# FROM CLOUD TO EDGE

DECEMBER 2020

REPLY

# INDEX

# EXECUTIVE HIGHLIGHTS

## The Cloud Computing Market after the Coronavirus Pandemic

During this year's Coronavirus outbreaks, the use of cloud computing technologies has exploded. Across the world, millions of users started to use cloud-based platforms to collaborate, shop online, and entertain themselves. Cloud computing technologies for healthcare have gained attention even from corporate users previously worried about privacy and compliance.

In our 'Europe-5' cluster (Italy, Germany, France, Netherlands, and Belgium), the total IT services market is estimated to drop during 2020 and 2021. However, within this, the Infrastructure as a Service (IaaS)/Platform as a Service (PaaS) market is forecast to grow by at least 50% (2021 vs. 2019) in both optimistic and pessimistic scenarios.

Growth is also forecast in our 'Big-5' cluster (USA, United Kingdom, Brazil, China, and India). Driven by the huge development of all SaaS/IaaS/PaaS markets in the USA, this cluster will grow in all scenarios with IaaS/PaaS up to 55% (2021 vs. 2019).

## The Main Trends in the Cloud Computing Market

Not only is cloud technology the 'behind the scenes' foundation of a lot of today's mainstream services, but emerging technologies like AI, augmented reality and virtual reality, the Internet of Things, and quantum computing are also increasingly becoming part of the cloud providers' repertoire.

Reply used its proprietary platform Trend Sonar to spot relevant trends on the cloud market and clustering them in six families.

- Cloud strategy & transformation – the top trend in this field is the evolution of hybrid and multi-cloud, connecting public clouds to other public clouds and on-site workloads.
- Cognitive & intelligence cloud – AI as a Service is bringing services like marketing intelligence, customer service, robotic process automation, and analytics to a wider audience.
- HPC & big data cloud – as use cases in need of fast and high processing power are constantly increasing, cloud providers are adding high-performance computing (HPC) to their services and quantum cloud is gaining popularity.
- Cloud-native technology stack – top trends in this area are cloud automation and orchestration, cloud containers, and serverless computing.
- Edge computing and distributed cloud.
- Applications & industry-specific solutions.

## Focus on Edge Computing & Distributed Cloud

Edge computing can support computing tasks that cannot be done in the cloud and the need for edge solutions is set to accelerate. There are four main reasons why edge computing can play a vital role in IT architectures: latency, connectivity, security/privacy, and connection costs/transmitted data volumes. We defined four different 'flavours' of edge solutions: edge computing 'in the narrow sense', edge cloud, distributed cloud, and mobile edge computing.

Within the infrastructure market, it's evident that cloud computing will rule both the Europe-5 and Big-5 clusters, while edge computing will be a fast-growing market in the next 5 years. Germany will be the biggest European market for both cloud computing and edge computing; the USA will be the worldwide major market.

## Edge Computing & Distributed Cloud Use Cases According to Teknowlogy Group

This chapter includes the description of use cases and a weighting of each case on 6 main evaluation axis: latency, connectivity, security/privacy, transmitted data volume, initial costs, and maintenance overhead. For each case, the most appropriate architecture for today's scenarios is suggested, with notes on how this may change in the mid-term future.

- Connected vehicles: connected service chains, and driver assistance and autonomous vehicles.
- Digital factory: connected worker, digital twin, predictive maintenance, digital quality control, and smart intra-logistics.
- Digital government and smart cities: smart safety systems, smart parking infrastructure, smart urban infrastructure, smart environmental solutions, and smart traffic management.
- Digital healthcare: fleet management and predictive maintenance of medical devices.
- Smart home and buildings: automation and predictive maintenance, facilities management, security and control, and smart energy management.
- Smart retail and CPG: customer self-service, and smart tracking and tracing.
- Smart transport: smart infrastructure and intelligent transport systems, and smart deliveries and freight transport.
- Smart energy, and digital mining and exploration.

## Applications & industry-specific solutions

Among booming trends, cloud for education and healthcare led the hype in the last 12 months with cloud in manufacturing and retail among the trends gaining relevant volumes all over the world.

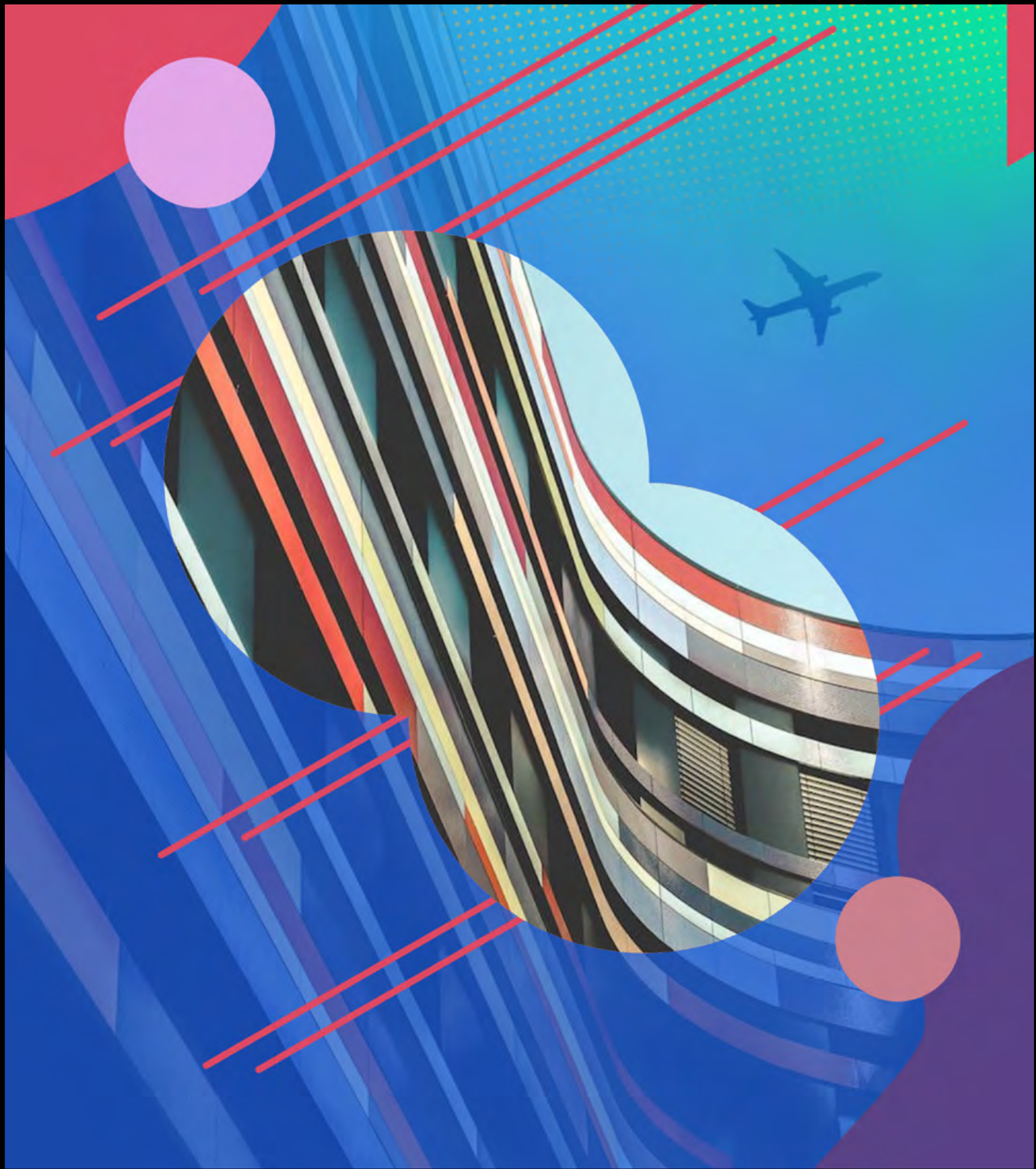
This chapter includes insights from different Reply companies for relevant organisations in manufacturing, telecoms, logistics, energy, and retail.

## Conclusions

Cloud computing is more pervasive every day in both business and consumer environments. Companies must adopt a 'holistic' approach and design cloud strategies that keep in account security, efficiency, and cost control. Being cloud-native is an integral part of this strategy and containerisation is helping companies create multi-cloud architectures involving different cloud providers, private cloud, and edge components.

Edge computing is here to stay. Distributed cloud and edge architectures will increase the speed of data processing, reduce time lag, and enable technologies like the IoT and autonomous vehicles. Hybrid models like edge cloud will be pushed by the hyperscalers and the wide 5G rollout will give Telcos a relevant role in the new ecosystem, especially thanks to mobile edge computing.

Although the pandemic is leading to cuts in IT/OT budgets, the case histories shared within this Research show how the edge computing and the distributed cloud can be used as a strategic lever.



# The Cloud Computing Market after the Coronavirus Pandemic

> "Cloud is seen as a lifesaver for businesses through a period of uncertainty, with employees suddenly scattered across a corporate diaspora. All of a sudden, all doubts about the cloud model — especially with security and hidden costs — evaporated."

Joe McKendrick, An Executive's View Of The COVID-19 Crisis: Cloud Computing Is Proving Itself [McKendrick, 2020]

Index

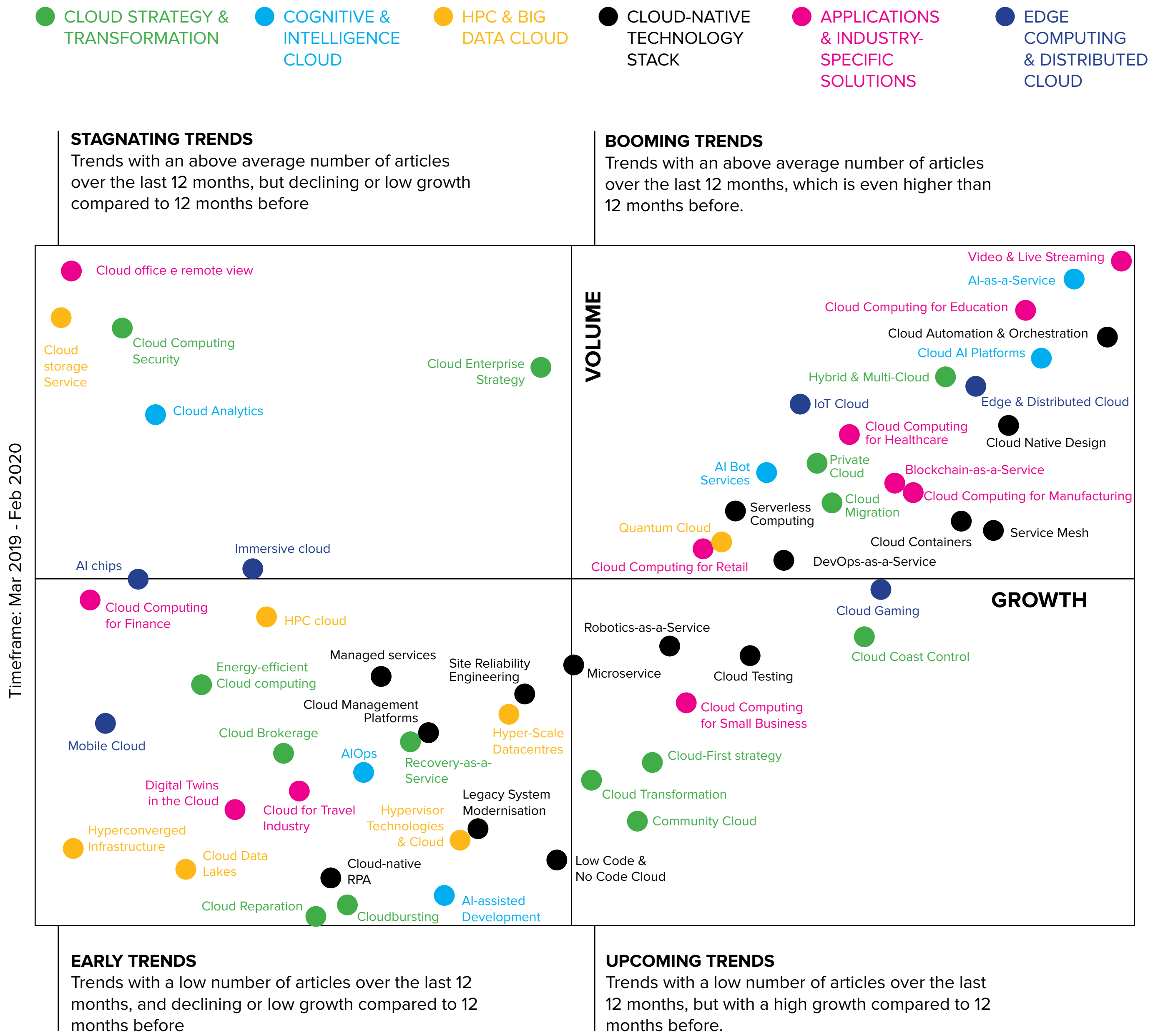
## Around the world, cloud computing became the most popular ICT area during Coronavirus peaks

After 15 years of steady growth, public attention on cloud computing exploded during 2020's Coronavirus outbreaks. Companies that had already adopted flexible, cloud-based processes during recent years faced these harsh times with more confidence. Others raced to adopt cloud technologies to enable remote working. Across the world, millions of users started to use cloud-based platforms to collaborate, shop online, and entertain themselves.

To understand the evolutions of cloud computing trends before and after Coronavirus, we used Reply's Trend Sonar and ran our AI algorithms twice: in March (before major Coronavirus outbreaks) and in December (when major outbreaks were evident).

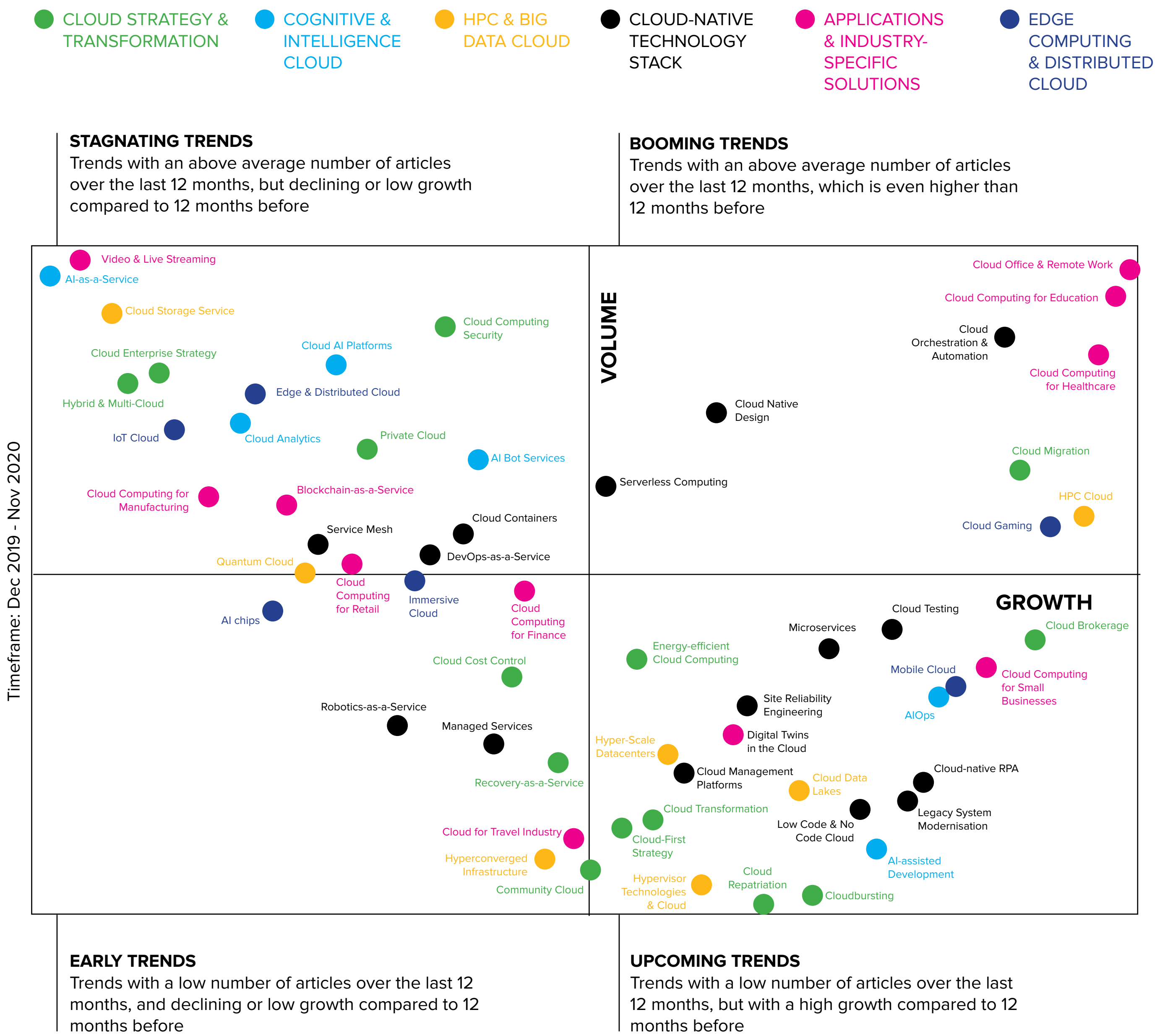
More info about Reply Trend Sonar

### Cloud computing trends hype-cycle, updated at the end of February 2020



At this first check, some trends were already clear. AI as a Service and cloud AI platforms were booming, following the increasing interest in artificial intelligence and machine learning in our professional and private lives. As we'll discuss, edge and distributed cloud were and are crucial topics for the immediate future of cloud-based solutions in relevant industries.

### Cloud computing trends hype-cycle, updated at the end of November 2020



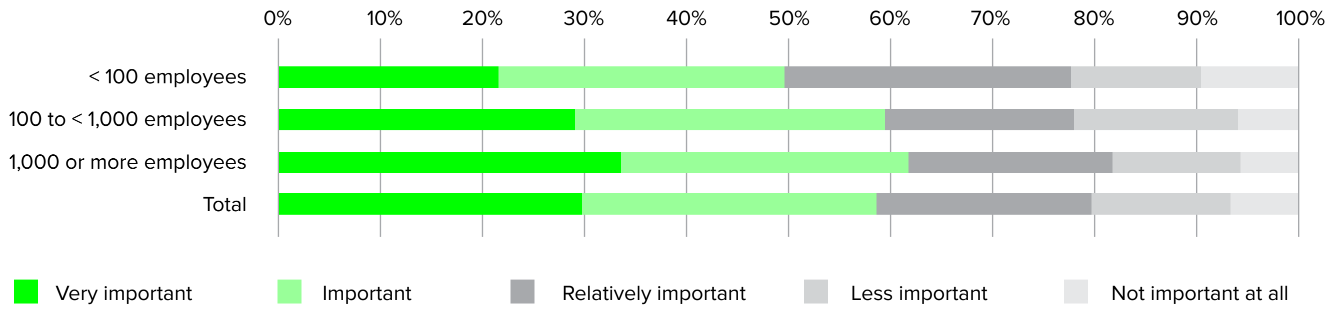

Nine months later, some trends had gained more strength. Cloud computing technologies for healthcare had gained attention even from corporate users previously worried about privacy and compliance. High-performance computing enabled by cloud increased its popularity significantly, thanks to use in pharmaceutical, life science, and other industries impacted by Coronavirus.

Lockdowns presented challenges to cloud data centres, with Internet usage going up 50% in some parts of the world and access to critical information now even more essential.

## Expenditure for cloud computing services will keep growing even in a troubled global economy

"How importantly do you rate IaaS/PaaS/SaaS on your IT agenda?"

Source: Teknowlogy Group (2019)

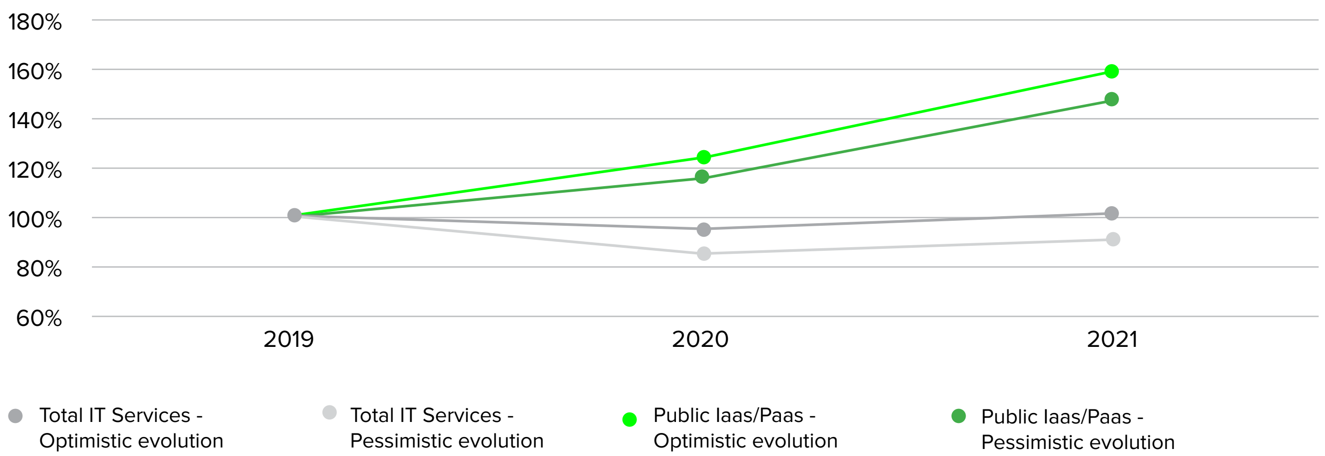



Just a few months ago, at the end of 2019, cloud computing seemed more crucial for bigger companies than for smaller ones. We're certain that Coronavirus changed the perception of cloud computing amongst SMEs and, even more importantly, among end-users. From our outlook on international ICT markets, we observed that cloud-related technologies are the key to moving boldly on reacting and restarting activities.

**Europe-5**

Public IaaS/PaaS vs. total IT services (% expected evolution)

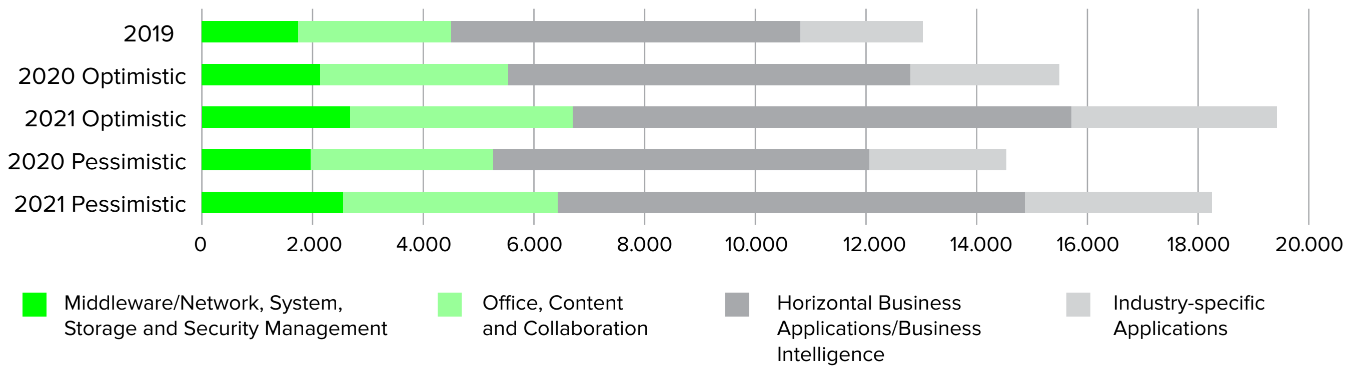
Source: Teknowlogy Group (2020)




Looking at Italian, German, French, Dutch and Belgian markets as a 'Europe-5' cluster, the whole IT services market is estimated to decrease in 2020, with an improvement forecast for 2021 matching 2019 expenditures in optimistic estimations. Investment in public cloud technologies is estimated to grow in all scenarios for both years; the estimations by the end of 2021 are for growth of at least 50% vs. 2019, in all analysed countries.

Source: Teknowlogy Group (2020)

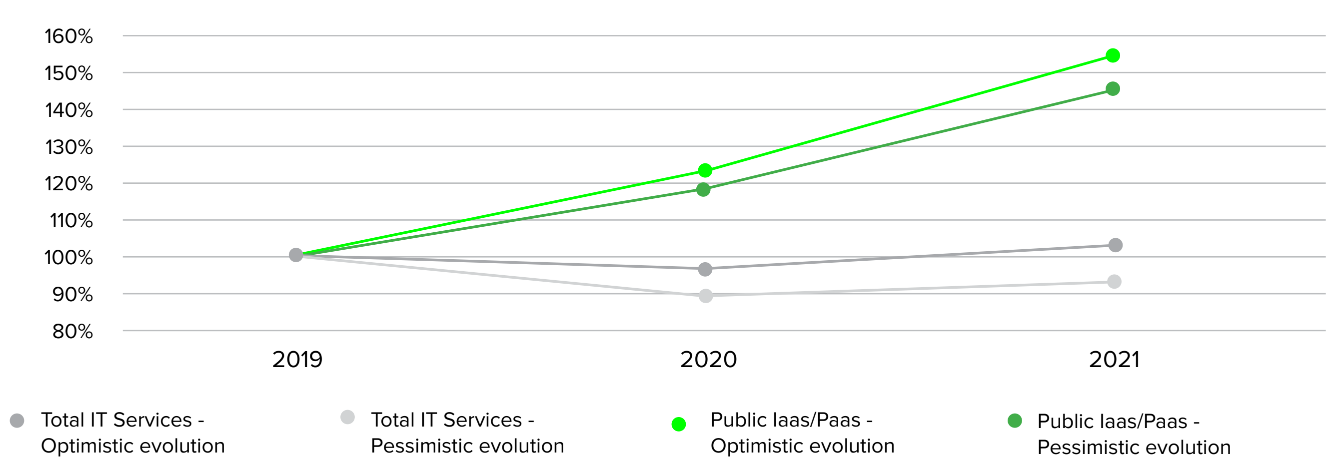
**Europe-5** Software as a service market, expected evolution per segment (million €)




As a whole, Software as a Service (SaaS) within Europe-5 is forecast to be in strong growth on both pessimistic (+40% 2021 vs. 2019) and optimistic (+48% 2021 vs. 2019) scenarios.

Source: Teknowlogy Group (2020)

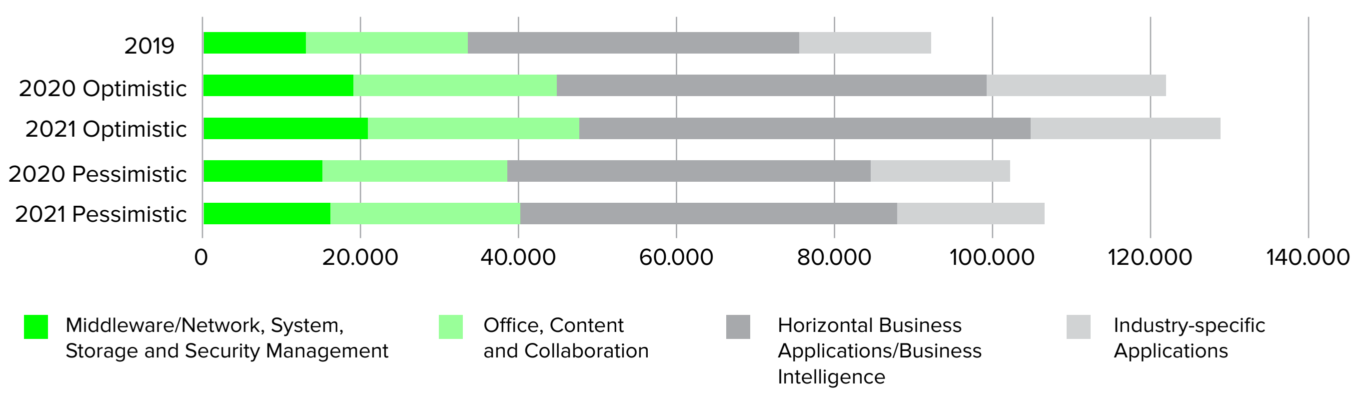
**Big-5** Public IaaS/PaaS vs. total IT services, % expected evolution




In the 'Big-5' cluster of US, UK, Brazilian, Chinese and Indian markets, total IT services are expected to recover by the end of 2021 in the optimistic scenario and to return to 96% of the 2019 market size by the end of 2021 in the pessimistic scenario. Both analysed scenarios forecast strong growth of cloud computing markets, up to +55%.

Source: Teknowlogy Group (2020)

**Big-5** Software as a Service market, expected evolution per segment (million €)



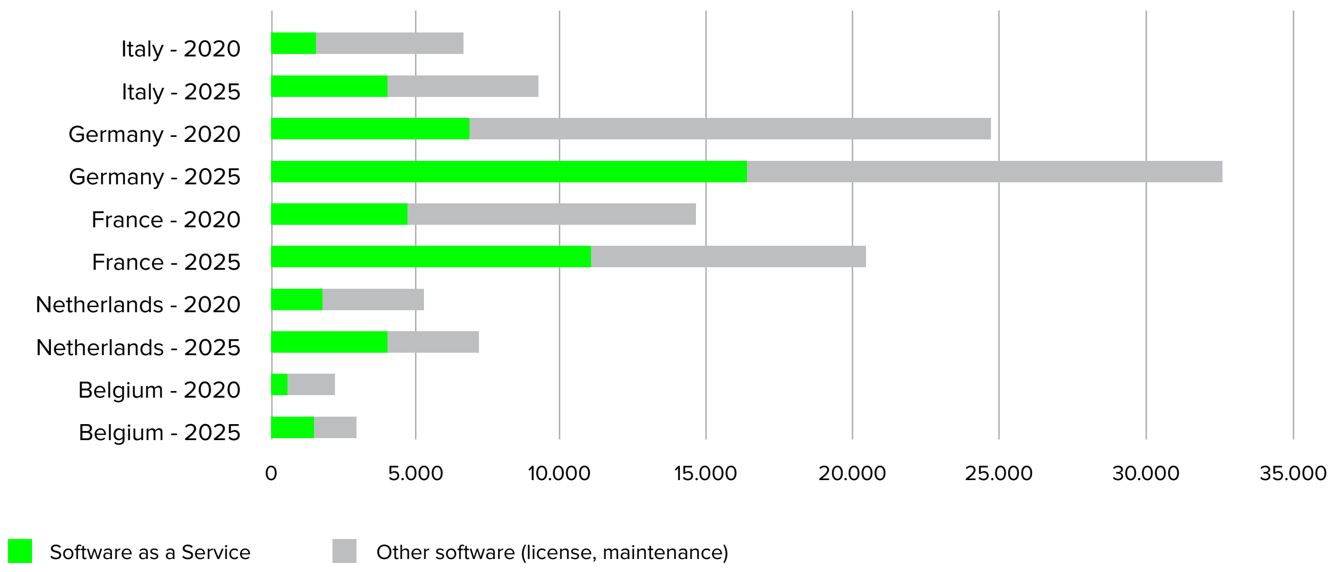

Looking at the segments, it's evident that horizontal business applications and business intelligence is the leading area in all Big-5 scenarios: a growth of at least 13% by the end of 2021 vs. 2019 is forecast in all scenarios.

In the mid-term, the SaaS market is projected to grow faster in every country analysed, in both the Europe-5 and Big-5 clusters.

**Europe-5**

Share of Software as a Service in the software market (million €)

Source: Teknowlogy Group (2020)

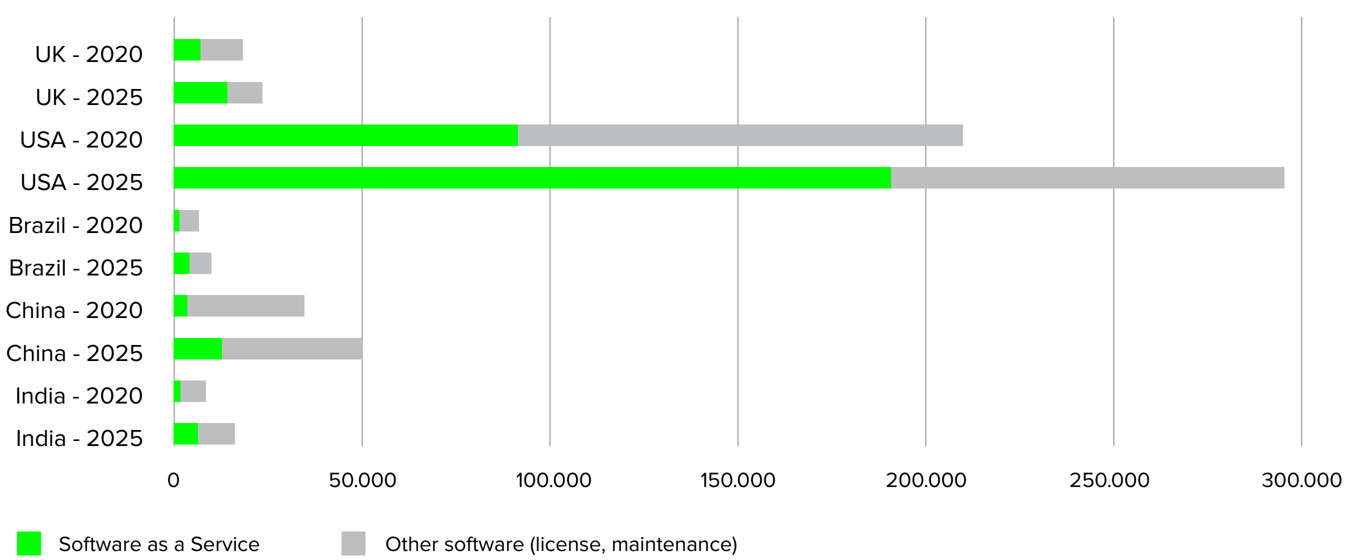



The whole Europe-5 cluster will grow from 29% to 51% of a software market that will double in just 5 years, thanks to the growth of SaaS.

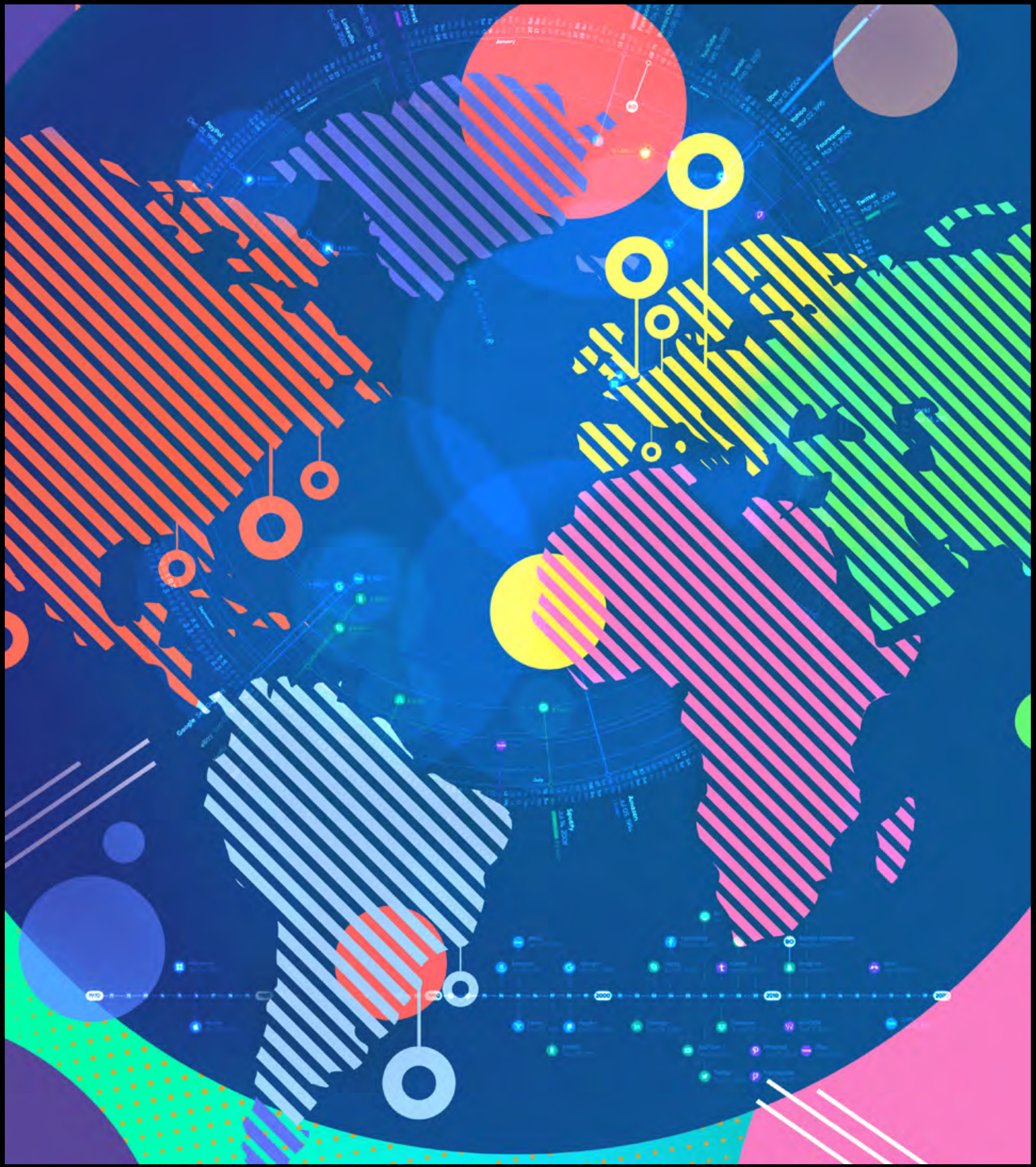
**Big-5**

Share of Software as a Service in the software market (million €)

Source: Teknowlogy Group (2020)




Volumes of SaaS will grow fast in all Big-5 countries. In the USA and the UK, they will double; in India and China, the market will quadruple.



# The main trends in the Cloud Computing Market

> In addition to the continuation of digital projects once business returns to normality, we anticipate many businesses new to using cloud services during the crisis will continue use and become paying customers

Matthew Ball, Canalys [TechCrunch, 2020]

Index

## The cloud computing market is experiencing amazing times

Cloud technology is the 'behind the scenes' foundation of a lot of today's mainstream services. Emerging technologies like AI, augmented reality and virtual reality (AR/VR), the Internet of Things (IoT), and quantum computing are also increasingly becoming part of the cloud providers' repertoire. For example, the 'AI as a Service' concept is opening artificial intelligence up to a broader consumer base, providing smaller businesses with easy access to AI-enhanced business services accessible via cloud services.

Data volumes are growing exponentially, thanks to ever-increasing levels of device connectivity, as well as new workloads due to smart data, real-time analytics, video streaming and mobile applications. These are fuelling enormous demand for storage and high-speed processing of data. Cloud providers are increasingly adding high-performance computing (HPC) to their service landscape to address companies' need for fast processing of big data volumes and provide for AI-enhanced use cases. First breakthroughs in quantum computing have opened the race for revolutionary cloud services.

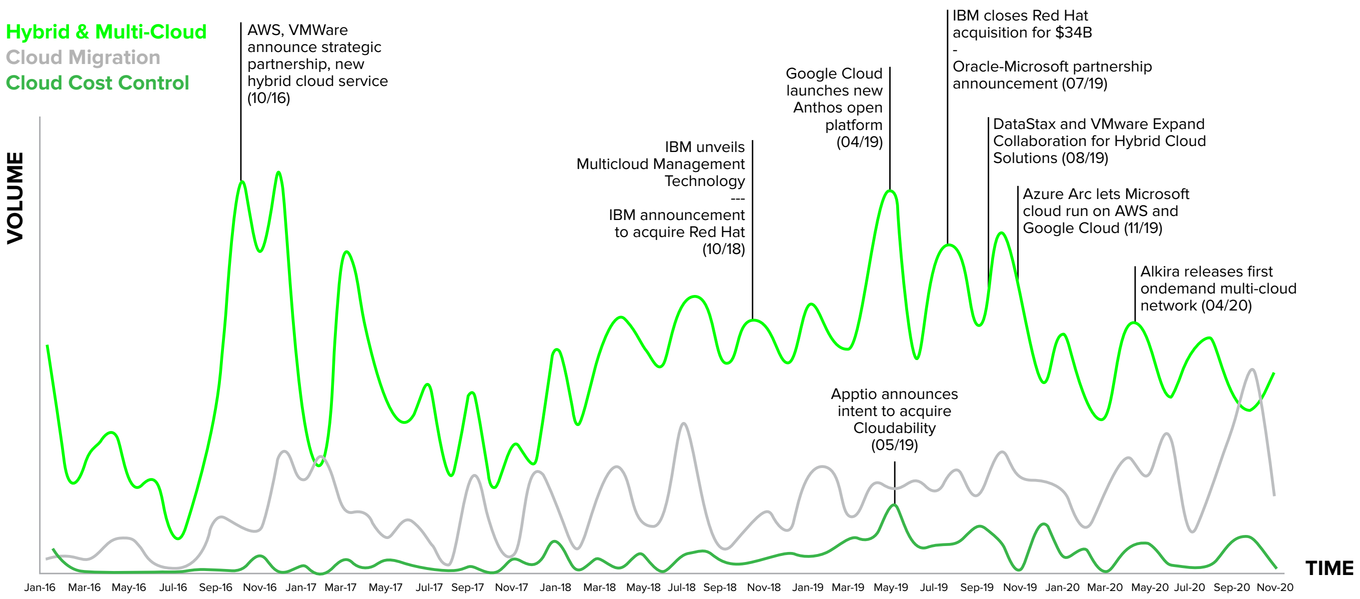
Today, being cloud-native is the new norm. Even in traditionalist industries like banking and insurance, the design of architectures not involving cloud technologies is now strongly challenged.

The need for lower costs and more efficient ICT infrastructure is driving the use of shared cloud computing resources. With growing cloud adoption, more businesses are transferring mission-critical business applications into the cloud, pursuing a hybrid multi-cloud strategy to enhance service flexibility.

# Cloud strategy & transformation

**Cloud strategy & transformation**

Main trends registered from Reply Trend Sonar, per volume of mentions




As adoption of cloud-native development and infrastructure increases, a strong trend from businesses towards hybrid multi-cloud strategies can be recognised, connecting public clouds to other public clouds and on-site workloads. This enables businesses to avoid vendor lock-in and profit from the best services of both worlds.

More and more organisations are deploying workloads across multiple Infrastructure as a Service (IaaS) providers and moving mission-critical business applications into the cloud. Automation tools and cloud management platforms incorporating AI will be tackling the challenge of managing complex multi-cloud environments. Furthermore, cost control will play an increasingly vital role, alongside cloud security, in being at stake in an increasingly complex hybrid multi-cloud world.

Among other trends included in this family, energy-efficient cloud computing is fast growing and thanks to cost-saving measures imposed on ICT managers due to the pandemic, we can expect growing attention on the cost/benefit analysis of each application now running on public clouds.

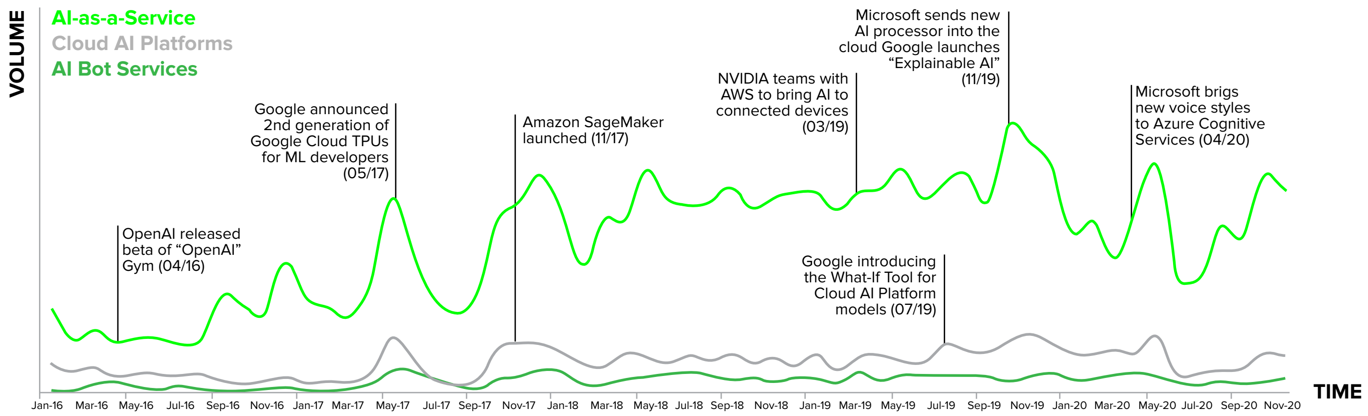
Aside from proprietary solutions of major hyperscalers, a new generation of startups is supporting the design and deployment of cloud strategies.

- Volterra aims to provide communications service providers and enterprises with a platform to run workloads seamlessly on any combination of public and private clouds.
- Alkira has unveiled Alkira cloud Services Exchange, a unified, on-demand, multi-cloud offering enabling cloud architects and network engineers to build and deploy a ‘point and click’ multi-cloud network in minutes.
- vArmour has developed an API-driven security technology that enables continuous compliance across hybrid environments.
- Clumio is offering backup services for public, hybrid and multi-cloud use cases with a SaaS model.

# Cognitive & intelligence cloud

**Cognitive & intelligence cloud**

Main trends registered from Reply Trend Sonar, per volume of mentions




Cloud technology is democratising artificial intelligence such as deep learning, machine learning, robotic process automation, language and vision through more and more AI as a Service applications. This allows users to outsource artificial intelligence for core business processes while removing big data handling and processing limitations. The need to manage massive data volumes (e.g. through IoT), as well as enabling smarter and real-time decision making, is paving the way for AI capabilities to turn into a core technology for businesses, as well as a differentiator for cloud service providers.

Cloud AI platforms are making intelligence applications usable for smaller businesses on a larger scale, optimising business processes or advancing customer experiences. Although not yet as advanced, AI-powered bot services are aiming for conversational interfaces and speech recognition for a broader customer base.

An increasing number of startups and industry-specific players are flocking into the AI ecosystem, addressing specific industries and use cases.

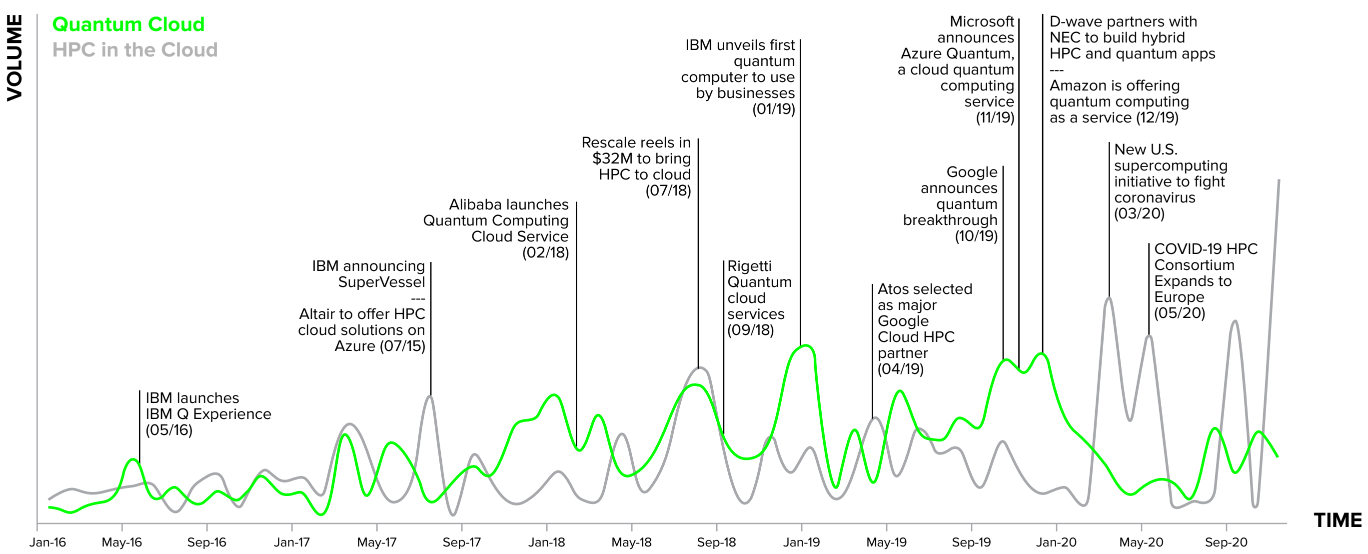
- ThoughtSpot is an AI-driven business intelligence and big data analytics platform that helps to explore, analyse and share real-time business analytics data easily.
- Obviously AI is a cloud-based service that delivers predictive analytics without requiring users to code, based on a combination of natural language processing and AutoML-like capabilities.
- Algorithmia offers a cloud-agnostic AI automation platform for enterprises.
- Checkr has built an AI-backed process to handle background checks, enabling companies to make easier hiring decisions.

- Chorus.ai operates a conversation intelligence platform for sales teams, plugging into Zoom Video calls and coaching a sales rep in real-time on the next best answer to give.

## HPC & big data cloud

**HPC & big data cloud**

Main trends registered from Reply Trend Sonar, per volume of mentions




As big data volumes explode and business use cases for fast and high processing power are constantly increasing, cloud providers are adding high-performance computing to their cloud services. In the meantime, companies are taking a hybrid approach combining quantum and HPC for scalable solutions. Reply is supporting different customers in interpreting and using the possibilities of both HPC and big data cloud.

After the hype surrounding IBM unveiling the first quantum computer for business usage last year, companies including Amazon, Google, Microsoft, and Intel have been demonstrating progress in quantum research and attempts to commercialise quantum services through the cloud. Although still at an early stage, commercialising the quantum cloud could revolutionize the market, conducting complex calculations in a fraction of today's time.

Reply Trend Sonar identified several innovative players in this field.

- Rescale's mission is to provide a highly powerful simulation platform that empowers the world's engineers and scientists.
- Archanan has beta launched its cloud-based development platform for building and testing at-scale code.
- Quantum Machines is building both hardware and software to operate quantum computers.
- Zapata computing is a quantum software company that offers computing solutions for industrial and commercial use.



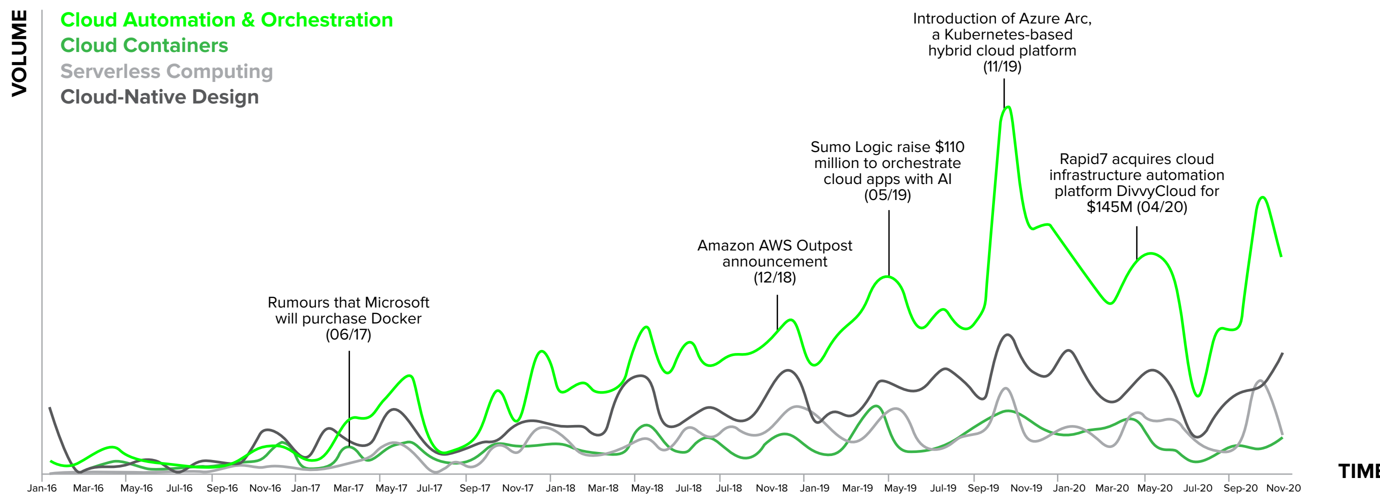


- ProteinQure uses quantum computing and machine learning to simulate designs for protein-based drugs.

## Cloud-native technology stack

**Cloud-native technology stack**

Main trends registered from Reply Trend Sonar, per volume of mentions




Seeing cloud as a critical component of digital transformation, cloud-native computing – deploying applications as microservices packaged in containers and dynamically orchestrating them across platforms – is the strongest wave of digital disruption in the cloud environment. Cloud container popularity is increasing with Docker as the most prominent solution in the container domain.

Cloud automation & orchestration is mainly driven by the rising popularity of Kubernetes, as well as cloud providers introducing these services to achieve compatibility across hybrid environments. Another major trend is serverless computing, allowing companies to redistribute the entire infrastructure and exert more control over cloud hosting costs on a "pay as you go" model.

Several startups are exploiting the potential of this new architectural paradigm, both industry-specific and cross-industry.

- Spectro Cloud allows organisations to roll out their own Kubernetes service on a managed platform without relying on a large vendor.
- Kubecost aims at providing visibility into Kubernetes resources to reduce spend and prevent resource-based outages.
- Styra, a leader in cloud-native authorisation, created Open Policy Agent to solve authorisation challenges that arise from the speed and scale of containerised application environments.
- The Serverless framework lets users develop and deploy serverless applications across all major cloud providers.

# Focus on Edge Computing & Distributed Cloud

“We envision that edge computing could have as big an impact on our society as cloud computing.”

Khalaf Khatatneh, Osama Nawafleh, Ghassan Al-Utaibi,
The Emergence of Edge Computing Technology over Cloud Computing
[IJPTT, 2020]



## Edge computing is already starting to reshape the enterprise computing landscape - but what it is and what it can deliver are often misunderstood

Edge is often seen as a threat to cloud computing. However, the relationship between the two is more complementary: edge computing can support computing tasks that cannot be properly done in the cloud. With the growing usage of IoT solutions, closer Information Technology/Operational Technology integration and the integration of Industrial Control Systems in the IT stack, as well as future 5G campus solutions for low-latency applications, the need for edge solutions is set to accelerate.

Edge computing has at least four different ‘flavours’ which we define as follows.

- **Edge computing ‘in the narrow sense’**
  There are several definitions of edge computing, usually associated with concrete use cases. In general, edge computing is a layer between a physical device or the physical world and the centralised data centre. This could be a private or public cloud, an on-site central data centre or a hosted/housed data centre. Usually, the term ‘edge computing’ means that the compute unit is placed on-site near to or on the shop floor or the data sources it handles, is a standard server/storage system or appliance, and in most cases is owned by the user-organisation.

- **Edge cloud**
  Edge cloud is often synonymously used for on-site public cloud systems or appliances like AWS Outposts, Microsoft Azure Stack, Oracle Cloud at Customer, or Google Anthos. The idea is to have the compute units on-site and dedicated for low latency and high bandwidth and have the managed environment of a public cloud.

- **Distributed cloud**
  Distributed clouds provide low latency compute, with the compute units not on-site but nearby (< 100 km), allowing low latency without local infrastructure while providing the managed environment of a public cloud. The whole infrastructure is owned by a public cloud provider. This is also the business model of some Telcos: they can open their switching centres and transmission towers’ own distributed cloud services. In combination with 5G, this will be a real differentiator.

- **Mobile edge computing**
  Similar to the distributed cloud, mobile edge computing provides very low latency compute. The compute units are not on-premise but very near-by (<5km, ideally < 1km placed in the cell tower), allowing very low latency without local infrastructure. The management can either be done by the customer/user or by a service provider or the Telco itself. This can be a valid business model

for Telcos and their service provider partners. For customers, this ensures a clearer separation between the public cloud and the edge, while connectivity to on-premise infrastructures and the public cloud is a given.

Reply and Teknowlogy Group indicate that there are four main reasons why edge computing can play a vital role in IT architectures.

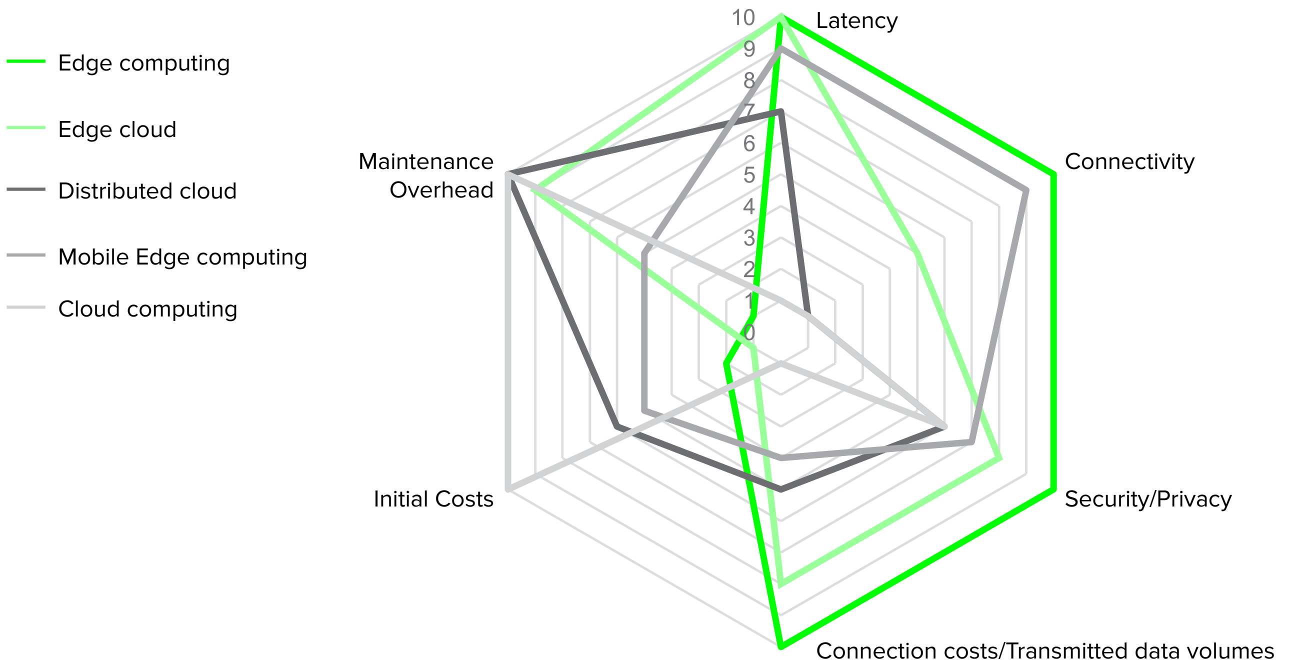
- Latency: some use cases have real-time or at least near-real-time requirements, so response times can be an issue if the processing is done in a far-off data centre or if some network nodes are involved, such as in the public cloud or other data centres, which are hundreds of kilometres away.

- Connectivity: some use cases need computing power in areas where broadband connectivity or even mobile connectivity is not available, meaning local computing is needed.
- Security/privacy: in some use cases data must not be distributed due to compliance rules, while in others, users just want some data to remain within their perimeter.
- Connection costs and transmitted data volumes: even if connectivity is available, it can be worthwhile analysing data at the edge and gathering only the results in a central data centre or in the cloud to save connection costs.

Depending on the actual use case, the different flavours of edge computing are more or less advantageous.

Source: Teknowlogy Group, 2020

**Comparison of the different models of edge computing and cloud computing**

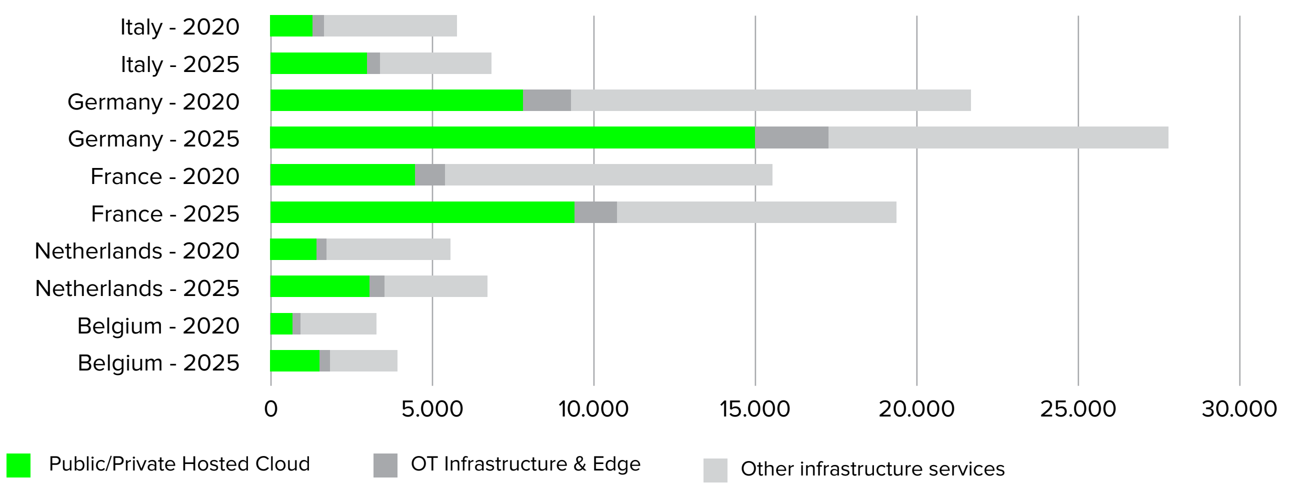



Edge computing offers clear advantages if low latency, connectivity, security or privacy and the transmitted data volumes are an issue. The trade-offs are relatively high initial costs and maintenance overheads. On the other side of the scale is cloud computing, where initial costs and maintenance overheads are moderate, but latency, connectivity, and the transmitted data volumes with associated costs can be an issue. Edge cloud and distributed cloud sit between the two extremes.

## Edge computing as a relevant part of the OT (Operational Technology) market will grow fast in the next five years

**Europe-5** Share of public/private hosted cloud and of OT infrastructure & edge in the infrastructure service market (million €)

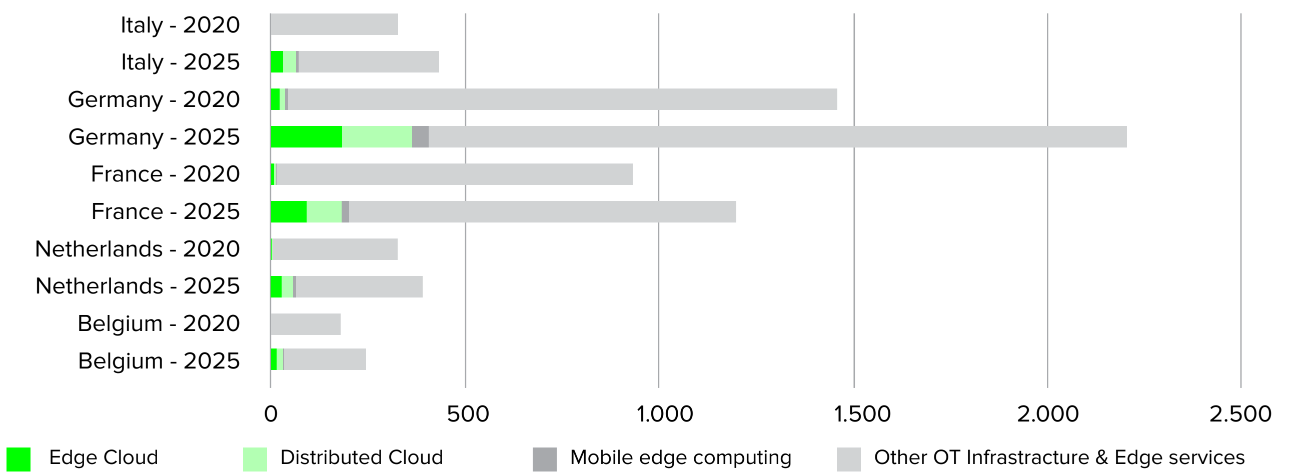
Source: Teknowlogy Group (2020)




The infrastructure service market is forecast to grow for all Europe-5 countries. The biggest increase is forecast for Germany, with a growth of 28% (2025 vs. 2020). Both cloud computing and edge computing will contribute to this increase.

**Europe-5** Share of different edge models in the OT infrastructure & edge service market (million €)

Source: Teknowlogy Group (2020)

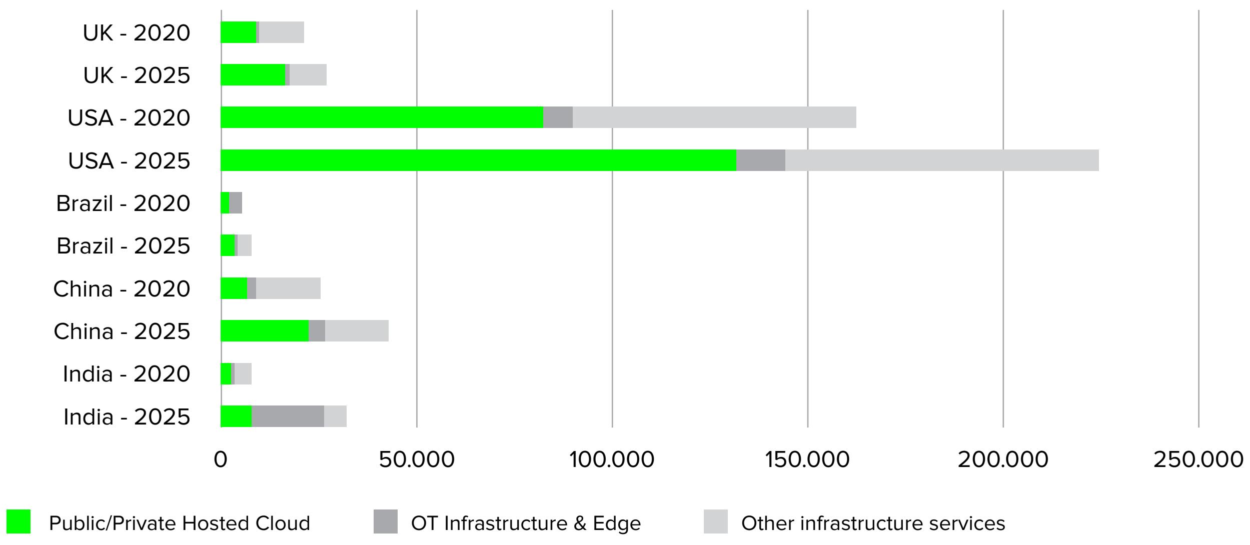



In the OT infrastructure & edge service market, the European leadership of Germany becomes evident in all the different 'flavours' of the edge computing arena. Even if still limited in 2020, both the edge cloud and distributed cloud segments are forecast to become (at least) ten times bigger within the cluster in just five years; mobile edge computing growth at least by a factor 7 in the same time. The cumulating OT Infrastructure & edge service market for the Europe-5 cluster is forecast over 4.5 billion Euro in 2025, and both edge cloud and distributed cloud will weigh for 8% each one.

**Big-5**

Source: Teknowlogy Group (2020)

Share of public/private hosted cloud and of OT infrastructure & edge in the infrastructure service market (million €)

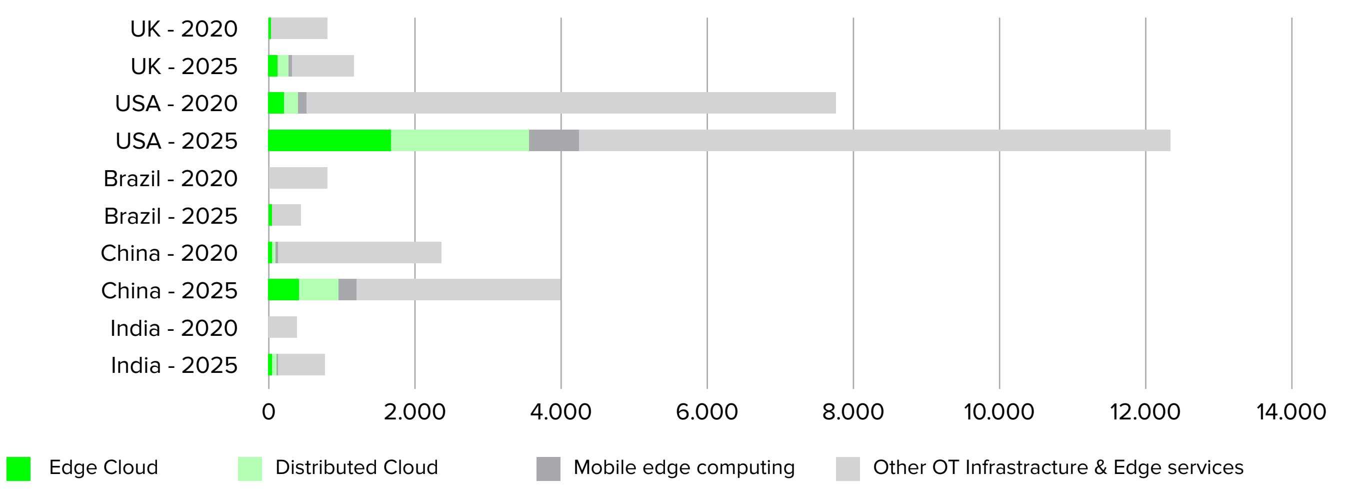



Looking at the Big-5 cluster, both the public/private hosted cloud and OT infrastructure & edge markets are forecast to grow up to 60% in the USA. The whole cluster is forecast to reach almost 183 billion Euro for the public/private hosted cloud market and 19 billion Euro for the whole OT infrastructure & edge market.

**Big-5**

Source: Teknowlogy Group (2020)

Share of different edge models in the OT infrastructure & edge service market (million €)

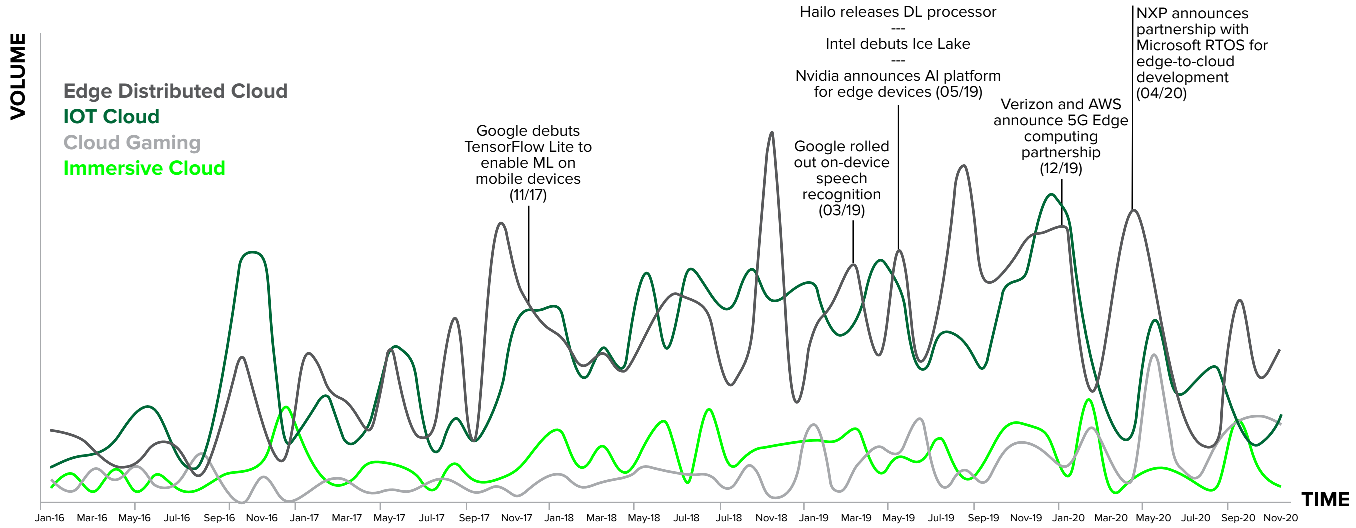



As with cloud computing, the USA will also lead edge computing volumes. Looking at the whole Big-5 cluster, the distributed cloud market will reach 2.7 billion Euro, the edge cloud 2.3 billion Euro and mobile edge computing 1.1 billion Euro in 2025.

## The edge computing and distributed cloud trends identified by Reply Trend Sonar merge towards an 'Internet of everything' in the near future

**Edge computing & distributed cloud**

Main trends registered from Reply Trend Sonar, per volume of mentions




The whole edge computing and distributed cloud topic involve all the trends towards decentralised and distributed multi-cloud infrastructures as well as the cloudification of the edge, with cloud giants pushing the computational decision making to the edge. Furthermore, the trend of the IoT cloud is growing with IoT/ IIoT platforms enhancing device connectivity. Edge will also increasingly support gaming and AR/ VR technologies, enabling cloud gaming and immersive cloud. A future of cloud-to-edge technology will enable what is termed the 'Internet of everything', with the cloud as an aggregation point for most relevant data and back-end functions, supported by analytics and real-time functions at the edge. Decentralised cloud approaches are driven by advancements of edge platforms and artificial intelligence, as well as connectivity-enhancing technologies like 5G or Wi-Fi 6.

Analysing the players, apart from cloud giants, the most trending player is the real-time analytics startup Swim.ai, followed by Xnor.ai (recently bought by Apple), edge AI startup Kneron, chips startup Greenwaves, and mobile edge computing platform Affirmed (recently acquired by Microsoft). Many other startups are gaining attention, thanks to the thriving business development perspective.

- Cloudian launched a new edge analytics subsidiary called edgematrix, providing solutions for the requirement of AI to process large data sets at the edge.
- Boinc allows researchers to create volunteer networks of home PCs to solve computational problems within a distributed cloud network.
- Cubbit is aiming to be the first eco-friendly, secure and distributed cloud provider without a proprietary data centre to maintain.

# Edge Computing & Distributed Cloud Use Cases According to Teknowlogy Group

“ Edge computing in all its flavours can drive significant new business models and bridge the latency, connectivity and privacy gap to cloud computing ”

Wolfgang Schwab, Head of Cyber Security, Teknowlogy Group

## Reply asked Teknowlogy Group to identify the most relevant use cases in significant industries

For each use case, Teknowlogy Group experts identified both state of the art and mid-term evolution possibilities. This legend illustrates their view about technical, functional, and business requirements expected for each use case.

| | Latency | Connectivity | Security/ privacy | Transmitted data volume (connectivity costs) | Initial costs | Maintenance Overhead |
|---|---|---|---|---|---|---|
| ○ | No specific latency requirements | No specific connectivity requirements | No specific security/ privacy requirements | No specific data volume requirements | No specific business requirements | No specific maintenance overhead requirements |
| ◔ | Low latency requirements | Low-speed connectivity requirements | Low security/ privacy requirements | Low requirements (2,5G/copper cable) | Low business requirements | Low (minimum/static) maintenance overhead requirements |
| ◑ | Medium latency requirements | Medium connectivity requirements | Medium security/ privacy requirements | Medium requirements (3G/DSL) | Medium business requirements | Medium maintenance overhead requirements |
| ◕ | Medium-high latency requirements | Medium-high connectivity requirements | Medium-high security/ privacy requirements | Medium-high requirements (4G/VDSL) | Medium-high business requirements | Medium-high maintenance overhead requirements |
| ● | High latency requirements (real-time) | High broadband connectivity requirements | High security/ privacy requirements | High requirements (5G/fibre optics) | High business requirements | High (complex/ continuous) maintenance overhead requirements |

## Connected vehicles

Connected cars, trucks, buses, ships, trains, and other vehicles continuously and bi-directionally communicate with ecosystems (e.g. owners, drivers, insurers, garages) and environments (traffic signals, other vehicles, smart homes). IoT-related technologies enable smart services such as traffic management, predictive maintenance, and after-sales solutions.

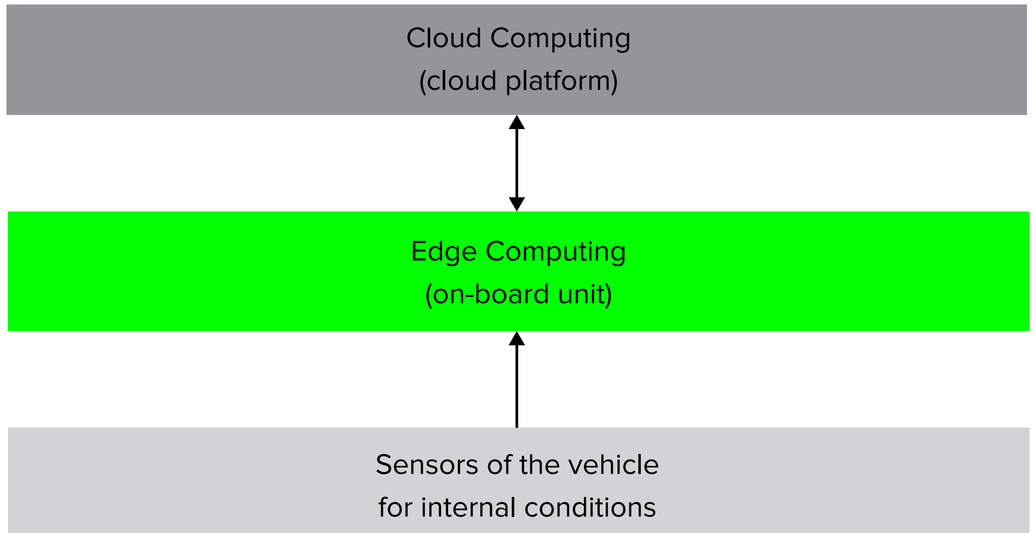
**Connected service chains**
Connected service chains include digital technologies such as mobility, sensors, artificial intelligence and innovative driver interfaces. These are paving the way for connectivity-related smart services such as remote diagnostics and predictive maintenance, automated garage service, situation-based insurance, driver assistance and extended mobility services.

Most challenging requirements: connectivity, which is not a given in any region; maintenance overheads which should be limited for infrastructure in the vehicle; and the initial cost of the solution.

| Latency | Connectivity | Security/privacy | Transmitted data volume (connectivity costs) | Initial costs | Maintenance Overhead |
|---|---|---|---|---|---|
| ○ | ● | ◕ | ◕ | ◑ | ● |

Currently preferred approach: two-tier with a small onboard edge computing unit that gathers the necessary data, pre-analyses it and sends it to appropriate cloud platforms for further analysis.

**Architecture for 'connected service chains' use case**




Mid-term future: will not change much.

**Driver assistance and autonomous vehicles**

Autonomous vehicles perceive their surroundings with the help of a variety of techniques (such as RADAR, LiDAR, GPS, odometry and computer vision) for self-driving and navigation. Sophisticated control systems interpret sensory information to identify optimal navigation paths as well as obstacles (other vehicles, pedestrians, road damage) and relevant signage. Autonomous vehicles are divided into six different levels, ranging from non-automated to fully automated systems. Although fully automated vehicles are still futuristic dreams when it comes to public car or truck traffic, driver assistance systems are already important today.

Most challenging requirements: latency as real-time information on road obstructions can be vital; security as incorrect information can lead to fatal decisions; high connectivity requirements (for external information, but the main functions must work without them); data volumes, depending on the type of assistance system or autonomy level. Maintenance overheads and initial costs need to be limited, to keep the overall price of the vehicle at a minimum.

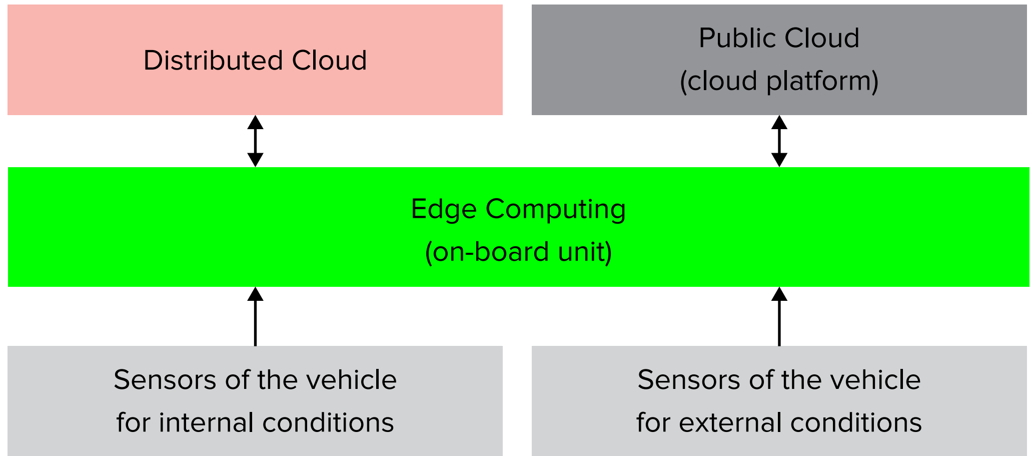
| Latency | Connectivity | Security/privacy | Transmitted data volume (connectivity costs) | Initial costs | Maintenance Overhead |
|---|---|---|---|---|---|
| ● | ◕ | ● | ◑ | ◑ | ● |





Currently preferred approach: three-tier with an on-board edge computing unit which gathered data from on-board sensors and interprets the information from the two other tiers, i.e. a distributed cloud for information external of the vehicle which is time-critical and a cloud platform for less time-critical data.

**Architecture for 'driver assistance and autonomous vehicles' use case today**




As vehicles become more autonomous over time, this use case will develop to a four-tier model, as edge cloud units alongside major roads and mobile edge computing solutions will be used to better support real-time needs.

## Digital factory

A digital factory uses smart products and smart services to become a highly efficient and integrated cyber-physical production system. This covers the improvement of internal production processes, intralogistics and the supply chain, including the delivery of smart products and services to help others in realising a digital factory.

**Connected worker**

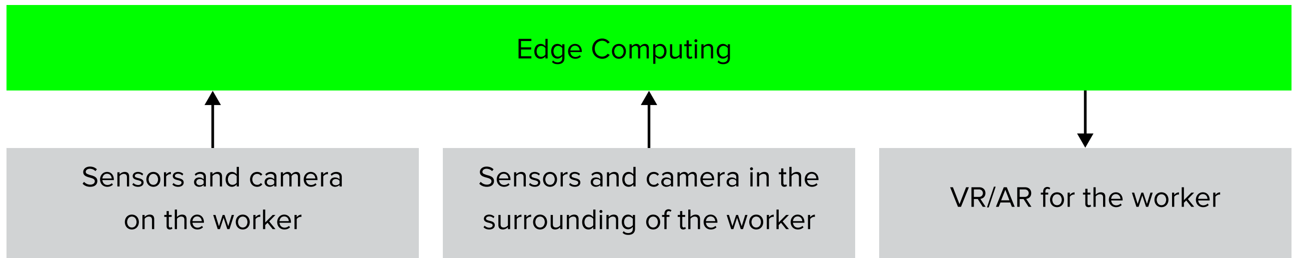
Connected workers use digital worker support systems (via augmented reality or other visualisation technologies) to improve decision-making, quality and efficiency. In addition, they can collect data via sensors (e.g. via wearables or cameras) and feed them back to engineering and production systems.

| Latency | Connectivity | Security/privacy | Transmitted data volume (connectivity costs) | Initial costs | Maintenance Overhead |
|---|---|---|---|---|---|
| ● | ● | ● | ◔ | ◑ | ◑ |

Most challenging requirements: latency, as real-time video guidance on the next steps in the maintenance process of a machine can be vital; connectivity if the plant is in a rural area; security, as incorrect information can lead to wrong actions by the worker.

Currently preferred approach: pure edge computing, which receives sensor and video data from the worker and potentially its surroundings, analyses this data and provides the worker with relevant information.

**Architecture for 'connected worker' use case today**




Mid-term future: not much change although 5G availability should help to drive down operating costs by enabling the distributed cloud to replace edge computing.

**Digital twin**

A digital twin allows the virtual development, testing, production, and maintenance of a physical product by using digital technologies such as virtual reality. The digital product can be interacted with in the same way as would be possible with the physical product. A physical product can also gather sensor data that can be used to update a 'digital twin' copy of the product's state in near-real-time.

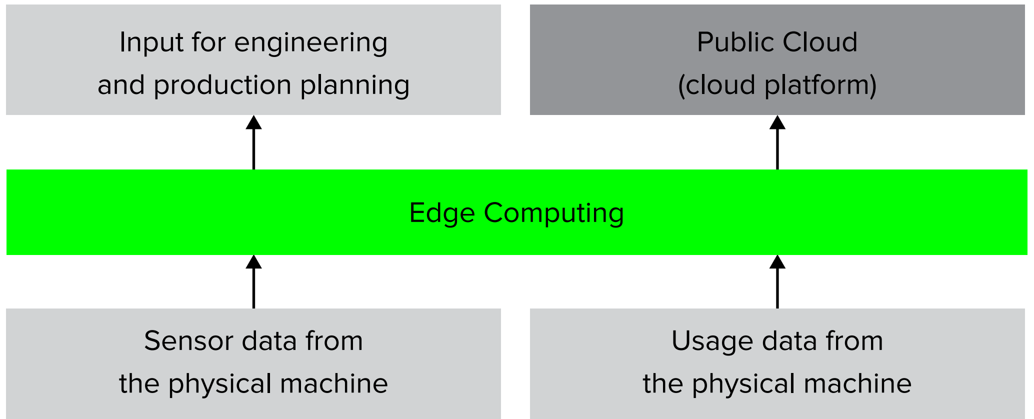
Digital twins are useful in production because not only products but also entire production plants can be reproduced as digital twins so that procedures can be tested and production processes can be optimised before actual production. Therefore, digital twins show two different components of the use case. Digital twins at a customer site have no significant issues, but digital twins at the manufacturer site can have high connectivity requirements and transmitted data volumes.

To build a digital twin that serves both internal and external needs, the views of the customer and the manufacturer must be combined. This leads to a system with low latency, high connectivity and high transmitted data volume requirements.

| Latency | Connectivity | Security/privacy | Transmitted data volume (connectivity costs) | Initial costs | Maintenance Overhead |
|---|---|---|---|---|---|
| ● | ● | ○ | ● | ◔ | ◔ |

Currently preferred approach: two-tier with an edge computing system to gather the required data and feed the on-site digital twin for engineering and production planning, and a public cloud instance from the manufacturer to run its own digital twin.

**Architecture for 'digital twin' use case today**




Mid-term future: will not change much, but 5G could mean the on-site edge computing infrastructure could be replaced by a distributed cloud approach, helping to minimise operating costs.

**Predictive maintenance**

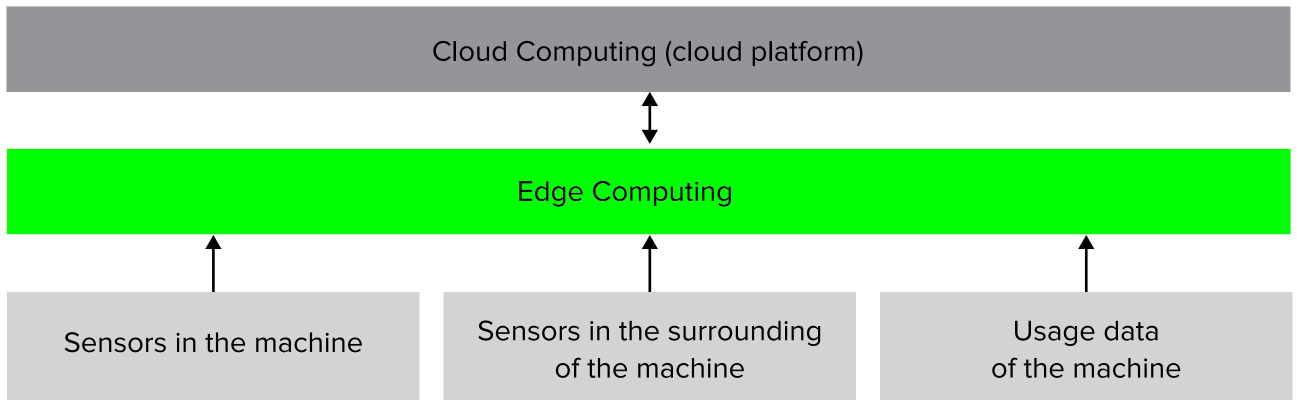
Predictive maintenance allows upfront scheduling of maintenance services to prevent unexpected equipment failures, with the help of automatic alert gathering and triggering of incident tickets. To be able to do so, sensor data inside and outside the equipment needs to be analysed and related actions need to be triggered.

Most challenging requirements: connectivity requirements are high as is the transmitted data volume. The maintenance overheads and initial costs need to be limited, as most buyers will not accept high additional costs for machines.

| Latency | Connectivity | Security/privacy | Transmitted data volume (connectivity costs) | Initial costs | Maintenance Overhead |
|---|---|---|---|---|---|
| ○ | ● | ○ | ● | ◑ | ◕ |

Currently preferred approach: two-tier with an edge computing unit that gathers the necessary data, analyses it and sends appropriate service requests or accumulated data to the cloud platform of the service provider in charge.

**Architecture for 'predictive maintenance' use case today**



Mid-term future: will not change much but 5G availability could help to reduce operating costs by replacing edge computing infrastructure with distributed cloud use.

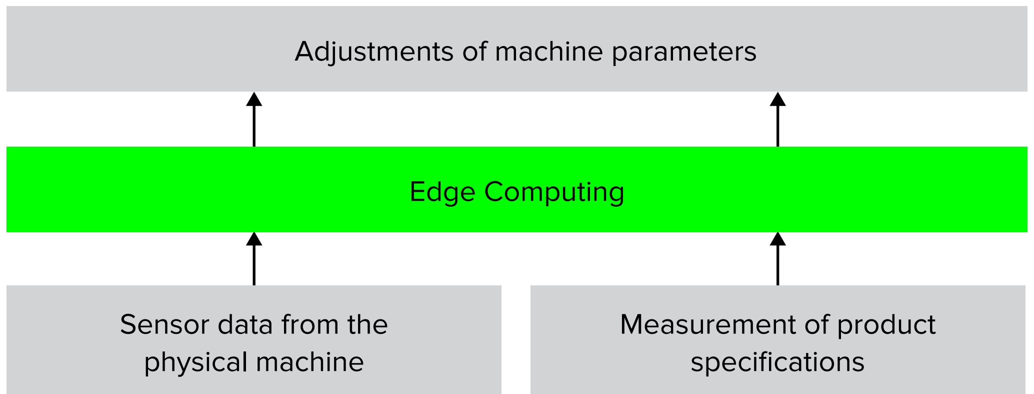
**Digital quality control**
This case covers the automatic adjustment of the production processes based on sample specifications and the analysis of data collected by sensors during the production processes and analysed to reduce the number of defective end-products.

Most challenging requirements: latency, connectivity and security requirements are high as all triggered actions have a direct influence on the production quality and the bottom line. Maintenance overheads and initial costs need to be limited, as production managers are usually cost-sensitive.

| Latency | Connectivity | Security/privacy | Transmitted data volume (connectivity costs) | Initial costs | Maintenance Overhead |
|---|---|---|---|---|---|
| ● | ● | ● | ◔ | ◑ | ◑ |

Currently preferred approach: pure edge computing which gets sensor and measurement data from the production machine and the product, analyses it and provides the machine with adjustments to optimise quality.

Architecture for 'digital quality control' use case




Mid-term future: will not change much – if 5G is available, the on-site edge computing infrastructure could be replaced by a distributed cloud approach but most production managers will prefer an on-site edge computing implementation.
Smart intra-logistics

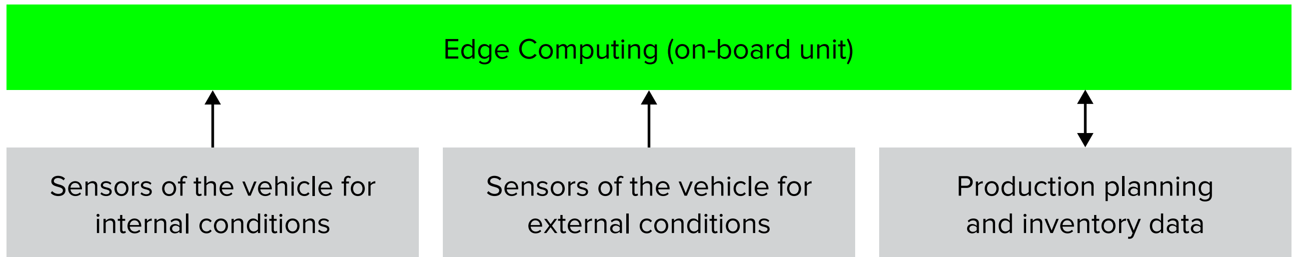
**Intra-logistics**
is an extremely complex system. Based on production planning, warehouse management and parts list data, components, partially-finished, and finished products are transported to the next processing machines or a warehouse. Autonomous vehicles use the optimal route without getting into trouble or endangering employees. Accordingly, environmental data must be processed as well as information about the payload and the destination.

Most challenging requirements: latency, as real-time information on obstructions can be vital; security, as manipulated information can lead to fatal decisions; connectivity requirements and data volumes can also be high.

| Latency | Connectivity | Security/privacy | Transmitted data volume (connectivity costs) | Initial costs | Maintenance Overhead |
|---|---|---|---|---|---|
| ● | ◕ | ● | ◑ | ◑ | ◑ |

Currently preferred approach: pure edge computing which receives sensor data from the autonomous transport vehicle and the production and inventory or logistics systems, analyses them and transports the given payload from the origin to the destination via an optimal route.

Architecture for 'smart intra-logistics' use case




Mid-term future: will not change much – if 5G is available, the on-site edge computing infrastructure could be replaced by a distributed cloud approach. However, most production managers will prefer an on-site edge computing implementation as long as production planning systems and inventory systems are not migrated to the (distributed) public cloud.

## Digital government and smart cities

The integration of digital, IT-based systems can improve operational efficiency and enhance the citizen and visitor experience. These solutions are based on IoT networks and platforms that collect, secure and combine data from other ecosystems, remote equipment, and mobile devices.
Distributed cloud is the preferred edge approach in all digital government and smart cities use cases as maintenance overheads are limited and communication with other cloud platforms is mandatory.

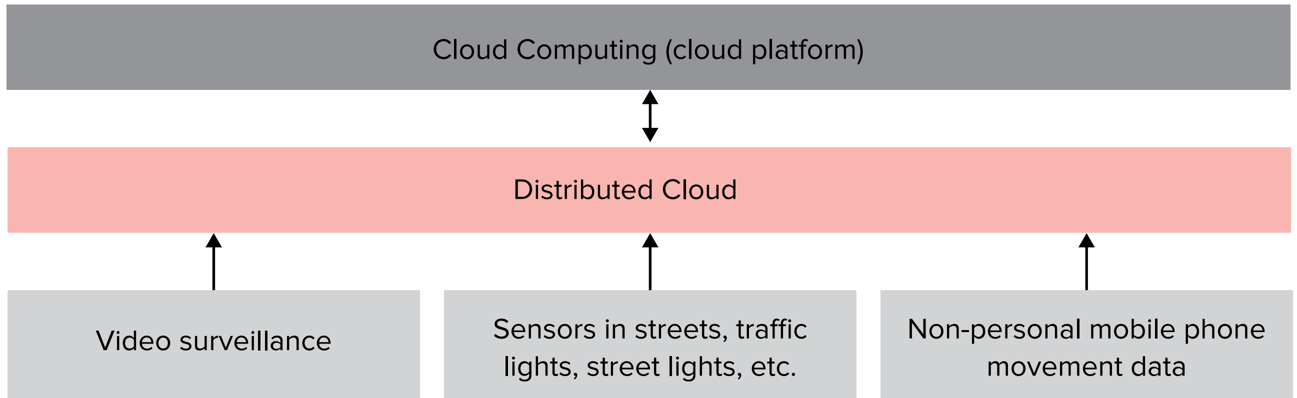
**Smart safety systems**
Smart safety systems are based on a diverse set of technologies and platforms used for improving the safety and security of indoor/outdoor public and private areas (such as parks, stations, and shopping malls). They include systems for the police, firefighters, and military forces and analyse all kinds of data, recognising anomalies and potential risks and triggering appropriate actions.

Most challenging requirements: latency, as real-time information on smoke or fire alerts can be vital; connectivity requirements are high for internal systems such as video cameras and data volumes can be high, depending on the number of sensors and especially when incorporating HD video cameras. Maintenance overheads and initial costs need to be limited.

| Latency | Connectivity | Security/privacy | Transmitted data volume (connectivity costs) | Initial costs | Maintenance Overhead |
|---|---|---|---|---|---|
| ◕ | ● | ◑ | ● | ◑ | ◑ |

Currently preferred approach: two-tier using distributed cloud and public cloud is preferable. Sensor, video and mobile phone data are collected in a distributed cloud system and pre-analysed. An in-depth analysis is performed in the public cloud where additional data can be used in a big data and AI module.

Architecture for 'smart safety systems' use case




Mid-term future: will not change much. 5G availability will optimise latency and the number of possible sensors in an area.

**Smart parking infrastructure**
On- and off-street parking concepts and infrastructure components (e.g. parking sensors) monitor and scan available spaces and provide cars with the navigation data to reach an available parking space on an optimal route. The same infrastructure can be used to reserve a parking lot for a certain point in time in a given area.

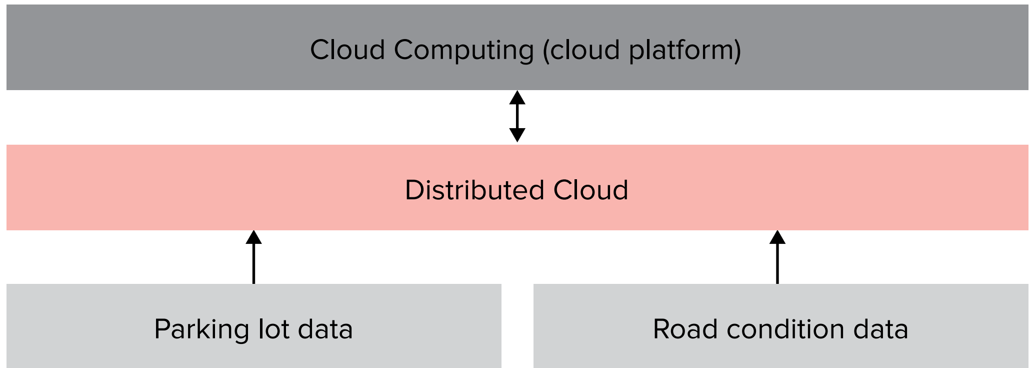
Most challenging requirements: latency, as parking information will be out of date if the information takes too long to get processed; connectivity requirements and data volumes can be high. Maintenance overheads and initial costs need to be limited.

| Latency | Connectivity | Security/privacy | Transmitted data volume (connectivity costs) | Initial costs | Maintenance Overhead |
|---|---|---|---|---|---|
| ◕ | ● | ◑ | ◑ | ◑ | ◑ |



Currently preferred approach: two-tier using distributed cloud and public cloud. Parking sensors data are collected in a distributed cloud system and analysed. A parking information and guiding app on the public cloud allows users to search for and reserve a free parking space, and receive information at which point in time parking is easier.

Architecture for 'smart parking infrastructure' use case




Mid-term future: will not change much. 5G availability will optimise latency and the number of possible sensors in an area.

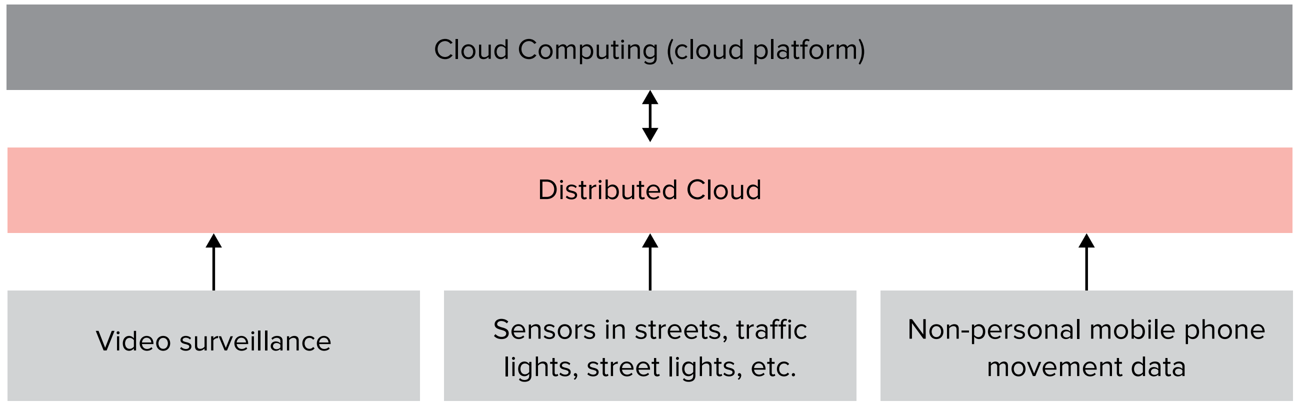
**Smart urban infrastructure**
Street lights, smart benches, smart info screens and displays equipped with connected sensors enable real-time data gathering for smart safety systems. They also serve as a channel to provide data to citizens on topics such as weather, municipal services and transport.

Most challenging requirements: latency can be a major issue as real-time information on smoke or fire alerts can be vital; connectivity requirements and data volumes can be high especially when in using HD video cameras. Maintenance overheads and initial costs need to be limited.

| Latency | Connectivity | Security/privacy | Transmitted data volume (connectivity costs) | Initial costs | Maintenance Overhead |
|---|---|---|---|---|---|
| ◕ | ● | ◑ | ● | ◑ | ◑ |

Currently preferred approach: two-tier using distributed cloud and public cloud. Sensor, video and mobile phone data are collected in a distributed cloud system and pre-analysed. An in-depth analysis is performed in the public cloud where additional data can be used in a big data and AI module. Relevant information is relayed to citizens.

**Architecture for ‘smart urban infrastructure’ use case**




Mid-term future: will not change much. 5G availability will optimise latency and the number of possible sensors in an area.

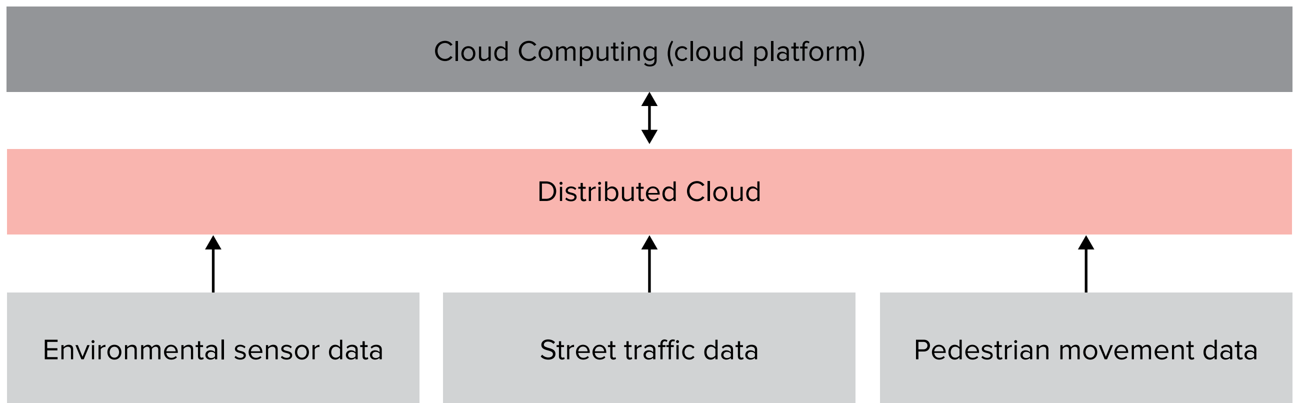
**Smart environmental solutions**
IoT-based solutions consist of various types of sensors and connectivity modules which monitor environmental pollutants or phenomena such as noise, air pollution, radiation and waste management, and trigger appropriate actions, including the re-routing of traffic.

Most challenging requirement: connectivity of the different sensors and the systems needed to react to analysis results.

| Latency | Connectivity | Security/privacy | Transmitted data volume (connectivity costs) | Initial costs | Maintenance Overhead |
|---|---|---|---|---|---|
| ◔ | ● | ◑ | ◑ | ◑ | ◑ |

Currently preferred approach: two-tier using distributed cloud and public cloud. Sensor data is collected in a distributed cloud system and pre-analysed. An in-depth analysis is performed in the public cloud where additional data can be used in a big data and AI module. Relevant information is passed back to smart urban infrastructures and smart traffic management systems.

**Architecture for ‘smart environmental solutions’ use case**





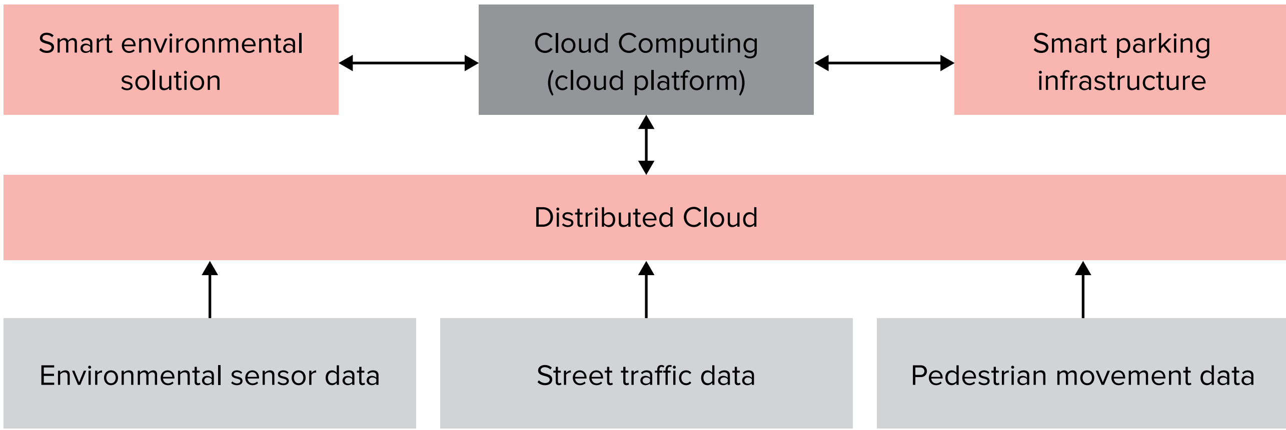

Mid-term future: will not change much. 5G availability will optimise latency and the number of possible sensors in an area.

**Smart traffic management**
This covers connected traffic infrastructure that delivers actionable insights to optimise the flow of traffic. The infrastructure usually consists of sensors in the streets to monitor the traffic flow and of smart environmental solutions and smart parking solutions.

| Latency | Connectivity | Security/privacy | Transmitted data volume (connectivity costs) | Initial costs | Maintenance Overhead |
|---|---|---|---|---|---|
| ◔ | ● | ◑ | ● | ◑ | ◑ |

This requires a combination of smart environmental solutions and smart parking solutions, so a two-tier approach using distributed cloud and public cloud is preferable. Sensor data is collected in a distributed cloud system and pre-analysed. An in-depth analysis is performed in the public cloud where additional data can be used in a big data and AI module. Relevant information is relayed to smart urban infrastructures and smart traffic management systems to optimise the traffic flow.

**Architecture for ‘smart traffic management’ use case**




Mid-term future: will not change much. 5G availability will optimise latency and the number of possible sensors in an area.

## Digital healthcare

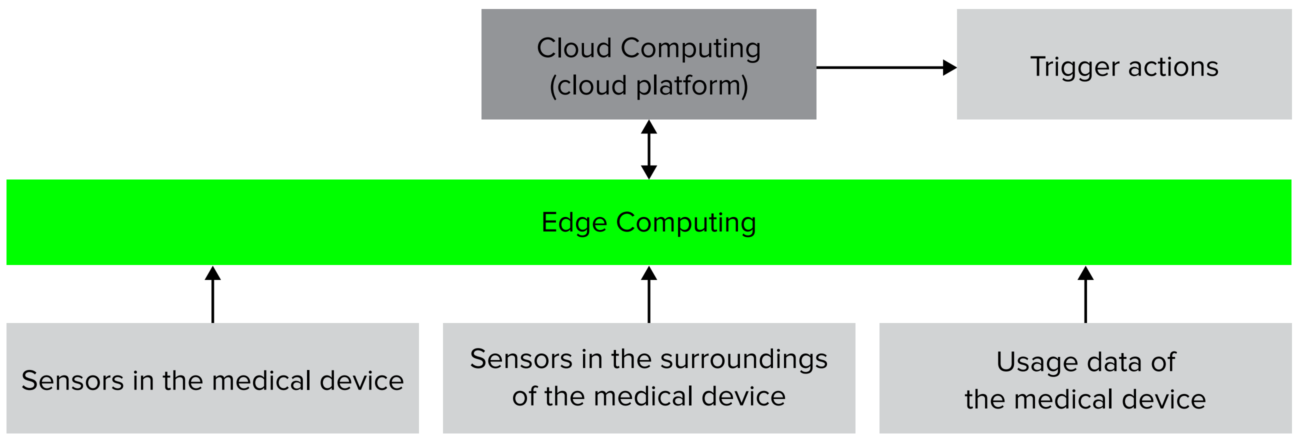
Digital healthcare is the convergence of the digital revolution with health, healthcare, living and society. IoT-related technologies are used to improve access, reduce costs, increase quality and security, reduce inefficiencies in healthcare delivery and make medication more precise in combination with personalised genomics.

**Fleet management and predictive maintenance of medical devices**
Fleet management is a common issue in hospitals and large medical practices, as devices tend to get misplaced. Predictive maintenance allows upfront scheduling of maintenance services (based on analytics) to prevent unexpected equipment failures with the help of automatic alert gathering and triggering of incident tickets. To be able to do so, sensor data inside and outside the medical devices need to be analysed and related actions need to be triggered. The highest requirements relate to connectivity and security.

| Latency | Connectivity | Security/privacy | Transmitted data volume (connectivity costs) | Initial costs | Maintenance Overhead |
|---|---|---|---|---|---|
| ◔ | ● | ● | ◔ | ◑ | ◑ |

Currently preferred approach: a two-tier approach using an edge computing unit and public cloud. Sensor data is collected in an edge computing system and pre-analysed. An in-depth analysis is performed in the public cloud where additional data can be used in a big data and AI module for predictive maintenance and trigger maintenance requests to a service provider.

Architecture for 'fleet management and predictive maintenance of medical devices' use case




Mid-term future: will not change much. As latency and data volume is not a big issue, the edge computing unit will shrink to a small routing unit, ensuring connectivity with the public cloud.

## Smart home and buildings

This is the use of technical systems and technology in buildings (residential and institutional) to increase the quality of living/working, safety and energy efficiency. They use connected and remotely controlled devices and installations as well as automated processes such as heating, surveillance, domestic appliances and entertainment.

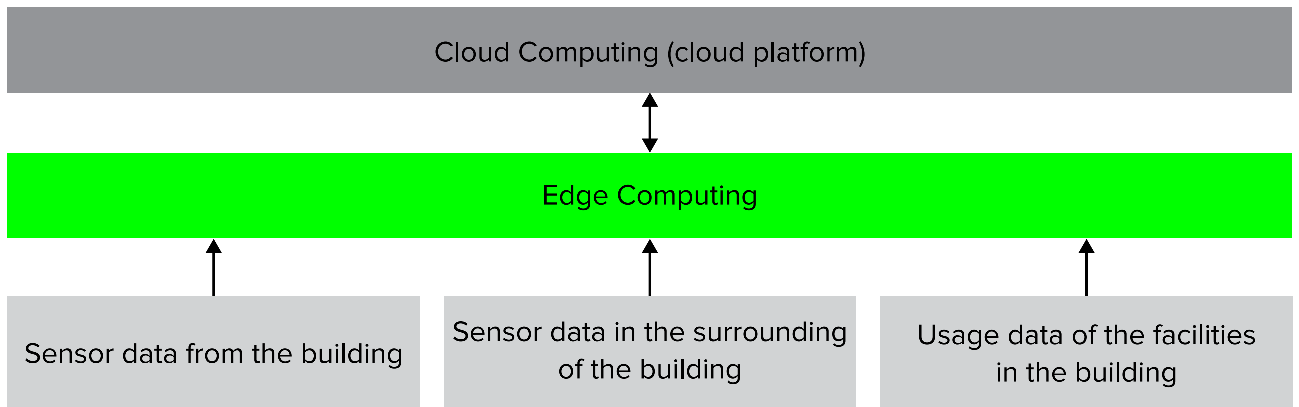
**Automation and predictive maintenance**
Predictive maintenance enables upfront scheduling of maintenance services (based on analytics) to prevent unexpected equipment failures with the help of automatic alert gathering and the triggering of incident tickets. This also includes the exchange of information between the various service providers for the building.

Most challenging requirements: connectivity requirements and transmitted data volumes are high. Maintenance overheads and initial costs need to be limited, as most buyers will not accept high additional costs.

| Latency | Connectivity | Security/privacy | Transmitted data volume (connectivity costs) | Initial costs | Maintenance Overhead |
|---|---|---|---|---|---|
| ○ | ● | ◔ | ● | ◑ | ◑ |

Currently preferred approach: two-tier using an edge computing unit to collect the required data, analyse it and send appropriate service requests or accumulated data to a cloud platform, which then triggers the appropriate service provider in charge.

Architecture for 'automation and predictive maintenance' use case today



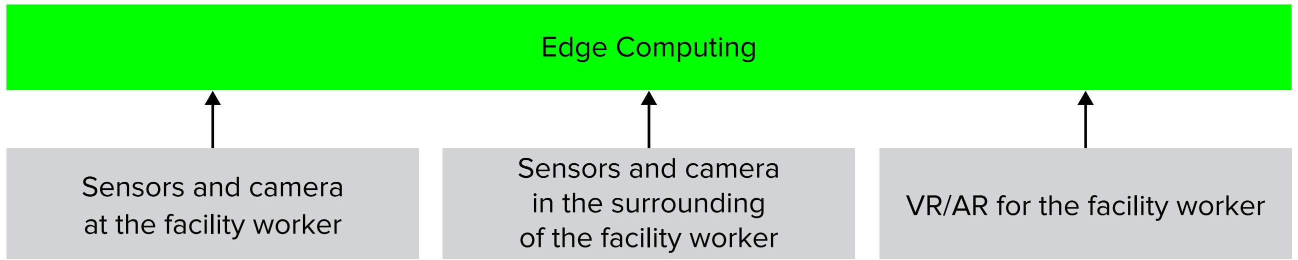

Mid-term future: will not change much, but 5G availability could help lower operating costs by replacing the on-site edge computing infrastructure with a distributed cloud approach.

**Facilities management**
Augmented reality becomes an important technology in facilities management, as even untrained workers, equipped with smartphones, tablets or AR headsets, can virtually zoom into systems for maintenance and repair purposes.

| Latency | Connectivity | Security/privacy | Transmitted data volume (connectivity costs) | Initial costs | Maintenance Overhead |
|---|---|---|---|---|---|
| ● | ◕ | ● | ◑ | ◑ | ◕ |

Most challenging requirements: latency, as real-time video information on the next steps in the maintenance process of a facility such as a lift can be vital; connectivity, if the building is in a more rural area; and security as incorrect information can lead to wrong actions by the worker. Maintenance overheads should be limited for the on-site infrastructure and the worker device as well as the initial costs.

**Architecture for 'facilities management' use case today**




Currently preferred approach: pure edge computing which receives sensor and video data from the worker and potentially its surroundings, analyses it and provides the worker with relevant information.

Mid-term future: will not change much but 5G availability, even in-house, could reduce operating costs by replacing the on-site edge computing infrastructure with a distributed cloud approach.

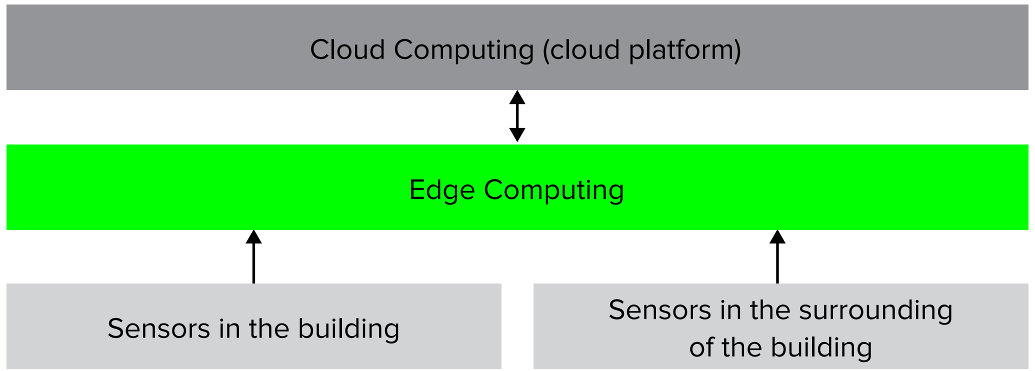
**Security and control**
Security cameras have been used for many years to monitor activity in buildings. With IoT technology such as pattern recognition software, an intelligent system can automatically detect anomalous patterns in the video data and immediately alert authorities of a possible intrusion.

Most challenging requirements: security and especially privacy, as otherwise the security and control systems can be used for intrusion and spying.

| Latency | Connectivity | Security/privacy | Transmitted data volume (connectivity costs) | Initial costs | Maintenance Overhead |
|---|---|---|---|---|---|
| ◑ | ◑ | ● | ● | ◑ | ◑ |

Currently preferred approach: two-tier using an edge computing unit and a public cloud layer. In the edge computing layer sensor data is pre-analysed and data aggregated. In-depth analysis such as pattern recognition is performed in the public cloud.

**Architecture for 'security & control' use case today**




Mid-term future: will not change much but with higher acceptance of edge cloud solutions, the edge computing unit could be replaced by an edge cloud solution.

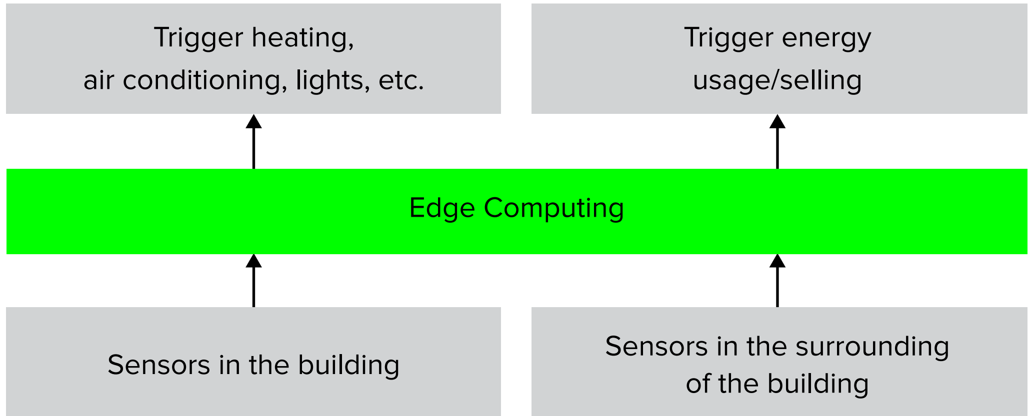
**Smart energy management**
The idea behind smart energy management is that thermostats and multiple switches learn about user behaviour and allow remote control to optimise energy consumption.

Most challenging requirements: security and especially privacy, otherwise the energy management system can be used for intrusion and spying.

| Latency | Connectivity | Security/privacy | Transmitted data volume (connectivity costs) | Initial costs | Maintenance Overhead |
|---|---|---|---|---|---|
| ◔ | ◔ | ● | ◔ | ◑ | ◑ |

Therefore a pure edge computing approach is preferable, now and in the mid-term future.

**Architecture for 'smart energy management' use case**



## Smart retail and CPG

This covers the integration of digital devices, connectivity modules, hardware and software into products, stores and warehouses. This can improve customer experience, loyalty and retention, as well as in-store operations and warehouse management.

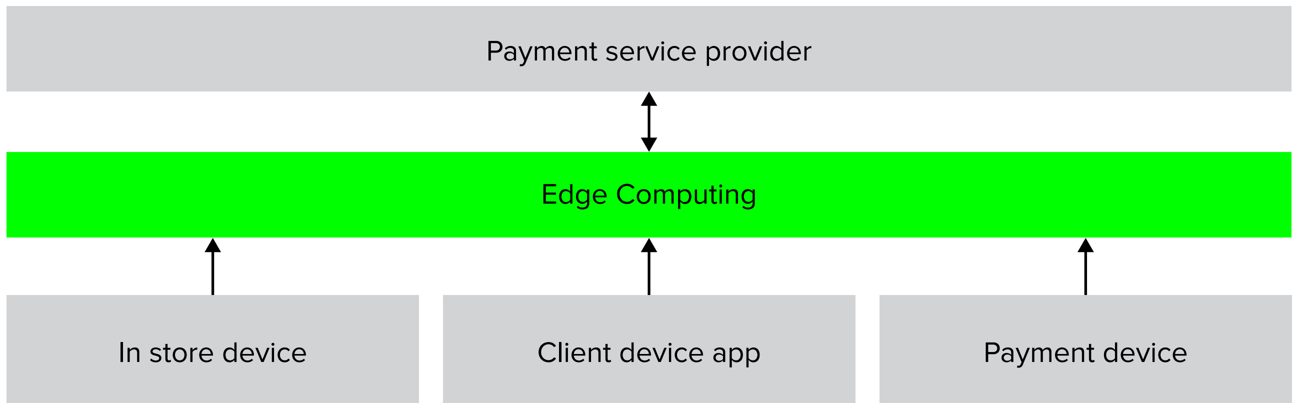
**Customer self-service**
In-store digital devices and apps help customers locate specific products, provide instant information on the items and offer self-service payment.

Most challenging requirements: security, to provide accurate information on products and locations, and ensure safe payment; connectivity can be an issue as well.

| Latency | Connectivity | Security/privacy | Transmitted data volume (connectivity costs) | Initial costs | Maintenance Overhead |
|---|---|---|---|---|---|
| ◔ | ◑ | ● | ◔ | ◑ | ◑ |

Currently preferred approach: pure edge computing.

Architecture for 'customer self-service' use case



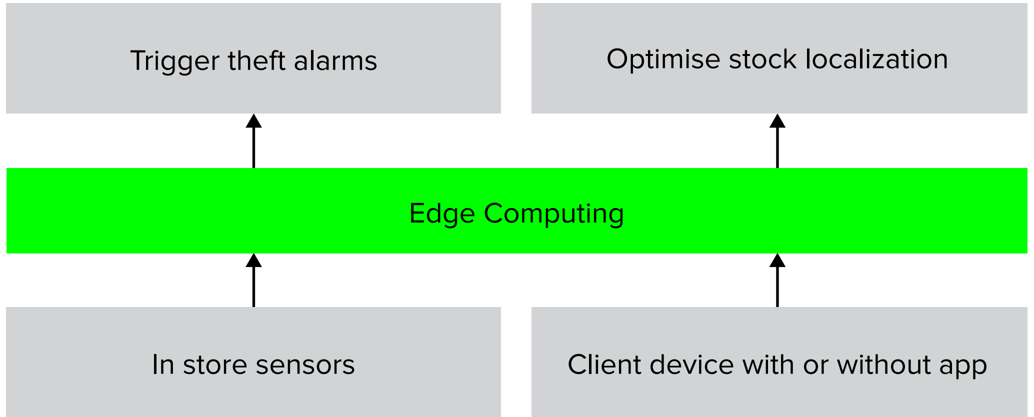

Mid-term future: will not change much over time, although retailers with a more public cloud mindset could replace edge computing units with an edge cloud unit, lowering maintenance overheads.

**Smart tracking and tracing**
This is the use of environmental sensors and connectivity modules (such as RFID, Wi-Fi, beacons and Bluetooth) to detect movement, temperature and noise or to create heat maps, enabling organisations to analyse and optimise store operations. Most challenging requirements: security, to ensure correct data collection and prevent personal data from being stolen; connectivity can be an issue as well.

| Latency | Connectivity | Security/privacy | Transmitted data volume (connectivity costs) | Initial costs | Maintenance Overhead |
|---|---|---|---|---|---|
| ◔ | ◕ | ● | ◔ | ◑ | ◑ |

Currently preferred approach: pure edge computing.

Architecture for 'smart tracking & tracing' use case




Mid-term future: will not change much over time, although retailers with a more public cloud mindset could replace edge computing units with an edge cloud unit, lowering maintenance overheads.

## Smart transport

Smart transport comprises applications which enable various users to become better informed as well as to make safer, more coordinated, and 'smarter' use of transport networks.

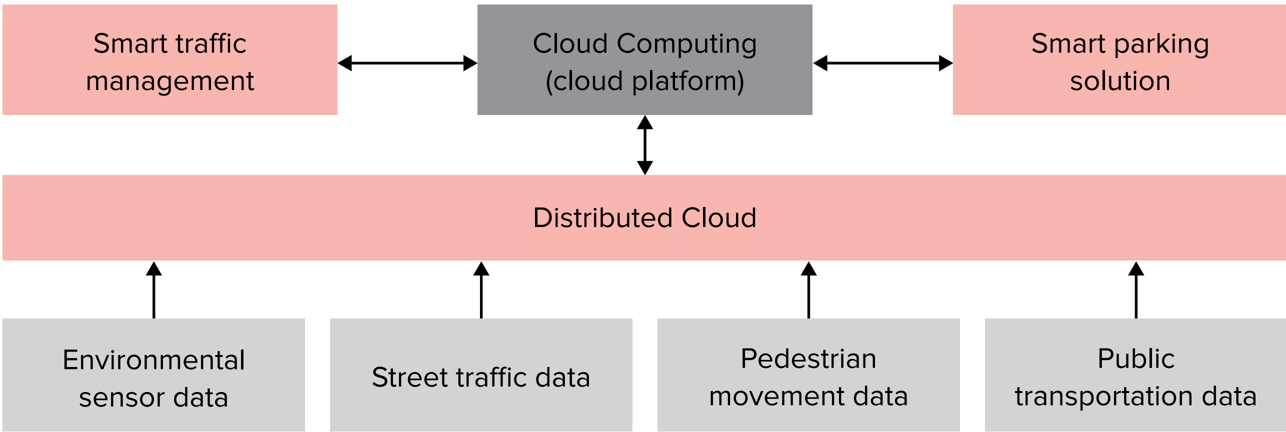
**Smart infrastructure and intelligent transport systems**
Solutions in this space are based on connected assets such as video cameras, toll collection points, parking sensors, displays and traffic signs. They combine with cloud-based platforms that integrate the data collected from the assets and provide actionable insights to optimise the flow of traffic and people, both indoors and outdoors.

Therefore, the requirements are a combination of smart traffic management and smart parking solutions.

| Latency | Connectivity | Security/privacy | Transmitted data volume (connectivity costs) | Initial costs | Maintenance Overhead |
|---|---|---|---|---|---|
| ● | ● | ● | ● | ◑ | ● |

Currently preferred approach: two-tier using distributed cloud and public cloud. Sensor data is collected in a distributed cloud system and pre-analysed. An in-depth analysis is performed in the public cloud where additional data can be used in a big data and AI module. Relevant information is relayed to smart parking infrastructure and smart traffic management systems to optimise the traffic flow.

Architecture for 'smart infrastructure and intelligent transport systems' use case




Mid-term future: will not change significantly, although 5G availability will enable latency to be optimised and the number of possible sensors in an area to be increased.

**Smart deliveries and freight transport**
Apart from providing data about the vehicles, IoT-enabled solutions can be used to monitor the condition of the transported assets/goods. Additionally, new methods of delivery through drones or robots can be introduced and controlled.

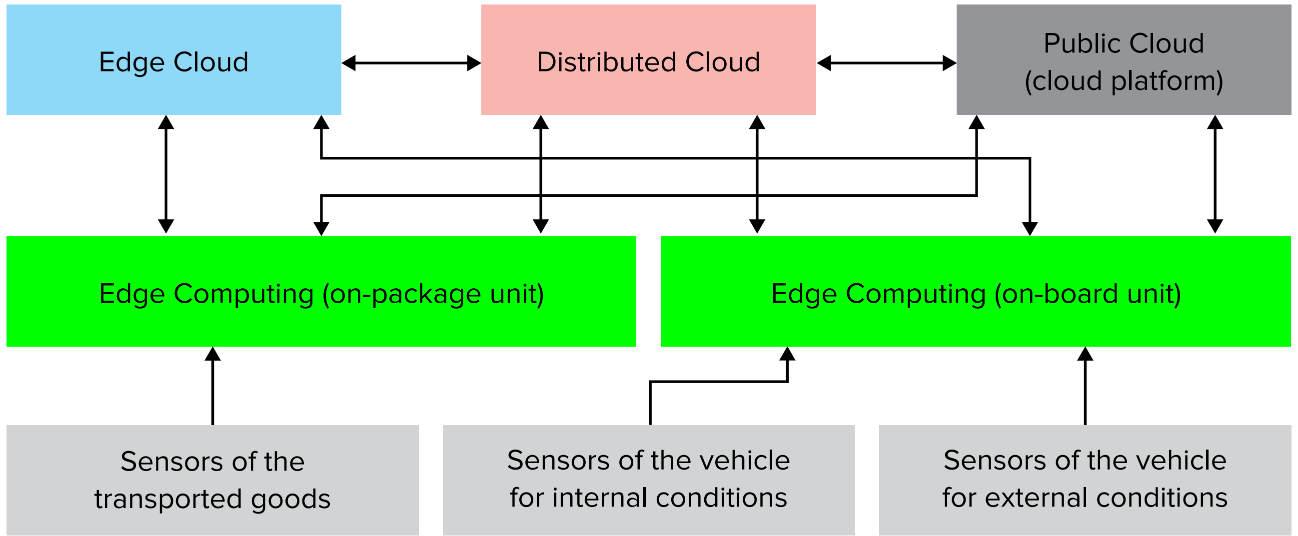
The requirements for this use case are relatively high. On one hand, the monitoring of the location (GPS) and condition (temperature, pressure/altitude) requires some storage, as connectivity in a plane or on a container vessel is virtually non-existent. On the other hand, smart delivery through drones, robots or autonomous vehicles requires connectivity and has real-time needs concerning latency.

| Latency | Connectivity | Security/privacy | Transmitted data volume (connectivity costs) | Initial costs | Maintenance Overhead |
|---|---|---|---|---|---|
| ● | ● | ● | ◔ | ◑ | ● |

Therefore a four-tier approach is preferable, both now and in the mid-term future. An on-package edge computing unit to monitor the transport conditions of the transported goods; an onboard edge computing unit which gathers data from on-board sensors and interprets the information from the three other tiers. This includes distributed cloud for information from outside of the vehicle which is time-critical, while edge cloud units alongside major roads will be used to better support real-time needs, and a cloud platform can be leveraged for less time-critical data.



Architecture for 'smart deliveries and freight transport' use case




## Other interesting use cases

Although this collection of use cases doesn't attempt to list all the possible edge computing applications across all industries, we would mention two more relevant use cases that require a type of edge computing.

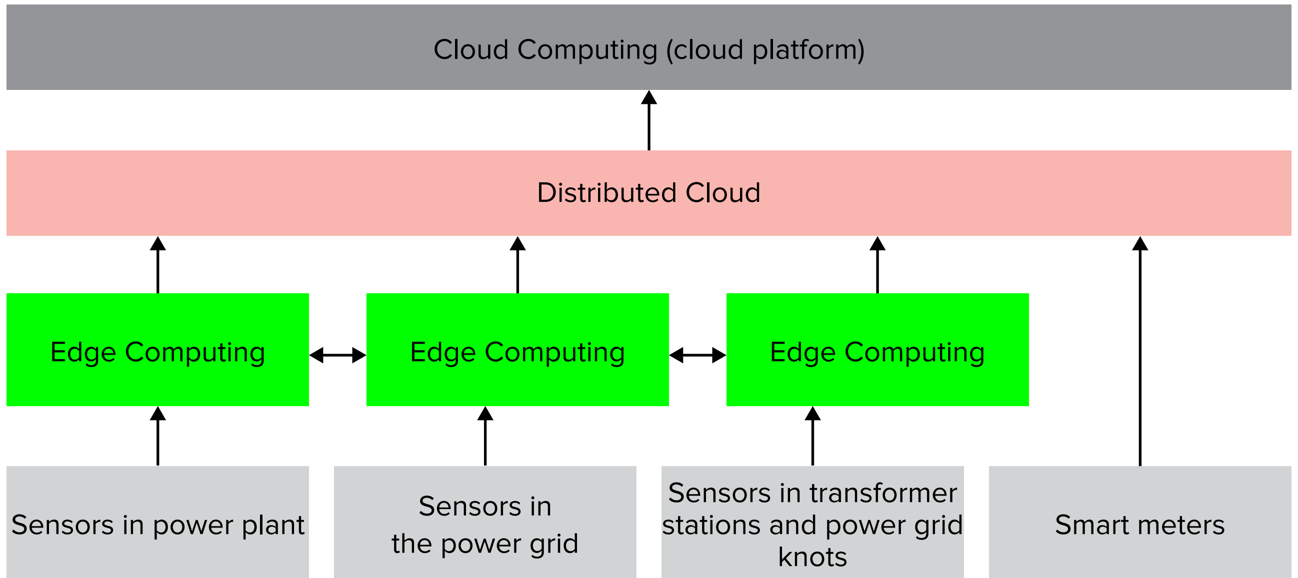
**Smart energy**
Here we refer to the use of IoT technologies and analytics (including artificial intelligence) to develop or optimise end-to-end energy management systems, as well as to enable new business models for energy consumption.

Most challenging requirements: latency, as potential blackouts need urgent action to be prevented; connectivity and security, as customer usage data needs to be protected and new business models with pricing depending on current electricity prices are on the horizon. Transmitted data volumes can be high but are mainly transmitted over the power grid itself, so no external costs apply.

| Latency | Connectivity | Security/privacy | Transmitted data volume (connectivity costs) | Initial costs | Maintenance Overhead |
|---|---|---|---|---|---|
| ● | ● | ● | ○ | ◔ | ◔ |

Therefore, a relatively complex three-tier approach is preferable. This consists of edge computing units in each power plant, transformer station and power grid knots. Data is analysed locally and actions are triggered as appropriate. Information is shared with other edge computing units and distributed cloud instances with which smart meter data is also analysed. Aggregated data is propagated to a public cloud, where users can view information on their power contracts.

**Architecture for 'smart energy' use case**




Mid-term future: will not change much, although 5G availability will enable latency to be optimised and the number of possible sensors in an area to be increased so that local edge computing units could be replaced by distributed clouds. But as the power supply belongs to the critical infrastructure providers, most of them would refuse to rely on systems controlling their supply infrastructure which are outside their sphere of influence.

**Digital mining and exploration**

This is the use of IoT technologies and analytics (including artificial intelligence) to develop or optimise exploration for oil and mining. This can help improve operational efficiency, develop more accurate and agile exploration/transportation planning ('from pit to port'), and enable more effective collaboration with business partners throughout the value chain.

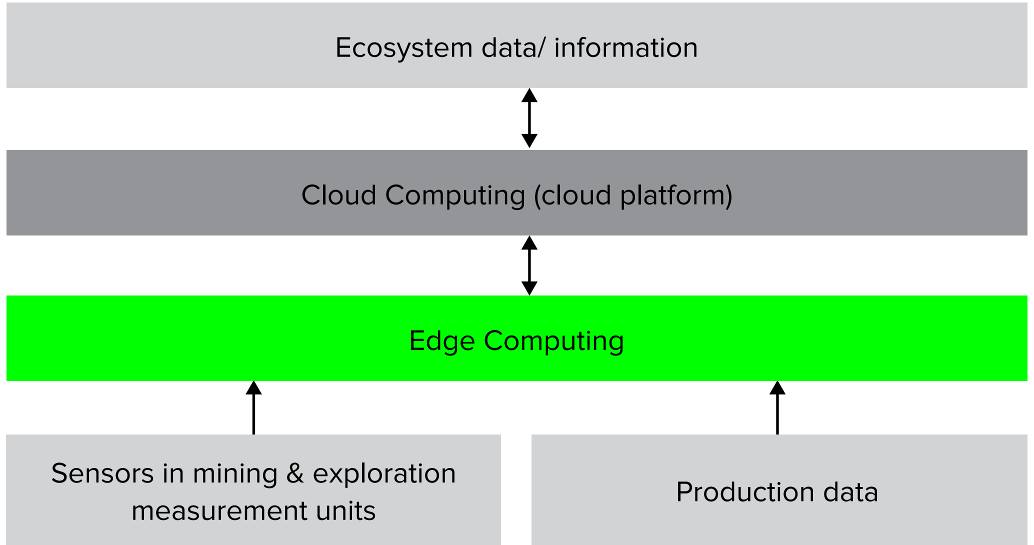
Most challenging requirements: connectivity, transmitted data volumes and related costs. As oil fields and most mines are in rural areas, high-speed broadband connections are either impossible or require extremely expensive solutions such as satellite links.

| Latency | Connectivity | Security/privacy | Transmitted data volume (connectivity costs) | Initial costs | Maintenance Overhead |
|---|---|---|---|---|---|
| ◔ | ● | ◔ | ● | ◑ | ◑ |

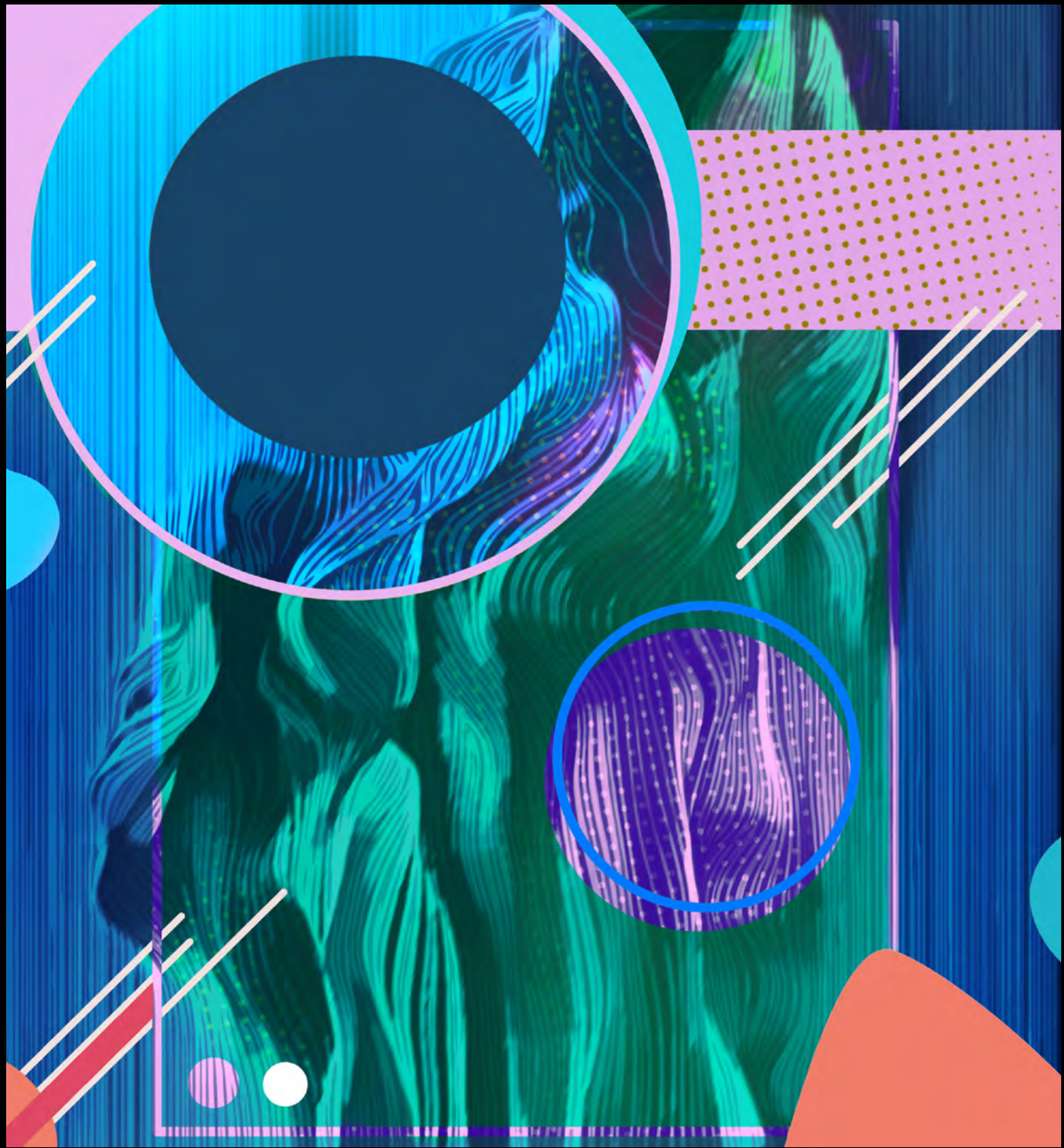
Therefore, local data processing and aggregation are needed. As the ecosystem needs to be included in the data flow, some information must be pushed to a public cloud platform for further distribution, resulting in a two-tier approach.



**Architecture for 'digital mining and exploration' use case**




Mid-term future: depending on the costs and quality of the WAN connection of an oil field or mine, the edge computing infrastructure could be replaced by an edge cloud infrastructure to lower maintenance overheads.



# Applications & industry-specific solutions

> It is clear that the future of work has changed, which will mean businesses must implement up-to-date edge computing. IT leaders will over time learn to adapt their strategies to deliver optimum results in an environment in which edge computing is most effective and as such, early adopters will reap the most success.

Justin Day, Why Covid-19 has accelerated the need for Edge Computing [Day, 2020]

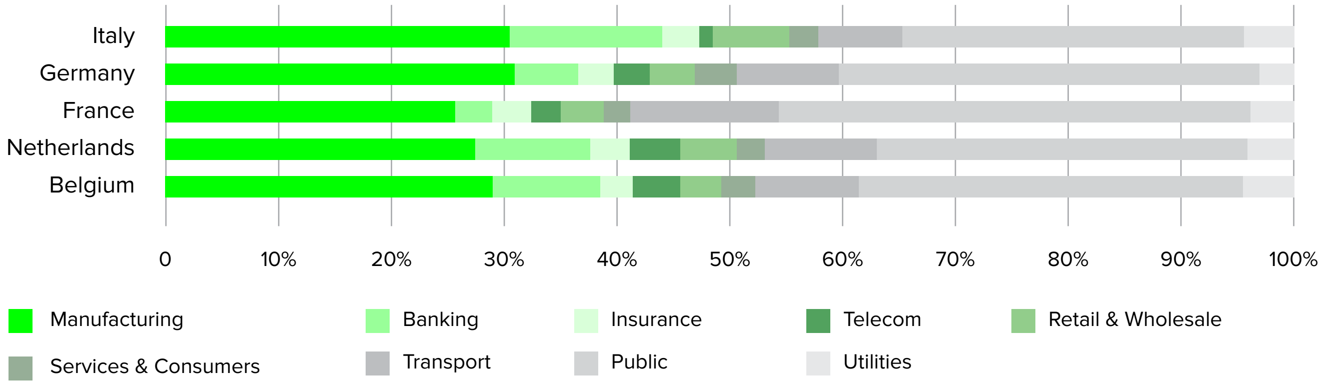


## Manufacturing is leading both cloud computing and edge computing markets

Among booming trends, cloud for education and healthcare led the hype in the last 12 months with cloud in manufacturing and retail among the trends gaining relevant volumes all over the world.

**Europe-5** Software as a Service market (% per industry)

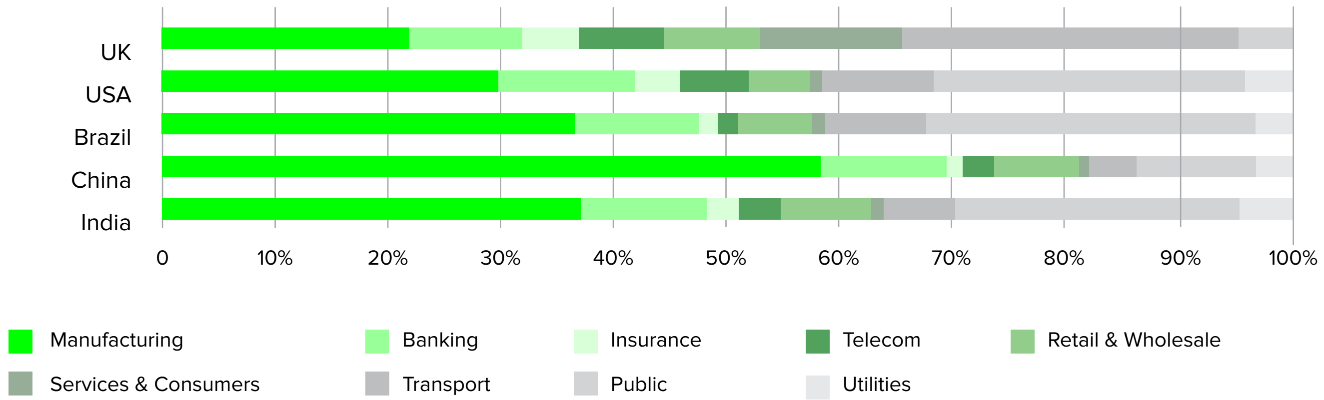
Source: Teknowlogy Group (2019)




Looking at the European market, it's evident that the main segments are Services & Consumers, and applications for Manufacturing. The sum of these market segments is greater than 60% in all analysed countries.

**Big-5** Software as a Service market (% per industry)

Source: Teknowlogy Group (2019)




The cloud for manufacturing is the main market in Brazil, India and China. In the latter, it's estimated up to 58% of the total SaaS market and forecast up to 2.5 billion Euros by the end of 2021.

GKN introduced an edge gateway to support its additive manufacturing solution. The project, supported by Concept Reply, aimed to industrialise and digitise additive manufacturing for automotive series processes (IDAM). The project - sponsored by the German Federal Ministry for Education and Research - aims to transfer the technology of additive manufacturing with metals into an industrialised and highly automated process, such as that of the automotive industry.

Read the full article

Read the full article

Industrie Reply, is helping companies to deploy technology innovations using the Industrial Internet of Things and edge computing. By offering a new way to identify use cases and scale IIoT solutions, customers are able to stay ahead of the technological innovation cycle, generating substantial added value for their business and helping to gain competitive advantage.

Read the full article

Brick Reply, specialising in advanced solutions for manufacturing operation management, has launched a new app based on its proprietary cloud-based suite. Using simulation and artificial intelligence technologies, Shop-floor Digital Twin enables factory staff to take proactive action to correct abnormal situations before they lead to production problems or stoppages.

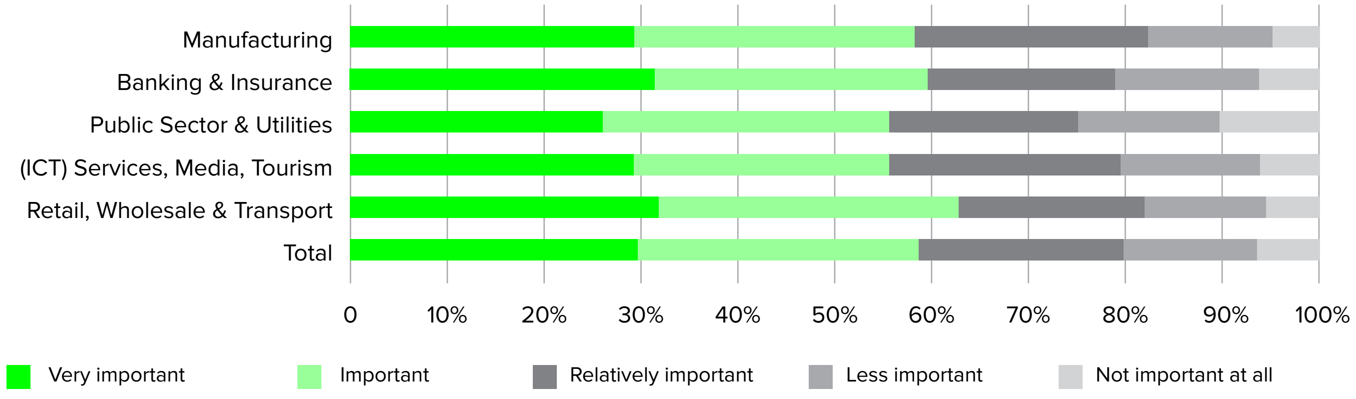
Read the full article

IoT technologies enable manufacturing companies to monitor and analyse equipment. However, different systems use different 'languages', making data hard to process. Cluster Reply's unique solution to this challenge, Factor Control Tower, uses a brand-agnostic operating model. It enables companies to remotely monitor and manage their equipment and use the generated data to make informed production and efficiency decisions.

## Logistics and Utilities are starting to appreciate the value of cloud and edge computing

Source: Teknowlogy Group (2019)

**"How importantly do you rate IaaS/PaaS/SaaS on your IT agenda?"**




ICT managers within Retail, Wholesale & Transport industries seem the ones most interested in working on cloud technologies. Although public sector and utilities show the least enthusiasm, 35% of managers in these industries thought they would increase their spend on cloud in the next two years, even before Coronavirus catapulted cloud computing into the top of priorities of CIOs across the globe.

> "Our robots were not only required to process data in real-time but also to communicate it at the same speed. We, therefore, needed a high-performing and reliable system, capable of managing processes in parallel with the simultaneous exchange of information with multiple systems."

Alessandro Subert, Chief Application Officer, Nexive

E-commerce continues to grow at a rapid pace and the delivery sector must keep up with it: deliveries that are increasingly quicker, able to reach customers wherever they are and offer greater traceability and reliability. In recent years, players in the sector have had to revise their product and service offerings, adapting to a dynamic and constantly evolving system.

Nexive had already selected the Lea Reply platform which, thanks to the 'Hub & Network' mobile and Web application, makes it possible to follow the entire logistics chain, from picking up the package to its final delivery. The introduction of the edge made it possible to manage and remotely control sorting robots, which today can move around the warehouse to collect useful information (such as the weight or dimensions of parcels) and organise the parcels into the correct containers or at the appropriate shipping gates. Read the full article

All the 'limitations' typical of a cloud solution have been overcome, thanks to the implementation of the edge component. On the one hand, latency has been reduced to a minimum, while on the other hand, the possibility of maintaining continuity even in the absence of a connection has increased with the processing of 'offline' data, enabling secure and resilient local operations.

The IoT and edge computing are key to enabling Utilities to manage the complex, heterogeneous systems that generate, distribute and store our energy. Sense Reply is helping Utilities revolutionise their business models and create new business capabilities by implementing edge components, IoT and big data platforms. Read the full article

With 30 different photovoltaic plants to manage, located in eight different Italian regions, one of the European leading renewable energy groups decided to implement an IoT and edge computing-based solution. Working with Concept Reply, the group has developed an intelligent system that provides detailed information on production and reliability, enabling them to optimise service from the plants and avoid possible disruptions. Read the full article

## The telecommunications industry is experiencing a dramatic transformation

Monolithic systems are making way for disaggregated systems, following the logic of separation between hardware and software: a key element today for making the control, management, and operation of networks more scalable, flexible and economically sustainable. Indeed, the combination of innovative microservices with an 'agile' organisational culture promises to shorten the time-to-market and to enable a more immediate offer of new services. In this context, network virtualisation technologies facilitate the development of 'hyper-scalable' solutions and greater process optimisation.

Read the full article

Open source and edge computing are the basis of Deutsche Telekom's new virtualised network infrastructure, co-developed in partnership with Reply and selected domain experts. Software and infrastructure upgrades are faster than traditional chassis-based networking technology. The adoption of so-called 'CO-PoDs' (Central Office Point of Delivery) – modules made up of hardware, open-source software and network connectivity – enables operators to provide and host voice and data services quickly and reliably. CO-PoDs can be located in Telcos' existing central offices, or next to customers, to enable edge computing, mobile edge computing and cloud edge service models.

> “Connectivity between company offices, data centres and the cloud is essential for facilitating the secure and reliable creation and execution of corporate applications.”

Ferruccio Antonelli, Sparkle's Head of Backbone Solutions Marketing

Read the full article

Sparkle has embarked on a path of evolution of its infrastructure. This path focuses on first integrating the cloud functionality, then edge services, into the network's points of presence, thus bringing the computational and storage capacity closer to the customers' offices. This reduces the access latency to these resources and mitigates the issues of reliability and security associated with long transmission routes. Net Reply designed a high-level orchestration model, introducing a so-called service orchestrator into the architectural design. This favours territorial proximity when possible, to ensure data compliance with the applicable regulation, or keeping the service close to the user to reduce latency and enable new scenarios and services.

## Reply's view on cybersecurity

More info on Reply's Security Practice

Cloud computing is a shared technology model where different organisations are responsible for implementing and managing different parts of the stack. As a result, proper distribution of security responsibilities is key to protect cloud-based systems, data and infrastructure.
The way cloud security is delivered will depend on the integration between security capabilities made available by the cloud provider and those that can be put in place by the consumer. Besides that, no matter the technical implementation details, cloud security will be a joint responsibility between the service consumer and the solution provider.

Spike Reply, the Reply Group company focused on consultancy services and integrated solutions for business security and fraud management, developed a methodology to performs security-related assessments on the configurations of cloud-based environments to identify the applicable security requirements, discover possible gaps and provide insights about the related remediation tasks. However, Spike Reply is also aware that traditional cloud computing can hardly satisfy the needs of IoT and mobile services due to reasons such as location unawareness, bandwidth shortage, operation cost imposition, lack of real-time services and data privacy guarantee.

These limitations of cloud computing pave the way for the advent of edge computing, a technology that is believed to be able to cope with the demands of the ever-growing IoT and mobile devices. Data collection and transmission from an increasing number of connected devices, however, requires a better approach to processing and analysing, as well as new security standards.

Edge computing brings those tasks closer to data sources, either enabling execution within devices themselves or outsourcing to local servers and data centres instead of central locations. The basic idea is to minimise data transmission time as much as possible, but with the introduction of a new paradigm and new technologies, security issues become more and more important.

Specifically in the IoT and Edge computing (including Edge cloud, distributed cloud, and mobile edge computing) space, user organisations are entering new technologies which need to be handled with some care. The specific security needs of cloud computing are widely understood, and the same is valid for on-premise edge computing, but IoT sensors and proprietary IoT gateways are not always optimised for security and it's often difficult to update their software. For mobile edge computing, the security challenge is clear, but the service provider selection is crucial.

Another issue is the use of data coming from potentially insecure third-party devices. A strong edge security policy should therefore segregate data flows coming from trusted edge devices from those produced by untrusted devices. Moreover, it should use virtual private networks on the communications layer as well as strong encryption and authentication.

Spike Reply also underlines the importance of deploying network intrusion detection systems as well as physical protection. To ensure a secure edge system, it is crucial to use strong network security rules to prevent access to sensitive systems in the core infrastructure layer and the edge layer and to adopt safe authentication practices. Thus, edge computing can cope with security at its best and enhance a secure cloud 'proximity connectivity'.

# CONCLUSIONS

> Newer concepts like edge computing are regularly discussed alongside the cloud, often as if they are each exclusive approaches to infrastructure. However, using one does not eliminate the ability to use the other. Some people also believe that edge computing will eventually replace traditional cloud computing, however, this isn't the case. Both technologies have important and distinguishable roles within an IT ecosystem.

Nick Offin, Cloud computing vs. Edge computing [Offin, 2020]

## Cloud computing is almost everywhere today; it will be everywhere soon

As cloud technology will be omnipresent, a holistic strategy including security, architecture, multi-cloud and edge integration will be the fundamental core of successfully leveraging the advantages of cloud computing and maximising cloud investment on an organisational level. Cost efficiency can be optimised by moving the right applications into the cloud, rethinking network architecture beyond business units and implementing a robust network spanning hybrid-multi-cloud environments and the edge, as well as on-site data centres.

Due to the increasing pressure for agility, rapid development and delivery, companies should upgrade their IT to be 'Kubernetes-ready', making 'cloud-native' an integral part of their strategy. Transforming towards cloud-native development, based on a container infrastructure, makes it much easier to scale up or down compared with traditional development environments. The path towards a cloud-native mindset demands a cultural shift within development and operations teams, reconsidering a wide range of activities and technologies, as well as processes.

Emerging technologies like AI or quantum computing are increasingly becoming accessible 'off the shelf' via the cloud and 'as a Service' models. This means they are extending their reach to a broader application in the workplace, providing business users with simple and cost-efficient access to easily consumable AI without a hefty price tag. Organisations capable of leveraging the power of these technologies in the cloud will be able to set themselves apart from the competition. For cloud service providers these capabilities will become a major differentiating factor.

## Edge computing is currently one of the most hyped topics in IT and it's becoming a fast-growing market

Mobile edge computing, distributed cloud, and edge architectures will be able to massively increase the speed of data processing, reducing time lag and enabling technologies like the IoT and autonomous vehicles. What's more, as privacy concerns rise rapidly alongside the shift to cloud environments, building networks that allow local or on-device processing and decision making, leaving the data on the edge of the network without any interaction in the cloud, will help companies cope with the data security aspect.

In its narrow definition, today's edge computing is closely related to manufacturing use cases where latency, connectivity, security/privacy and connectivity costs play a vital role. For these use cases, edge solutions, especially hardware for shop-floor usage, are key. Currently, most solutions in place are self-managed; in the future, service provider management will become more important. A key performance indicator will be recovery time in case of failures. Edge security will be the next important topic in this space.

Edge cloud is currently being promoted mainly by the hyperscalers. While such solutions can address latency issues effectively, connectivity, security/privacy, and transmitted data volumes depend on the actual offer. In general, edge cloud is often used as a hybrid cloud implementation building block for general-purpose solutions. Either the management is done by the hyperscalers or by a service provider; self-management is either not possible or very rare. Edge cloud is especially interesting for customers in regulated sectors that want to implement cloud-native solutions but are currently not allowed or willing to move to the public cloud. This means edge cloud is a viable bridging technology on the way to the public cloud.

Mobile edge computing platforms are appearing on the market. The idea is to locate compute power in 5G base stations to offer an edge-computing-like latency experience. The hyperscalers are signing partnerships with bigger Telcos to put in compute units there and Telcos are looking for service providers to offer managed mobile edge computing offers on their own. Different offers will probably come from service providers, housing providers, and start-ups too. Although the 5G rollout will take some time, the mobile edge even with 4G and distributed cloud approach are promising business models as customers no longer need an on-site infrastructure and are still guaranteed low latency.

At Reply, we believe that edge computing in all its flavours will be an amazing enabler for companies interested in operational efficiency. Where the Coronavirus pandemic is leading to cuts in IT/OT budgets, the case histories shared within this Research show how to use edge computing and distributed cloud as a strategic lever. The collection of use cases demonstrates a broad range of possible implementation. We're sure that the amazing effervescence of both hyperscalers and startups will enable us to design new cases every year, especially thanks to the growing relevance of 5G and the IoT.

# APPENDIX

## 'From Cloud to Edge' Research project was led by Reply Market Research Hub, with the support of Teknowlogy Group

The following list contains references for the sources cited in this Research.


- [Day, 2020] Justin Day, Why Covid-19 has accelerated the need for Edge Computing, 2020
- [IJPTT, 2020] Khalaf Khatatneh, Osama Nawafleh, Ghassan Al-Utaibi, The Emergence of Edge Computing Technology over Cloud Computing, International Journal of P2P Network Trends and Technology
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