MetaOS

INSIGHTS

Overview

The Directorate-General for Communications Networks, Content and Technology has invested €60 million in six complementary research and innovation projects under Horizon Europe topic :

HORIZON-CL4-2021-DATA-01-05: Future European platforms for the Edge: Meta Operating Systems.

The report illustrates the development of Europe's "Meta-Operating Systems" concepts

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Executive Summary

MetaOS cluster consisted as a group of six EU-funded projects, which created a digital continuum, where data and applications move between devices, edge nodes, and clouds, enabling faster, smarter, and more secure data processing. The MetaOS initiative has worked over a period from 2021 – 2025, having supported 6 projects under the European Funding Programme Horizon Europe. It reflects the EU's strategic priorities: strengthening technological autonomy, ensuring security and trust in digital systems, and maintaining global competitiveness in fast-moving fields such as AI, IoT, and edge–cloud computing.

The MetaOS cluster presents how Europe's "Meta-Operating Systems" concept is transforming cloud–edge–IoT computing.

Already validated in energy, mobility, agriculture, and viticulture, MetaOS technologies are proving their real-word value reducing latency, saving energy, and strengthening Europe's digital sovereignty in the emerging area of industrial edge infrastructures. This initiative has received EUR 60 million in EU support.

Moving beyond traditional cloud-centric models that send vast amounts of data to distant data centres, MetaOS introduces a continuum model that unites IoT devices, edge nodes, and the cloud into a single, intelligent infrastructure. At its core, MetaOS instances orchestrate distributed computing resources as one coherent platform, enabling data to be processed closer to its source. The result is a foundation for interoperable, secure, and energy-efficient digital systems that enhance performance, protect privacy, and serve both European citizens and industries. Several industrial solutions of a MetaOS are illustrated in this report.

Looking ahead

The lessons learned from these pilots will provide a strong foundation for new initiatives in areas such as swarm computing, large-scale edge AI in the energy sector, and the creation of a generative AI–powered digital backbone for Europe. The rapid evolution of AI represents a major opportunity for European industries. As generative and agentic AI mature, and real-time data processing becomes widespread at the network edge, entirely new possibilities will emerge for new initiatives in areas such as swarm computing, large-scale edge AI in the energy sector, and the creation of a generative AI–powered digital backbone for Europe.

Building on MetaOS platform concepts, Europe is well positioned to take a lead on AI-powered edge systems, connecting innovation, industry, and policy in pursuit of a human-centric, competitive, and sustainable digital future.

For more information on the projects and their use case, explore the initiatives: aerOS, ICOS, FLUIDOS, NebulOus, NEPHELE, and Nemo with all projects details as well as market pathways to be found in the portal www.eucloudedgeiot.eu

THE PROJECTS ALLOCATED €4.3 MILLION THROUGH OPEN CALLS TO EXPAND THEIR DEVELOPER BASES. THE RESPONSE DEMONSTRATES MARKET INTEREST:

255

Applications from

32

Countries

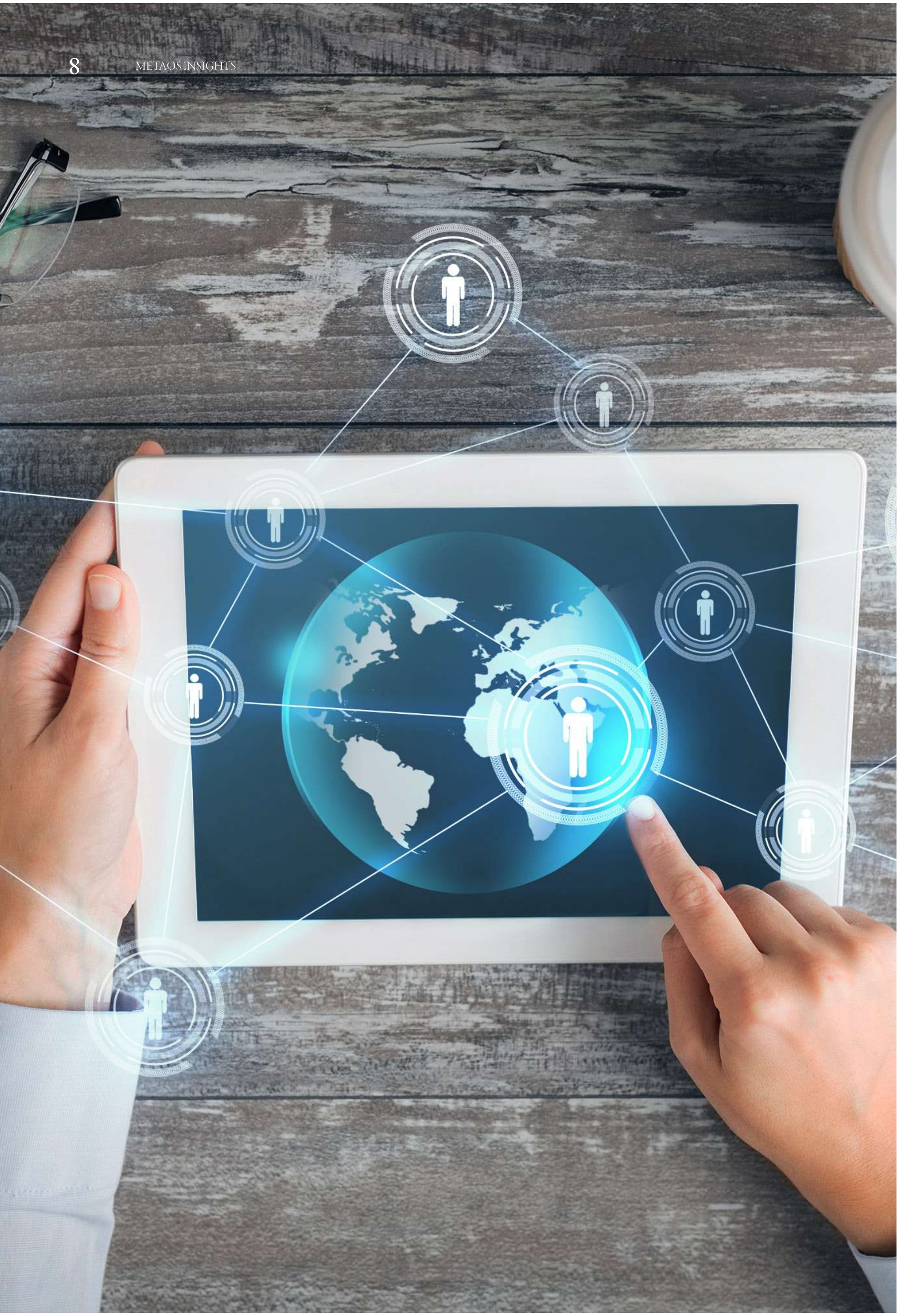
91%

from small and medium enterprises

45

funded companies are now building applications on MetaOS platforms, creating an ecosystem that extends beyond the original consortium members.

This expansion shows how standardised edge computing interfaces enable rapid application development across agricultural, automotive, energy, and manufacturing sectors.



MetaOS Projects

EUROPEAN EDGE COMPUTING STRATEGY

INTERNET OF INTELLIGENT THINGS

The MetaOS initiative lays the groundwork for edge computing technologies that deliver critical data streams to AI-powered IoT and decentralised intelligence applications.

These projects demonstrate unique approaches to system engineering via the orchestration, distribution, and coordination of resources across multiple sectors.

All the while, simultaneously aligning with Europe's data, green, and industrial strategies.

Building on established industrial expertise, Europe has developed strong capabilities in Smart IoT operating systems for industrial applications.

The projects supported by Horizon Europe have developed edge operating systems for the energy, farming, mobility, and automotive sectors, leveraging advances in European chip development

Industry experts from multiple sources predict that 80% of data processing will shift to network edges within five years, leading to the "Internet of Intelligent Things."

This presents European industry with opportunities to capture edge computing markets through smart infrastructures, interoperability standards, and regulatory frameworks.

Market Testing

EUROPEAN EDGE COMPUTING

The MetaOS projects tested their platforms through competitive processes designed to elicit interest from external developers.

Each project ran open calls with funding ranging from €60,000 to €200,000 per application, targeting companies that could build on the platform architectures.

The aerOS project received 38 proposals for its first call, funding seven applications that addressed port logistics, agricultural machinery visibility, and energy consumption analysis.

Geographically, the call saw interest from organisations ranging from Spain, Italy, the Netherlands, Serbia, and Cyprus, a clear indicator of cross-border developer interest.

These open calls provided market validation that the platforms could support third-party development. Companies built applications without the need to fully understand the underlying complexity of container orchestration, protocol translation, or resource allocation. Instead, they focused on sector specific problems while the MetaOS platforms handled the edge computing infrastructure.

This division of labour approximates the pattern that enabled the explosion of smartphone app stores, but has not yet taken hold in industrial applications.

2030

New pilot programs launched in 2025 focus on cross-sector edge platform solutions to support standardisation and adoption by small and medium enterprises and startups.

According to the Draghi report, the Digital Decade target of deploying 10,000 climate-neutral edge nodes by 2030 suggests that the European edge computing market is still in its early stages of development.

MetaOS

TECHNICAL FOUNDATION

Edge computing is the next logical step after today's de facto dominant cloud computing model.

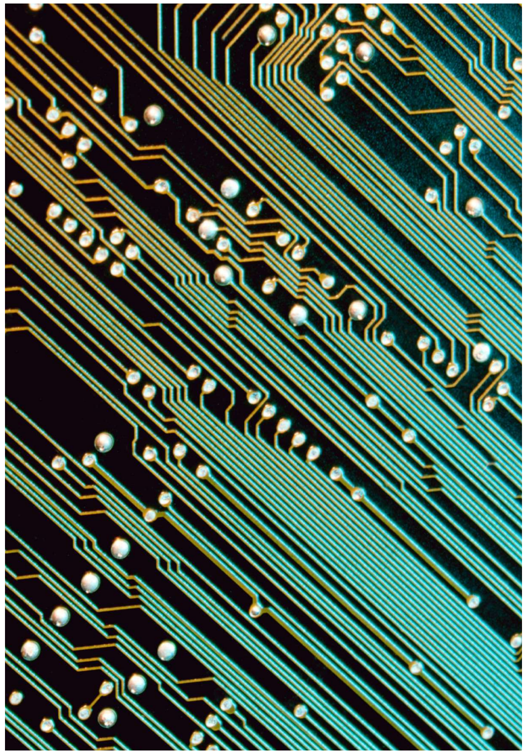
By eliminating the need for long-distance connections, edge computing enables resilience, near real-time operations, enhanced security, privacy, and protection, while also reducing energy consumption and carbon footprint.

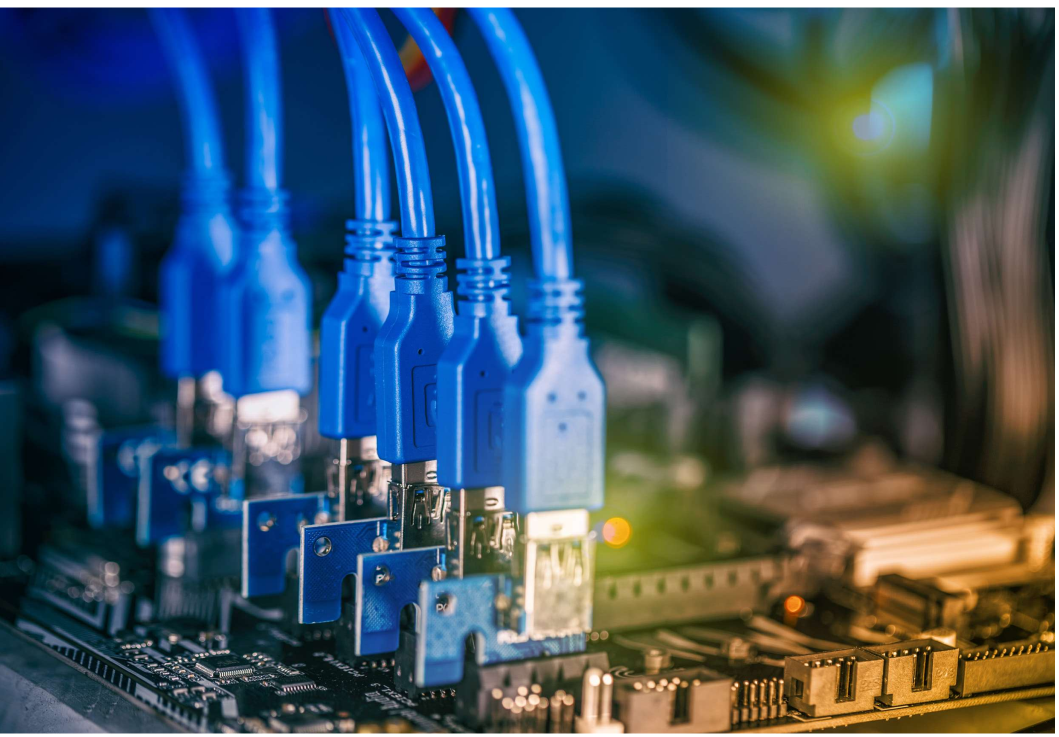
Europe holds a competitive advantage where cloud IT and operational technology intersect, particularly in industrial automation, manufacturing systems, and energy infrastructure management.

Advancements in computing chips and IoT node capabilities have enabled the introduction of cloud technologies, via containers and visualisers, to the industrial world of fixed systems, transforming them into connected, automated entities.

As the software and hardware components are separated, a software, firmware, or hardware layer known as a hypervisor is required to manage and allocate computing resources. Hypervisors introduce new challenges due to their inherent complexity; however, system integrations offer new opportunities for key industrial sectors.

Investing in digital platforms for IoT and edge computing across various sectors and companies is necessary to capitalise on this technological transition. These platforms must enable European industry to compete effectively in emerging edge computing markets while maintaining technological sovereignty and regulatory compliance.





MetaOs

INDUSTRIAL OPERATING SYSTEMS

European companies hold strong positions in industrial and business sectors, including enterprise systems, manufacturing, smart energy systems, home appliances, mobility, agriculture, and green technologies. These sectors are transitioning toward software-defined systems that enable functionalities to be programmed and updated remotely.

The Meta Operating System concept was born to address this transition.

A standard operating system manages hardware in a single device and hides the technical complexity from programmers. A MetaOS extends this across multiple connected devices, coordinating their hardware and masking the complexity of managing them together.

A MetaOS orchestrates applications and services across different domains. In automotive applications, this means coordinating powertrain and telematics functions. In the charging infrastructure, this means integrating energy and mobility systems. This approach enables the creation of new operational models by deploying and managing distributed computing workloads on container-based edge platforms.

Container-based platforms and microkernels streamline the deployment and operation of edge computing environments, making them more flexible, for example, through over-the-air software updates. A MetaOS provides high-level abstractions for functions and services across edge devices, similar to how Android manages smartphone applications.

Given this cross-domain approach, edge computing requires orchestration to ensure applications optimally utilise all connected devices and systems. An open ecosystem of developers could build around a MetaOS, creating application marketplaces that combine software development speed with customisation and rapid deployment.

This model has flourished in consumer electronics but has shown limited adoption in select industrial sectors, including building automation and agriculture.

MetaOs

ACROSS INDUSTRIAL SECTORS

Through competitive open calls, 45 additional companies received funding to build applications on these platforms, transforming abstract technical capabilities into sector-specific solutions.

The applications range from haptic communication devices to electric vehicle charging management to precision irrigation systems. This expansion demonstrates how a standardised edge computing platform serves to enable the rapid deployment across diverse industrial contexts.

The examples below show how each platform addresses operational challenges that a remote, centralised cloud computing model cannot meet, including latency, connectivity, and data sovereignty requirements.

CarOS is a concept that establishes application marketplaces for software-defined vehicles, enabling automotive manufacturers to remotely deploy and update vehicle functions.

An AgriOS is considered as a platform to connect farming operations for real-time agricultural management and crisis response coordination.

A TerraviewOS has been branded by the Swiss company Terraview to provide edge computing for viticulture operations, processing vineyard sensor data locally for precision farming decisions.

EnergyOS is a platform that transforms energy sector operations by processing grid management data at distribution points rather than centralised facilities.

AgriOS

CONNECTED FARMING

The example demonstrates how MetaOS platforms address specific industrial constraints.

In agriculture, geography presents a unique set of connectivity limitations. Factor in time-sensitive decisions that need to be made in the field, the need for local processing capabilities is readily apparent.

Modern agricultural operations rely heavily on cloud-based systems, including weather forecasting, resource planning, decision support tools, crop analytics, pathogen databases, maintenance services, management platforms, and irrigation control systems. These systems require significant computing resources and long-term data storage that individual farms cannot maintain locally.

Farm Management Information Systems analyse data from sensors, weather stations, tractors, and harvesting equipment to optimise resource usage and crop

yields. However, cloud-based processing creates challenges for remote agricultural operations with limited network connectivity and those crucial decisions made in the field.

Agricultural vehicles generate substantial sensor data from monitoring crop conditions, soil quality, and harvesting operations that require immediate processing. TTControl (controlled by TTTech Computertechnik), integrated into machinery, handles time-sensitive decisions locally, while data can synchronise with cloud services when time and connectivity permit.

A THREE-LAYER APPROACH

Cloud services provide weather data, crop analytics, pathogen identification, and maintenance scheduling.

A middleware layer manages data storage, cybersecurity, and access policies for robotic operating systems.

Field-level edge computing processes real-time sensor data from tractors and harvesting equipment, utilising real-time kinematic positioning to enable precise location tracking for planting and harvesting operations.

Processing data at the field level rather than transmitting everything to cloud facilities enables immediate responses to conditions. Time-sensitive decisions, such as obstacle detection, crop quality assessment, or irrigation adjustments, are executed then and there, on machinery to generate instant responses.

In contrast, resource-intensive analyses, such as seasonal crop predictions or pathogen pattern recognition, are processed in cloud facilities when connectivity permits.

TTControl participates in the aerOS project, demonstrating flexible edge applications on connected tractors. Drones collect aerial data that complements ground-level sensors, feeding information into learning algorithms that enhance the machinery's ability to understand complex farming processes.

Container-based platforms streamline the deployment of edge applications in agricultural settings.

Farmers can deploy specialised applications for specific tasks, such as precision spraying, variable-rate seeding, or harvest quality monitoring, without the need to modify the underlying machinery.

TTControl's approach addresses connectivity limitations in rural areas while enabling a data-driven approach to agriculture.

CarOS

SOFTWARE-DEFINED VEHICLES

In opposition to Agriculture, Automotive applications face different constraints.

Safety-critical functions require guaranteed response times that cloud connectivity cannot provide. At the same time, manufacturers want to update non-critical systems remotely throughout the vehicle's operational lifetime.

Modern vehicles contain over one hundred electronic control units, each controlling specific functions from braking to infotainment. This fragmented architecture creates engineering complexity and blocks software updates over a vehicle's lifetime.

Carmakers are pursuing their own operating system platforms, following Tesla's example of controlling the full software stack. European manufacturers are taking a collaborative approach, sharing the engineering burden of replacing hundreds of distributed control units with a centralised computing architecture.

The MetaOS cluster had limited automotive use cases, but this work connects to broader European efforts. On March 5, 2025, the European Commission unveiled an Industrial Action Plan for the European Automotive Sector. A key element is the European Connected and Autonomous Vehicle Alliance, launched in 2025 to bring together European automotive stakeholders. The alliance develops shared software and hardware building blocks, including a software platform for software-defined vehicles and AI solutions.

Application marketplaces offer third-party navigation, entertainment, and productivity services across vehicle brands.

Horizon Europe partnerships make €1 billion available for the automotive sector during 2025-2027, with €350 million dedicated to next-generation battery technology.

A CarOS provides a standardised software layer across different vehicle models, similar to Android or iOS in smartphones. The architecture operates in distinct layers: application marketplaces offer third-party services across vehicle brands, platform interfaces provide standardised access for developers, system services manage vehicle-specific functions, and a hypervisor enables the parallel execution of safety-critical and non-safety-critical software on shared computing resources.

Safety-critical operations like braking, steering, and collision avoidance execute on vehicle hardware for immediate response, operating independently of network connectivity. Non-critical functions like infotainment updates leverage cloud-based services when connectivity permits.

The HAL4SDV project under the European Chips Act brings together automotive manufacturers and suppliers to develop hardware abstraction platforms that separate software from underlying vehicle hardware. This enables software-defined vehicle architectures for both safety-critical and non-safety-critical applications.

Component-based software architecture enables over-the-air updates, decoupling software development from hardware production cycles. Manufacturers can introduce new functions throughout the vehicle's operational lifetime without requiring physical access to reprogram control units.

European automotive companies recognise that controlling vehicle operating systems provides competitive advantages that hardware manufacturing alone cannot deliver, preventing dependence on foreign software platforms while enabling the marketplace business models that software-defined vehicles require.

TerraviewOS

OS FOR VITICULTURE

Viticulture faces a different challenge; the integration of multiple data sources to enable time-sensitive decisions.

A vineyard manager monitoring for disease cannot wait for data to travel to remote data centres, get processed, and return as an alert. Vineyard management depends on soil sensors, weather stations, drone imagery, satellite observations, and manual inspections.

Traditional aprocess and integrate these disparate sources. By the time data gets analysed in a distant facility and returns as an alert, the infection window has passed. Disease outbreaks, nutrient deficiencies, and harvest timing require decisions based on current conditions.

TerraviewOS from Terraview GmbH provides a cloud-native service that operates through edge devices installed at vineyard sites. These edge devices handle data collection locally, while the central service provides cloud-based processing.

The architecture integrates edge and cloud processing, with each edge device acting as a FLUIDOS node corresponding to a vineyard section that manages one or more vineyardvs and shares resources across the network.

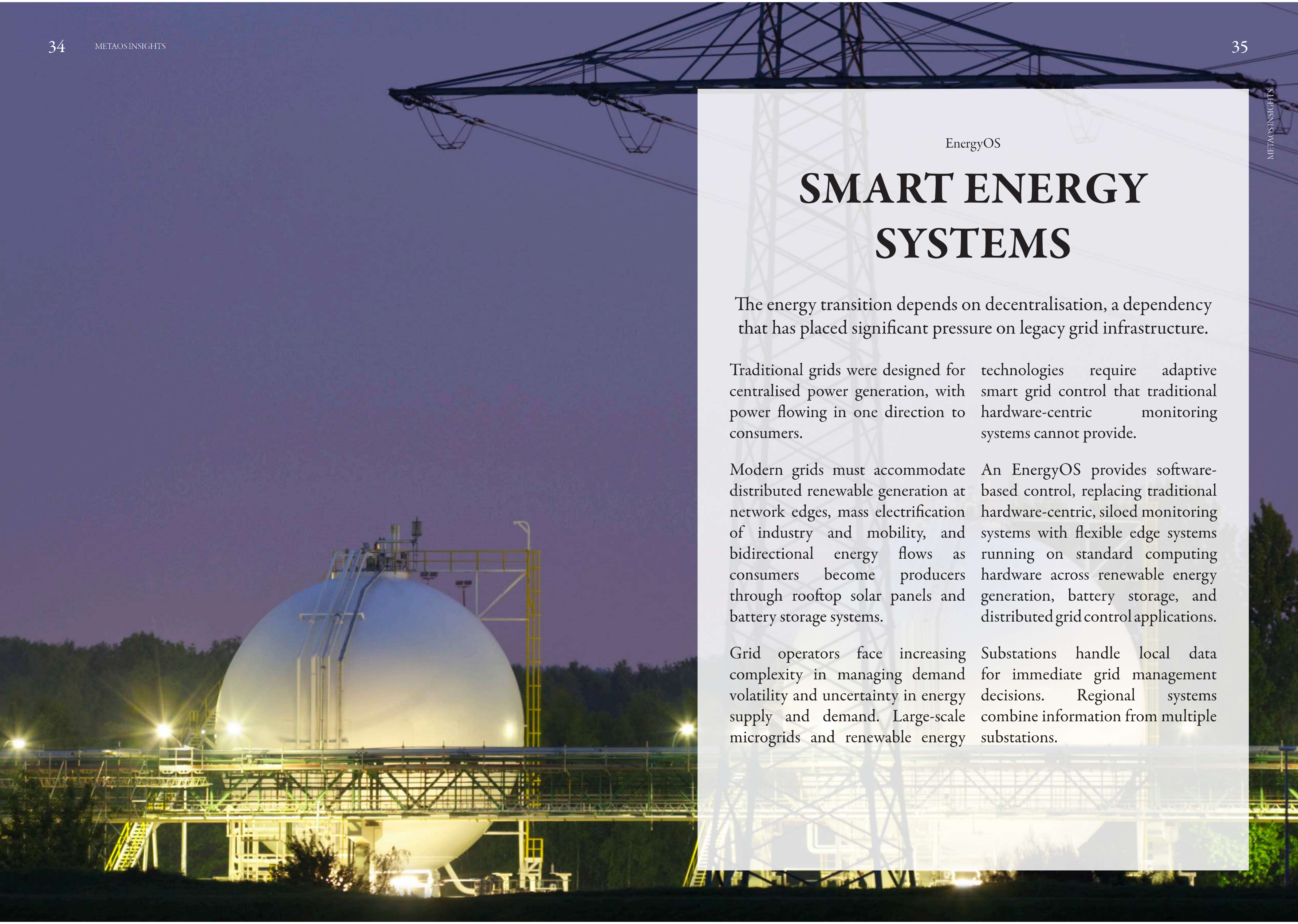
Processing vineyard data at edge locations rather than transmitting everything to centralised facilities enables faster responses to changing conditions. Time-sensitive decisions, such as irrigation adjustments and disease outbreak alerts, are executed on edge devices for rapid response.

Resource-intensive analysis, such as seasonal yield prediction processes using cloud services, combines artificial intelligence with historical data and real-time information.

The platform of the Swiss-based company Terraview improves operational efficiency by enabling vineyard managers to make quick, informed decisions based on data rather than intuition. It keeps them one step ahead of potential disease outbreaks by analyzing weather patterns, humidity levels, and historical disease occurrence data.

Likewise, the system identifies nutrient deficiencies through visual analysis and can provide yield estimates by combining meteorological data with soil sensors and plant health indicators.

The platform improves operational efficiency by presenting complex data through easy-to-understand interfaces that vineyard managers can access on-site. Real-time monitoring replaces periodic manual inspections with ongoing, continuous assessment, thereby providing the viticulture industry with a never-before-seen level of quality and consistency.



EnergyOS

SMART ENERGY SYSTEMS

The energy transition depends on decentralisation, a dependency that has placed significant pressure on legacy grid infrastructure.

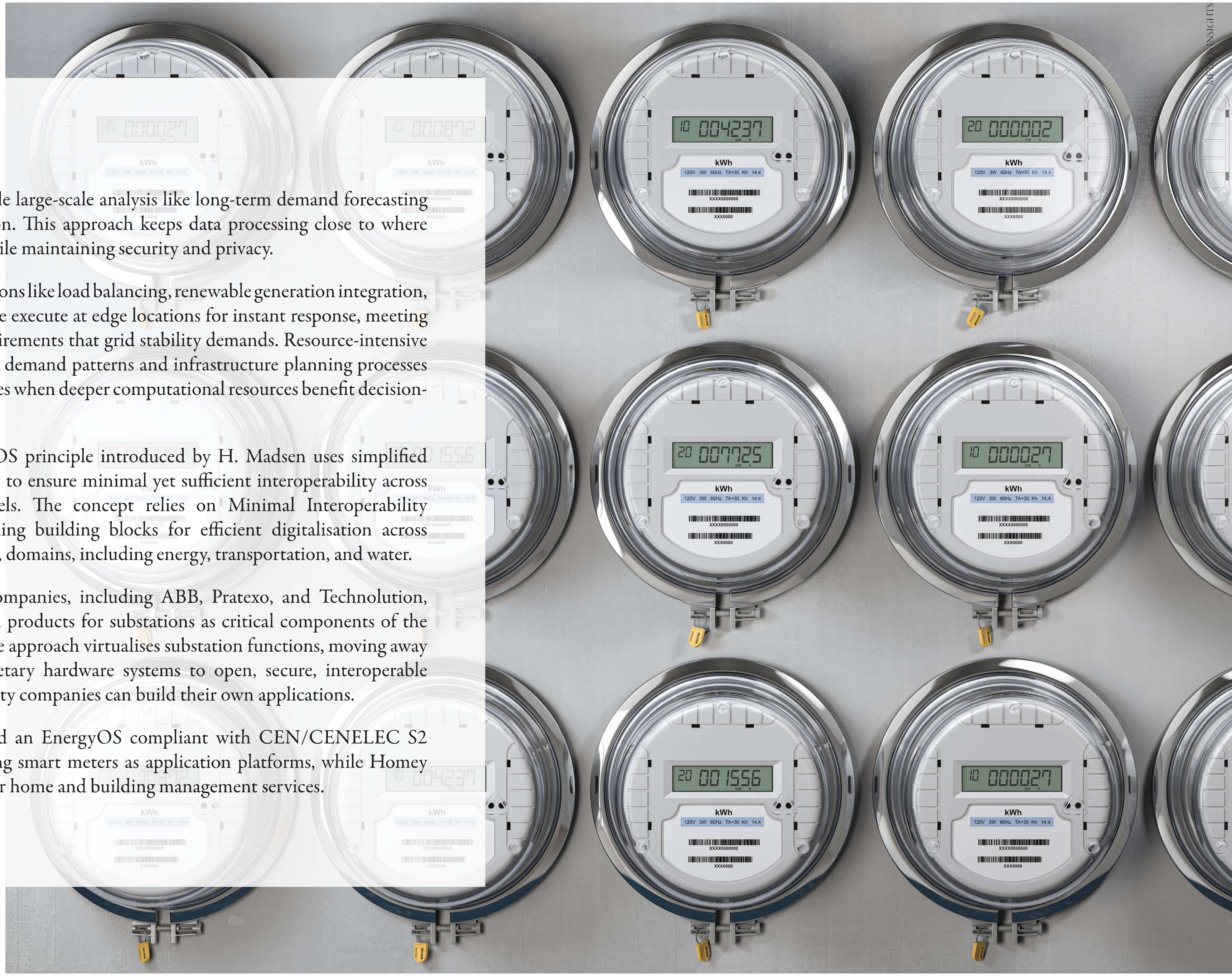
Traditional grids were designed for centralised power generation, with power flowing in one direction to consumers.

Modern grids must accommodate distributed renewable generation at network edges, mass electrification of industry and mobility, and bidirectional energy flows as consumers become producers through rooftop solar panels and battery storage systems.

Grid operators face increasing complexity in managing demand volatility and uncertainty in energy supply and demand. Large-scale microgrids and renewable energy technologies require adaptive smart grid control that traditional hardware-centric monitoring systems cannot provide.

An EnergyOS provides software-based control, replacing traditional hardware-centric, siloed monitoring systems with flexible edge systems running on standard computing hardware across renewable energy generation, battery storage, and distributed grid control applications.

Substations handle local data for immediate grid management decisions. Regional systems combine information from multiple substations.



Cloud services handle large-scale analysis like long-term demand forecasting and grid optimisation. This approach keeps data processing close to where decisions happen while maintaining security and privacy.

Time-sensitive decisions like load balancing, renewable generation integration, and demand response execute at edge locations for instant response, meeting the low-latency requirements that grid stability demands. Resource-intensive analysis like seasonal demand patterns and infrastructure planning processes through cloud services when deeper computational resources benefit decision-making.

The Smart Energy OS principle introduced by H. Madsen uses simplified Flexibility Functions to ensure minimal yet sufficient interoperability across relevant system levels. The concept relies on Minimal Interoperability Mechanisms, providing building blocks for efficient digitalisation across different, but related, domains, including energy, transportation, and water.

Several industrial companies, including ABB, Pratexo, and Technolution, use EnergyOS-based products for substations as critical components of the distribution grid. The approach virtualises substation functions, moving away from closed, proprietary hardware systems to open, secure, interoperable platforms where utility companies can build their own applications.

Technolution piloted an EnergyOS compliant with CEN/CENELEC S2 standards, positioning smart meters as application platforms, while Homey offers an app store for home and building management services.

MetaOS

TURBINE MONITORING AT THE EDGE

Wind turbines operate in harsh offshore environments where maintenance requires expensive vessel deployments.

Wind turbines contain sensors monitoring turbine specifications, location, weather conditions, and component status.

Operators need continuous monitoring to optimise performance and prevent unplanned breakdowns, but wind turbines generate enormous sensor data measuring wind speed, direction, power output, temperature, pressure, and component status that cannot be transmitted to distant data centres for real-time processing.

Traditional maintenance relies on scheduled inspections and reactive repairs, but offshore locations make physical access expensive and weather-dependent.

TTTech's edge computing platform processes operational data locally at turbine sites, enabling remote diagnostics and real-time performance monitoring without depending on constant connectivity to distant data centres.

The platform architecture separates safety-critical and non-critical functions through virtualisation.

Safety-critical operations, such as emergency shutdown systems and blade pitch control, run independently on dedicated computing resources, while non-critical functions, such as performance analytics and predictive maintenance, share computing capacity on the same hardware through virtual separation.

METAOS INSIGHTS

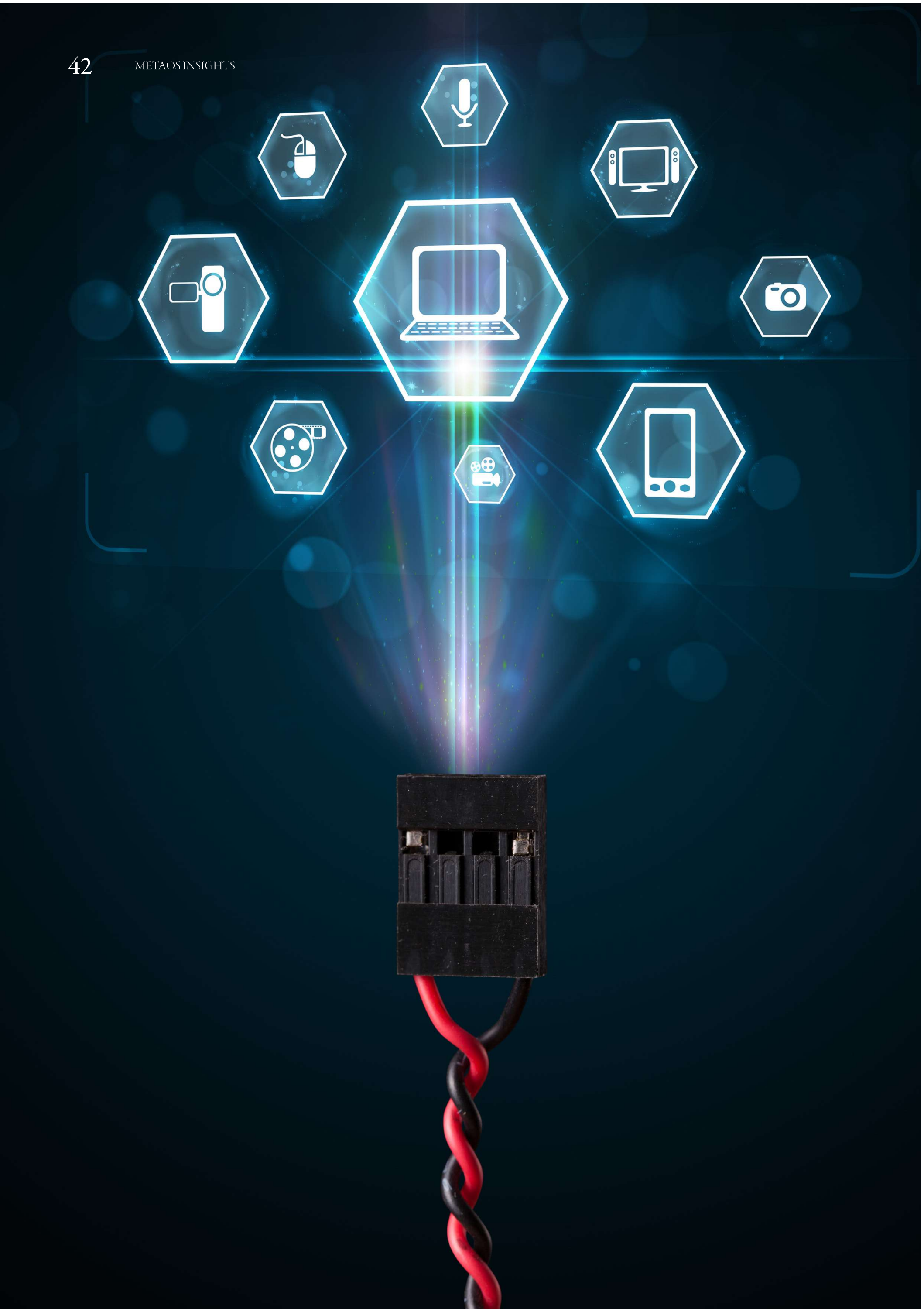
Time-sensitive decisions, such as adjusting blade angles based on wind conditions or detecting component vibrations that indicate bearing failures, are executed locally for instant response. Detailed performance analysis and long-term maintenance planning can use cloud resources when connectivity permits.

Container-based software deployment enables over-the-air updates for wind turbine operations, allowing operators to update software, deploy new diagnostic tools, and add monitoring capabilities without requiring physical access to offshore installations.

The platform architecture enables secure data sharing with third parties without compromising critical operations. Non-critical operational data from turbine sensors or inspection drones can be made available to maintenance contractors, weather forecasters, or grid operators at specific access points while critical control systems remain isolated.

An open computing platform creates opportunities for application marketplaces at turbine locations. Developers could create specialised applications for predictive maintenance, performance optimisation, or environmental monitoring that operators install like smartphone apps.

Machine learning and artificial intelligence applications could analyse turbine performance patterns and predict maintenance needs, creating an AI app store specifically for wind energy operations that processes data locally rather than requiring constant cloud connectivity.



OpenOs

PLATFORMS FOR EDGE COMPUTING

Edge applications utilise containerisation technologies (e.g. Docker) that enable portability across various hardware platforms. Edge software platforms essentially eliminate underlying hardware differences, enabling system interoperability across diverse industrial ecosystems. Platform services include multi-protocol integration for operational technology, data processing and filtering, local analytics, data storage, security services, and cloud connectivity.

Crucially, these platforms must operate independently of specific protocols, clouds, hardware, or operating systems, while still utilising component-based architectures that support flexible application deployment. A hallmark of effective edge software platforms is an openness to different sector-specific ecosystems. This receptivity has led to standard interfaces that enable third-party applications to access and process operational data.

Open-source software facilitates the creation of developer and innovator ecosystems around open-edge platforms. A leading initiative of this type with broad cross-industry support is the Linux Foundation's LF Edge. EdgeX Foundry, one of the most significant projects under the LF Edge organisational umbrella, provides a flexible platform that facilitates interoperability between operational technology devices and edge applications.

Several MetaOS projects integrate open-source solutions, enabling European developers to build on established open-source foundations rather than creating proprietary alternatives. These projects include ZetaScale/Eclipse and Nuvla.io/Sixsq.

Competitive Positioning Through

PLATFORM CONTROL

The MetaOS initiative is not iterating on existing technology. It demonstrates a different paradigm for European industrial digitalisation.

The current model requires manufacturers to route operational data through foreign cloud platforms, accepting dependency on high-speed connectivity and relinquishing control over data access and processing locations. The MetaOS approach processes data at its source, operates during network failures, and keeps industrial information under European control.

This matters for competitive positioning. Companies that control edge platforms can determine who accesses industrial data and how applications interact with physical operations. The exponential growth of connected IoT devices and systems, combined with the increasing use of AI, will drive the need for data processing at the edge and facilitate the transformation of key sectors. The MetaOS cluster has developed commercially available industrial solutions that manage hardware resources through abstraction layers, introducing application-oriented business processes similar to those found in consumer app stores.

Global spending on edge computing continues to rise, driven by the increasing adoption of multi-core microcontrollers from European semiconductor manufacturers. Data localisation becomes increasingly essential for European industrial digitalisation in the transport, manufacturing, energy, and agriculture sectors.

Industrial applications that require low latency and high data volumes benefit from edge computing, which enhances performance and security by processing data locally rather than transferring it to distant data centres. Since emerging industrial applications require low latency and significant data volumes steered by AI, edge computing enables better performance and reduces latency for connected assets, thereby keeping data transfers more secure.

The emerging cloud-edge-IoT process creates an environment distinctly different from today's cloud and data processing market, one that is currently dominated by American hyperscalers.

Without a coordinated European action, industrial operators will develop siloed, isolated solutions that lack interoperability and open standards. As stated in the v report, new pilot programs launched in 2025 focus on cross-sector edge platform solutions to support standardisation and adoption by small and medium enterprises and startups.

Edge computing creates demand for European chip manufacturing capacity, particularly for mainstream chips above 28 nanometers and chiplet architectures that leverage European strengths in automotive, sensor, and power-control applications. The Digital Decade target of deploying 10,000 climate-neutral edge nodes by 2030 suggests that the European edge computing market is still in its early stages of development.

The convergence of AI and IoT is inevitable and will result in smart products that adapt in real-time, creating service-driven experiences for both consumers and businesses. The creation of these experiences creates monetisation opportunities for equipment manufacturers and system integrators, but also requires new approaches in the engineering of complex systems such as energy grids.

The potential of Edge AI represents significant opportunities for European industries. When generative AI arrives, including the realisation of real-time data processing at edge locations, entirely new possibilities for industrial applications are opened.

The AI-powered processing of data from various industrial systems at edge locations enables capabilities previously impossible. When viewed in light of the evolution toward open AI application marketplaces at the edge, this shift could reshape European industrial value chains, enabling new business models and competitive advantages in sectors where Europe maintains operational technology leadership.