. EdgeInfra[37] is a Dutch start-up that provides neutral micro-datacenter and colocation services at the edge of network in Europe.

Edge computing is an important market also covered by hardware companies. HPE launched its family of edge computing devices: Edgeline Converged Edge Systems[38] accompanied by dedicated remote management solutions. Also NVIDIA launched its edge computing platform ranging from the Jetson Nano to the Jetson TX2[39]. The hardware offer of NVIDIA is complemented also by an edge computing platform: EGX[40] based on Kubernetes. eDell is also offering edge computing hardware based on Intel chipsets[41]. eDell and Intel together also invested on edge computing hardware companies like FogHorn[42]. A plethora of smaller players are also active in this segment. Some of them focusing only hardware, other proposing complete solutions for general purpose usage or specific industrial scenarios.

The supplier analysis evidences that:

- **Large investments are ongoing the delivery of hardware and software platforms to support edge computing.**
- **Most of the available solutions, especially by hyperscalers, are not interoperable and aims at moving data from the edge to specific cloud infrastructures or platforms.**
- **While, given the demand analysis, there is a clear interest toward public edge offering, the current market offering is rather limited and not mature.**

---

32 https://azure.microsoft.com/en-us/services/iot-edge/

33 https://cloud.google.com/iot-core

34 https://aws.amazon.com/about-aws/global-infrastructure/localzones/

35 https://www.telecomitalia.com/tit/en/archivio/media/comunicati-stampa/telecom-italia/corporate/istituzionale/2019/CS-TIM-Google-07-11-2019.html

36 https://www.mutable.io/

37 https://www.edgeinfra.net/

38 https://www.hpe.com/uk/en/product-catalog/servers/edgeline-systems/pip.hpe-edgeline-el1000-converged-iot-system.1008670396.html

39 https://www.nvidia.com/en-us/autonomous-machines/embedded-systems/jetson-tx2/

40 https://www.nvidia.com/en-us/data-center/products/egx-edge-computing/

41 https://www.dell.com/en-us/work/shop/gateways-embedded-computing/sc/gateways-embedded-pcs/edge-gateway

42 https://www.foghorn.io/

3.2.1 Infrastructure component analysis

The edge market is still in its infancy, however its complexity is starting to be recognized. As evidenced by the supplier analysis, market actors range from system integrators, major cloud providers, hardware and software vendors, telecom operators and more.

In this scenario, different players and strategies come into play. Components can be categorized as:

- Computing devices. Hardware and hardware management solutions for deploy computational capacity at the edge.
- Platforms. Services to orchestrate resources on the edge and edge-native services designed to provide analytics capacities of different type at the edge.
- Applications. Applications specialized to run in the edge for specific verticals taking into account specific needs of the scenario.

4 R&I PROJECT ANALYSIS

4.1 Open Source Projects

4.1.1 Gateway/CPE Platforms

EdgeX Foundry, Home Edge, Edge Virtualization Engine are Linux Foundation projects aiming to provide a platform for edge computing devices. Such an open source platform can, for example, host proprietary programs currently run on IoT gateway products.

Computing devices: Hardware support for EdgeX and EVE is similar: they support x86 and ARM-based computing devices; A typical target can be a Linux Raspberry Pi with 1GB RAM, 64bit CPU, 32GB storage.

Service platform: EdgeX uses a micro-service architecture. Microservices on the gateway are connected together, and to outside applications, through REST, or messaging technologies such as MQTT and AMQP.

Edge cloud applications: Target applications for EdgeX include Industrial IoT (e.g., IoT sensor data and actuator control mixed with augmented reality application for technicians). Home Edge focuses on smart home use cases, including using AI lifestyle and safety applications.

4.1.2 Edge Cloud Management Platforms

This set of open-source projects setup and manage clouds of individual edge computing devices. StarlingX extends OpenStack to provide virtualization platform management for edge clouds, which are distributed (in the range of 100 compute devices), secure and highly available.

Akraino Edge Stack, another project from the Linux Fundation Edge, has a wider scope of developing a management platform adapted for the edge (e.g., covering 1000 plus locations), aiming for zero-touch provisioning, and zero-touch lifecycle management.

Computing devices: Compute devices are typically Linux-based application servers or more constrained devices.

Service platform: StarlingX adds new management services to OpenStack by leveraging building blocks such as Ceph for distributed storage, Kubernetes for orchestration. The new services are for management of configuration (enabling auto-discovery and configuration), faults, hosts (enabling host failure detection and auto-recovery), services (providing high availability through service redundancy and multi-path communication) and software (enabling updates).

Edge cloud applications: An edge computing platform may support a wide range of use cases. E.g., autonomous vehicles, industrial automation and robotics, cloud RAN, metering and monitoring, mobile HD video, content delivery, healthcare imaging and diagnostics, caching and surveillance, augmented/virtual reality, small cell services for high density locations (stadiums), universal CPE applications, retail.

4.1.3 Related Projects

Open Edge Computing is an initiative from universities, manufacturers, infrastructure providers and operators, enabling efficiently offloading cloudlets (VMs) to the edge. Computing devices are typically powerful, well-connected servers located in mobile networks (e.g., collocated with base stations or aggregation sites). The service platform is built on top of OpenStack++, an extension of OpenStack to support cloudlets. This project is mentioned here as a related project because of its edge computing focus, and potential for some IoT use cases. Nevertheless, its primary use cases are typically non-IoT related, such as offloading processing-intensive applications from a mobile device to the edge.

4.2 Products

4.2.1 IoT Gateways

Multiple products are marketed as IoT gateways (Amazon Greengrass, Microsoft Azure IoT Edge, Google Cloud IoT Core, and gateway solutions from Bosh and Siemens). They are typically composed of a software frameworks that can run on a wide range of IoT gateway hardware devices to provide local support for cloud services, as well as some other local IoT gateway features such as relaying communication and caching content. Remote cloud is both used for management of the IoT gateways, and for hosting customer application components. Some IoT gateway products (Amazon Snowball) have a primary purpose of storing edge data on premises, to enable physically moving this data into the cloud without incurring digital data transfer cost.

Computing devices: Typical computing devices run Linux, Windows or a Real-Time OS over an ARM or x86 architecture. The level of service support on the computing device can range from low-level packages giving maximum control to embedded developers, to high-level SDKs. Typical requirements can start at 1GHz and 128MB RAM, e.g., ranging from Raspberry Pi to a server-level appliance.

Service platform: IoT gateways can provide a range of service including: running stateless functions; routing messages between connected IoT devices (using a wide range of IoT protocols); caching data; enabling some form of synchronization between IoT devices; authenticating and encrypting device data. Association between IoT devices and gateway based can require a device certificate.

Edge cloud applications: Pre-processing of IoT data for later processing in the cloud is a major driver. Use cases include industrial automation, farming, etc.

4.2.2 Edge Cloud Platforms

Services such as MobileEdgeX provide a platform for application developers to deploy software (e.g., as software containers) on edge networks.

Computing devices: Bare metal and virtual servers provided by mobile network operators are used as computing devices.

Service platform: The service platform provides end device location service, using GPS data obtained from platform software deployed in end devices, correlated with location information obtained from the mobile network. The service platform manages the deployment of application instances (containers) on servers close to end devices, using a declarative specification of optimal location from the application provider.

Edge cloud applications: Use cases include autonomous mobility, asset management, AI-based systems (e.g., quality inspection, assistance systems, safety and security cameras) and privacy-preserving video processing. There are also non-IoT use cases such as augmented reality and gaming.

4.3 Standards Initiatives

4.3.1 ETSI Multi-access Edge Computing

The ETSI MEC industry standardization group develops specifications that enable efficient and seamless integration of applications from vendors, service providers, and 3rd parties across multi-vendor MEC platforms. Basic principles followed include: leveraging NFV infrastructure; being compliant with 3GPP systems; focusing on orchestration, MEC services, applications and platforms.

Computing devices: Computing devices are typically application servers, attached to an eNodeB or at a higher level of aggregation point, and provide service to end users.

Service platform: The mobile edge platform offers an environment where the mobile edge applications can discover, advertise, consume and offer mobile edge services. The platform can provide certain native services such as radio network information, location, bandwidth management etc. The platform manager is responsible for managing the life cycle of applications including informing the mobile edge orchestrator of relevant application related events, managing the application rules and requirements including service authorizations, traffic rules, DNS configuration.

Edge cloud applications: Some of the use cases for MEC are IoT-related, including: security and safety (face recognition and monitoring), sensor data monitoring, active device location (e.g., crowd management), low latency vehicle-to-infrastructure and vehicle-to-vehicle (V2X, e.g., hazard warnings), video production and delivery, camera as a service.

4.3.2 Edge Computing Support in 3GPP

The 3GPP standards organization included edge computing support in 5G. Integration of MEC and 5G systems has been studied in ETSI as well.

Computing devices: From 3GPP standpoint, a mobile device may access any computing device located in a local data network, i.e., traffic is steered towards the local data network where the computing device is located.

Service platform: An external party may influence steering, QoS and charging of traffic towards the computing device. Session and service continuity can ensure that edge service is maintained when a client device moves. The network supports multiple-anchor connections, which makes it possible to connect a client device to both a local and a remote data network. The client device can be made aware of the availability of a local area data network, based on its location.

Edge cloud applications: Edge cloud applications in 3GPP can help support the major use cases envisioned for 5G, including massive IoT and V2X.

4.3.3 Industrial Internet Consortium

The Industrial Internet Consortium aims to standardize industrial IoT, fog, and edge computing. It produced a reference architecture for the fog, which has been published as IEEE standard P1934 in 2018.

Computing devices: Fog nodes include computational, networking, storage and acceleration elements. This includes nodes collocated with sensors and actuators, roadside or mobile nodes involved in V2X connectivity. Fog nodes should be programmable and may support multi-tenancy. Fog computing devices must employ a hardware-based immutable root of trust, i.e., a trusted hardware component which receives control at power-on.

Service platform: The service platform is structured around "pillars" including: security end-to-end, scalability by adding internal components or adding more fog nodes, openness in term of discovery of/by other nodes and networks, autonomy from centralized clouds (for discovery, orchestration and management, security and operation) and hierarchical organization of fog nodes.

Edge cloud applications: Major use cases include smart cars and traffic control, visual security and surveillance, smart cities.

4.4 Research projects

A healthy number of European R&I projects cover edge. At the moment, usage is broad of terms like edge computing and fog networks, which are similar but different, indicating the need for more research and innovation into architectural capabilities, which would lead to a more common standardised language to describe the edge computing market and its components. The research should start from good coverage of networking elements (e.g., low latency capabilities) and expand into security, big data processing, and edge application management capabilities, which are key components of the edge ecosystem.

The analysis has highlighted a lack of vertical use cases, with just a few examples in the smart city and manufacturing domains. To increase the adoption of edge use cases, it makes sense to look for more industry-specific use cases within particular sectors – those that solve individual business problems – to increase relevance and adoption.

4.5 Summary

The analysis of projects and standards evidence that:

- **There are two main approaches to edge computing, and their convergence and interoperability has not been yet properly explored**. The first one is pushed by Telecommunication industry and leverage on achievements in the area of Network Functions Virtualization Infrastructure, and supposedly is suitable for offer multi-tenant edge infrastructures. The second, pushed by Industrial IoT, largely focus on light weight edges and private edges deployment. This is evidenced also by the different underlying technologies. Interestingly enough, both industries are anyhow largely investing on supporting open source initiatives connected to the MEC and Industrial IoT.
- **Available platforms are yet limited in the ability to manage a large plethora of edge endpoints. This is mostly due to the limited automation support included**.

5 CONCLUSION, CHALLENGES, OPPORTUNITIES

5.1 Adoption challenges and opportunities

Whilst the research shows a great potential for adoption of edge computing in different application areas and sectors, market research also identifies issues that may limit such adoption. Early edge deployments show that organizations are concerned about:

1. Their ability to manage assets, control costs, and ensure physical and data security.
2. Lack of skills: one in five organizations lacks the internal skills needed to support edge computing adoption.
3. The distributed and often remote nature of edge IT makes human intervention in edge components expensive and potentially unaffordable.
4. Telecommunication industry and industrial IoT players are promoting a variety of technologies and standards for edge computing. This may lead to interoperability issues and create additional barriers.

Moving computation to edge infrastructure may also increase costs for hardware acquisition and maintenance, possibly slowing adoption.

As the supply side develops edge service and technology offerings, there is uncertainty in the demand side about which solutions are likely to succeed and when public offers will be available at scale. Potential users want to avoid lock-in but cannot anticipate how technological directions or market-ready solutions will evolve. Overall, uncertainty about the edge market and technology is slowing investment. On the other side, the offer scenario is developing quickly, with flourishing partnerships across Telcos, Cloud and service providers, infrastructure and software vendors, bringing to market new approaches. Overall, if adoption from SMEs will still be limited to precise and well-delimited use cases, large enterprises are expected to increasingly adopt edge solutions over the next 24 months.

Given these barriers to adoption, IDC predicts that the overall expenditure on edge computing is not likely to increase in the next 24 months.

S-E Challenge 1: Concern about stranded edge investments. Investing in the wrong emerging technology is a risk. The supply side should facilitate edge adoption and deployment by mitigating the risk of lock-in.

Recommendation: See challenges E2, E3, E4 and E5 below.

SMEs are even less ready to adopt edge computing. An IDC survey reveals that many are not ready due to investment costs, lack of skills and lack of public offers.

S-E Challenge 2: Edge is complex and expensive for SMEs. Help smaller organisations to improve their readiness and maturity, and reduce the complexity of edge computing adoption, while making it affordable.

S-E Recommendation 2: Develop a European strategy focusing on SME adoption that supports the deployment and the maturation of edge computing technologies while in parallel fosters the development of needed skills in the European market, to ensure that adoption by SMEs will not suffer the same issues as cloud computing. [Deployment and Policy]

5.2 Supply-side challenges and opportunities

The supply side analysis indicates that large investments are being made in the hardware and software platform segments to support edge computing. However, most of the available solutions, especially by large public IaaS providers (e.g. AWS Snowball), are not interoperable and aim at moving data from the edge to specific cloud services or platforms. Analysis also indicates that there is no public "edge infrastructure as a service" (EIaaS) offering. Specifically, there appears to be no publicly accessible EIaaS offering in Europe (although some are appearing in the US).

Such offering is important for small players that do not have the capacity to afford investment on creating edge infrastructures for their business, and that would benefit from moving the edge cost model from CAPEX to OPEX.

The situation seems motivated by a) large players trying to reap the most out of their current investments in core cloud infrastructure offerings; b) complexity and cost of maintaining large edge infrastructures with current technologies.

H-CLOUD webinars evidenced that a European Cloud infrastructure federation (or marketplace in its earliest steps), as envisioned in the EUSD, should aim at incorporating as well edge resources and to make them easier to access.

S-E Challenge 3: Uncertain return on edge investments. Facilitate the widespread use of edge technology, so it reaches critical mass as a public edge capability.
S-E Recommendation 3: embrace the opportunity to establish an interoperable and/or federated European public edge infrastructure market by defining policies that will preserve European core values (such as data privacy), while not creating market barriers. [Research and Deployment]

While the federation or marketplace of traditional cloud infrastructures may not have a sufficient market appeal due to the market dominance of large players, the increasing demand for edge resources (or services) may open new interesting opportunities. This, in particular as discussed also in the H-CLOUD webinars, could create an opportunity for Tier 2 providers, notably those associated with mobile networks, to take a more prominent role in edge infrastructure build out, leveraging their existing footprint of distributed facilities and human resources. The webinars evidenced that so far operators are not yet fully embracing the edge approach and opening their edge resources to the ecosystem of their stakeholders interested to edge capacities. Research and Innovation initiatives should look into solutions, for example leveraging federation and multi-edge approaches, to allow the creation of widespread edge infrastructure across different providers.

There are questions over the scalability of largely distributed cloud-edge infrastructure. Especially where it combines different private and public infrastructures. It may not be possible to scale such applications using the same solutions and technologies used today. Beyond that, solutions need to be affordable to ensure that also small players have the financial capacity of adopting them. In particular, H-CLOUD webinars evidenced how

S-E Challenge 4: Ensure scalability and affordability of edge computing solutions and deployments to cope with the demands of the foreseen usage scenarios, also by small players.
S-E Recommendation 4: promote the deployment at scale of edge computing solutions. Available platforms are still limited in the ability to manage a large number of edge endpoints, and installing/maintaining those endpoints will be costly. Research should continue to explore automation of cloud continuum from infrastructure layer up to the final application, taking into account different scenario specific demands. [Research and Deployment]

EUSD and NISE successful implementation will largely depend on successful wide deployment of edge infrastructures and services. In fact, edge processing capacities may play a key role in several data space verticals, such as agriculture, health, manufacturing and mobility. The implementation of the high impact project needs to ensure that edge capacities will be affordable, or their adoption will not take up.

S-E Challenge 5: Concerns about edge interoperability. Edge computing research and innovation solutions are coming from the telecommunications sector as well as multiple Industry 4.0 initiatives, but their approaches are diverging. This will create interoperability issues and increase the complexity of adoption and management.
S-E Recommendation 5: establish a forum promoting a tighter collaboration between different industries to facilitate the convergence of the different solutions related to edge computing, with the aim to define a single and unified standard for edge computing infrastructure in Europe. Public authorities should play a role in supporting such a standard by including it in relevant public procurements [Policy, Research and Deployment]

Research and Innovation solutions should research methods and technology implementations to ensure that edge computing solutions scale as foreseen by the market usage scenarios. Deployment initiatives should not only cover core cloud infrastructures, but also public and private edge infrastructures able to support specific domains such as smart cities and health care scenarios.

The implementation of the ambitious High Impact Project on European data spaces and federated cloud infrastructures (cf. EUSD) demands for interoperable solutions. The more complex will be achieving interoperability, the more complex will be the technical governance of European federated cloud infrastructure building on edge computing facilities. The definition and adoption of a single reference standard for Edge, and hence its inclusion as requirement in the implementation of the project via tenders or other mechanisms will be instrumental to this aim.

H-CLOUD webinars evidenced that the collaboration between edge stakeholders (spanning from telco operators, to small cloud players and technology providers) is essential to achieve the creation of European edge ecosystem.

S-E Challenge 6: Limited investment on trusted data access solutions for the edge. As of today most of the solutions available for trusted access to data rely on specific hardware facilities - software based solutions are still lacking. This limits a lot the flexibility and potential adoption of public edge infrastructure offering where guarantees about trusted access to data are required.

S-E Recommendation 6: support the research and deployment of trusted data processing environments. Europe cloud industry should deliver a open reference solution for trusted computing at the edge supporting multi tenants in isolation and compatible with the different EU privacy and security regulations [Research and Deployment]

This challenge was evidenced in one of the H-CLOUD webinars, and clearly highlights some core enablers yet missing or not mature enough to support the implementation of EUSD vision. Trusted data access is essential for data spaces where confidential or sensible data are exchanged and processed. Without maturity of such capacities, data spaces may not reach a sustainable uptake.