Edge Deployment Data Report

4th report

Edge Observatory for Digital Decade, Edge Computing Nodes: Characterisation, Deployment Monitoring and Trajectories – STUDY 2022/012

Disclaimer

This report was prepared for the Directorate-General for Communications Networks, Content and Technology, Future Networks (CNECT.E) by the Technopolis Group under the Framework Contract SMART 2019/0024, Lot 1: Edge Observatory for the Digital Decade, focusing on Edge Computing Nodes: Characterisation, Deployment Monitoring, and Trajectories, reference No. 2022/012. The views expressed in this document are solely those of the authors and should not, under any circumstances, be regarded as an official stance of the European Commission. The European Commission does not guarantee the accuracy of the information contained within this report and shall not be held responsible for any use thereof. References herein to any specific products, specifications, processes, or services by trade name, trademark, manufacturer, or otherwise do not constitute or imply the European Commission's endorsement, recommendation, or preference. The author has taken all necessary precautions to ensure that they have secured, where required, permission to use any part of the manuscript, including illustrations, maps, and graphs, for which intellectual property rights already exist, from the rightful holder(s) of such rights or their legal representative.

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2. Introduction

2.1. Introductory remarks

This report is designed to conduct a thorough comparative analysis, juxtaposing the findings of the Edge Deployment Data Report 3 (EDDR3), which pertains to the adoption and deployment of edge nodes by EU member states in 2024, with data from international counterparts. It intends to contrast EU strategies and outcomes with those of peer countries to highlight differences, identify trends, and assess competitive standing in the global landscape of edge computing adoption. By drawing distinctions and parallels, the report will explore how the European Union's strategy aligns with or diverges from international trends and how these measures fare against the backdrop of worldwide technological advancement and industrial competition. It will also investigate the challenges and opportunities EU member states face within this dynamic and rapidly evolving sector to highlight areas for potential growth and collaboration.

2.2. Report structure

The report is structured as follows: Chapter 2 sketches the methodology and data collection approach. The chapter also offers a literature view of the adoption of edge computing technologies. Chapter 3 provides an outlook of edge adoption and deployment across regions. More specifically, it analyses the uptake of edge across the European Union, North America, and Asian markets. It also addresses the global expansion of edge node networks. Chapter 4 concludes.

3. Methodology

3.1. Desk research

A comprehensive desk study was conducted with four primary objectives: (1) to compare the deployment of Edge Nodes (ENs) and edge computing infrastructures between the European Union (EU) and international counterparts; (2) to identify and select critical stakeholders for in-depth interviews; (3) to explore and catalogue use cases and applications of edge computing across different global regions; and (4) to map out specific deployment locations and target areas for edge infrastructure. The research process was underpinned by a robust methodology, utilising various information sources, databases, and mapping tools deemed essential for a detailed analysis of current and emerging trends in edge computing infrastructure.

The desk research incorporated data from a selection of key databases, each providing valuable insights into the deployment and placement of ENs for the selected countries. The following resources were consulted:

- **Data Centre Map[1]:** This research tool and database comprehensively overview data centre locations. Industry leaders such as Equinix, Verizon, AWS, Microsoft, and others use and update them. The database currently lists 7,448 data centres across 140 countries, offering a broad perspective on global infrastructure.
- **Global Datacentre Map[2]:** Developed by DevOps professionals, this database maps the data centre locations of all major cloud and hosting providers. It includes 1,380 data centres spread across 670 distinct global locations, providing a detailed view of the hosting landscape.
- **Edge Centres[3]:** Specialising in sustainable edge data centres, this resource focuses on enhancing connectivity in remote and underserved areas. The facilities, often powered by renewable energy, are strategically positioned across the USA, Australia, and the APAC region, making this database crucial for understanding regional edge deployments.
- **EdgeConneX[4]:** Known for creating custom-built, carrier-neutral data centres, EdgeConneX positions edge infrastructure closer to customers. Its detailed database and mapping efforts were instrumental in enriching our comparative analysis.
- **LeadingEdgeDC[5]:** This resource is dedicated to establishing a network of regional edge data centres across Australia to reduce latency in underserved areas. The data provided by LeadingEdgeDC was particularly useful for identifying colocation opportunities within Australia.
- **Major Cloud Providers:** Information from AWS, Google Cloud, and Microsoft Azure was also consulted. These providers offer detailed mappings of their global infrastructure, including hyperscale edge data centres, providing critical insights into the broader cloud and edge landscape.

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[1] Data Center Map. (n.d.). Global data centres. https://www.datacentermap.com/

[2] Data Center Map. (n.d.). Global data centres map. https://map.datacente.rs/

[3] Edge Centres. (n.d.). Sustainable edge data centres. https://edgecentres.com/

[4] EdgeConneX. (n.d.). Global edge data centres map. https://www.edgeconnex.com/global-map/

[5] Leading Edge Data Centres. (n.d.). Regional edge data centres. https://leadingedgedc.com/

This structured approach ensured the research was comprehensive, allowing for a thorough analysis of global edge infrastructure and its deployment across various regions.

3.2. Interviews with selected stakeholders

This iteration focused on interviewing the IPCEI-CIS (Important Projects of Common European Interest—Common Infrastructure and Services) Facilitation Group's workstream coordinators. These coordinators were selected for their pivotal roles in steering significant projects to advance Europe’s digital infrastructure.

4. Regional outlook of edge adoption and deployment

4.1. The European Union

4.1.1. Divergent growth patterns and strategic contributions

The European Union (EU) has demonstrated remarkable growth across its member states from 2022 to 2030, marked by substantial economic expansion and increased integration. This section provides a comprehensive statistical analysis of these trends, country-specific contributions, sectoral growth, and the broader implications for the EU's future trajectory.

The projections provided by this study in previous reports reveal a striking increase in the EU's overall deployment metrics, with total values rising from 498 in 2022, with the ambition of achieving 10,000 by 2030. This represents a cumulative growth of approximately 1,907.63%, underscoring the exponential nature of the EU's economic expansion. The compound annual growth rate (CAGR) during this period is approximately 38.16%, indicating consistent growth and a significant acceleration as the decade progresses. This growth pattern suggests the EU is experiencing broad-based economic expansion and deepening economic integration among its member states. The comparison between 2022 and 2024 showcases a statistically significant acceleration in deployment metrics across the EU27. The total number of deployments increased from 498 in 2022 to 1,836 in 2024, reflecting a substantial 268.87% growth over two years. This represents an average annual growth rate of approximately 102.81%, signalling an exponential growth pattern.

The EU 27 average, which increases from 18.4 in 2022 to 370.3 by 2030, further illustrates the widespread nature of this growth. Such a dramatic rise in the average indicates that growth is not limited to a few dominant economies; instead, it is distributed across the Union, reflecting the success of EU-wide economic policies and the benefits of a unified market. The relatively moderate increase in the standard deviation of growth among member states indicates that, while disparities exist, they are managed effectively, allowing for a balanced economic landscape.

A country-level analysis further reinforces this trend. Germany, for instance, increased its deployment count from 157 in 2022 to 652 in 2024, a 315.29% rise, with an average annual growth of 124.36%. France saw an increase from 111 to 532 in the same period, marking a 379.28% rise, with an average annual growth rate of 139.25%. Italy experienced the most significant relative increase, growing from 29 to 152 deployments, resulting in a 424.14% rise, with an annual growth rate of 148.12%. The sharp increase from 2022 to 2024 also signals a clear trend towards accelerated deployment across the EU.

This dominance is underpinned by several factors, including Germany's strong industrial base and export-led growth and France's diversification into technology and services, which have outpaced traditional sectors in recent years. The higher growth rate in France suggests a narrowing economic gap with Germany, driven by strategic investments in innovation, the digital economy, and the deployment of edge computing infrastructure.

Beyond these two large economies, Southern and Eastern European countries are also displaying significant growth. For example, Poland will increase its deployments from 17 in 2022 to 82 in 2024, on its way to 401 by 2030. Similarly, Spain is set to grow from 74 deployments in 2022 to 301 in 2024, reaching 956 by 2030. In contrast, the Nordic countries, such as Finland and Denmark, exhibit steady and sustainable growth patterns. Finland will increase its deployments from 10 in 2022 to 47 in 2024, reaching 226 by 2030. Similarly, Denmark will grow from 10 in 2022 to 46 in 2024, reaching 206 by 2030.

4.1.2. Technical considerations and limitations for deployment/placement

The deployment of ENs within the EU presents a complex set of technical, geographic, socioeconomic, and regulatory challenges that must be navigated to ensure successful and equitable implementation. This section delves into the granular details of these challenges, offering an incisive analysis of the limitations that may hinder deployment efforts and proposing strategic considerations for overcoming these obstacles.

4.1.2.1. Geographic and climate constraints

The EU's topography is highly diverse, ranging from flat plains to mountainous regions. This diversity poses significant challenges for ICT placement. In mountainous areas, for example, the physical difficulty of construction and maintenance can increase costs and reduce the feasibility of widespread deployment. Additionally, the availability of existing infrastructure, such as power and connectivity, varies across regions, influencing where edge nodes can be efficiently deployed.

The geographic scale of supply systems also affects the deployment of ENs. Smaller-scale systems might require more generation capacity due to reliance on local renewable resources, which can be less consistent than larger-scale supply. Consequently, ENs in these areas may need to incorporate energy storage solutions or backup power to maintain consistent operation, which can impact the design and cost of these nodes.

Northern Europe, including countries like Finland, Sweden, and Norway, faces severe winter conditions that can impede deployment timelines and affect the reliability of ENs infrastructure. Cold temperatures can cause equipment failures, necessitating the development and deployment of ruggedised hardware capable of withstanding extreme environments.

4.1.2.2. Socioeconomic and digital Infrastructure disparities

Economic heterogeneity among EU member states is critical to deployment's pace and scale. Wealthier nations like Germany and France can allocate substantial resources towards cutting-edge technology and rapid infrastructure rollouts. In contrast, less affluent countries, particularly in Eastern and Southern Europe, may need more funding and thus lag in deployment. This discrepancy risks creating a digital divide, where certain regions benefit from advanced edge computing capabilities while others fall behind, exacerbating existing economic inequalities.

The readiness of existing digital infrastructure varies significantly across the EU. Countries with well-established broadband networks and high levels of digital literacy are better positioned to integrate edge computing technologies quickly. Conversely, regions with underdeveloped telecommunications infrastructure may require substantial upgrades before edge nodes can be effectively deployed. These upgrades could involve expanding fibre optic networks, enhancing mobile network coverage (including 5G), and significant investments in local data centres to support edge node operations.

4.1.2.3. Regulatory fragmentation and compliance challenges

Although the EU aims for regulatory harmonisation, there remains to be considerable variability in how member states implement and enforce regulations related to data protection, telecommunications, and environmental impact. For instance, while the General Data Protection Regulation (GDPR) provides a common framework, its interpretation and application can vary by country, potentially complicating cross-border data processing and storage at the edge. Furthermore, discrepancies in spectrum allocation for wireless communication and differences in environmental regulations can create additional barriers to the uniform deployment of edge nodes across the Union. Spectrum availability directly influences the technical feasibility of deploying edge nodes that rely on high-speed, low-latency connections. Differences in spectrum bands, auction prices, and prioritisation, such as whether it is allocated for industrial versus consumer use, can create bottlenecks in regions where spectrum is scarce or expensive. This uneven allocation creates a fragmented technical landscape where the capabilities of edge nodes in one region/location may differ substantially from those in another, complicating the development of a cohesive and optimised pan-European edge network.

The need of adhering to a multitude of regulatory requirements increases the complexity and cost of deployment, particularly for multi-national corporations operating across several EU member states. Compliance with stringent data protection standards and the need to navigate different national regulations require significant legal and technical resources, which can slow down deployment and increase operational costs.

4.1.2.4. Strategic deployment and future-proofing

Given the above challenges, the deployment of ENs must prioritise resilience[6]. This includes developing redundant systems that can take over in the event of node failure and using distributed ledger technologies to ensure data integrity across the network. Additionally, implementing ENs clusters in geographically diverse locations can mitigate the risk of localised failures affecting overall service continuity.

To bridge the socioeconomic and digital divides, the EU could consider targeted economic interventions, such as providing financial incentives for deployment in underdeveloped regions, subsidising infrastructure upgrades in economically disadvantaged areas, or those in which ENs deployment is progressing less rapidly. Policy interventions include establishing a centralised regulatory body that standardises and simplifies compliance across member states, reducing the burden on companies operating in multiple countries.

The future success of deployment hinges on continuous innovation in both hardware and software. Research and development should focus on creating scalable solutions that can adapt to varying regional needs and evolving technological landscapes. For example, developing modular ENs that can be easily upgraded or expanded as technology advances would help future-proof the deployment against obsolescence. Furthermore, integrating artificial intelligence (AI) and machine learning (ML) at the edge can enhance the capabilities of these nodes, allowing for more intelligent data processing and decision-making closer to the data source.

[6] Resilience, in the context of EN deployment, refers to the system's ability to withstand and rapidly recover from a variety of disruptions, including hardware and software failures, cyber-attacks, environmental hazards, and socio-economic disparities. This encompasses the implementation of redundant architectures, robust security measures, geographically distributed node clusters, and adaptive regulatory frameworks, ensuring continuous service availability, data integrity, and operational stability across the entire edge computing infrastructure.

The EU must also consider the geopolitical implications of relying on external suppliers for critical edge computing components. To mitigate the risks associated with global supply chain disruptions, the EU should invest in developing a robust domestic manufacturing base for edge node components, which encompass high-performance processors (e.g., Intel Xeon Scalable and NVIDIA A100 GPUs), advanced networking hardware (such as Cisco Nexus switches, Juniper Networks routers, and Ericsson 5G radio units), secure memory modules (including Samsung DDR5 RAM, Micron NVMe SSDs, and SK Hynix LPDDR5), FPGA accelerators (like Xilinx Alveo and Intel Stratix), storage solutions (such as Seagate Exos enterprise HDDs and Western Digital Ultrastar SSDs), and power management systems from Delta Electronics and APC by Schneider Electric. A pivotal aspect of these components is their reliance on semiconductors and rare earth elements (REEs), which are essential for manufacturing advanced electronic devices and enabling high-efficiency performance in edge nodes. Semiconductors, particularly those fabricated using cutting-edge nanometer-scale lithography processes (e.g., 5nm and below), are fundamental to the computational power and energy efficiency of ENs, as smaller transistor sizes enhance processing speeds and reduce power consumption. REEs are critical for producing high-strength magnets, capacitors, and various electronic substrates integral to networking hardware and sensors. The dominance of the semiconductor and REE markets by countries such as the United States, China, South Korea, and Japan underscores the strategic vulnerability of the EU's edge computing infrastructure, as these regions control significant portions of the global supply chains and technological advancements in these domains.

Strategic partnerships within the EU and with allied nations can further strengthen supply chain resilience and ensure that the deployment of edge nodes is not vulnerable to international political tensions or trade disputes.

By addressing these considerations with a granular and technically focused strategy, the EU can ensure that the deployment of edge nodes is not only successful but also sustainable and resilient in the face of future challenges. This comprehensive approach will be crucial in maintaining the EU's leadership in the global digital economy, ensuring that all member states benefit from the advancements in edge computing and that the Union remains competitive on the world stage.

4.1.3. Sectoral growth and projections: A quantitative forecast

Looking ahead to 2030, statistical projections indicate that the energy, technology, and services sectors will be the primary drivers of the EU's continued growth. The energy sector, particularly renewable energy, is expected to see significant expansion, driven by the EU's commitment to the European Green Deal[7] and the transition to a low-carbon economy. Germany and Spain are likely to lead this growth, with projections indicating that their contributions to renewable energy could exceed 40% year-on-year post-2025[8]. The integration of edge computing in energy management systems is expected to enhance the efficiency and responsiveness of renewable energy grids, thereby supporting this sector's growth.

The technology sector is also poised for substantial growth, with countries like the Netherlands and Ireland emerging as critical hubs for digital innovation. These countries are expected to experience growth rates in the technology sector surpassing 50% annually[9], supported by

[7] European Commission. (2019). "The European Green Deal." https://ec.€opa.eu/green-deal

[8] International Renewable Energy Agency (IRENA). (2020). "Innovations for a Renewable-Powered Future: Solutions for Integrating Distributed Renewables." Retrieved from https://www.irena.org

[9] European Commission. (2022). "European Innovation Scoreboard." https://ec.€opa.eu/innovation-scoreboard

favourable regulatory environments, a highly skilled workforce, and access to capital. This growth is critical as the EU aims to strengthen its position in the global digital economy.

The services sector, particularly in tourism, finance, and education, is projected to maintain robust growth. Southern European countries, including Italy and Greece, are capitalising on their cultural and historical assets to boost tourism, while Luxembourg and Ireland continue to grow as financial services centres. These projections are based on statistical models that incorporate historical growth patterns, current investments, and policy directions within the EU, suggesting that these sectors will play a crucial role in stabilising the overall growth trajectory and reducing the risk of over-reliance on any single industry.

4.1.4. Europe Edge Computing Market

The European edge computing market is on a significant upward trajectory. It is expected to grow from approximately €11,121.54 million in 2022 to €34,262.95 million by 2028, representing a CAGR of 20.6% from 2022 to 2028[10]. This substantial growth underscores the increasing adoption and integration of edge computing technologies across various industries within the EU and beyond.

One of the primary drivers of this market expansion is the widespread adoption of the Internet of Things (IoT) across diverse sectors. The IoT has facilitated the connection of millions of devices to the internet, leading to an exponential increase in data generation. Traditionally, industries relied heavily on centralised cloud computing and storage solutions to manage this influx of data. However, edge computing, which processes data at or near the location where it is generated or used, is increasingly becoming the preferred approach. This shift is due to edge computing's ability to manage data more efficiently, reduce connectivity costs, and enhance security protocols, making it particularly advantageous for automotive, agriculture, oil and gas, healthcare, and others.

The robust deployment of internet infrastructure in advanced European countries, coupled with the rollout of new technologies such as 5G and fibre optic networks, further accelerates the adoption of edge computing. These advancements have paved the way for new use cases, including Fixed Wireless Access, Massive IoT, and Critical IoT, which rely heavily on the capabilities of edge computing to process data in real-time. The improved bandwidth and connectivity provided by 5G networks enable the connection of more devices to the internet, which generates more significant data volumes and needs enhanced processing capacities at the edge.

Government initiatives aimed at digitalising economies across Europe also contribute to the exponential growth of data traffic. These initiatives are designed to harness the full potential of digital technologies, thereby creating more data that can be processed and used to drive innovation and economic growth. As a result, the edge computing market is poised to play a crucial role in supporting these digital transformation efforts across the continent.

The edge computing market in Europe, encompassing both European Union (EU) member states and non-EU countries on the European continent, is segmented by individual nations, with key markets including Germany, France, Italy, the United Kingdom, Russia, and other European nations. Among these, Germany and the Netherlands, primarily EU member states, are leading adopters of IoT technologies, particularly in the manufacturing, residential,

[10] GII Research. (2024). European Edge Computing Market Forecast & Regional Analysis 2023-2028. https://www.giiresearch.com/report/tip1394035-€ope-edge-computing-market-forecast-regional.html

healthcare, and finance sectors. These countries have witnessed significant implementation of IoT solutions that are closely integrated with big data analytics, machine learning (ML), 5G connectivity, and artificial intelligence (AI).

While sectors like retail and agriculture have been slower to adopt IoT compared to manufacturing and finance, they are expected to emerge as key consumers of IoT devices shortly. As these sectors increase their use of IoT, the demand for edge computing solutions is likely to rise correspondingly. This is particularly relevant in the European Commission's Digital Europe program, which invests in deploying common European data spaces across agriculture, energy, healthcare, manufacturing, and transport sectors. These initiatives aim to ensure that more data becomes available across European economies, thereby fuelling the growth of edge computing as a critical infrastructure component.

4.1.4.1. Market segmentation and competitive landscape

Components, organisation size, applications, and verticals further segment the European edge computing market. In 2022, the hardware segment held the largest market share, reflecting the ongoing demand for physical infrastructure to support edge computing deployments. Large enterprises were the dominant organisation size segment, indicating that bigger companies are currently in charge of implementing edge computing solutions.

In terms of applications, smart cities represented the largest market share in 2022. The development of smart cities relies heavily on edge computing to manage vast amounts of data generated by various connected devices and sensors. Other significant applications include the Industrial Internet of Things (IIoT), remote monitoring, content delivery, augmented reality, and virtual reality.

When analysed by verticals, the IT and telecom sector emerged as the largest segment in 2024, confirming the trend observed in 2022,, driven by its need for efficient data management and real-time processing capabilities. Other key verticals include manufacturing, energy and utilities, government, retail and consumer goods, transportation and logistics, and healthcare. The diverse applications of edge computing across these sectors underscore its growing importance as a foundational technology in the digital economy.

4.2. The EU, in comparison with international developments

The projections for the deployment of ENs within the EU from 2022 to 2030 has exhibited a strong trajectory of growth, reflective of the region’s commitment to advancing its digital infrastructure. However, a critical analysis of these developments, particularly in comparison with global peers in regions such as North America and Asia-Pacific (APAC), reveals both strengths and areas for improvement in the EU’s approach.

The EU's ENs deployment, growing from 498 in 2022 to 2,257 in 2024, with projections reaching 10,000 by 2030, represents a significant leap, underscoring the region’s efforts to establish a comprehensive pan-European network of ENs. This growth, which corresponds to a cumulative increase of approximately 1,860% indicates not just a quantitative expansion but also a broader commitment to regional economic integration and the integration of unserved regions, due to lack of backbone infrastructure or bare connectivity. However, when compared with the deployment strategies observed in other regions, particularly in the APAC market, the EU's growth presents a complex picture.

The EU's approach to deployment and placements is inherently shaped by its status as a political and economic union of 27 member states, each with its own regulatory environment, economic conditions, and technological priorities. This multi-state structure contrasts sharply with the centralised decision-making processes observed in countries like the United States, South Korea, China and Japan, where national strategies can be more quickly and uniformly implemented.

For example, South Korea’s rapid deployment of 5G infrastructure and subsequent Edge Network results from highly coordinated national policies that align closely with the country’s broader economic and technological goals. Similarly, Japan’s integration of edge computing with quantum technologies and renewable energy is facilitated by a centralised strategy that enables swift adaptation to emerging trends. These countries benefit from a unified approach that allows for more agile and decisive action.

China's leading role in Edge Computing can be attributed to its centralised, state-driven model. Leading Chinese technology companies such as Alibaba, Tencent, and Baidu operate under a "mixed ownership" policy, which mandates close integration with state-owned telecom operators like China Telecom, China Mobile, and China Unicom. This arrangement centralises the deployment of edge clouds under government oversight, resulting in a highly coordinated and expansive rollout of edge data centres nationwide.

In contrast, the United States follows a markedly different approach characterised by market-driven, decentralised strategies. In the U.S., the deployment of edge nodes is led by a combination of hyperscale cloud providers like Amazon Web Services (AWS), Google Cloud, and Microsoft Azure, alongside telecom operators and neutral host providers. The U.S. market thrives on innovation and competition, with private enterprises independently pursuing edge computing initiatives that cater to specific business needs. This environment has fostered the development of regional commercial edge data centres and on-premises edge solutions, particularly in sectors like finance, healthcare, and manufacturing, where data control and latency are critical.

In contrast, the EU’s decision-making process is inherently more complex. Policy decisions must be negotiated among member states with diverse priorities and levels of technological advancement. While this approach promotes regional equity and inclusivity, it can also result in slower implementation of cutting-edge technologies. However, the EU’s structure offers a unique advantage: the ability to tailor strategies to the specific needs of different regions, thus addressing the diverse economic landscapes within the Union. This flexibility is crucial for balancing the varying levels of digital maturity across the EU and ensuring that less developed regions are not left behind in the digital transformation.

The EU’s economic landscape is characterised by significant diversity, ranging from highly developed economies like Germany and France to emerging markets in Eastern Europe. This diversity has profound implications for the deployment of ENs and the broader digital infrastructure. In more developed economies, there is a robust private sector capable of substantial investment in advanced technologies, often supported by strong public-private partnerships. For instance, Germany and France have been at the forefront of quantum research, AI development, and edge computing, leveraging their industrial strength and innovation ecosystems to drive technological advancement.

However, in less economically developed member states, the capacity for private investment in digital infrastructure is more limited. These regions may rely more heavily on EU funding and public sector initiatives to drive edge node deployment. The European Commission’s Digital Europe Programme and the Connecting Europe Facility are examples of EU-level initiatives designed to bridge these gaps by providing financial support for digital projects across the Union. Despite these efforts, deployment speed and technological sophistication disparities remain, highlighting the ongoing challenge of achieving a uniform level of digital maturity across all member states.

This economic diversity also impacts the scale and scope of ENs deployments. In more affluent regions, ENs are being deployed with a focus on supporting advanced applications, such as AI, real-time analytics, and smart city initiatives. In contrast, in less developed regions, the priority may be on establishing basic connectivity and digital services, with edge computing seen as a longer-term goal. This divergence reflects the differing immediate needs and capabilities of member states, which the EU must continue to address through targeted investments and policy support.

The EU has strategically prioritised connectivity, quantum computing, and sustainable technologies in its digital transformation agenda. Initiatives such as the European Quantum Communication Infrastructure (EuroQCI) and the Green Deal underline the EU's commitment to integrating advanced technologies and sustainability into its digital infrastructure. This approach is designed not only to enhance the EU's technological capabilities but also to align with broader policy goals, such as reducing carbon emissions and promoting digital sovereignty.

In comparison, countries like Japan and South Korea have taken a more concentrated approach, focusing their ENs deployments in high-demand urban centres and integrating them closely with cutting-edge technologies like 5G and quantum computing. For instance, Japan’s roadmap for digital infrastructure emphasises the deployment of regional cloud services and the integration of multi-access edge computing (MEC) to support emerging technologies like autonomous driving and remote surgery. This targeted strategy allows these countries to maximise the efficiency and impact of their deployments, ensuring that their digital infrastructure can support the most advanced applications.

The EU's approach, while more geographically dispersed, is similarly forward-looking. However, the challenge lies in ensuring that these advanced technologies are not only deployed but are also fully integrated into the existing digital infrastructure across all member states. This requires a coordinated effort to harmonise standards, promote interoperability, and foster innovation across the Union.

Public-private partnerships (PPPs) have been a cornerstone of the EU’s strategy for digital infrastructure development. The EU’s policy frameworks encourage collaboration between the public and private sectors to drive innovation and investment in digital technologies. However, the effectiveness of these partnerships varies across member states, reflecting the differing levels of economic development and regulatory environments.

In contrast, countries like South Korea and Japan have implemented highly effective PPPs that have accelerated the deployment of edge infrastructure. These partnerships are often backed by strong governmental support and clear regulatory frameworks, which give the private sector the confidence and incentives needed to invest heavily in digital infrastructure. The EU, while supportive of PPPs, faces the challenge of aligning the interests of multiple stakeholders across its member states, each with its own regulatory context and economic priorities.

More targeted and coordinated investment strategies that align with national, and EU-level digital agendas are needed to enhance the effectiveness of PPPs in the EU. This could involve creating more flexible funding mechanisms that can adapt to the specific needs of different regions and fostering a regulatory environment that encourages innovation and investment while safeguarding public interests.

The underlying business models driving edge computing deployment in China and the EU further illustrate the differences between these regions. In China, the close integration between cloud providers and state-owned telecoms under a state-controlled framework leads to a more uniform and large-scale deployment of edge infrastructure. This approach ensures that edge computing resources are widely available across the country, supporting the Chinese government's broader technological self-reliance and global competitiveness goals.

However, the EU's landscape is shaped by a more diverse set of business models. European companies often pursue private edge cloud implementations driven by the desire to maintain control over data and operations. This is particularly prevalent in finance, manufacturing, and healthcare sectors, where data sovereignty and compliance with stringent EU data protection regulations are critical. As a result, many enterprises in the EU opt for on-premises edge solutions, which, while offering greater control, do not contribute to the broader network of commercial edge data centres that are more prevalent in China.

In the United States, the market-driven approach encourages a diversity of business models, with enterprises often opting for private edge clouds and on-premises solutions to retain control over data and operations. This decentralised approach supports various applications and industries, enabling greater flexibility and innovation.

The EU has implemented several key initiatives to support the development of essential technologies and enhance its digital infrastructure, ensuring digital sovereignty and economic resilience across member states. Notably, the Important Project of Common European Interest – Microelectronics and Communication Technologies (IPCEI ME/CT) focuses on research and development projects encompassing the entire microelectronics and communication technology value chain, from materials and tools to chip design and manufacturing processes. This initiative aims to enable digital and green transformation by creating innovative microelectronics and communication solutions and developing energy-efficient, resource-saving electronic systems and manufacturing methods. The IPCEI ME/CT supports technological advancements in sectors such as 5G and 6G communications, autonomous driving, artificial intelligence (AI), and quantum computing, while also assisting energy companies in their green transition efforts. Expected to introduce novel products to the market by 2025 and complete the overall project by 2032, the initiative anticipates the creation of approximately 8,700 direct jobs, alongside numerous indirect employment opportunities.

In addition to the IPCEIs, the White Paper on "How to master Europe's digital infrastructure needs?", which addresses current challenges in deploying future connectivity networks and proposes strategies to attract investments, foster innovation, enhance security, and achieve a true Digital Single Market. Additionally, the Recommendation on the security and resilience of submarine cable infrastructures outlines actions to improve the protection and robustness of these critical networks through better EU-wide coordination, governance, and funding. By leveraging existing initiatives like the IPCEI on Next Generation Cloud Infrastructure and Services, Connecting Europe Facility (CEF), and Digital Europe Programme, and enhancing collaboration through the Smart Networks and Services Joint Undertaking (SNS JU), the EU aims to build a unified and secure digital ecosystem. Furthermore, measures to harmonise telecom and cloud regulations, accelerate the copper switch-off by 2030, and promote the greening of digital networks are being considered to ensure a level playing field and sustainable growth. Together, these initiatives reflect the EU’s strategic commitment to creating a secure, innovative, and resilient digital infrastructure that supports its economic and technological ambitions.

4.3. North America

The North American edge computing market is projected to expand significantly, growing from approximately €14.7 billion in 2022 to €48 billion by 2028, reflecting a compound annual growth rate (CAGR) of 21.8%[11]. This substantial growth is driven by the increasing demand for ultra-low latency and enhanced bandwidth efficiency, which are critical for supporting real-time applications across various industries. The region's advanced technological infrastructure, particularly in the United States (US), combined with the rapid deployment of 5G networks, underpins this expansion, enabling widespread adoption of edge computing solutions. In particular, the proliferation of connected devices and the surge in IoT applications are catalysing this growth as businesses seek to leverage the benefits of processing data closer to the source to reduce latency and improve operational efficiency.

As the market matures, the deployment of ENs is expected to reach saturation in key urban and industrial hubs by the latter part of the decade. Initially, the expansion will be concentrated in regions with high demand for low-latency processing, such as smart cities, industrial IoT applications, and financial services. However, as these areas become saturated, the focus will likely shift towards optimising existing deployments and expanding edge infrastructure into more suburban and rural areas, where connectivity challenges still exist.

4.3.1. United States (US)

4.3.1.1. Edge computing market

The US edge computing market has emerged as a significant segment within the global technology landscape, characterised by rapid growth and substantial investment. Valued at € 5.41 billion in 2023, the market is forecasted to expand at a compound annual growth rate (CAGR) of 31.2% from 2024 to 2030, potentially reaching a valuation of € 38.31 billion by the end of the forecast period[12].

Companies like Microsoft, with their Azure platform, are at the forefront of this transformation, offering a variety of services that facilitate the deployment of edge computing solutions. Azure, for instance, provides services such as Azure Kubernetes Service Edge Essentials, which automates running containerised applications at scale, and Azure Stack, which extends Azure services and capabilities to the network's edge. These services enable businesses to deploy applications closer to end-users, reducing latency and improving performance.

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[11] GII Research. (2024). *North America Edge Computing Market Forecast & Regional Analysis 2023-2028*. https://www.giiresearch.com/report/tip1394040-north-america-edge-computing-market-forecast.html

[12] Grand View Research. (2024). *U.S. edge computing market size and growth*. Retrieved from https://www.grandviewresearch.com/industry-analysis/us-edge-computing-market-report.

The US edge computing market is dominated by major cloud services providers such as Microsoft Azure, Amazon Web Services (AWS), and Google Cloud. These players offer comprehensive edge computing solutions that integrate seamlessly with their respective cloud ecosystems.

4.3.1.2. Policies, investment and enabling conditions

Edge computing is increasingly integral to federal operations, offering transformative potential in real-time data processing and decision-making. The Department of Defence (DoD) is a leading adopter, using edge computing in projects like Project Maven for object detection via computer vision and predictive maintenance for military materiel. Based on the U.S. Department of Defense FY2025[13] budget allocation for Project Maven, an AI and machine learning initiative, the funding is approximately €279 million from the Research, Development, Test, and Evaluation (RDT&E) budget (Department of Defense, 2024). The Department of Homeland Security (DHS) is deploying edge computing for border security, while the National Oceanic and Atmospheric Administration (NOAA) is exploring its use in weather forecasting (DoD, 2022; DHS, 2022; NOAA, 2022).

The Biden-Harris administration has articulated a clear vision for advancing digital infrastructure, where edge computing plays a central role. This vision is embedded in broader initiatives such as the National AI Initiative Act of 2020. This act, supported and reinforced under the current administration, seeks to enhance the United States' leadership in AI, particularly emphasising integrating edge computing capabilities to enable real-time AI applications in critical sectors. Establishing the National Artificial Intelligence Research Resource (NAIRR) Task Force[14] is a direct outcome of this act, aimed at democratising access to AI resources, including the necessary edge computing infrastructure to support widespread research and application.

The federal government's commitment to edge computing is further reflected in the Federal Data Strategy[15], which aligns with the administration's goals of improving data governance and efficiency across agencies. The strategy explicitly supports the deployment of edge computing to enhance real-time data processing and operational responsiveness. By focusing on the proximity of data processing to the data source, this strategy not only improves efficiency but also enhances data security and privacy—key concerns in federal operations.

Moreover, the American Jobs Plan proposes substantial investments in digital infrastructure, positioning edge computing as a critical enabler of modernised public services and infrastructure resilience. This plan delves into the need for expanded broadband access, particularly in underserved areas, which is essential for effectively deploying edge computing.

A cornerstone of the administration's plan is the investment in cutting-edge microchip research and manufacturing, which is crucial for the advanced hardware required for edge computing. Semiconductors are the bedrock of all modern electronics and computing systems, including those at the network's edge.

[13] Department of Defense. (2024). Budget Justification for Research, Development, Test, and Evaluation (RDT&E). https://comptroller.defense.gov/Portals/45/Documents/defbudget/FY2025/budget_justification/pdfs/03_RDT_and_E/RDTE_OSD_PB_2025.pdf

[14] White House Office of Science and Technology Policy. (2023, January 24). National Artificial Intelligence Research Resource Task Force releases final report. https://www.whitehouse.gov/ostp/news-updates/2023/01/24/national-artificial-intelligence-research-resource-task-force-releases-final-report/

[15] U.S. Office of Management and Budget. (2021). Federal Data Strategy. https://strategy.data.gov/

In July 2022, Congress passed the CHIPS Act of 2022 to bolster domestic semiconductor manufacturing, design, and research, aiming to enhance economic and national security and strengthen America's chip supply chains. The U.S. share of global semiconductor manufacturing has declined from 37% in 1990 to just 12% today, largely due to significant government investments by other countries in chip production incentives, a strategy not matched by the U.S. Additionally, federal funding for chip research has stagnated as a percentage of GDP, while other nations have increased their research investments. The CHIPS Act[16] addresses these issues by providing grants for semiconductor manufacturing, boosting research investments, and offering an investment tax credit for chip manufacturing. The Semiconductor Industry Association (SIA) also advocates for extending these tax credits to semiconductor design. The administration's support for semiconductor manufacturing, as evidenced by partnerships with companies like TSMC and Micron Technology, ensures a supply of the advanced chips that are necessary for edge devices.

Internationally, the Biden administration's policies align with global trends, where nations like Germany and Japan are spearheading edge computing initiatives as part of their national digital strategies. For instance, Germany's Gaia-X project[17] focuses on creating a federated data infrastructure that supports decentralised computing models, similar to edge computing principles. This initiative is a testament to the growing recognition of edge computing as a strategic asset in maintaining digital sovereignty and industrial competitiveness.

Japan's Society 5.0 strategy further exemplifies this trend, emphasising integrating AI and IoT through edge computing to create a super-smart society. The alignment of the Biden administration's goals with these international initiatives highlights the global movement towards embracing edge computing as a cornerstone of future technological ecosystems.

Through various channels, the Biden-Harris administration has directed significant federal investments towards edge computing. For instance, the Defence Advanced Research Projects Agency (DARPA) has launched the Edge-DNN program to develop energy-efficient, AI-driven edge computing solutions for defence applications. While precise investment numbers for this specific program are not widely disclosed, other DARPA projects related to AI and microelectronics provide some insights. DARPA is heavily investing in areas like AI and edge computing, with funding in related projects often reaching upwards of €381 million for AI initiatives[18]. This level of investment suggests a substantial allocation for Edge-DNN, as it is part of DARPA's broader push to integrate AI with tactical edge deployments, essential for military and IoT applications. This program aligns with the administration's broader defence strategy, prioritising integrating advanced technologies to maintain the United States' military superiority.

The U.S. Army has procured a €11 million supercomputer housed in a deployable container to enhance computing capabilities across the DoD[19]. This HPC system, capable of six petaflops, features advanced hardware such as IBM Power9 processors and Nvidia GPUs, tailored for

[16] Semiconductor Industry Association. (2022). CHIPS Act of 2022. https://www.semiconductors.org/chips/
[17] Gaia-X Hub. https://gaia-x-hub.de/en/
[18] DataCenterDynamics. (2023). *DARPA's Hyper-Dimensional Data Enabled Neural Network proposal seeks to improve AI at the military edge*. https://www.datacenterdynamics.com/en/news/darpas-hyper-dimensional-data-enabled-neural-network-proposal-seeks-improve-ai-military-edge/
[19] Data Center Dynamics. (2023). US Army buys $12m IBM supercomputer in a shipping container, will test tactical edge deployments. https://www.datacenterdynamics.com/en/news/us-army-buys-12m-ibm-supercomputer-shipping-container-will-test-tactical-edge-deployments

machine learning and inferencing workloads. The system includes 22 nodes for machine learning, 128 nodes for inferencing, and robust storage and networking infrastructure. Designed to be deployable to the tactical edge, this HPC-in-a-Container provides the military with significant computational power that can be deployed near combat zones, although its exact applications remain confidential.

The DoD views this mobile supercomputer as crucial for supporting AI, ML, and data analytics in remote and tactical environments, addressing challenges traditionally faced by war fighters due to the distance between them and cloud resources.

Similarly, the Department of Energy (DOE) has been pivotal in funding edge computing projects aimed at enhancing the resilience of the national energy grid. These investments are critical in addressing emerging threats such as climate change and cyber-attacks, where real-time data processing at the edge can provide timely and actionable.

In the civilian sector, the National Science Foundation (NSF) has spearheaded the creation of regional edge computing hubs through substantial funding initiatives. These hubs are designed to foster research and development in edge computing across various domains, including healthcare, agriculture, and environmental science. The administration's support for these hubs reflects its commitment to decentralising technology innovation and ensuring that edge computing's benefits are accessible across different regions and sectors.

Figure 1: Leading investors in Edge Computing according to Crunchbase data.

Company	Facility	Hardware	Network	Cloud Infrastructure	Application /Software	Systems Integration	Funding $ Million
DataBank	x						410
vXchnge	x						405
Compass Datacenters	x						403.4
C3.ai					x		331
Docker				x			307.9
D2iQ				x	x		247.3
Mavenir					x		159.2
EdgeConneX	x						122
Big Switch Networks			x				119.5
Vapor IO	x						90
FogHorn			x	x	x		72.5
Iguazio					x	x	72
Qwilt			x		x		65.1
Zephyr (Vasona Networks)					x		36.6
Flexenclosure	x						35.9
Kontron		x					38.67
EDGE (DADI)				x	x		30
VANTIQ					x		28.3
Wirepas			x				20.4
Rigado		x	x	x			20.2
Golem					x		17.2
iExec					x		12
Litmus Automation				x	x		10.7
Swim.ai					x		10
ClearBlade			x		x		9.05
AirMap (Hangar Technology)					x		6.5
EdgeMicro	x						6
DartPoints	x						5.5
Crosser					x		5.2
Camgian Microsystems		x			x		1.6
Total	**8**	**3**	**6**	**6**	**17**	**1**	**3,098.72**

Source: STL Partners edge ecosystem tool.

According to STL[20], thirty companies focused on edge computing have raised €2.84 billion, a small fraction compared to the €54.96 billion invested annually by Amazon, Microsoft, and Google in hyperscale data centres. Notable recipients include vXchnge and DataBank, which are developing edge data centres. Investments also target cloud computing companies like Docker and D2iQ, which are expanding into edge solutions. Early-stage funding is prevalent now, with a shift to later-stage investments reported in 2022 as the market consolidates.

The United States enjoys a significant advantage in the edge computing market due to numerous key edge providers, including EdgeConneX, AWS, Google, and Microsoft. This advantage is bolstered by continuous and increasing investments, the proliferation of IoT, and the high quality and widespread coverage of 5G networks, considered among the best in the world[21] (Statista).

[20] *Ibidem*
[21] Statista (2023), Number of cities in which 5G is available 2023 by country, https://www.statista.com/statistics/1215456/5g-cities-by-country/

Despite the rapid advancements and strategic investments, several challenges persist in the widespread adoption of edge computing. Data security and privacy are paramount concerns, particularly in decentralised edge environments where data is processed close to the source. The Biden administration's Executive Order on Improving the Nation's Cybersecurity[22] highlights these concerns and calls for enhanced security measures across all digital infrastructures, including edge computing networks.

The issue of interoperability and standards also presents a significant hurdle. The diversity of edge computing applications necessitates a cohesive approach to standardisation, ensuring that systems across different platforms can seamlessly integrate and operate. The administration has supported efforts by the National Institute of Standards and Technology (NIST) to develop guidelines and standards that promote the safe and effective deployment of edge computing technologies.

4.3.1.3. Edge node deployment and density

Mapping the deployment and density of ENs across the US presents significant methodological challenges, particularly in replicating the comprehensive quantitative models seen in European studies. The complexity of the U.S. market, combined with the limitations of current research, makes it difficult to capture the full scope of edge computing infrastructure. This analysis is primarily based on publicly available data from major cloud providers such as Google, Amazon, and Verizon and does not account for on-premises or privately managed edge solutions. As a result, the findings may offer an incomplete view of the edge node landscape in the U.S., potentially skewing comparisons with the European Union.

As of 2024, an overview of publicly available mapping information from major providers in the edge computing sector reveals that the US currently hosts a relatively limited number of edge computing sites. Most of these providers, including some of the largest players in the industry, have established only a few dozen edge locations nationwide, primarily concentrated in major metropolitan areas with dense populations. States with lower population densities, such as Wyoming and Vermont, appear to have minimal edge computing infrastructure at this stage. This distribution speaks of the early stage of edge deployment, with a focus on regions where demand for low-latency services is highest, while less populated areas remain largely underserved.

Google Cloud Platform (GCP) has strategically deployed approximately 12 ENs across the US, concentrating these nodes in key metropolitan areas to optimise data delivery, reduce latency, and ensure high performance and reliability for its cloud services.

On the West Coast, GCP has deployed ENs in Los Angeles, California, and Oregon locations. Los Angeles, a global hub for the entertainment and media industries, demands ultra-low latency for services like streaming, gaming, and cloud computing. It is a vital location for edge infrastructure. Oregon is a crucial node, leveraging its proximity to Pacific Rim submarine cables, which enhances domestic and international data flow between the U.S. and Asia-Pacific regions.

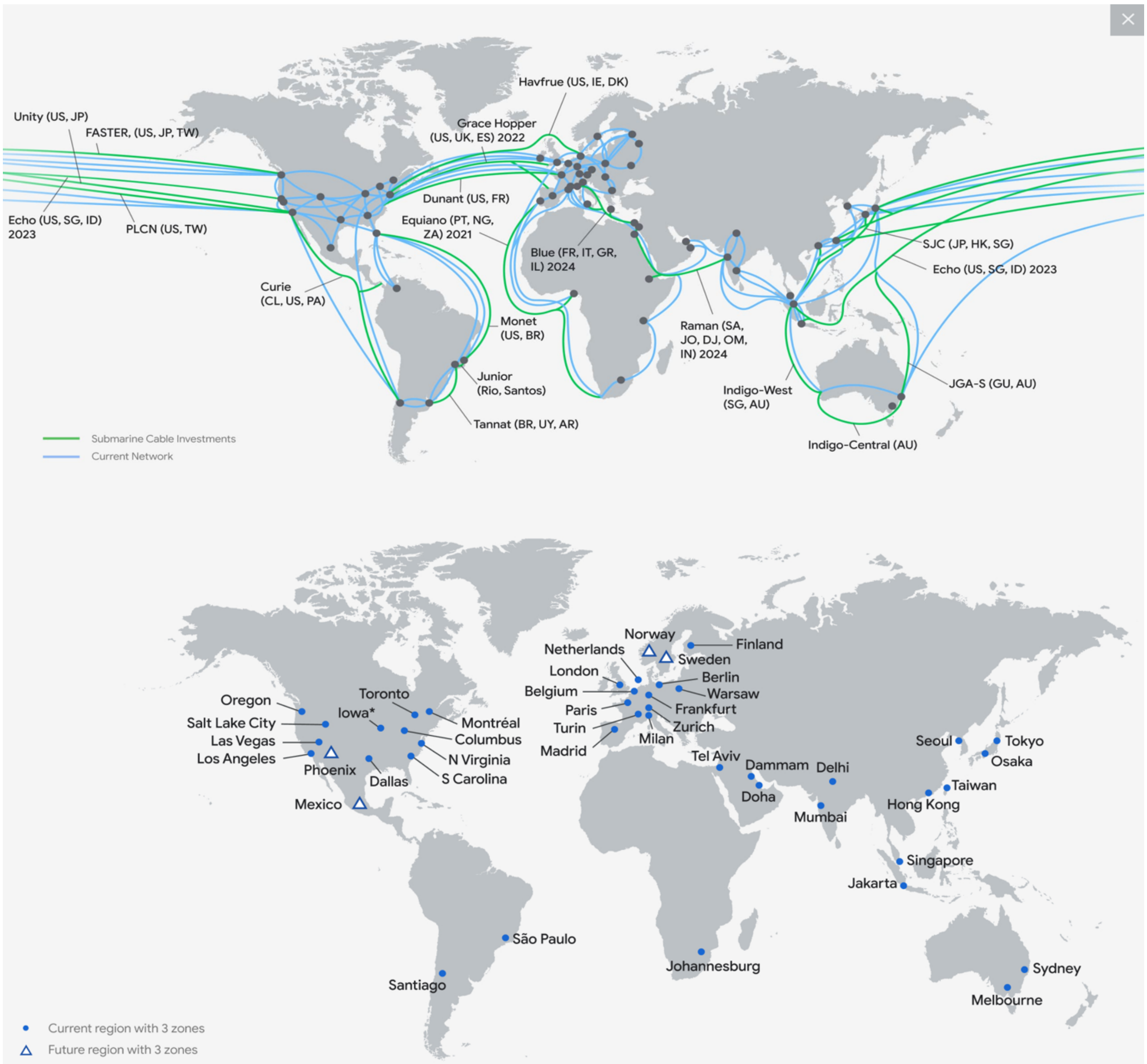
The East Coast features GCP ENs in Northern Virginia and South Carolina. Northern Virginia, known as "Data Center Alley," hosts most of the world's internet traffic. GCP's edge nodes cater

[22] White House. (2021, May 12). *Executive Order on Improving the Nation's Cybersecurity*. The White House. https://www.whitehouse.gov/briefing-room/presidential-actions/2021/05/12/executive-order-on-improving-the-nations-cybersecurity/

to the region's federal agencies, financial institutions, and large enterprises that require secure, reliable, and low-latency cloud services. South Carolina supports the growing technological landscape in the southeastern U.S., providing essential infrastructure for regional businesses and industries.

In the Central United States, GCP's ENs in Dallas, Texas, and Iowa are strategically positioned to distribute data across the country. Dallas, a major economic hub, supports a wide range of industries, including finance, healthcare, and energy, all of which rely on high-performance cloud services. Iowa's central location balances data load between the East and West Coasts, ensuring redundancy and efficient data transfer.

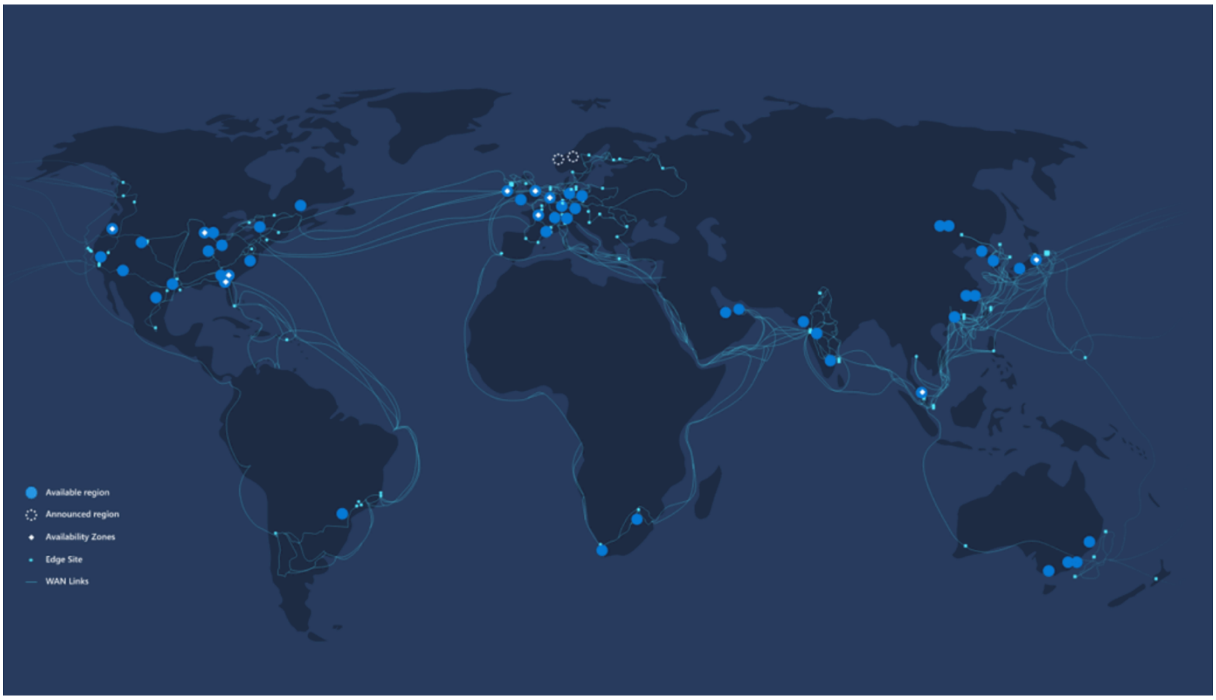
Figure 2: Edge points of presence - Google Cloud



Source: Google Cloud.

Microsoft Azure has meticulously deployed 14 edge sites across the US. These ENs are strategically located in proximity to major data consumption hubs, including key urban centres such as Los Angeles, San Francisco, Northern Virginia, and New York. Each site serves as a high-performance node that minimises the physical distance data must travel, significantly reducing latency for real-time applications in sectors such as financial trading, healthcare diagnostics, and AI-driven analytics. Furthermore, these sites are strategically placed near vital submarine cable landing points, such as those on the Pacific and Atlantic coasts, enhancing Azure's ability to facilitate high-speed, cross-continental data transfers, thereby bolstering the network's global connectivity and resilience.

Figure 3: Microsoft Azure edge sites.



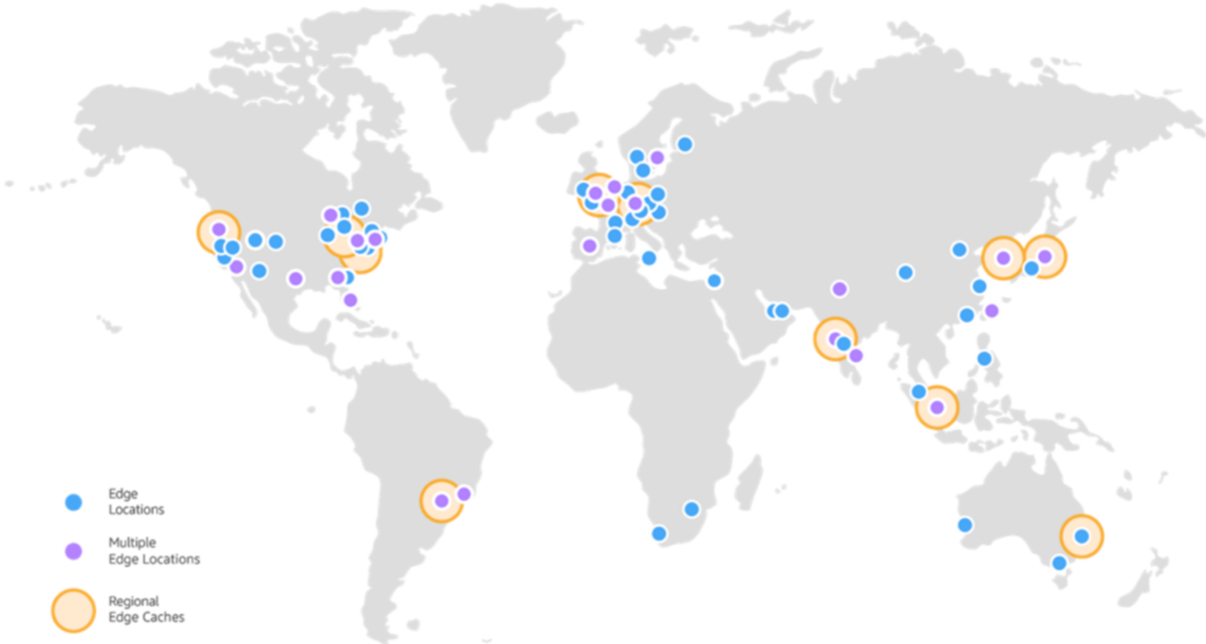
Source: Microsoft.

Amazon Web Services (AWS) has developed an extensive and highly technical network of edge locations and regional edge caches across the US, forming the core infrastructure that underpins its global cloud service offerings. In the US, AWS operates 61 edge locations strategically deployed in major metropolitan areas and is supported by additional regional edge caches.

The deployment of these ENs spans key urban centres with high population densities and significant cloud service demand. For instance, in the Northeast, AWS has concentrated multiple edge nodes in Newark, NJ, and New York, NY, facilitating ultra-low latency access to financial services, media, and entertainment sectors that require real-time data processing capabilities. Similarly, on the West Coast, critical tech hubs like San Jose, CA, and Seattle, WA, host edge locations that are integral to supporting the vast computational needs of the Silicon Valley and Pacific Northwest regions, where advanced technologies like AI, big data analytics, and cloud-based services are prevalent.

In addition to these high-density regions, AWS has strategically distributed its ENs across less densely populated areas, ensuring nationwide coverage and robust service reliability. Cities such as Atlanta, GA; Denver, CO; and Phoenix, AZ, are central nodes in AWS's network, providing essential load balancing and redundancy. This distribution strategy allows AWS to maintain consistent service levels across the country, catering to both urban and rural areas and addressing the growing demand for edge computing driven by the proliferation of IoT devices, 5G networks, and real-time analytics.

Figure 4: AWS Edge Locations.



Source: AWS infrastructure.

Lumen Technologies has developed a robust network of edge computing sites across the US, designed to deliver latency of less than five milliseconds, a critical requirement for modern applications that demand real-time processing capabilities. Based on the provided map, Lumen has deployed and planned 58 edge sites across the country, strategically positioned to ensure low-latency access to cloud services and edge computing resources for various industries, from finance and healthcare to gaming and media.

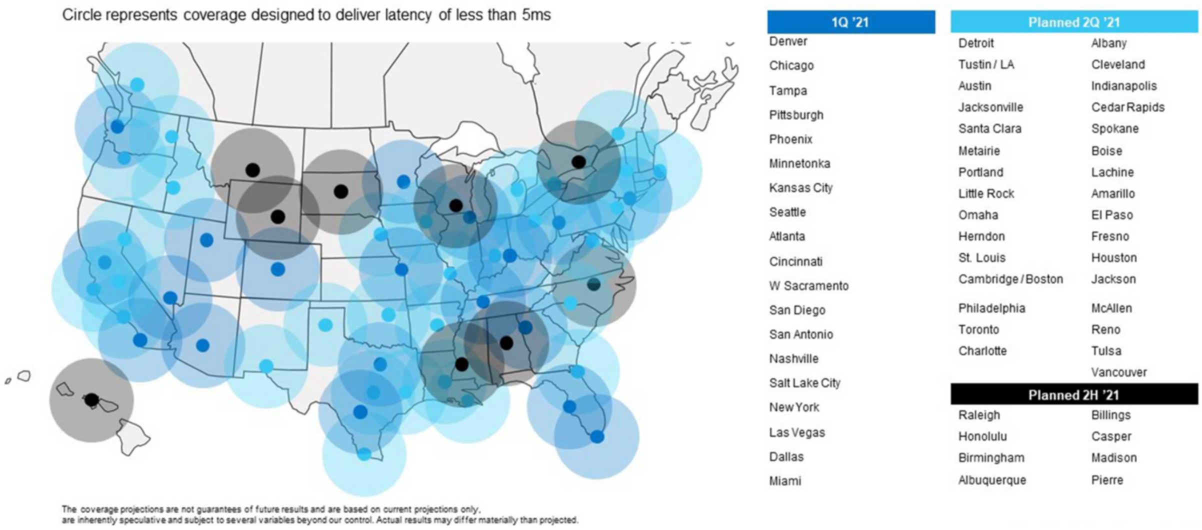
Lumen's edge sites are distributed across vital metropolitan areas, covering major economic hubs and extending into less densely populated regions but still critical for nationwide service coverage. Notable locations include:

- West Coast: Cities like Seattle, San Diego, and Los Angeles are key nodes in Lumen's edge network. They serve as gateways to the Pacific Rim and support the high demand for cloud services in technology-driven markets like Silicon Valley. These sites are essential for delivering low-latency services to industries that rely heavily on real-time data processing, such as streaming, gaming, and tech start-ups.
- Central US: Lumen's presence in cities such as Dallas, Austin, and Denver ensures that its edge computing capabilities are accessible to businesses across the central United States. This central placement is crucial for load balancing across the country and providing consistent service levels in regions far from coastal data centres. Industries such as energy, manufacturing, and finance, which are prevalent in these regions, benefit from the high-performance, low-latency infrastructure.
- East Coast: With sites in New York, Atlanta, and Miami, Lumen's edge network supports some of the most densely populated and economically significant regions of the U.S. These sites are significant for financial services, media companies, and government agencies that require ultra-low latency for mission-critical applications.

Lumen’s deployment strategy is driven by the need to meet the increasing demand for edge computing, particularly as AI, IoT, and 5G applications continue to grow. The network’s design clearly focuses on reducing latency, which is a key factor for applications requiring real-time processing, such as autonomous vehicles, smart cities, and advanced analytics. By ensuring that a significant portion of the U.S. population is near an edge site, Lumen can provide the necessary infrastructure to support these advanced technologies.

The spread of these ENs sites across densely populated areas and more remote locations highlights Lumen's commitment to broad service coverage. The careful planning of edge sites in cities like Omaha, Salt Lake City, and Birmingham ensures that even regions traditionally underserved by high-tech infrastructure can benefit from low-latency, high-performance computing.

Figure 5: Lumen edge bare metal deployments.



Source: Lumen Technologies.

The current deployment is heavily skewed towards high-density urban centres, with the highest demand for low-latency services. This is evident in clustering edge nodes in metropolitan areas like Los Angeles, New York, and Northern Virginia. The rationale is clear: these regions are economic powerhouses with industries—such as finance, media, and technology—that require immediate data processing capabilities. For instance, AWS’s distribution of 61 edge nodes across the U.S. includes nodes in densely populated regions and key secondary cities, reflecting a more dispersed approach than other providers. In contrast, GCP and Microsoft Azure have focused their deployment in fewer, more strategic locations, with 12 and 14 nodes, respectively, prioritising latency-sensitive industries in urban markets.

Despite the apparent robustness of this infrastructure, the data reveals significant gaps in less populated areas. While efficient in the short term, this urban-centric deployment strategy risks exacerbating the digital divide as demand for real-time processing expands into rural and suburban areas. The assumption that low population density equates to low demand for edge computing may prove short-sighted as IoT, 5G, and AI technologies permeate all aspects of the economy, requiring a more evenly distributed network.

From a statistical perspective, the current deployment reflects a risk-averse approach, optimising for current demand rather than anticipating future needs. This strategy is understandable but may not suffice as the digital landscape evolves. The ongoing expansion of edge nodes, particularly in underserved regions, will be essential for maintaining service parity nationwide and supporting the widespread adoption of next-generation technologies.

Moving forward, a more granular analysis of edge node capabilities, beyond mere location counts, will be beneficial for a detailed comparison with EU situation. This includes evaluating the computational power, network integration, and redundancy of these nodes, which are critical factors in determining their effectiveness in meeting the needs of different industries. This would help have more transparent and standardised reporting on edge infrastructure to enable better comparative analysis and strategic planning.

4.4. Edge computing in emerging Asian markets

The Asia-Pacific region offers significant growth opportunities for the Edge Computing market, which is driven by rapid urbanisation, increasing disposable incomes, and improved healthcare access. Market expansion strategies include product localisation, strategic partnerships, and investment in research and development.

The Asia Pacific edge computing market has experienced significant growth, with projections estimating an expansion from €8,563.74 million in 2022 to €30,081.64 million by 2028, boasting a CAGR of 23.3%[23]. This growth is underpinned by the emergence of 5G networks, which necessitate edge computing for instant communication experiences. The market is dominated by China, India, and Japan, driven by a solid manufacturing base and increasing IoT adoption. The manufacturing sector is rapidly digitalising and leveraging IoT technologies. Government initiatives for smart cities further boost IoT demand in e-government and smart traffic management. With more than 400 million 5G subscriptions expected by 2025 and the continued dominance of 4G, telecom operators' revenues are set to rise, accelerating the adoption of edge computing to support high-capacity, low-latency applications.

Southeast Asia, in particular, is poised to witness substantial growth in the edge computing sector. IDC has identified Asia as the "frontline" for the IoT market as of 2020, a testament to the region's swift adoption and interest in edge computing technologies. The region's IT industry and rapid economic development create a fertile ground for the deployment at scale of edge computing solutions. Looking ahead, the IDC forecasts Asia/Pacific spending on edge to be €39.77 billion in 2023, a 17% increase over 2022. This indicates a strong and ongoing investment in edge computing technologies across the region. The market is expected to continue its growth trajectory, reaching above €96.50 billion by 2029, with a CAGR of 30% from 2022 to 2029.

4.4.1. South Korea

4.4.1.1. Edge computing market

Seoul, South Korea, is emerging as a leading market in the Asia-Pacific region due to its critical mass population, strong infrastructure, and centralised structure. The market, worth €632.7 million in 2022, is projected to grow at a five-year CAGR of 19%. The primary growth driver is hyperscale, with major US cloud platforms establishing in-country data centre infrastructure.

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[23] Business Market Insights. (n.d.). Asia-Pacific edge computing market report. Retrieved August 7, 2024, from https://www.businessmarketinsights.com/reports/asia-pacific-edge-computing-market

This market now features a dynamic competitive landscape, with significant expansion in capacity to meet hyperscale, enterprise, and retail demand.

Once dominated by domestic operators with a strong legacy telco presence, the Seoul market now features a dynamic competitive landscape with major global operators, new platforms supported by infrastructure-focused investment vehicles, and various joint ventures. As of Q4 2022, the market has 496.3MW of built-out capacity, with an additional 970MW in the development pipeline[24]. This expansion primarily caters to hyperscale requirements, though enterprise and retail demand persist, driving uptake in interconnection services.

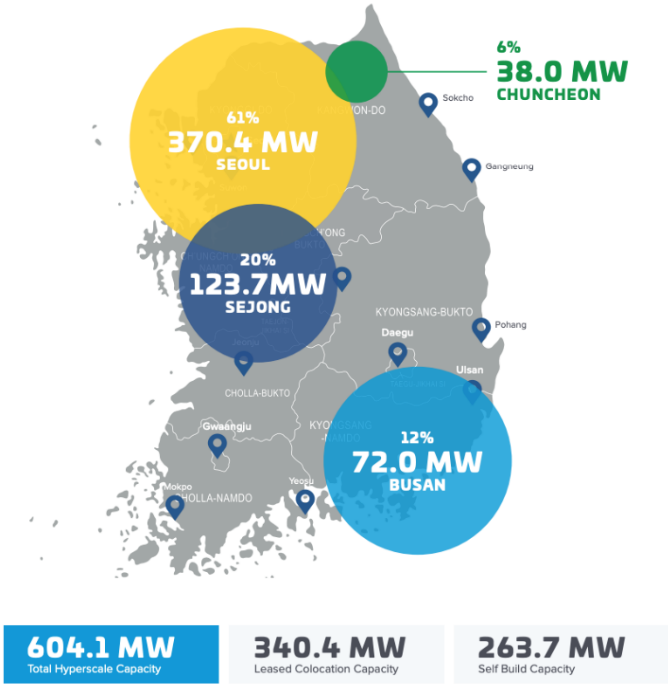
Seoul's demand profile is particularly compelling. US-based hyper scalers are entering on masse, Chinese hyper scalers are present, and domestic cloud infrastructure platforms like NAVER and Kakao are expanding and consuming data centre colocation capacity. Additionally, South Korea's domestic content industry is increasing infrastructure demand, with some content and social media platforms potentially procuring their infrastructure, reaching multi-MW levels sooner than expected.

According to the EdgeconneX | Structure Research Korea Report 2023[25], the Seoul Data Centre Colocation market is experiencing substantial growth, with its market size increasing from €527.4 million in 2021 to a projected €1,692.9 million by 2028. This growth, reflecting a 5-year CAGR of 19%, is driven by significant investment in infrastructure to meet the increasing demand. The contracted and built-out capacities are steadily increasing, highlighting the proactive development strategies in place to cater to future requirements.

Regarding critical MW market size, the total colocation capacity is expected to expand from 496.3MW in 2022 to 1,355.3MW by 2028. This growth is mainly driven by the need to support hyperscale requirements, though enterprise and retail demands also play a role. The consistent excess of contracted capacity over current built-out capacity indicates ongoing and forward-looking investments. Each year's strategic expansion in maximum built-out capacity underscores Seoul's importance as a global data centre hub.

[24] Edgeconnex. (2023). *Seoul Data Center Market Report*. Retrieved from Edgeconnex Report.
[25]EdgeConneX. (2023). South Korea Market Report: Expanding the Digital Frontier. https://www.edgeconnex.com/wp-content/uploads/2023/07/Edgeconnex_Korea-Report_FINAL.pdf

Figure 6: South Korea Hyperscale Capacity Distribution by Region.



Source: EdgeconneX | Structure Research Korea Report 2023.

4.4.1.2. Policies, investment and enabling conditions

South Korea, a nation renowned for its technological prowess, is making significant strides in the field of edge computing, a key component in the next wave of digital transformation. The government and private sector's collaborative efforts propel the country towards a leading position in this arena.

The South Korean government has been proactive in promoting cloud computing, establishing a national strategy in 2015 and updating guidelines in 2018 to encourage private cloud use in the public sector. The government has identified cloud computing as a key area in its national digital strategy. It aims to develop high-speed, energy-efficient cloud infrastructures and transition the software market to a Software as a Service (SaaS) model.

In 2020, the South Korean government unveiled a monumental stimulus package known as the 'New Deal,' which included the 'Digital New Deal'[26]. This initiative marks trillions of wins for advancing digital technologies such as AI, blockchain, and edge computing. The government's commitment to these technologies is evident in its substantial financial investment, specifically emphasising the development and deployment of edge computing infrastructure and applications. In 2024, the South Korean government will continue to strengthen its digital transformation through significant investments. The Ministry of Science and ICT has allocated €85 million[27] to boost cloud computing, marking a notable increase from 2023. This funding, including €21 million for cutting-edge cloud services, is pivotal in supporting the infrastructure needed for edge computing, which relies on localised data processing for applications like AI and IoT.

[26] Ministry of Science and ICT. (2022). Korea aims to lead digital transformation, creating 903,000 new jobs by 2025. https://www.msit.go.kr/eng/bbs/view.do?sCode=eng&mId=4&mPid=2&pageIndex=&bbsSeqNo=42&nttSeqNo=443&searchOpt=&searchTxt=#:~:text=Korea%20aims%20to%20lead%20digital,903%2C000%20new%20jobs%20by%202025.

[27] W.Media.https://w.media/south-korea-to-invest-91-5-million-in-cloud-computing-sector-growth/

Additionally, €6 million is directed towards cloud-based SaaS development, and €7.4 million will help convert traditional software into SaaS models. An innovation fund of €18.6 million further underscores the government's focus on nurturing SaaS ventures, which are crucial for scaling edge computing. These investments reinforce South Korea's position as a leader in advancing cloud and edge technologies, essential for its growing digital economy.

The South Korean hyperscale data centre market is forecasted to grow from €3,720.81 million in 2023 to an estimated €6,469.53 million by 2032, with a CAGR of 6.58% between 2024 and 2032[28]. This expansion is driven by the rising demand for cloud services, big data analytics, and the rapid growth of the IT and telecommunications sectors in the country.

Key factors propelling the market include the increased adoption of AI, IoT, and edge computing, all of which require significant computing power and storage capabilities. The government's focus on positioning South Korea as a technological hub is also accelerating market growth, while sustainability initiatives are pushing for the development of energy-efficient data centres. Additionally, trends such as the rollout of 5G and improved connectivity are contributing to the growth of hyperscale data centres in the region.

Geographically, the capital region, encompassing Seoul and Incheon, leads the market due to its advanced infrastructure and high concentration of technology companies. Major players in South Korea's hyperscale data centre market include Samsung SDS, LG CNS, KT Corporation, SK Telecom, and Naver Cloud, each of whom drives growth through strategic investments and innovations in data centre technologies.

This initiative, backed by substantial public investment of €16.38 billion (2020-2022) and an additional €40.74 billion by 2025, aims to foster a robust digital economy. Key objectives include promoting the application of AI by making government data accessible, encouraging the collection and use of sector-specific data, and establishing a public-private data control centre.

The plan also encompasses nationwide 5G and AI coverage across all primary, secondary, and tertiary industrial sectors. In the education sector, the South Korean government is focused on enhancing digital education at all levels of mandatory schooling and improving online education for universities and job training centres. Other focus areas include establishing smart healthcare systems, e-commerce (especially for SMEs), smart cities, and a modern logistics infrastructure.

Moreover, the Ministry of Science and ICT has announced plans to expand support for local firms transitioning to ultra-fast networks and invest in mobile edge computing research and development. This policy demonstrates the ministry's recognition of the transformative potential of edge computing and its importance in sustaining South Korea's competitive edge in the technology sector.

Additionally, South Korea has enacted legislation on the Development of Cloud Computing[29] and the Protection of Users, ensuring that the protection of citizens' data and information is prioritised as new technologies emerge.

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[28]Credence Research. South Korea Hyperscale Data Centre Market. https://www.credenceresearch.com/report/south-korea-hyperscale-data-center-market

[29] Statues of the Republic of Korea (2022), ACT ON THE DEVELOPMENT OF CLOUD COMPUTING AND PROTECTION OF ITS USERS, https://elaw.klri.re.kr/eng_mobile/viewer.do?hseq=60378&type=part&key=43

The collaboration between SK Telecom (SKT) and Amazon Web Services (AWS) is a pivotal development in South Korea's edge computing landscape. Together, they launched South Korea's first 5G edge cloud service, named SKT 5GX Edge. This service integrates AWS Wavelength at the edge of the 5G multi-access edge computing (MEC) networks. It is a game-changer for companies seeking to build mobile applications with ultra-low latency.

SK Telecom, South Korea's largest mobile carrier, has taken a significant step by opening its 5G mobile edge computing platform to third parties and enterprise customers. This move not only diversifies the ecosystem but also fosters innovation by enabling a multitude of players to develop and deploy edge computing applications.

Similarly, KT, another South Korean telecommunications giant, has constructed mobile edge computing telecom centres in eight major cities. This infrastructure is designed to harness the maximum capacity of 5G's low latency, enhancing the performance of edge computing applications nationwide.

Despite opportunities, foreign cloud providers face challenges in the public sector due to strict regulations, including the Cloud Security Assurance Program (CSAP), which mandates specific security certifications[30].

The South Korean government has recently made substantial R&D investments, strongly emphasising supporting emerging researchers and technologies[31]. The total investment amounts to up to €1.26 billion. The Ministry of Science and ICT (MSIT) has outlined its 2024 budget to focus on five key areas. Among these, some relevant are:

- Securing core technologies of strategic value: MSIT plans to invest €1.69 billion to maintain a significant technological lead in critical areas and develop next-generation and original technologies in 12 Critical and Emerging Technologies.
- Cultivating science, technology, and digital talent: MSIT will allocate €1.99 billion to support the growth of emerging researchers and produce core personnel in Critical and Emerging Technologies. This investment aims to develop digital talents that are ready for practical application.
- Promoting digital diffusion: With an investment of €913.22 million, the government aims to integrate hyperscale AI into specialised sectors such as law, healthcare, and public services, ensuring that all citizens can benefit from AI advancements in their daily lives.

Additionally, the overall government R&D budget, including allocations managed by MSIT, has been set at €18.55 billion. This includes specific support for students and employees in small and medium-sized enterprises (SMEs). The budget for establishing and operating advanced research equipment has also been expanded by €30.38 million. This expansion covers the construction and operation of large-scale research infrastructure, such as enhanced supercomputing facilities (€2.8 million), a multipurpose synchrotron radiation source (€7.7

[30] International Trade Organisation (2023), South Korea - Country Commercial Guide; Information and Communication Technology, https://www.trade.gov/country-commercial-guides/south-korea-information-and-communication-technology

[31] Ministry of Science and ICT (2024), KRW 18.6 trillion budget approved for MSIT in 2024, https://www.msit.go.kr/eng/bbs/view.do?sCode=eng&mId=4&mPid=2&pageIndex=&bbsSeqNo=42&nttSeqNo=944&searchOpt=ALL&searchTxt=

million), a rare isotope accelerator (€3.85 million), new research reactors for export (€7.7 million), and the KSTAR project (€2.45 million).

Apart from some regulatory hurdles that could affect market entry for foreign companies and investors, South Korea remains a highly fertile environment for developing and enhancing edge and cloud computing technologies. As a global leader in ICT, South Korea boasts an advanced infrastructure and some of the fastest internet speeds in the world, particularly in tech hubs like Seoul and Busan. These factors position the country well for both domestic and international collaborations aimed at further advancing its cloud and edge computing capabilities.

The country offers a robust network, reliable power infrastructure, and a favourable business climate, making it attractive for data centres and tech companies. Major firms like Samsung, SK Hynix, LG, and Naver are based here. With a stable political environment and openness to investment, South Korea continues to invest heavily in innovative technologies such as advanced semiconductors, AI, big data, and quantum computing, solidifying its status as a top ICT powerhouse.

4.4.1.3. Edge nodes deployment and density

South Korea is rapidly solidifying its position as a critical growth market for hyperscale cloud providers in the Asia-Pacific (APAC) region. While traditional core hubs like Singapore, Hong Kong, and Tokyo continue to dominate, South Korea, particularly Seoul, is now moving into the conversation as a tier 1 market. This shift reflects broader trends in global internet infrastructure, where hyperscale providers are transitioning from centralised deployments in established hubs to a more distributed architecture that brings data processing closer to users.

Seoul's emergence as a hyperscale hub is driven by several factors. Firstly, South Korea's highly urbanised and densely populated landscape creates substantial demand for low-latency, high-performance cloud services. Industries such as gaming, media, and finance are particularly reliant on real-time data processing, making the deployment of edge nodes in Seoul and other major cities a strategic priority for hyperscale providers.

Moreover, South Korea's leadership in 5G deployment further enhances its attractiveness as a hyperscale market. Integrating 5G with cloud infrastructure necessitates edge computing capabilities to handle the massive data throughput and low-latency requirements of 5G applications. Hyperscale providers are, therefore, likely to continue expanding their presence in South Korea to capitalise on the country's advanced telecommunications infrastructure.

South Korea's growth as a hyperscale market is part of a larger trend in the APAC region, where emerging markets like Seoul, Jakarta, and Mumbai are increasingly seen as essential to the global cloud strategy. This shift is driven by the limitations of traditional hubs, such as the moratorium on new data centre developments in Singapore, which has forced providers to look for alternative locations. South Korea, with its stable regulatory environment and strong technological base, is an ideal candidate for this expansion.

However, while South Korea is on the rise, the market remains highly competitive, and the capacity of existing infrastructure will be tested as demand continues to grow. Moreover, expanding hyperscale infrastructure in South Korea will require substantial investment, not just in data centres but also in supporting power and connectivity infrastructure to ensure reliability and scalability.

Publicly available reports and data need to provide comprehensive details on the placement of these nodes, making it difficult to fully assess the extent of hyperscale cloud infrastructure within South Korea. This lack of transparency presents challenges for our study, as it restricts our ability to accurately map and analyse the deployment density and strategic positioning of edge nodes in the region. Consequently, our findings may be constrained by these data limitations, underscoring the need for more granular reporting in future research efforts to better understand the evolving cloud landscape in South Korea.

4.4.2. China/ People's Republic of China (PRC)

4.4.2.1. Edge Computing Market

The edge computing market in China has demonstrated a remarkable growth trajectory. In 2022, the market generated approximately €747 million in revenue and is projected to surge to €12.5 billion by 2030[32]. This represents an expected CAGR of 42.2% from 2023 to 2030, indicating a robust and rapidly expanding market.

The hardware segment was identified as the largest revenue-generating component in 2022, underscoring the significant investment in the physical infrastructure necessary for edge computing deployment. Moreover, IDC forecasts that the CAGR of China's overall edge computing server market will reach 23.1% from 2021 to 2026, outpacing the global growth rate of 22.2%. This suggests that China's edge computing market is growing rapidly and outperforming the global average, positioning the country as a leader in this technological domain.

In 2022, China's edge computing industry witnessed an explosion of innovation, with seven out of the top ten organisations filing the most patents for edge computing being Chinese[33]. This surge in intellectual property creation indicates a strategic emphasis on developing proprietary technologies and solutions within the edge computing sphere. Patent filings are a critical indicator of a country's innovation capacity and commitment to advancing a particular technological sector.

One of the key drivers for edge computing innovation in China is the smart grid sector. The country's vast 5G infrastructure is being leveraged to enhance smart grid operations, which require real-time data processing and analytics. Additionally, edge computing is increasingly used in applications that demand immediate data exploitation, such as video processing and analytics, autonomous vehicles, and robotics.

The global edge data centre market, valued at approximately €8.61 billion in 2022, is expected to grow at a CAGR of 18.4% from 2023 to 2030, reaching around €32.11 billion by 2030. Key players in this market include multinational corporations such as Fujitsu, Hewlett Packard Enterprise Development LP, Huawei Technologies Co., Ltd., IBM, NVIDIA Corporation, Schneider Electric, and Vertiv Group Corp.

China is expected to remain the edge spending leader until 2027, with Asia/Pacific spending on edge computing forecasted to reach approximately €40.2 billion in 2024, marking a 17%

[32] Note: The conversion from USD to € was done based on the average exchange rate of 1 USD = 0.92 €, which may vary slightly depending on real-time currency fluctuations. Grand View Research. (2023). Edge Computing Market Size, Share & Trends Analysis Report. Retrieved from Grand View Research.

[33] EqualOcean. (2023). Edge Computing in China: A Deep Dive. Retrieved from EqualOcean.

increase over 2023[34]. The market's expansion reflects China's broader ambitions to lead in the technological sphere. As the market matures, we expect to see more innovation, increased investment, and a competitive landscape fostering domestic and international collaborations. Given these trends, the edge computing market in China is poised for a promising future, with significant implications for global technology and business strategies.

4.4.2.2. Policies, investment and enabling conditions

The Chinese government's commitment to establishing China as a global leader in new technologies and Industry 4.0 is a significant driver of digital advancement, particularly in the realms of 5G and the IoT. As the largest and most advanced IoT market worldwide, China is seeing its major operators embark on ambitious 5G initiatives, including the deployment of standalone 5G networks starting in 2020. This leadership in 5G and IoT is creating a conducive environment for edge computing, positioning mobile operators at the forefront of technological innovation[35].

China has set ambitious targets for the nation's computing capabilities. By 2025, China aims to reach an aggregate computing performance of 300 exaflops, a significant leap from the 197 exaflops reported in the previous year ("China's national computing plan targets 300 exaflops of compute, edge, and advanced storage"). This goal is part of a broader national computing plan that underscores the importance of edge computing in the country's technological advancement. The Ministry of Industry and Information Technology (MIIT) has been instrumental in this push, signalling strong government backing for edge computing initiatives.

4.4.2.2.1. Towards 2025: the "Made in China" and the "14th Five Year Plan" strategies

Among the key strategies adopted by China, the "Made in China 2025" initiative aims to drive the country's economic growth until 2025. Recognising its position as the "world's factory," the strategy sets the foundations for the short-term Chinese economy. One main priority is to enhance the quality of domestically produced materials, ensuring China remains a global economic leader. Additionally, the strategy emphasises reducing reliance on foreign technology imports and investing in in-house innovation, allowing Chinese companies to compete both nationally and globally. In this sense and introducing the relevance of the Made in China 2025 strategy in Edge, significant investments are being made to advance AI, IoT, and 5G coverage, promoting better use of edge computing[36].

Another key policy document is the 14th Five-Year Plan (2021-2025)[37], which outlines the priorities for these years. Part V of the plan specifically addresses "An Initiative to Build a Digital China." The Chinese government acknowledges the vast potential of big data for numerous applications and plans to leverage this for economic and industrial growth. The plan aims to accelerate the development of integrated research and development in general-purpose processors, cloud computing systems, and core software technologies. Key advancements will focus on cutting-edge technologies like quantum computing, quantum communications, neurochips, and DNA storage. The plan also encourages enterprises to provide open-source codes, hardware designs, and application services. Emerging digital industries, including artificial intelligence, big data, blockchain, cloud computing, and cybersecurity, will be

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[34] IDC. (2023). According to IDC, Asia/Pacific Spending on Edge Expected to Reach $43.7 Billion in 2023, Driven by Rising Demand for Low Latency Services. Retrieved from https://www.idc.com/getdoc.jsp?containerId=prAP51260523

[35] GSMA (2020), Edge computing in the 5G era; Technology and market development in China, https://data.gsmaintelligence.com/api-web/v2/research-file-download?id=51249270&file=2903-240220-Edge-China.pdf

[36] Institute for Security & Development Policy (2018), Made in China 2025, ISDP

[37] The People's Government of Fujian Province (2021), Outline of the 14th Five-Year Plan (2021-2025) for National Economic and Social Development and Vision 2035 of the People's Republic of China, Fujian Government

strengthened. The quality of industries such as communications equipment, core electronic components, and key software will also be enhanced.

The efforts in Edge Computing are also demonstrated by the government support for new technologies and significant investment in 5G and IoT networks. GSMA[38] Intelligence forecasts that Chinese operators will invest nearly €183.20 billion in new 5G networks from 2018 to 2025. As 5G networks expand, edge use cases will grow to include autonomous driving, sporting events, and gaming. According to the ECC, over 100 edge computing projects are operational in 40 cities across various sectors, including smart campuses, smart manufacturing, AR/VR, cloud gaming, smart ports, smart mining, and smart transportation. However, challenges remain regarding the optimal placement of the network 'edge,' necessary investment levels, and appropriate business models.

The digitalisation initiative will also encompass society, smart cities, government (open access and sharing of public data), and cyber communities[39].

4.4.2.2.2. The Action Plan for the High-Quality Development of Computing Infrastructure

The Chinese government is taking a proactive approach to developing edge computing. The Ministry of Industry and Information Technology has issued a revised "Action Plan for the High-Quality Development of Computing Infrastructure"[40].

As the key reference for government initiatives in advancing Edge computing in China, this document recommends a thorough analysis of the primary drivers, objectives, and tasks outlined in the Action Plan for the High-Quality Development of Computing Power Infrastructure.

Drivers:

- Diversifying supply and optimising Layout: Mobilise various market entities to build a coordinated development system for general-purpose computing, intelligent computing, and supercomputing. Promote the integrated application of new-generation information technology (IT) and computing facilities, guiding the intelligent upgrading of computing operations.
- Demand-driven and strengthening empowerment: Adhere to market demand orientation, promoting the integrated development of computing and the real economy.
- Innovation as a driver: Leverage the innovative role of scientific research institutes, universities, and enterprises in technological breakthroughs and the conversion of scientific and technological achievements into practical applications. Form a consolidated force for the development of the technology industry.
- Green, low-carbon, secure, and reliable: Ensure that the development of computing is sustainable, environmentally friendly, secure, and dependable.

By 2025, the following goals are set:

- Compute scale: Achieve a computing scale exceeding 300 EFLOPS, with intelligent computing making up 35%. Ensure balanced and coordinated development between eastern and western regions.

[38] GSMA (2020), 5G Driving Edge Computing Momentum in China Finds New GSMA Study, GSMA

[39] Centre for Security and Emerging Technology (2023), Action Plan for the High-Quality Development of Computing Power Infrastructure, Georgetown

[40] Centre for Security and Emerging Technology. (2023). China's Compute Infrastructure Action Plan. Georgetown University. Retrieved from https://cset.georgetown.edu/publication/china_compute_infrastructure_action_plan/

- Carrying capacity: National hub data centre clusters will achieve direct network transmission with latency no higher than 1.5 times the theoretical latency. Optical transport network (OTN) coverage in key application sites will reach 80%, and 40% of backbone networks and metropolitan area networks will support innovative technologies like IPv6 and SRv6.
- Storage capacity: Total storage capacity will exceed 1800 EB, with advanced storage capacity making up over 30%. Disaster recovery coverage for core and important data in key industries will reach 100%.
- Application empowerment: Create new computing businesses, models, and formats. Increase compute penetration in industry, finance, healthcare, transportation, and other fields. Promote large-scale applications in energy, education, and other sectors. Establish over 30 application benchmarks in key areas.

The Chinese government has set ambitious tasks to enhance its computing infrastructure and capabilities. These include improving the Comprehensive Supply System to meet increasing demands, boosting the efficiency of the national computing Carrying Capacity by enhancing data transmission and network infrastructure and strengthening Storage capacity to ensure greater flexibility, efficiency, and reliability. Additionally, the government aims to deepen Compute-Enabled Industry Applications, promote the development of Green and Low-Carbon Computing for a more sustainable future, and fortify Security Assurance Capabilities to protect data and computing infrastructures.

4.4.2.2.3. Further investments and obstacles
China's substantial investments in 5G and IoT pave the way for rapid edge computing growth, positioning the country as a global leader in digital innovation.

With 5G prioritised as a national strategy, China aims to drive widespread digital transformation. By 2025, it will have nearly 800 million 5G users, representing half its mobile connections. To support this, Chinese telecom operators are investing €228.71 billion in mobile networks between 2018 and 2025, with €164.67 billion dedicated to 5G, accounting for nearly 20% of global 5G spending. The rollout of 5G Standalone (SA) networks will further enhance industry applications, making 5G the key enabler of edge computing, which relies on fast, low-latency connections to process data closer to users.

China leads the world in IoT with over 1 billion cellular IoT connections by 2019, and three-quarters of its companies have already implemented IoT solutions. The country's dominance in supplying critical technologies such as sensors and microchips supports global IoT growth and edge computing expansion. These investments are crucial for enabling edge computing in data-intensive IoT scenarios, where real-time processing closer to the edge improves efficiency and responsiveness[41].

While the Chinese government is committed to advancing digital transformation and recognises the importance of edge computing across various sectors, certain challenges were identified[42] within the current policy framework, including:

- Regulations: National and local regulations for edge data centres are largely based on guidelines for centralised cloud data centres. These regulations often do not account for the smaller scale and unique energy requirements of edge computing, creating misalignment with edge-specific needs.
- Standards: The lack of clear, unified standards for edge computing hinders widespread adoption. Despite efforts by domestic and international bodies, the market remains fragmented, making coordination complex.
- Industry-Specific Policies: Many industry verticals, such as energy and law enforcement, have stringent data policies. This can lead to developing isolated, private network solutions rather than more open, public network-based approaches, slowing broader edge computing adoption."

4.4.2.3. Edge Nodes Deployment and Density
A comparative analysis of the global distribution of commercial edge data centres reveals a significant disparity between China and the rest of the world. By the close of 2023, projections indicate that China will host over 5,700 telco-controlled data centres, whereas the rest of the world will collectively manage approximately 560 commercial data centres. This 10:1 ratio illustrates China's substantial lead in deploying edge computing infrastructure. Should the Chinese government maintain its current level of investment and strategic focus on this sector, this disparity will likely increase dramatically over the next four years. Such an expansion could position China as a dominant, perhaps even unchallenged, leader in the global edge computing

[41] Equal Ocean (2023), Overview of the Chinese Edge Computing Industry, https://equalocean.com/analysis/2023022019475#:~:text=To%20meet%20the%20network%20demand,of%20global%205G%20network%20investment.
[42] Based on a survey among Chinese businesses developed by GSMA, reference to GSMA (2020), Edge computing in the 5G era; Technology and market development in China, https://data.gsmaintelligence.com/api-web/v2/research-file-download?id=51249270&file=2903-240220-Edge-China.pdf

market, raising important considerations for the competitive dynamics of international technology infrastructure development.

The disparity in the numbers of edge data centres between China and the West is striking, but these figures alone do not capture the full complexity of the situation. In the West, the prevalence of private edge clouds implemented by individual enterprises significantly alters the comparative picture. The real difference lies not in the level of investment but in the underlying business models that drive these developments.

In China, leading technology companies like Alibaba, Tencent, and Baidu have been compelled to integrate their cloud operations with state-owned telecom operators through a policy of "mixed ownership." This arrangement has effectively centralised the deployment of edge clouds under government control, stifling independent initiatives and creating a monolithic approach to edge computing. In contrast, the U.S. market operates in a more decentralised and experimental environment, where hyperscale's, telecom operators, and neutral hosts pursue various strategies and business models. These entities are investing in regional commercial edge data centres, while many individual enterprises are opting for on-premises cloud solutions to retain greater control over their data.

The Chinese domestic edge computing industry can be segmented into three distinct components: upstream, midstream, and downstream. Each plays a critical role in the overall ecosystem. Upstream, the industry's foundation includes Cloud service providers and hardware equipment manufacturers. Cloud service providers, such as Alibaba and Tencent, are pivotal in offering edge computing platforms and application software that enable the broader ecosystem. They provide the essential infrastructure that supports the deployment and operation of edge solutions. Meanwhile, hardware manufacturers contribute by supplying the needed physical components, including edge controllers and edge AI chips.

In the midstream segment, telecom operators, edge operators and management service providers are key players. Telecom operators like China Telecom, China Mobile, and China Unicom are central to this layer, leveraging their extensive network infrastructure to support edge computing. These operators face new demands to enhance connectivity through 5G and other advanced network technologies that offer large bandwidth and low latency, essential for the efficient operation of edge computing. They are also tasked with integrating infrastructure capabilities and adapting edge computing environments to meet these demands. Service providers in this segment focus on operations such as community cloud construction and edge cloud hosting, providing the necessary management and operational services to ensure the seamless functioning of edge computing ecosystems.

The downstream segment of the edge computing industry involves Over-The-Top (OTT) manufacturers like HBO, Netflix, and CNBC, which use edge computing to decentralise content delivery, bypassing traditional content delivery network (CDN) providers for enhanced performance. Smart terminals and application developers, such as Tencent and Hikvision, also provide software and hardware solutions based on telecom operators' MEC platforms. This interlinked ecosystem, with upstream, midstream, and downstream components working in synergy, drives the expansion and sophistication of edge computing. This collaborative structure is crucial for advancing and broadening edge computing applications across various sectors, offering significant potential for innovation and growth.

4.4.3. Japan

4.4.3.1. Edge Computing Market[43]

The global edge computing market has been experiencing significant growth, reaching approximately €102.69 billion in 2020 and is projected to double to €226.8 billion by 2025[44]. In Japan, the edge infrastructure market, particularly focused on hardware, was valued at around €2.71 billion in 2021 and is expected to grow to €4.59 billion by 2026. This expansion is driven by the increasing adoption of edge computing across various industries, particularly in applications requiring real-time decision-making capabilities. These use cases include AR/VR, AI-driven machine control and monitoring in manufacturing, video streaming, drone operation, autonomous driving, and remote surgery. Additionally, edge computing is becoming essential for handling large data volumes in geographically remote locations, reducing the reliance on central data centres.

A notable development within this space is the rise of edge AI, which integrates AI processing with edge computing to minimise communication with cloud servers. Traditionally, AI processing required data to be sent to either on-premises systems or cloud environments, but edge AI offers significant benefits, including reduced communication costs, lower latency, and enhanced privacy protections. The Japanese market for edge AI products and services has shown remarkable growth, with sales increasing to €48.26 million in fiscal 2021 and projected to rise to €73.71 million in fiscal 2022. The market is forecasted to maintain an annual growth rate of 41.3%, reaching €271.53 million by fiscal 2026[45]. This rapid growth underscores the critical role that edge AI is expected to play in the future of data processing and real-time analytics.

While Japan's edge computing market is advancing steadily, it is instructive to compare it with neighbouring China, which is anticipated to experience a CAGR of over 38% from 2024 to 2030. The disparity in growth rates can be attributed to the differing scales of industrialisation, technological adoption, and the overall market size of the two countries. However, Japan's expected CAGR of 43%[46] from 2024 to 2030 indicates a particularly strong growth phase, potentially outpacing China's in the latter half of the decade.

Despite the promising outlook, challenges persist in the Japanese edge computing market. Industry experts like Mr. Masayuki Shimokawabe, Research Manager at IDC Japan, have noted a need for more understanding and awareness of edge computing among enterprise buyers. This knowledge gap could impede the adoption rate and the full realization of edge computing's potential benefits.

[43] The conversion from Japanese yen (JPY) to Euros (€) was based on an approximate exchange rate of 1 JPY = 0.0069 €, which may vary depending on current exchange rates.

[44] Statista. (n.d.). Edge computing market revenue worldwide from 2019 to 2030. Statista. Retrieved August 9, 2024, from https://www.statista.com/statistics/1175706/worldwide-edge-computing-market-revenue/

[45] Ministry of Internal Affairs and Communications. (2023). Information and Communications in Japan: White Paper 2023. Retrieved from https://www.soumu.go.jp/johotsusintokei/whitepaper/eng/WP2023/pdf/00_fullversion.pdf

[46] Grand View Research. (2023). Edge computing market size, share & trends analysis report. Retrieved from https://www.grandviewresearch.com/industry-analysis/edge-computing-market

On the other hand, this presents an opportunity for market players to engage in educational and promotional activities to raise awareness and demonstrate the value proposition of edge computing solutions. By addressing this knowledge gap, companies can facilitate a more robust integration of edge computing technologies within the Japanese enterprise landscape.

4.4.3.2. Policies, Investment and Enabling Conditions

4.4.3.2.1. Current status and issues

Over the past three decades, Japan has experienced what is often called the "Lost 30 Years," a period marked by a significant delay in digitalisation, leading to a sharp decline in its international competitiveness. The automobile industry, historically a mainstay of the Japanese economy, has faced drastic transformations due to the rise of digital technologies such as Connected, Autonomous, Shared, and Electric vehicles (CASE). This shift reflects broader industrial challenges; for example, the number of Japanese companies ranked among the world's top 10 by market capitalisation has plummeted from seven in 1989 to none by 2020, and Japan's share of the semiconductor market has drastically decreased from 50.3% in 1987 to just 10.0% in 2019.

Compounding this decline is a long-term stagnation in digital investment. While countries like the USA have significantly increased their digital investments—seeing a 3.6-fold increase from 1994 to 2018, which corresponded with a 2.8-fold increase in gross domestic product (GDP)—Japan's figures have remained relatively static, with both digital investment and GDP growing by only 1.1 times during the same period. Much of Japan's digital investment has focused on optimising existing practices rather than on transformative digital expansion (DX) that could generate new business value, particularly for SMEs. A startling 80% of IT budgets in Japanese firms are allocated to maintaining and operating existing systems, highlighting a conservative approach to digital innovation.

Another critical issue is the need for more digital talent. According to the International Institute for Management Development (IMD) World Digital Competitiveness Ranking, Japan ranks 49th in talent and 63rd in skills among 64 countries[47]. Furthermore, 40% of Japanese companies report a major need for more quality and quantity of digital talent, underscoring a significant gap that could hinder future technological and economic growth.

The overall decline in Japan's digital competitiveness, contrasted with advancements in other countries, has been stark. In 1992, the market capitalisation of major Japanese digital companies like Nippon Telegraph and Telephone Corporation (NTT), Fujitsu, NEC Corporation (NEC), and Hitachi was €102.3 billion, compared to €27.9 billion for United States companies grouped under Google, Apple, Facebook, Amazon, and Microsoft and virtually nothing for China's Baidu, Alibaba, and Tencent. By 2020, this landscape had shifted dramatically: US firms soared to €6.975 trillion and Chinese firms to €1.302 trillion. Japanese companies lagged at €167.4 billion.

The explosive increase in data traffic due to the digitalisation of society has underscored the need for substantial infrastructure improvements, particularly in Japan's vision for implementing Society 5.0[48] nationwide. This vision requires the establishment of data centres

[47] IMD World Competitiveness Online. (n.d.). Digital competitiveness of Japan. Retrieved from https://worldcompetitiveness.imd.org/countryprofile/JP/digital?internal=true

[48] Government of Japan (2015), Society 5.0., https://www8.cao.go.jp/cstp/english/society5_0/index.html

and micro edge data centres in rural areas to handle the anticipated 30-fold increase in data traffic over the next decade. Data processing must occur within 0.01 seconds to support technologies such as autonomous driving and drones. However, data transmission from rural areas to major urban centres like Tokyo or Osaka currently takes about 0.05 seconds, highlighting a significant challenge in meeting these new demands.

The COVID-19 pandemic has also revealed numerous issues and lessons regarding administrative services, underscoring the urgent need for a digital transformation of society, including an overhaul of existing regulations and institutions. Discrepancies between national and regional systems and flaws in online procedures have been particularly problematic, demonstrating the necessity for a more cohesive and digitally integrated administrative framework.

Another key area for improvement is the business environment concerning energy procurement. Restraining industrial electricity costs and securing carbon-free energy sources are essential for competitiveness in a rapidly evolving global market.

Moreover, other countries' large-scale industrial policies in digital generic technology reinforce the competitive landscape. For instance, China has significantly invested in its semiconductor industry, with the "Integrated Circuit Industry Investment Fund"[49] investing over €33.5 billion in semiconductor-related technology in 2014 and 2019, supported by additional funds from rural governments. In Europe, the "Digital Compass 2030" initiative aims to create secure, high-performance, and sustainable digital infrastructure focusing on networks, semiconductors, and quantum computing with an investment of €125.96 billion. The US has also taken substantial steps, passing the National Defence Authorization Act (NDAA)[50] of 2011, which includes grants totalling over €2.79 billion and establishing the "Multilateral Microelectronics Security Fund." Furthermore, the Senate passed the U.S. Innovation and Competition Act (USICA), which includes a €4.65 trillion investment in semiconductors, reflecting a significant commitment to securing a lead in critical technologies.

4.4.3.2.2. New directions and target public policy

Fifty years ago, in 1972, Japan introduced the “Building a New Japan” plan, which aimed to decentralise the country by redistributing industries and developing nationwide transportation and telecommunications infrastructure. However, instead of achieving decentralisation, the plan inadvertently accelerated urbanisation and led to uniformity in administrative services across the nation, failing to overcome the challenges posed by geographical distance.

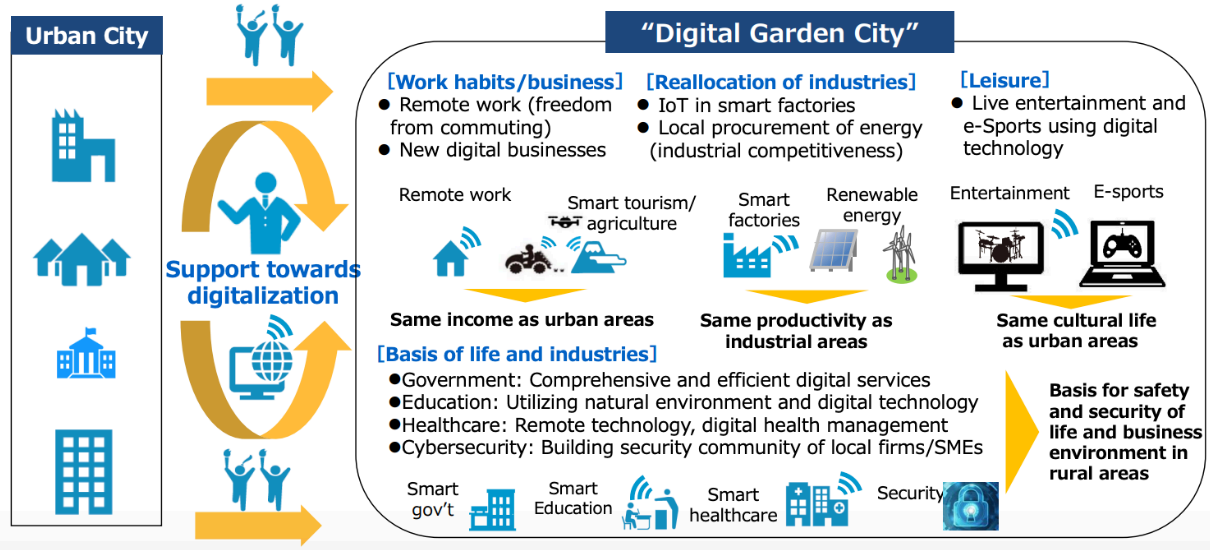
In contrast, the 2022 initiative, “Building a New Digital Japan,” seeks to harness digital technology to achieve what the original plan could not. This new strategy focuses on creating a "Digital Garden City," emphasising regional diversity and local charm. By leveraging the irreversible trend towards digitalisation, accelerated by the COVID-19 pandemic, Japan aims to reform national and regional administration, drive industrial innovation, and develop digital infrastructure. The goal is to create new jobs and businesses in rural areas, fostering prosperous and diverse communities where individuals can enjoy a high quality of life.

[49] For more information on the "China Integrated Circuit Industry Investment Fund," you can refer to SEMI. (n.d.). China Integrated Circuit Industry Investment Fund. Retrieved from https://www.semi.org/en/business-markets/tag/china-integrated-circuit-industry-investment-fund

[50] For further details on the NDAA for Fiscal Year 2024, you can view the official documents here and here.

While the 1972 plan resulted in increased urbanisation and a loss of regional distinctiveness, the 2022 plan seeks to revitalise rural areas through digital transformation, promoting regional originality and diversity.

Figure 7: Vision for a Digital Garden City Nation.



Source: Economic and Industrial Policy Bureau, METI Ministry of Economy, Trade and Industry.

Previously, Japan's digital policies were marked by a failure to fully recognise the transformative potential of digital technology, resulting in fragmented investment and only partial digitisation. This approach maintained the status quo, leading to a period known as the "Digital Defeat," where Japan fell behind in global competitiveness due to these insufficient and misaligned efforts.

In contrast, the new strategy is dynamic and comprehensive, emphasising real transformation across all sectors. It prioritises digital investment as a catalyst for economic growth and urges a cohesive vision between the public and private sectors. Key focus areas include enhancing cloud and software industries, upgrading critical infrastructure like semiconductors and data processing technologies, and fostering a business environment attuned to the digital age through regulatory reform and strategic procurement.

As part of Japan's new digital policy, the country focuses on creating strategic partnerships and tendering collaborative initiatives with key global players. A prime example is the strengthened alliance between Japan and France in Edge AI. This collaboration has been particularly evident in their joint leadership within the Global Partnership on Artificial Intelligence (GPAI), where Japan recently succeeded France as the GPAI Council Chair.

In line with these policy directions, Japan and France have launched a joint call for proposals on Edge AI[51], a critical area that combines AI with edge computing to enhance privacy, reduce latency, and improve operational security. Edge AI is increasingly vital as AI technologies are integrated into diverse systems, such as smartphones, medical devices, and industrial applications. Unlike cloud-based AI, Edge AI processes data locally, offering significant benefits in energy efficiency, real-time performance, and data security—key elements for sectors like healthcare, telecommunications, and Industry 4.0.

[51] Japan Science and Technology Agency (JST). (2022). Guidelines for Joint Call for Proposals on Edge AI: JST-ANR Joint Research Program [PDF]. Retrieved from https://www.jst.go.jp/inter/sicorp/download/fr/edge_ai2022/guidelines.pdf

This joint initiative seeks to harness the shared vision of Japan and France, promoting high-quality research collaborations between academia and industry in both countries. By addressing key challenges such as AI for embedded systems, distributed AI, and Green AI, the initiative aims to advance the practical application of Edge AI, fostering innovation that can be directly transitioned into marketable products and services.

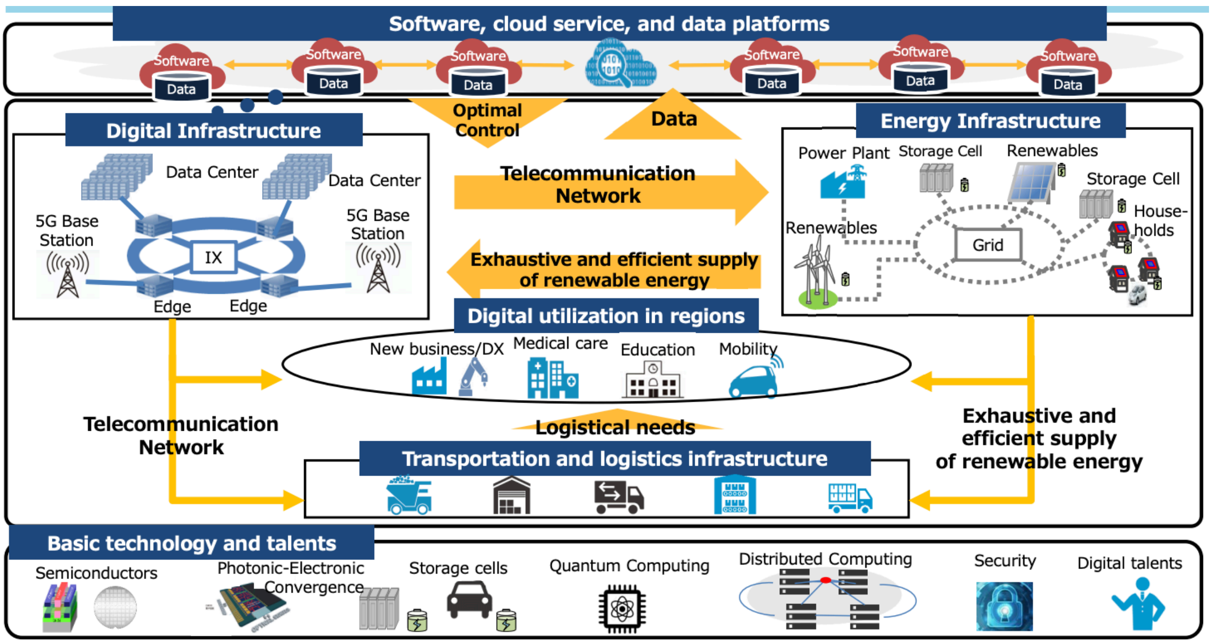
This shift aligns with global trends where countries are intensifying efforts to build robust digital infrastructures and foster innovation. By adopting these measures, Japan aims to catch up and potentially lead in digital advancements, ensuring economic resilience and growth in an increasingly digital world.

In essence, Japan's strategic pivot towards comprehensive digital integration reflects a critical and necessary response to past inadequacies, positioning it for a stronger future in the digital global economy.

4.4.3.3. Edge Nodes Deployment and Density

Japan's strategic roadmap for advancing its digital and energy infrastructure is a comprehensive plan that strongly emphasises edge computing and deploying edge data centres. Starting in 2022, the focus is on laying the groundwork for developing hybrid and public cloud infrastructures, essential for supporting the growing demands of IoT and facilitating a shift from traditional on-premise systems to more agile, cloud-based operations. The parallel expansion of 5G networks and optical fibre is critical to handle the anticipated surge in data traffic, ensuring that the infrastructure can support real-time data processing. These efforts are coupled with a forward-looking approach to optimising data centre locations and promoting renewable energy, reflecting Japan's commitment to building a sustainable and resilient digital infrastructure.

Figure 8: Japan industrial roadmap.

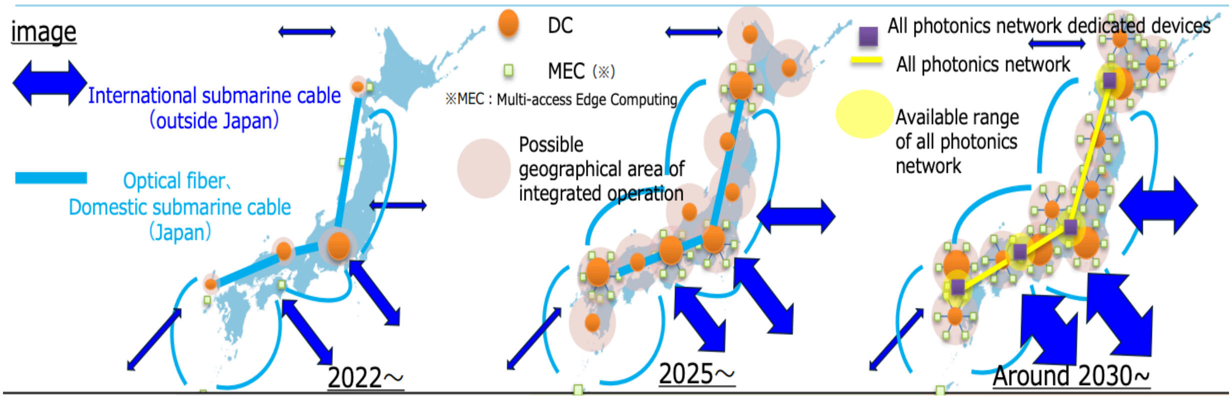


Source: Economic and Industrial Policy Bureau, METI Ministry of Economy, Trade and Industry.

As the plan progresses toward 2025, Japan envisions a significant evolution in its digital infrastructure by deploying regional cloud services and hyper-distributed computing. These developments are key to enhancing the efficiency and responsiveness of the nation's data networks. Integrating multi-access edge computing (MEC) and quantum cryptography advancements will strengthen edge environments' security and processing capabilities, crucial for supporting emerging technologies like Digital Twin systems and IoT platforms. This phase underscores Japan's dedication to building a robust digital ecosystem that meets the demands of advanced applications such as autonomous driving and remote surgery and ensures data security and processing efficiency.

Toward 2030, Japan anticipates the full-scale implementation of quantum computing and the deployment of an all-photonics network, which will revolutionise data transmission and processing speeds. The plan's emphasis on using renewable energy as the primary power source for this advanced digital infrastructure showcases a strategic alignment with environmental sustainability goals. Developing next-generation semiconductors and advanced storage batteries will further enhance the infrastructure's resilience, ensuring it can support the growing demands of a data-driven economy.

Figure 9: Japan's phased development of integrated digital and photonic infrastructure (2022-2030).



Source: Economic and Industrial Policy Bureau, METI Ministry of Economy, Trade and Industry.

Conclusion

The EU is actively pursuing a leading role in edge computing, reflecting its broader ambitions to enhance physical and cybersecurity, achieve climate neutrality, and uphold rigorous regulatory standards. These objectives are intricately linked to the EU's commitment to fostering technological innovation while remaining aligned with European values. However, attaining global leadership in edge computing entails navigating substantial challenges, mainly when competing against regions with significant technological and resource advantages, including the United States, China, Japan, and South Korea.

In the United States, edge computing advancements are significantly propelled by large technology firms endowed with substantial financial resources and expansive domestic markets. Prominent entities such as AWS, Microsoft Azure, and Google Cloud have invested enormously in edge infrastructure, leveraging their extensive R&D budgets to drive rapid innovation. The substantial financial resources of these companies facilitate the scaling and deployment of cutting-edge technology. Additionally, the high level of R&D expenditure in the U.S. supports the development of advanced microprocessors, network optimisation techniques, and integrated AI solutions. The vast domestic market further provides ample opportunities for large-scale testing and deployment of edge applications, enhancing the innovation ecosystem.

In contrast, China's edge computing landscape benefits from a centralised government model, which enables streamlined decision-making and large-scale implementation of projects. The Chinese government's strategic approach, exemplified by initiatives such as the "New Generation Artificial Intelligence Development Plan," allows for rapid and coordinated advancements in edge computing technologies. State support and subsidies play a crucial role in the rapid development and deployment of infrastructure by tech giants such as Huawei and Alibaba. Furthermore, China's massive population of over 1.4 billion creates a substantial domestic market for edge applications, fuelling demand and facilitating large-scale deployment.

Japan and South Korea, while smaller in scale compared to China, are making significant strides in edge computing through their focus on technological innovation and strategic investments. Japan's emphasis on high-precision manufacturing and advanced robotics integrates seamlessly with edge computing to enhance industrial applications and IoT solutions. South Korea's strategic focus on 5G deployment and smart city initiatives is driving the integration of edge computing into urban infrastructure and industrial automation, demonstrating the country's commitment to advancing next-generation technologies.

The EU faces distinctive challenges due to its decentralised governance structure. The union's framework, characterised by diverse national policies and varying levels of economic development across member states, complicates the implementation of a cohesive edge computing strategy. The regulatory diversity within the EU necessitates careful navigation to develop uniform edge computing solutions, while the complexity of coordinating across multiple sovereign states adds further layers of difficulty.

Additionally, the EU must contend with market and infrastructure constraints. With a population of approximately 450 million, the EU's market size is significantly smaller than China's, which impacts the scale and scope of edge computing infrastructure and applications. Leveraging existing telecommunications infrastructure across the EU is crucial, yet this requires overcoming regional disparities in network capabilities and technological readiness.