D2.1: ECOSYSTEM DEFINITION AND REQUIREMENTS

ANNEX 8: CLUSTER 3E DEFINITION AND REQUIREMENTS

This annex covers Cluster 3E - Energy System Resilience and Efficiency in Western Greece, exploring how COP-PILOT supports the deployment of advanced ICT and energy technologies across three interconnected use cases spanning grid flexibility, biogas co-production, and EV charging infrastructure. It demonstrates how edge intelligence, predictive analytics, and IoT-enabled platforms can drive cost reductions and operational improvements while advancing resilient, low-carbon energy systems across distributed locations in Western Greece.

D2.1: Ecosystem definition and requirements

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Abstract	The COP-PILOT platform is an open collaborative system for managing services across IoT, edge and core computing environments. COP-PILOT is built to enable secure and intelligent operations that connect diverse sectors. This document brings together an ecosystem of technical blueprints and services models across 5 main domains to support the development of these infrastructures. With a focus on seamless cross domain integration, it lays the foundation for private edge deployments and digital ecosystems across Europe. This deliverable sets the direction for building a platform that drives smarter, more secure, and collaborative digital transformations across multiple industries.
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Nature of the deliverable:	R	
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PU	Public, fully open, e.g. web (Deliverables flagged as public will be automatically published in CORDIS project's page)	X
SEN	Sensitive, limited under the conditions of the Grant Agreement	
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Classified C-UE/ EU-C	*EU CONFIDENTIAL under the Commission Decision No2015/ 444*	
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* R: Document, report (excluding the periodic and final reports)

DEM: Demonstrator, pilot, prototype, plan designs

DEC: Websites, patents filing, press & media actions, videos, etc.

DATA: Data sets, microdata, etc.

DMP: Data management plan

ETHICS: Deliverables related to ethics issues.

SECURITY: Deliverables related to security issues

OTHER: Software, technical diagram, algorithms, models, etc.

CLUSTER 3E INTRODUCTION

The energy-related Greek pilot of the COP-PILOT project, identified as Cluster 3E, is focused on enhancing energy system resilience and efficiency through three use cases (UC#3E.1–3E.3), mapped directly to the cluster's specific objectives. The cluster includes a distributed, yet interconnected ecosystem of innovative energy applications powered by advanced ICT and energy technologies across multiple locations in Western Greece.

Specifically, the cluster includes locations in: i) Patras (πNET 5G test and UoP laboratory environment), where through the use of a distribution grid simulator and an advanced testbed featuring 5G and beyond communication infrastructure, the cluster will test the real-time flexibility harvesting using a cloud-edge platform, ii) a Biogas electricity co-production plant located in Preveza, which will be enhanced with new type of sensors to monitor the anaerobic digestion in the facility, and processing at the edge to improve electricity generation in cross sector industries. Iii) A cluster of EV charging stations at the broader area of Western Greece (owned by DEI - Public Power Corporation) where predictive maintenance and energy forecasting at the edge will enhance charging reliability.

The cluster faces different physical challenges in the deployment of equipment at industrial and urban locations where housing and maintenance of equipment is subject to different constraints, as well as technical, in term of lack of training data, data privacy issues and interfacing between different stakeholders.

Cluster 3E's strategic ambition is to integrate distributed RES and flexible loads into active distribution networks using advanced edge intelligence, predictive analytics, and IoT-enabled platforms. It demonstrates significant business impact by enabling cost reductions in grid operation, EV maintenance and biogas operations This aligns with COP-PILOT's broader vision of promoting resilient, low-carbon energy systems through technological innovation and cross-sector orchestration.

ANNEX 8.A: UC3E.1 - HARVESTING IN REAL-TIME FLEXIBILITY FROM ACTIVE ELECTRICITY DISTRIBUTION GRIDS

Description

Short Description

In a laboratory environment, this use case focuses on developing and validating a cloud-edge platform designed to unlock real-time flexibility from active distribution networks. As the energy grid evolves to integrate more intermittent renewable sources, the ability to dynamically adjust demand and generation becomes critical. The proposed use case addresses this challenge by implementing two core analytics services. The first is the real-time estimation of flexibility, which continuously monitors distributed energy resources -including loads, generation, and storage- to determine the grid's available flexibility at any given moment. The second, optimal control for flexibility provision, enables the intelligent coordination of these assets to deliver services such as voltage regulation, demand response, and load shifting. This use case lays the groundwork for deploying highly responsive, data-driven grid control systems in the field by leveraging laboratory conditions to simulate real-world scenarios.

Complete Description

Pre-project description: Prior to the implementation of the project, the University of Patras had already developed key components relevant to the active distribution grid environment, including a sophisticated distribution grid simulator and stand-alone algorithms for real-time flexibility estimation and optimal DER control. ***These tools were successfully validated in isolation under laboratory conditions***. However, these assets were not integrated into a unified, real-time operational workflow. The flexibility estimation algorithms operated separately from the control logic, and the simulator was not used dynamically in conjunction with live telemetry or edge devices. ***As a result, while the technical capabilities were present, they lacked orchestration, rendering them unsuitable for practical real-time applications in a connected active grid environment***. This fragmented setup significantly limited the ability to emulate and act upon real-world scenarios. ***Operators could not interact with the system in a live feedback loop, and there was no streamlined process to harvest flexibility dynamically from DERs***. Without a common orchestration layer or seamless communication between cloud-based analytics and edge control platforms, the system could not support real-time decision-making. This gap prevented the use of the platform for operational deployment and grid-supporting services, reducing the practical impact of the tools developed at the university.

After-project description: The use case deployment relies on a cloud-edge computing infrastructure located in the laboratory environment of UoP that ensures real-time orchestration of DERs for flexibility services while respecting grid operational constraints. Centralised computing resources are employed at the cloud layer to run the training and calibration modes of required analytics. This layer enables DERs to participate in innovative distribution-level energy markets while ensuring scalability through containerized microservices using Docker and Kubernetes. The edge layer comprises far-edge devices and near-edge nodes that bring intelligence closer to DERs. Far-edge devices (e.g., Raspberry Pi units) replicate DER operations by collecting real telemetry data from the cluster of real demonstrators and executing low-latency control actions. Near-edge nodes with Graphic Processing Unit (GPU) acceleration enhance real-time decision-making by executing DER activations within sub-second timeframes, replicating the edge-residing functionalities of the DER controller part of an Advance Distribution Management System (ADMS). These nodes also act as a failover mechanism in case of cloud connectivity failures, ensuring uninterrupted grid support. The communication infrastructure is built on 5G/6G networks, leveraging URLLC, Software-Defined

Networking (SDN), and network slicing to provide dedicated, high-speed, and secure channels for real time energy applications. Standardised protocols such as OpenADR, IEC 61850, MQTT, and OPC-UA facilitate seamless integration between IoT sensors, DER controllers, and grid operators.

Main actors and roles

Table 8.1 Main actors and roles

Actor name	Actor type	Actor Description and Role	Actor Role
University of Patras	Research Institution	Hosts the lab-based distribution grid simulator and develops control/ analytics logic	Designs the cloud-edge platform, runs real-time analytics, evaluates control strategies for flexibility
Cloud Simulator	Digital Infrastructure	Simulated distribution grid environment with virtual DERs and network conditions	Emulates grid behaviour for testing flexibility estimation and optimal control algorithms
Edge Node (Jetson Orin)	Edge Device	Hardware platform emulating ADMS with real-time data processing capabilities	Receives and processes real-time data, runs microservices, and generates control decisions
COP-PILOT Platform	Digital Orchestration Layer	Central integration and coordination platform for services and data exchange	Deploys services, manages system configurations, coordinates communication between edge and cloud
ENIC	Technology provider	Offers domain-specific analytics services with direct added value to the operator	Offers the edge computing infrastructure and analytics services for the use case.
pNET	Testbed provider	Provider of 5G telco infrastructure for application validation	Offers connectivity of the real pilot to the COP-PILOT platform

Ambition, Motivation and Objectives

Motivation behind UC#3E.1: UC#3E.1 is motivated by the operational challenges faced in active distribution grids due to the growing integration of DERs, including rooftop PVs and small-scale batteries. At the University of Patras, existing tools—such as a distribution grid simulator and standalone flexibility estimation algorithms—were available but operated in isolation, without a unified workflow or real-time deployment logic. This disconnect meant that, while theoretically capable, the infrastructure could not support live interaction between DERs and grid management layers, preventing automated flexibility deployment in response to dynamic grid needs such as congestion or voltage violations.

The COP-PILOT project provides the opportunity to address this shortcoming by embedding UC#3E.1 within a larger orchestration framework capable of managing heterogeneous edge, IoT, and cloud resources. The use case aims to validate how COP-PILOT's can transform these standalone modules into a coherent real-time application. It will serve as a testbed to prove that the orchestration of *far-edge flexibility controllers* and *near-edge grid monitoring services*—enabled by the COP-PILOT secure integration fabric and service orchestrator— can support automated, scalable grid services across a distributed architecture.

Ambition behind UC#3E.1: UC#3E.1 aims to demonstrate the end-to-end orchestration of real-time flexibility services using COP-PILOT as a backbone. The ambition is to show that real-time data from IoT sensors and DERs can be securely collected, processed at the edge, and used to dynamically estimate and deploy flexibility across the grid—without manual intervention. This includes orchestrating analytics workloads across NVIDIA Jetson edge devices and coordinating grid-state simulations with containerized services managed by the COP-PILOT platform. By implementing distributed intelligence, UC#3E.1 seeks to move from reactive to proactive grid management.

More importantly, the use case aspires to serve as a blueprint for how other active grid environments can implement distributed, automated flexibility management using a secure, programmable orchestration layer. The project will validate COP-PILOT's ability to host vertical energy services, ensure SLA compliance via AI-based forecasting, and demonstrate how collaborative edge applications (hosted on open IoT platforms like FIWARE) can integrate seamlessly into a real-time, ***multi-layer control loop***. UC#3E.1 will thus showcase not only the feasibility but also the added business value of using a generic orchestration platform for sector-specific smart energy applications.

UC#3E.1 mapping with project objectives:

- **Obj#1 (platform orchestration):** UC#3E.1 validates the COP-PILOT platform's ability to orchestrate vertical energy applications over the IoT-edge-core continuum using standardized interfaces and infrastructure controllers.
- **Obj#5 (Use case demonstration):** The use case demonstrates a high-TRL pilot of energy sector services, supporting COP-PILOT's ambition to test intelligent orchestration in live energy environments.

UC#3E.1 mapping with project innovations:

- **Smart SLA preservation:** The use case applies COP-PILOT's SLA management tools to ensure flexibility services remain within operational limits, testing predictive violation detection and secure actuation in a grid context.
- **Edge-aware microservices deployment:** By deploying microservices for grid simulation and flexibility control at the near/far edge, UC#3E.1 validates COP-PILOT's ability to manage containerized intelligence services in energy systems.

Rationale for using the COP-PILOT platform:

- **End-to-end orchestration:** COP-PILOT enables UC#3E.1 to move beyond fragmented lab tools by orchestrating real-time flexibility estimation, control logic, and simulation synchronised across distributed nodes.
- **Secure integration fabric:** The Secure Integration Fabric (SIF) allows seamless and encrypted communication between the various components (DERs, simulators, analytics engines), enabling resilience, trust, and data integrity.

Challenges addressed

From disjointed tools to an integrated orchestration of the tools and real-time testing environment

Current: Flexibility estimation algorithms, grid simulators, and control modules existed as standalone tools without coordinated execution.

Final Ambition: UC#3E.1 integrates these components through the COP-PILOT orchestration platform, enabling a seamless, real-time control loop across the edge and cloud.

From manual workflows to zero-touch automation

Current: System relied on manual data handling and static simulations, which delayed responsiveness and limited scalability.

Final Ambition: The use case aims to demonstrate fully automated deployment, execution, and monitoring of flexibility services through COP-PILOT's zero-touch orchestration and SLA-aware service management.

Expected outcomes

- **Outcome:** Demonstration of real-time flexibility harvesting and optimal control using distributed edge intelligence à **Mapping:** Validates COP-PILOT's objective to orchestrate sector-specific services across the edge-cloud continuum, proving its adaptability to real-world energy applications (Project Objective O2 & O5).

- **Outcome:** Seamless integration of DER estimation, control, and simulation services through the COP-PILOT orchestration platform à ***Mapping:*** Supports project ambitions on composable service design and AI-driven orchestration**,** showcasing how COP-PILOT's architecture enables dynamic, SLA-compliant deployment of vertical energy services (Project Objective O1 & Innovation I1.1).

Key pain points

- **Lack of integrated orchestration across simulation, estimation, and control components||** ***Pain Point:*** Existing components at UoP (e.g., flexibility estimation algorithm, grid simulator) operate in silos, requiring manual execution and coordination **a** ***COP-PILOT Solution:*** Provides automated orchestration of microservices across the edge-cloud continuum, enabling cohesive, real-time operation and interaction among all UC modules.

- **Inability to execute real-time, dynamic flexibility deployment at scale ||** ***Pain Point:*** Manual workflows and absence of continuous monitoring prevent timely activation of flexibility in response to grid needs à ***COP-PILOT Solution:*** Enables SLA-driven, low-latency deployment of analytics and control logic through AI-assisted orchestration and secure communication via its Secure Integration Fabric (SIF).

UC Diagrams

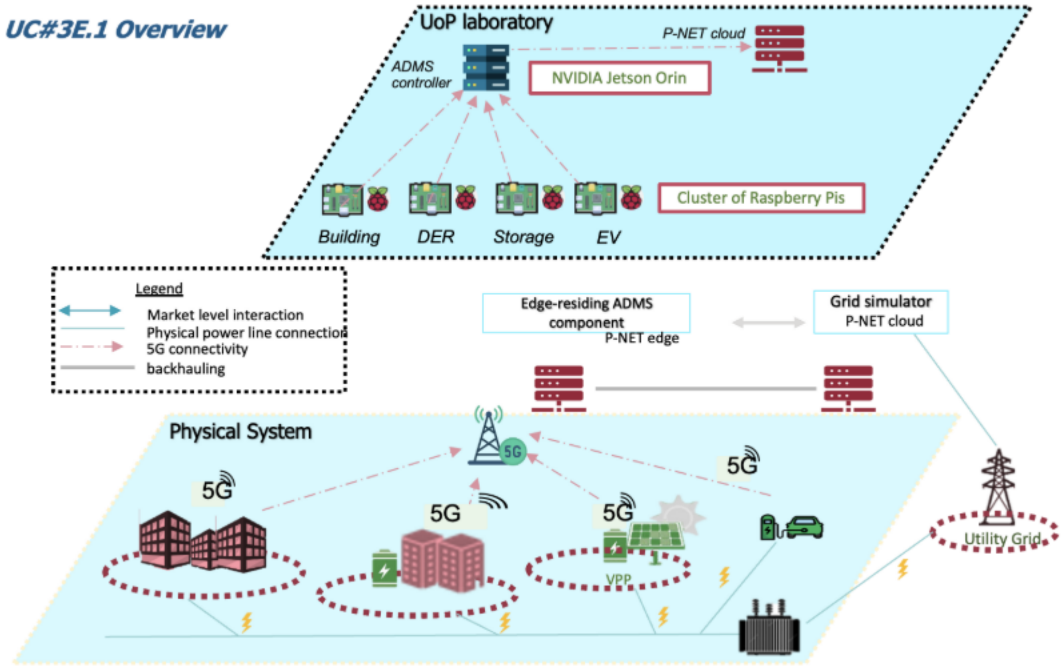

Figure 8.1 UC#3E.1 Overview

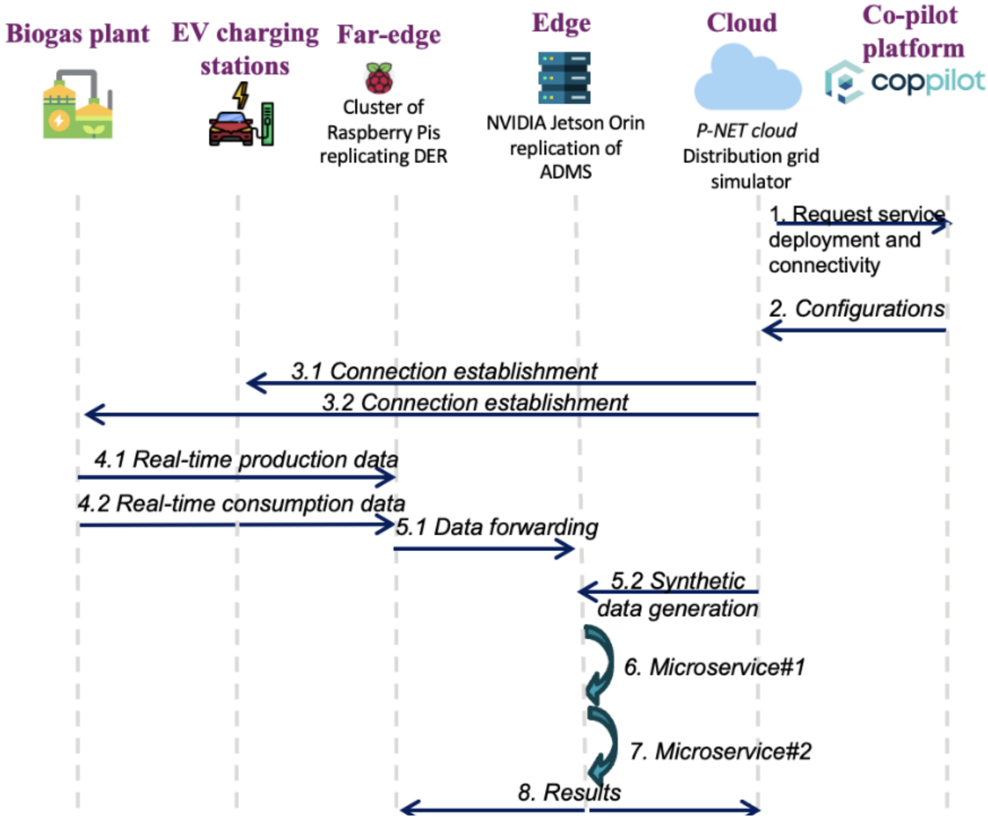

Figure 8.2 UC#3E.1 Flow diagram.

Step-by-step data and service flow

1. Request service deployment and connectivity: the co-pilot platform initiates the process by requesting the deployment of services and establishing the required connectivity with the cloud infrastructure.

2. Configurations: The cloud-based p-net distribution grid simulator performs system configurations in response to the request from the co-pilot platform.

3. Connection establishment:

    - **3.1:** a connection is established between the cloud infrastructure and the biogas plant to enable the transmission of real-time production data.

    - **3.2:** simultaneously, a connection is established between the cloud and the **EV** charging stations, allowing real-time consumption data to be collected.

4. Real-time data transmission:

    - **4.1:** the biogas plant sends real-time production data to the far-edge layer.

    - **4.2:** the EV charging stations transmit real-time consumption data to the far edge as well.

5. Data handling and processing:

    - **5.1:** the **far-edge layer**, which consists of a cluster of raspberry pi devices simulating DERs, **forwards all collected data** to the **edge layer**, where an NVIDIA jetson orin device replicates an advanced distribution management system (adms).

    - **5.2:** the edge system uses the received data to generate **synthetic datasets** for further analysis and simulation purposes.

6. **Microservice #1 execution**: The microservice related to the execution of flexibility harvesting estimation algorithms is triggered on the edge platform.

7. **Microservice #2 execution**: The second microservice related to the DERs control is invoked.

8. **Results delivery**: The outcomes from the microservices are sent back to the edge and far-edge layers, enabling local systems to act on the insights generated by the co-pilot-enabled infrastructure.

In UC#3E.1 we can identify two specific scenarios: ***Scenario#1:*** Flexibility Potential Satisfies Operator- Activation of Microservices #2 and ***Scenario#2:*** Flexibility Potential Insufficient- No Activation of Microservice #2.

Scenarios description

Scenario name:

Sufficient Insight Identified – Predictive Maintenance Triggered
Step No.:
#1
Step Event:
Service requested
Name of process/activity:
Request deployment of monitoring services
Description of process/activity:
COP-PILOT platform requests edge AI service deployment for health diagnostics
Service:
CREATE
Information producer (actor):
COP-PILOT Platform
Information receiver (actor):
Cloud (P-NET)
Information exchanged (IDs):
Deployment request for predictive maintenance microservice
Step No.:
#2
Step Event:
Cloud configuration
Name of process/activity:
Service initialization
Description of process/activity:
P-NET cloud returns configuration settings for sensor data ingestion
Service:
CONFIGURE
Information producer (actor):
Cloud
Information receiver (actor):
COP-PILOT Platform
Information exchanged (IDs):
Configuration parameters for edge deployment
Step No.:
#3

Step Event:
Connection established
Name of process/activity:
Establish data connection
Description of process/activity:
Cloud sets up connections with biogas and EV stations
Service:
CONNECT
Information producer (actor):
Cloud
Information receiver (actor):
EV/ Biogas pilots
Information exchanged (IDs):
Secure communication setup
Step No.:
#4
Step Event:
Real-time data received
Name of process/activity:
Data acquisition from field
Description of process/activity:
DERs send telemetry to Far-edge
Service:
REPORT
Information producer (actor):
Biogas/EV Stations
Information receiver (actor):
Far-edge
Information exchanged (IDs):
Production and consumption data
Step No.:
#5
Step Event:
Data forwarded
Name of process/activity:

Far-edge sends to Edge
Description of process/activity:
Data sent from Far-edge to Edge for processing
Service:
FORWARD
Information producer (actor):
Far-edge
Information receiver (actor):
Edge
Information exchanged (IDs):
Telemetry
Step No.:
#6
Step Event:
Flexibility estimated
Name of process/activity:
Run Microservice #1
Description of process/activity:
Edge estimates available DER flexibility
Service:
EXECUTE
Information producer (actor):
Edge
Information receiver (actor):
Internal
Information exchanged (IDs):
DER data
Step No.:
#7
Step Event:
Flexibility is sufficient
Name of process/activity:
Run Microservice #2
Description of process/activity:
Edge triggers DER control logic

Service:
EXECUTE
Information producer (actor):
Edge
Information receiver (actor):
Internal
Information exchanged (IDs):
DER setpoints
Step No.:
#8
Step Event:
Send results
Name of process/activity:
Report to COP-PILOT
Description of process/activity:
Edge reports control outcome to COP-PILOT
Service:
REPORT
Information producer (actor):
Edge
Information receiver (actor):
COP-PILOT Platform
Information exchanged (IDs):
Control feedback, voltage levels
Scenario name:
Insufficient Flexibility Identified — No DER Activation (Similar steps for #1-#6
Step No.:
#7
Step Event:
Flexibility is insufficient
Name of process/activity:
Decision not to trigger control
Description of process/activity:
Edge concludes flexibility is too low for action
Service:

EXECUTE
Information producer (actor):
Edge
Information receiver (actor):
COP-PILOT Platform
Information exchanged (IDs):
Flexibility insufficient flag
Step No.:
#8
Step Event:
Notify operator
Name of process/activity:
Send results to operator
Description of process/activity:
COP-PILOT notifies operator and logs outcome
Service:
REPORT
Information producer (actor):
Edge
Information receiver (actor):
COP-PILOT Platform/ Grid Operator
Information exchanged (IDs):
Outcome, no action taken

Requirements

Functional requirements

Table 8.2: Use Case functional requirements

Req. ID	Subject (+ Condition)	Commitment	Action + Object + {Constraint and/or Value}
FR1.1	Real-time flexibility estimation	Must	Continuously estimate flexibility available from DERs (refresh rate ≤ 1 min)
FR1.2	Optimal DER coordination	Must	Dynamically manage DER assets to provide flexibility services (voltage regulation, demand response)
FR1.3	Grid constraint monitoring	Must	Continuously monitor grid conditions (thermal limits, voltage)
FR1.4	Edge computing utilization	Must	Execute analytics locally at edge devices (NVIDIA Jetson Orin, Raspberry Pi)

FR1.5	Communication infrastructure	Must	Ensure reliable, low-latency communication via 5G (<1 sec latency) between far-edge and edge devices
FR1.6	Simulation of active grid conditions	Must	Simulate realistic scenarios using laboratory-based distribution grid simulators

Non-functional requirements

Table 8.3: Use Case non-functional requirements

Req. ID	Subject (+ Condition)	Commitment	Action + Object + {Constraint and/or Value}
NFR1.1	Latency	Must	Ensure data processing latency <1 second at edge nodes
NFR1.2	Reliability	Must	Maintain >99.9% uptime for real-time data analytics services
NFR1.3	Scalability	Must	Support scaling to additional DER assets and grid nodes (up to a city level)
NFR1.4	Security and privacy	Must	Ensure secure data communication and storage (encrypted transmission/storage)
NFR1.5	Interoperability	Must	Comply with standard protocols (OpenADR, IEC 61850, MQTT)
NFR1.6	Usability	Could	Provide intuitive UI dashboards for simulator users

KPIs and KVIs

UC/vertical Specific

Table 8.4 UC#3E.1 vertical specific requirements

KPI/KVI ID	Description
KPI#3E.1.1	% of real-time flexibility harvested vs. estimated potential per scenario
KPI#3E.1.2	Accuracy of flexibility estimation compared to actual DER behaviour (baseline scenario)
KVI#3E.1.1	Ability to orchestrate edge-based flexibility response under 1 seconds latency for a distribution grid with more than 100 nodes

Sustainability

Table 8.5 UC#3E.1 sustainability requirements

KPI/KVI ID	Description
KPI#3E.1.3	% of total energy demand met via flexible, distributed renewable sources
KVI#3E.1.2	System enables greater integration of renewables at the distribution level more than 10%

Environmental

Table 8.6 UC#3E.1 environmental requirements

KPI/KVI ID	Description
KPI#3E.1.4	Estimated CO_2 emissions avoided through reduced energy waste and improved charger uptime
KVI#3E.1.3	% of total charging energy dynamically optimized to reduce stress on the grid during high carbon-intensity periods

Societal

Table 8.7 UC#3E.1 societal requirements

KPI/KVI ID	Description
KPI#3E.1.5	% increase in grid flexibility available from citizen-owned DERs by 15%
KVI#3E.1.4	Lower cost of participation in grid services for local communities and prosumers by 5%

Operational and Efficiency

Table 8.8 UC#3E.1 operational and efficiency related requirements

KPI/KVI ID	Description
KPI#3E.1.6	End-to-end latency for DER activation (Edge request → device execution) less than 700 ms
KPI#3E.1.7	Average time to compute and respond to grid congestion scenario reduced by 50% compared to legacy solutions
KVI#3E.1.5	Decentralized orchestration reduces operational delays by 40% over legacy SCADA systems

Economic and Business

Table 8.9 UC#3E.1 economic and business requirements

KPI/KVI ID	Description
KPI#E.1.8	Reduction in cost per MW of flexibility enabled by edge-cloud system by 10%
KPI#E.1.9	Increase in ROI of edge-based deployment for DSOs in flexibility harvesting by 5% through simulated outcomes.
KVI#E.1.6	System supports new market models for localized flexibility trading

Scalability and EU Sovereignty

Table 8.10 UC#3E.1 scalability and EU sovereignty requirements

KPI/KVI ID	Description
KPI#E.1.10	Number of DERs supported per orchestrator instance without performance degradation

Legal and Ethics Requirements

Data Related Activities

The execution of Use Case 3E#1 involves extensive data-related activities across a cloud-edge infrastructure for the purpose of real-time flexibility harvesting and optimal DER control. The following outlines the key data management considerations:

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- Types of data collected: The UC will gather real-time telemetry data from DERS, including simulated and emulated loads, generation, and storage units. this includes power flows, voltage levels, der status, and environmental conditions.
- Data sources: Data is sourced from IoT-enabled smart meters, Raspberry Pi-based far-edge devices replicating DERS, and near-edge platforms (e.g., Jetson Orin) executing control logic. The cloud simulator and edge orchestration services may collect additional system performance data.
- Data collection purpose: The collected data will be used to dynamically estimate the flexibility potential of the distribution grid, optimize asset control, simulate active grid conditions, and support SLA-driven service orchestration.
- Data sharing and access: Data will be shared between edge, cloud, and orchestration layers via secure channels using standard protocols (e.g., MQTT, OPC-UA, IEC 61850). Access will be restricted to authorised partners (e.g., UOP, ENIC, PNET) based on defined roles in the use case.
- Consent and privacy: As the data is generated in a laboratory setting and does not involve personal user data, GDPR compliance is ensured through anonymisation and secure handling practices. No direct consent from individuals is required at this stage.
- Data re-use and availability: The data may be reused for simulation, performance benchmarking, and further research within the COP-PILOT project. Re-use outside the project scope will adhere to the data management plan (D1.2) and require proper anonymisation and licensing.
- Data security measures: end-to-end encryption (TLS), role-based access control, and physical security of edge/cloud infrastructure are in place. Network slicing and URLLC features of the 5G infrastructure add additional security and isolation.
- Data retention: Research data will be retained for a period aligned with project guidelines (typically 5 years post-project) and as specified in the D1.2 data management plan. Interim backups and redundant storage will be maintained to ensure data integrity.
- Transparency and fairness: All data processing activities are documented and traceable via the COP-PILOT orchestration platform. Any decisions made using data analytics will be explainable and auditable.
- Inclusiveness: Though UC #3e.1 is lab-based, it aims to ensure that the models and datasets developed are transferable and scalable to varied, real-world distribution grid environments, supporting energy equity and accessibility goals.

AI Systems

The AI system in UC#3E.1 is **machine-based** and implemented as a set of containerised microservices deployed across the edge-cloud continuum. These include:

- **Real-time flexibility estimation models**: These models analyze input data from simulated and emulated DERs to dynamically estimate available flexibility in the distribution grid.
- **Optimal DER control models**: These leverage AI-driven decision logic to orchestrate DER assets in real-time based on operational constraints and flexibility targets.

Level of autonomy: The system operates at **partial autonomy**. While AI modules can generate real-time decisions for flexibility control, final actuation can be configured to either occur automatically (zero-touch automation) or require validation from a human operator, depending on the operational scenario.

Adaptability: The system supports **post-deployment adaptability**. AI components include continuous learning or re-training capabilities based on feedback loops and updated data collected from DER simulations and system responses. If the topology and data change, the models can be recalibrated in the cloud and redeployed seamlessly to edge devices.

Inputs and Data Flow: The AI receives input from (i) Real-time telemetry via smart meters and emulated DERs, (ii) Environmental and system configuration parameters, and (iii) Historical performance data stored in local edge databases

Objective and utilization: The core objective of the AI is to: (i) Accurately estimate real-time flexibility potential, (ii) Enable dynamic, SLA-compliant grid support by controlling DERs under voltage, thermal, and market constraints, and (iii) Reduce human intervention in time-sensitive grid operation scenarios. These AI services enable **zero-touch orchestration**, particularly in scenarios with fluctuating RES input and unpredictable demand. **Automated Decision-Making and Oversight** Automated decisions include the Activation/deactivation of DER flexibility services.

Transparency and oversight: All AI decisions are logged and traceable through the COP-PILOT orchestration interface. Human-in-the-loop configuration is supported, especially during pilot and evaluation phases. Model explainability is ensured via visual output and diagnostic metrics on the operator dashboard.

Risk assessment and fundamental rights impact: A preliminary **risk assessment** has been planned to cover: (i) Algorithmic bias and fairness, (ii) Failure modes of real-time AI in edge environments, and (iii) Impact on operator decision autonomy.

Since the system does not interact with end users directly, **fundamental rights impacts** are minimal but still monitored, particularly for transparency and accountability.

AI Risk category: The AI system likely falls under **“*high-risk system*”** as per the draft **AI Act**, since it affects safety-critical infrastructure.

Training data:

- The models are initially trained on **synthetic datasets** generated from the UoP distribution grid simulator and real-time data from testbed devices.
- No personal data or demographic attributes are used in training.
- Efforts are made to ensure **data diversity and scenario coverage** to avoid edge condition failures and bias toward specific grid configurations.

- The data pipeline includes **validation and normalization stages** to ensure quality and prevent erroneous feedback loops.

Risk identification and assessment

Table 8.11 Use Case risk assessment

Risks	Likelihood (L / M / H)	Impact (L / M / H)	Mitigation
1. Unstable data connectivity between far-edge and edge	M	H	Implement buffer strategies and redundancy in data transfer protocols.
2. Insufficient DER flexibility to meet grid demand	H	M	Define fallback strategies (e.g. load shedding, alerts, reserve triggers)
3. Inaccurate telemetry from simulated DERs	L	M	Regular calibration and verification of synthetic data sources

ANNEX 8.B: UC3E.2 - ENSURING UNINTERRUPTIBLE POWER SUPPLY FOR FAST EV CHARGERS

Description

Short Description

As EVs become more prevalent, the demand for fast and reliable charging infrastructure rapidly increases. This use case addresses the growing need for high-performance EV DC charging stations by ensuring uninterruptible power supply and maximizing operational uptime. To support this, the approach integrates advanced forecasting and edge intelligence technologies. Hours-ahead and day-ahead forecasting models predict energy demand, user behaviour, and grid conditions, allowing for optimized energy provisioning and load management. In parallel, edge-based intelligence systems are deployed at the charging stations to enable predictive maintenance. These systems monitor critical hardware components in real-time, identifying potential faults or degradation patterns before they lead to failures. This dual-layered approach enhances the resilience and reliability of the charging network, ensuring a seamless user experience while supporting the broader goal of accelerating EV adoption across the energy ecosystem.

Complete Description

Pre-project description: Prior to the project, the highway DC fast charging infrastructure operated with standard sensor systems providing limited-resolution data on voltage and current. These systems lacked the granularity and intelligence needed to detect early-stage equipment degradation or forecast site-level demand effectively. Maintenance was primarily reactive, with faults identified only after component failures or customer complaints, leading to unplanned downtime and increased operational costs. The absence of local intelligence at each charging point made real-time decision-making and grid-aware coordination infeasible, limiting the overall reliability and responsiveness of the network. In addition, all the data generated on-field are transferred to the EV management platform. This leads to increased operational costs of the infrastructure creating bottlenecks especially in high scalability scenarios.

After-project description: Following the project implementation, each DC fast charging station was equipped with high-resolution inductive sensors capable of capturing detailed amperage and voltage data in real time. This sensor data is processed locally using NVIDIA Jetson-based edge AI units, enabling predictive maintenance algorithms to detect anomalies—such as connector wear or cooling inefficiencies—before failure occurs. In parallel, edge-based demand forecasting models now provide accurate short-term load predictions for each charging point, allowing dynamic power allocation and grid coordination. The result is a significantly more reliable, self-aware charging network with reduced downtime, optimized energy usage, and enhanced service continuity for EV drivers. By outfitting highway DC fast chargers with inductive high-resolution sensors and an edge AI platform, we provide a cutting-edge method to ensure reliability and optimize performance. The highest-resolution current and voltage sensors capture granular electrical signatures of each charging session, and high-speed sampling catches transient anomalies that would be invisible to traditional monitors. Then, we feed this data to an on-site NVIDIA Jetson enabling continuous, intelligent analysis – detecting faults in advance and forecasting power needs in real-time. This configuration aligns with emerging industry best practices, moving intelligence to the edge for instant insights, minimizing downtime, and ultimately giving EV drivers a more predictable and seamless charging experience.

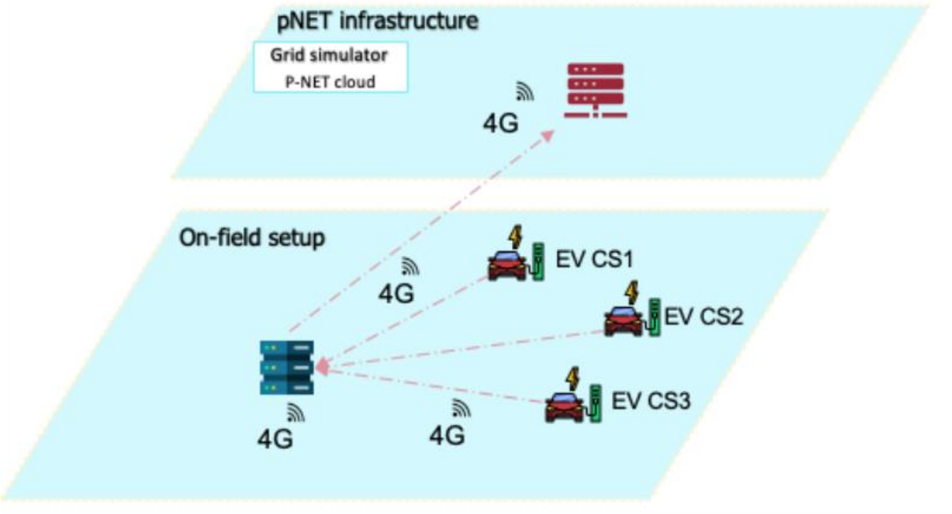

Figure 8.3 High-level diagram of the pilot site

Main actors and roles

Table 8.12 Main actors and roles

Actor name	Actor type	Actor Description	Actor Role
PPC Blue	Infrastructure Operator	National electricity provider managing EV charging networks	Provides EV charging infrastructure, enables data collection and maintenance interventions
EV Charging Stations	Energy Infrastructure	Fast-charging stations for electric vehicles deployed in urban and suburban areas	The infrastructure responsible for providing energy to the EVs
Sensor	High-resolution non-invasive sensors	Sensors measuring voltage and amperage per charging point	Acts as data sources, sending real-time amperage and current profiles in the edge device.
Edge	Edge Device	Local intelligence unit monitoring charger status and forecasting demand	Hosts predictive maintenance algorithms, performs local fault detection, forwards data to cloud
COP-PILOT Platform	Digital Orchestration Layer	Central management platform integrating predictive services and analytics	Manages forecasting services, ensures end-to-end connectivity and availability monitoring
ENIC	Technology provider	Offers domain-specific analytics services with direct added value to the operator	Offers the edge computing infrastructure and analytics services for the use case.

pNET	Connectivity provider	Provider of telco infrastructure for application validation	Offers connectivity of the real pilot to the COP-PILOT platform

Ambition, Motivation and Objectives

Motivation behind UC#3E.2: The increasing reliance on EVs for long-distance travel demands a robust, reliable fast-charging infrastructure—particularly along highways, where charger downtime can severely impact driver confidence and mobility. Currently, fast chargers suffer from limited predictive insight into component health, leading to reactive maintenance practices, unanticipated failures, and prolonged outages. These issues not only reduce the efficiency of charger networks but also hinder mass EV adoption by introducing uncertainty into long trips. Simultaneously, the growing density of EVs connected to fast chargers introduces strain on the electrical grid, especially during peak travel hours. Without accurate, real-time demand forecasting at the individual charger level, operators face difficulty in managing energy loads, risking both system-level inefficiencies and grid stability. There is a clear need for high-fidelity, edge-based monitoring and forecasting systems that provide actionable intelligence in real time, enabling improved operational reliability and energy management.

Ambition behind UC#3E.2: This use case aims to equip each highway DC fast charger with high-resolution, inductive sensors to capture fine-grained amperage and voltage data, enabling proactive health diagnostics through edge-deployed AI. The ambition is to shift from reactive to predictive maintenance models by continuously analyzing real-time electrical signatures, identifying anomalies before they lead to failures. This will improve charger uptime, reduce maintenance costs, and provide a consistent, dependable user experience for EV drivers. Additionally, the use case aspires to implement localized demand forecasting at the edge using NVIDIA Jetson platforms. By analyzing historical usage patterns and live sensor data, the system will anticipate per-charger energy demand, enabling load balancing, site-level energy optimization, and grid-responsive behavior. This dual-layer ambition—predictive maintenance and edge-side demand intelligence—positions the charging station as an autonomous, intelligent node within the broader energy and transportation ecosystems.

UC#3E.2 mapping with project objectives:

- **Increase charger availability and reliability** by detecting and responding to incipient hardware failures before they cause downtime.
- **Enable intelligent, localized energy management** through per-point demand forecasting that informs both on-site power distribution and grid interaction.

UC#3E.2 mapping with project innovations:

- **Smart SLA preservation:** The use case applies COP-PILOT's SLA management tools to ensure flexibility services remain within operational limits, testing predictive violation detection and secure actuation in a grid context.
- **Edge-aware microservices deployment:** By deploying microservices for grid simulation and flexibility control at the near/far edge, UC#3E.2 validates COP-PILOT's ability to manage containerized intelligence services in energy systems.

Rationale for using the COP-PILOT platform:

- COP-PILOT provides a scalable, interoperable framework that enables the seamless deployment of edge AI components alongside existing EV charging infrastructure, ensuring rapid prototyping and validation of advanced monitoring capabilities.
- The platform's support for secure edge-cloud orchestration allows for coordinated behaviour across multiple charging points, enabling the federation of insights and maintenance alerts without compromising data privacy or increasing network latency.

Challenges addressed

From reactive maintenance to predictive maintenance paradigm

Current: Reactive maintenance due to low-resolution monitoring

Final Ambition: Predictive maintenance enabled by high-resolution inductive sensors and edge AI, allowing early detection of anomalies such as overheating, connector wear, or electrical instability.

From aggregated to per charger demand forecasting

Current Challenge: Lack of per-charger demand forecasting leads to inefficient energy use and risk of grid overload.

Final Ambition: Real-time, edge-based demand forecasting at each charging point enables dynamic power allocation, smart grid interaction, and improved site-level energy management.

Expected outcomes

- Outcome: Early detection of charger component degradation and failure risks through real-time analysis of high-resolution current and voltage data → Mapping: Aligns with the objective to implement predictive maintenance using edge AI, reducing downtime and extending equipment lifespan.
- Outcome: Local, per-charger demand forecasting enables smarter energy distribution and mitigates peak load events → Mapping: Supports the goal of deploying decentralized AI to optimize charger utilization and enhance responsiveness to grid conditions, especially in highway environments.

Key pain points

- **Pain Point:** Lack of real-time, high-resolution diagnostics prevents early fault detection, leading to unexpected charger outages → COP-PILOT will enable edge AI integration with high-frequency sensor data, allowing for real-time anomaly detection and predictive maintenance.
- **Pain Point:** No localized demand forecasting per charging point results in inefficient power allocation and potential grid stress → COP-PILOT will support edge deployment of AI

forecasting models at each charger, enabling intelligent load management and improved grid interaction.

UC Diagrams

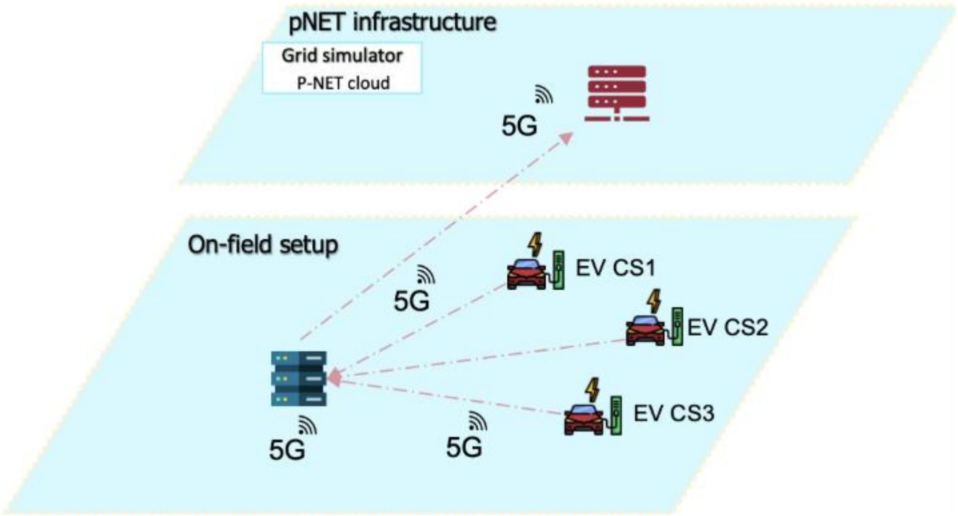

Figure 8.4 UC#3E.2 Overview

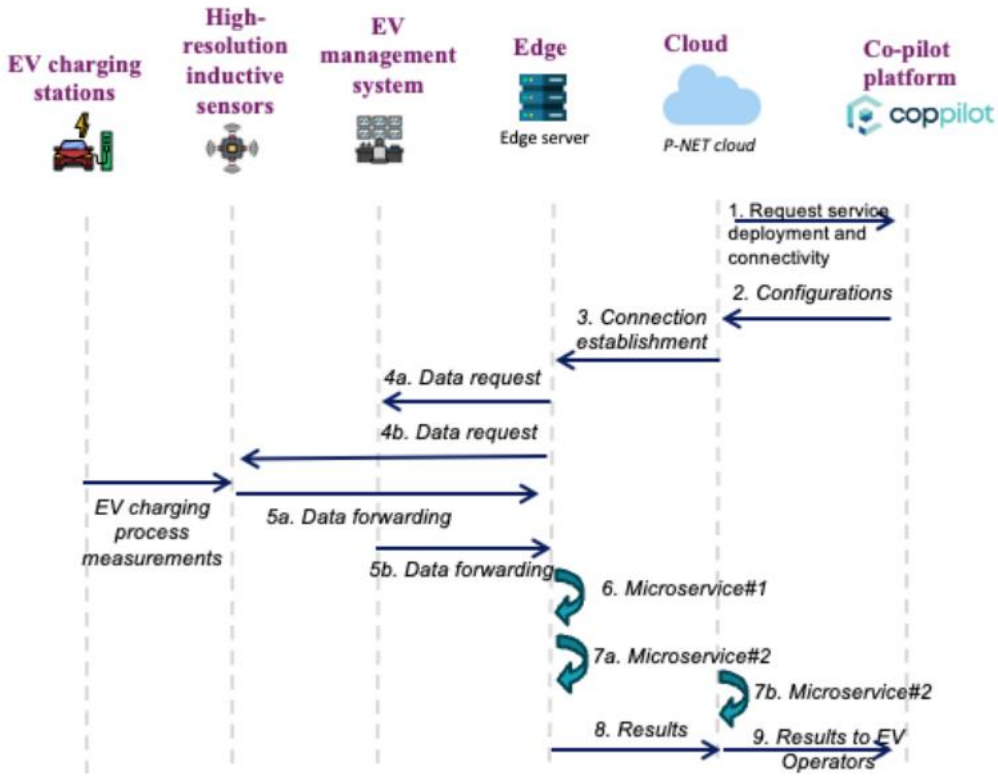

Figure 8.5 UC#3E.2 flow diagram

Step-by-step data and service flow:

1. Request service deployment and connectivity: The Co-Pilot platform initiates the process by requesting the deployment of services (predictive maintenance and demand forecasting) and establishing necessary connectivity with the P-NET cloud infrastructure.

2. Configurations: The cloud-based P-NET system performs the required configurations to support data exchange and service orchestration across the EV charging network, sensors, edge servers, and cloud.

3. Connection establishment:

    - 3.1A secure connection is established between the cloud and the edge computing layer (edge servers located near the EV charging stations)

    - 3.2: Simultaneously, a connection is set up with the EV charging stations to enable live streaming of charging session data (e.g., current, voltage, session duration).

4. Real-time data requests:

    - 4a: The edge server requests EV charging process data from the EV management system.

    - 4b: The EV management system in turn requests high-resolution current and voltage measurements from the inductive sensors deployed at each charging point.

5. Data forwarding and acquisition:

    - 5a: The inductive sensors transmit real-time measurement data to the EV management system.

    - 5b: The EV management system aggregates and forwards the collected data to the edge server for processing.

6. **Microservice #1 – Predictive Maintenance Execution:** The first microservice is activated at the edge level. It applies anomaly detection and health estimation algorithms to identify early signs of charger component degradation or faults using the incoming high-resolution sensor data.

7. **Microservice #2 – Demand Forecasting Execution:** In parallel, the second microservice runs demand forecasting algorithms at the edge. It predicts upcoming energy demand per charging point based on usage patterns, historical trends, and real-time inputs.

8. **Results delivery:** The outcomes from both microservices (maintenance alerts and demand forecasts) are compiled and transmitted back to the cloud for aggregation, reporting, and integration with wider system dashboards.

9. **Results to EV Operators:** Final results are sent from the Co-Pilot platform to EV network operators, enabling data-driven actions such as scheduling preventive maintenance and optimizing site-level energy distribution in coordination with grid services.

Scenarios description

Scenario name:
Sufficient Insight Identified – Predictive Maintenance Triggered
Step No.
#1
Step Event:
Service requested
Name of process/activity:
Request service deployment and connectivity
Description of process/activity:
COP-PILOT platform initiates orchestration request
Service:
CREATE
Information producer (actor):
COP-PILOT Platform
Information receiver (actor):
Cloud (P-NET)
Information exchanged (IDs):
Deployment request
Step No.:
#2
Step Event:
Cloud configuration
Name of process/activity:
System configuration
Description of process/activity:
Cloud responds with configuration settings
Service:
CONFIGURE
Information producer (actor):
Cloud
Information receiver (actor):
COP-PILOT Platform
Information exchanged (IDs):

Configuration parameters
Step No.:
#3
Step Event:
Connection established
Name of process/activity:
Link edge and data sources
Description of process/activity:
Data connections are created between EV charging stations, edge server, and sensors
Service:
CONNECT
Information producer (actor):
Cloud
Information receiver (actor):
Edge and Charging Stations
Information exchanged (IDs):
Secure links for telemetry transmission
Step No.:
#4
Step Event:
Real-time data captured
Name of process/activity:
High-resolution current/voltage measurement
Description of process/activity:
Sensors at the charging station capture detailed power flow metrics
Service:
REPORT
Information producer (actor):
High-Resolution Sensors
Information receiver (actor):
EV Management System
Information exchanged (IDs):
Amperage, voltage, timestamp
Step No.:
#5
Step Event:
Data forwarded to edge
Name of process/activity:
Send diagnostics data
Description of process/activity:
EV management system forwards measurement data to edge server for analysis
Service:

FORWARD
Information producer (actor):
EV Management System
Information receiver (actor):
Edge Server
Information exchanged (IDs):
Session diagnostics data
Step No.:
#6
Step Event:
Maintenance risk detected
Name of process/activity:
Run Microservice #1
Description of process/activity:
Edge AI analyzes power signatures and detects signs of impending fault
Service:
EXECUTE
Information producer (actor):
Edge Server
Information receiver (actor):
Internal (Edge AI system)
Information exchanged (IDs):
Anomaly markers, fault classification
Step No.:
#7
Step Event:
Results sent to COP-PILOT
Name of process/activity:
Report health status
Description of process/activity:
Predictive insights are forwarded to the COP-PILOT platform
Service:
REPORT
Information producer (actor):
Edge
Information receiver (actor):
COP-PILOT Platform
Information exchanged (IDs):
Maintenance alert, risk score
Step No.:
#8
Step Event:

Notify operator
Name of process/activity:
Maintenance scheduling suggestion
Description of process/activity:
COP-PILOT alerts EV operator to schedule proactive service
Service:
NOTIFY
Information producer (actor):
COP-PILOT Platform
Information receiver (actor):
EV Operator
Information exchanged (IDs):
Suggested maintenance window, diagnostic report

Scenario name:
Predicted Demand Spike – Forecast-Based Power Management Initiated
Step No.:
#1
Step Event:
Forecasting service requested
Name of process/activity:
Request demand forecasting microservice
Description of process/activity:
COP-PILOT requests activation of forecasting model on the edge
Service:
CREATE
Information producer (actor):
COP-PILOT Platform
Information receiver (actor):
Cloud (P-NET)
Information exchanged (IDs):
Forecasting service deployment request
Step No.:
#2
Step Event:
System configuration
Name of process/activity:
Define forecasting parameters
Description of process/activity:
P-NET cloud configures data model input streams and forecast horizon
Service:
CONFIGURE

Information producer (actor):
Cloud
Information receiver (actor):
COP-PILOT Platform
Information exchanged (IDs):
Forecast configuration file
Step No.:
#3
Step Event:
Data connection activated
Name of process/activity:
Enable station telemetry
Description of process/activity:
Real-time data links are formed between edge and EV charging points
Service:
CONNECT
Information producer (actor):
Cloud
Information receiver (actor):
Edge/Charging Points
Information exchanged (IDs):
Usage telemetry stream
Step No.:
#4
Step Event:
Usage data captured
Name of process/activity:
Real-time EV session monitoring
Description of process/activity:
Charging stations send usage history and live session details to the edge
Service:
REPORT
Information producer (actor):
Charging Stations
Information receiver (actor):
Edge
Information exchanged (IDs):
Session duration, kWh, arrival timestamps
Step No.:
#5
Step Event:
Run forecasting

Name of process/activity:
Execute Microservice #2
Description of process/activity:
Edge forecasts per-charger load for next time window using local AI model
Service:
EXECUTE
Information producer (actor):
Edge Server
Information receiver (actor):
Internal
Information exchanged (IDs):
Predicted load, time-stamped demand forecast
Step No.:
#6
Step Event:
Send prediction results
Name of process/activity:
Report forecast to platform
Description of process/activity:
Demand forecast is transmitted to the COP-PILOT platform for action
Service:
REPORT
Information producer (actor):
Edge
Information receiver (actor):
COP-PILOT Platform
Information exchanged (IDs):
Demand forecast series, confidence intervals
Step No.:
#7
Step Event:
Grid coordination initiated
Name of process/activity:
Notify EV operator or grid manager
Description of process/activity:
COP-PILOT alerts grid or site operator of expected high-demand window
Service:
NOTIFY
Information producer (actor):
COP-PILOT Platform
Information receiver (actor):
EV Operator / Grid Operator

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Information exchanged (IDs):
Forecast alert, recommended load balancing strategy

Requirements

Functional requirements

Table 8.13 Use case functional requirements

Req. ID	Subject (+ Condition)	Commitment	Action + Object + {Constraint and/or Value}
FR1.1	Edge server	Must	Collect and process high-resolution amperage and voltage data from inductive sensors in real-time
FR1.2	Predictive Maintenance Microservice	Must	Detect anomalies in charging behaviour and raise alerts for EV charger health degradation
FR1.3	Forecasting Microservice	Must	Predict per-charging-point energy demand within a 15-minute forecast horizon
FR1.4	EV Management System	Could	Forward processed sensor data to edge layer with less than 1-second delay
FR1.5	COP-PILOT platform	Must	Orchestrate service deployment to the edge based on user-defined configuration parameters
FR1.6	COP-PILOT platform	Must	Notify EV operators of predictive events and forecasting outcomes through an operator dashboard

Non-functional requirements

Table 8.14 Use Case non-functional requirements

Req. ID	Subject (+ Condition)	Commitment	Action + Object + {Constraint and/or Value}
NFR1.1	Edge AI system	Must	Perform model inference within 200 milliseconds per data packet
NFR1.2	System communication	Must	Ensure end-to-end latency below 2 seconds from sensor reading to operator alert
NFR1.3	Sensor module	Must	Operate within industrial temperature range (-40°C to +85°C)

NFR1.4	Data integrity system	Must	Verify all sensor input packets with 99.9% confidence level
NFR1.5	Cloud-edge integration	Must	Maintain 99.5% uptime in edge-cloud link for service availability
NFR1.6	System architecture	Must	Support modular microservice deployment and plug-and-play sensor compatibility

KPIs and KVI

UC/vertical Specific

Table 8.15 UC#E.2 vertical specific requirements

KPI/KVI ID	Description
KPI#3E.2.1	% reduction in unplanned charger downtime due to early anomaly detection
KPI#3E.2.2	% of EV charging sessions with accurate real-time current/voltage data captured
KPI#3E.2.3	Edge AI system enables fault prediction with at least 90% accuracy up to 24 hours in advance
KVI#3E.1.1	Forecasting model predicts per-point charging demand with a minimum of 85% accuracy within 15-minute intervals

Sustainability

Table 8.16 UC#E.2 sustainability requirements

KPI/KVI ID	Description
KPI#3E.1.3	Reduction in energy losses by optimizing charging patterns based on forecasted demand
KVI#3E.1.2	Increased efficiency supports integration of RES by smoothing EV load profiles during peak solar/wind availability

Environmental

Table 8.17 UC#E.2 environmental requirements

KPI/KVI ID	Description
KVI#3E.2.4	Estimated CO_2 emissions avoided through reduced energy waste and improved charger uptime
KVI#3E.2.5	% of total charging energy dynamically optimized to reduce stress on the grid during high carbon-intensity periods

Societal

Table 8.18 UC#E.2 societal requirements

KPI/KVI ID	Description

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KPI#3E.2.4	Improvement in customer satisfaction due to fewer failed charging attempts (target ≥ 95% uptime)
KVI#3E.2.6	Reduced number of emergency maintenance visits, lowering cost and response time for rural/highway locations

Operational and Efficiency

Table 8.19 UC#E.2 operational and efficiency related requirements

KPI/KVI ID	Description
KPI#3E.2.5	Latency between sensor detection and edge anomaly classification kept under 500 ms
KPI#3E.2.6	% improvement in charger throughput due to reduced downtime and dynamic queue balancing
KVI#3E.2.7	Edge-based forecasting reduces site-level peak demand by at least 10% via proactive load control

Economic and Business

Table 8.20 UC#E.2 economic and business requirements

KPI/KVI ID	Description
KPI#3E.1.8	Reduction in cost per MW of flexibility enabled by edge-cloud system by 10%
KPI#3E.1.9	Increase in ROI of edge-based deployment for DSOs in flexibility harvesting by 5% through simulated outcomes.
KVI#3E.1.6	System supports new market models for localized flexibility trading

Scalability and EU Sovereignty

Table 8.21 UC#E.2 Scalability and EU Sovereignty related requirements

KPI/KVI ID	Description
KPI#3E.1.10	Number of DERs supported per orchestrator instance without performance degradation

Legal and Ethics Requirements

Data Related Activities

The execution of Use Case 3E#2 involves extensive data-related activities across a distributed edge-cloud infrastructure, aimed at enabling real-time predictive maintenance and localized demand forecasting in highway EV fast-charging stations. The following outlines the key data management considerations:

- **Types of data collected:** The UC collects high-resolution telemetry data from fast charging stations, including voltage, amperage, temperature, session metadata, and sensor-derived health indicators. Additional data includes EV arrival patterns, charging duration, and power quality measurements.

- **Data sources:** Data originates from IoT-enabled inductive sensors embedded within charging units, EV management systems (EMS), and edge computing nodes (e.g., NVIDIA Jetson Orin). The COP-PILOT platform and associated orchestration tools collect operational insights for analytics and service delivery.

- **Data collection purpose:** The primary purpose is to detect anomalies in charger performance, estimate component health status, and forecast per-charger energy demand. This supports predictive maintenance planning, grid-aware power allocation, and improved charging availability.

- **Data sharing and access:** Data is exchanged securely between charging stations, edge devices, cloud analytics layers, and the COP-PILOT platform using industry protocols such as OCPP, MQTT, and HTTPS. Access is limited to authorized partners (e.g., UOP, P-NET, industrial providers) based on their role in the use case.

- **Consent and privacy:** As this UC is implemented in a controlled lab and pilot setting without personal user data, there are no GDPR concerns. Nevertheless, all sensor and system data are handled securely and anonymized to ensure privacy, with no personal EV driver data collected or processed.

- **Data re-use and availability:** Data will be reused within the COP-PILOT project to refine predictive models, validate AI algorithms, and benchmark system performance under various demand/load profiles. Any external re-use will follow the protocols outlined in the D1.2 Data Management Plan, ensuring anonymization and licensing compliance.

- **Data security measures:** Robust cybersecurity controls are in place, including TLS encryption, role-based access, and hardened infrastructure. Edge-to-cloud communications are safeguarded by network isolation and 5G URLLC support, minimizing risk of data leakage or tampering.

- **Data retention:** All research data will be stored securely for a minimum of 5 years post-project, in accordance with project guidelines. Data integrity is ensured via automated backups, redundant cloud-edge storage mechanisms, and access logs.

- **Transparency and fairness:** All data processing and AI model decisions are traceable via the COP-PILOT orchestration framework. Predictive outcomes (e.g., maintenance alerts or demand forecasts) are explainable and can be audited against raw sensor inputs and processing logic.

- **Inclusiveness:** While UC 3E#2 is tested in a highway charging station context, it is designed to produce models and datasets applicable across diverse geographies and operators. The goal is to foster scalable, equitable access to fast and reliable EV charging through smart infrastructure management.

AI Systems

The AI system in **UC#3E.2** is machine-based and deployed as a suite of modular, containerized microservices distributed across the **edge-cloud continuum**. These include:

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Predictive Maintenance Models: These AI models analyze high-resolution telemetry data from charging stations (amperage, voltage, session metadata) to detect anomalies and estimate the degradation level of power modules, connectors, and other critical components.

Demand Forecasting Models: Time-series models deployed at the edge use recent and historical data to predict charging demand per station, enabling proactive load balancing and energy optimization.

Level of autonomy: The system operates at partial autonomy. While AI modules can generate real-time decisions for flexibility control, final actuation can be configured to either occur automatically (zero-touch automation) or require validation from a human operator, depending on the operational scenario.

Adaptability: The system supports post-deployment adaptability. AI components include continuous learning or re-training capabilities based on feedback loops and updated data collected from DER simulations and system responses. If the topology and data change, the models can be recalibrated in the cloud and redeployed seamlessly to edge devices.

Inputs and Data Flow: The AI receives input from: (i) Real-time sensor telemetry (voltage, current, power, thermal data) from inductive sensors and EV management systems, (ii) Contextual and configuration parameters (station type, ambient temperature), and (iii) Historical logs stored on edge devices or cloud-based analytics platforms.

Objective and utilization: The AI system aims to: (i) Identify potential hardware failures in advance, reducing unplanned downtime through predictive maintenance, (ii) Forecast near-future charging demand at each station, enabling proactive power management, and (iii) Reduce human intervention by automating data interpretation and operational insight delivery at the edge. These functions enable AI-driven orchestration of service operations, especially valuable in remote highway charging stations with limited human support availability

Transparency and oversight: All AI decisions are logged and traceable through the COP-PILOT orchestration interface. Human-in-the-loop configuration is supported, especially during pilot and evaluation phases. Model explainability is ensured via visual output and diagnostic metrics on the operator dashboard.

Risk assessment and fundamental rights impact: A preliminary risk assessment has been planned to cover: (i) Algorithmic bias and fairness, (ii) Failure modes of real-time AI in edge environments, and (iii) Impact on operator decision autonomy.

Since the system does not interact with end users directly, fundamental rights impacts are minimal but still monitored, particularly for transparency and accountability.

AI Risk category: The AI system likely falls under “high-risk system” as per the draft AI Act, since it affects safety-critical infrastructure.

Training Data:

- Models are trained using **synthetic datasets** (simulated charging loads and fault conditions) and **real data** from testbeds.
- No **personal, location-based, or demographic data** is used.

- **Diverse operational scenarios** are included to avoid overfitting and to ensure robustness against rare conditions (e.g., power surges, extreme weather).
- The **data pipeline** includes steps for validation, normalization, and bias checking to prevent cascading model errors.

Risk identification and assessment

Table 8.22 Use Case risk assessment

Risks	Likelihood (L / M / H)	Impact (L / M / H)	Mitigation
1. False positives in predictive maintenance triggering unnecessary alerts	M	M	Implement confidence thresholds; validate anomalies with historical baselines.
2. Forecasting model underestimates peak demand during busy periods	M	H	Use ensemble models; integrate real-time input and weather/traffic signals.
3. Edge device failure (e.g., Jetson hardware overheating)	L	H	Rugged hardware; thermal monitoring; redundant backup unit per station.
4. Data synchronization issues between sensors and edge analytics	M	M	Use time-stamped data packets; validate time drift; buffer stream at edge.
5. Security breach or tampering with edge data	L	H	End-to-end encryption, role-based access, secure boot and firmware updates.
6. Lack of explainability in AI decisions leading to operator mistrust	M	M	Include interpretable AI outputs and audit logs via COP-PILOT interface.
7. Model drift due to evolving usage patterns (e.g., new EV types)	M	M	Periodic retraining; monitor model accuracy; adaptive learning frameworks.
8. Integration delays with legacy charger management systems	M	M	Use open protocols (OCPP); implement API middleware and simulator testing.

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ANNEX 8.C: UC3E.3 - PREDICTIVE MAINTENANCE AND MONITORING OF ANAEROBIC DIGESTION IN A BIOGAS PLANT

Short Description

This use case focuses on improving the reliability and performance of biogas plants, which play a vital role in supplying renewable energy to the electricity grid. At the heart of the initiative is the anaerobic digestion process, a biologically complex system whose efficiency directly influences the plant's energy output. A comprehensive monitoring and predictive maintenance framework is introduced to manage this complexity. Predictive maintenance algorithms are developed to analyse sensor data to anticipate equipment wear and potential failures, thus enabling timely interventions that reduce unplanned downtime. Complementing this, real-time process monitoring ensures key parameters such as pH, temperature, feedstock composition, and gas production remain within optimal ranges. Finally, electricity production forecasting capabilities provide grid operators with accurate projections of power availability from the plant, facilitating better integration into the energy mix and reinforcing grid stability.

Complete Description

Pre-project description: In the context of the global energy transition, biogas plants represent a cornerstone of biomass-based renewable energy systems, offering a sustainable and circular approach to electricity generation. Unlike solar or wind, biomass energy—especially biogas—uses organic waste materials, turning agricultural and food processing residues into usable electricity while simultaneously mitigating greenhouse gas emissions and reducing landfill dependency. The Preveza Biogas Plant in Western Greece, with a 2 MW capacity, exemplifies this sustainable model by converting organic waste into energy through anaerobic digestion (AD), a controlled biochemical process that produces biogas primarily composed of methane (CH_4) and carbon dioxide (CO_2). This gas is then used in cogeneration machinery to generate both electricity and heat at high efficiency levels, contributing to Greece's energy diversification and circular economy efforts.

Despite having advanced core equipment for biogas production, the plant's operational model **prior to the COP-PILOT project** lacked predictive maintenance capabilities. Monitoring the health and performance of the anaerobic digestion process was heavily dependent on manual sampling and the practical experience of the operators. Parameters such as pH levels, temperature, and gas composition were not monitored in real time but were instead checked intermittently, often using laboratory-based tests or periodic sensor readings. The absence of automated fault prediction or continuous condition monitoring mean that abnormalities in the digestion process are often detected reactively—after they have already started affecting biogas quality or equipment health. Consequently, this reactive maintenance model carried risks of unplanned downtime, reduced energy yield, and increased operational costs, while making the plant's operation vulnerable to human error and inefficiencies. EnakronIC has already developed the analytics algorithms in order to digest data from the sensors and provide insight into the AD process. However, the algorithms implementation in the field as well as the sensors installation will be activities taking place in COP-PILOT.

After-project description: Following the implementation of the COP-PILOT project, the Preveza Biogas Plant transitioned from a manually monitored, experience-dependent operation to a smart, data-driven facility enabled by edge intelligence and predictive maintenance technologies. The AD process will be continuously monitored using high-precision instrumentation, including the AwiFLEX gas analyzer for real-time measurement of key gas components (CH_4, CO_2, H_2S, O_2, H_2) and the Memosens CPS11E pH sensor, which ensures precise control of pH levels—crucial for microbial stability. These instruments will feed real-time data into an industrial-grade edge communication system (Ewon Flexy 205), which will interface with an on-site edge server. The server will execute predictive analytics and condition monitoring algorithms that detect anomalies, forecast maintenance needs, and support operational optimization. With this new system, data from the biogas process will no longer need to be manually sampled and interpreted. Instead, it will be streamed continuously, processed locally, and presented on an operator-friendly dashboard with visual analytics and early-warning alerts. The integration of digital twin concepts allows the system to simulate the digestion process under different operating conditions, enabling predictive what-if analysis. In the event of abnormal patterns, the system will autonomously notify operators, providing actionable insights before failures occur. This will significantly reduce the risk of unscheduled outages, improves plant uptime, and enhances the overall yield and profitability of the biogas production process. Furthermore, by increasing the precision and responsiveness of operational decisions, the plant will contribute more reliably to the renewable energy mix and support the broader decarbonization goals of the Greek and European energy sectors.

The proposed architecture leverages a Kubernetes-based cluster to manage resources and enable scalable deployment. It consists of a GPU-enabled Jetson Orin Nano device for running AI algorithms. Custom Docker images are built to include all necessary dependencies and NVIDIA libraries and leverage the full computational power of the Jetson Orin Nano. The AI algorithms, deployed as containerised microservices within the cluster, handle predictive analytics for biogas yield and process stability. Custom hardware designs, firmware and docker images are developed for the FPGAs, with Xilinx's Vitis AI development environment, to handle the high-speed preprocessing of sensor data to minimize latency and improve throughput, optimizing the real-time monitoring system. Helm charts are used to manage the deployment of containers within the cluster, while gRPC-based open APIs allow high-speed communication between microservices.

Testbed description

Figure 8.6 Aerial view of the biogas plant in Preveza, Greece

The "Bioaerio Prevezas 1 PC" is a unit for producing electricity from organic waste with a nominal power of 2 Mwe in N. Oropos, Preveza, Greece. The unit annually manages almost 100,000 tons of organic waste (liquid and solid cow manure, poultry manure, two-phase olive pomace and whey), from which is produced after two-stage anaerobic digestion: on the one hand, biogas which is used as fuel for the production of electricity through two internal combustion engines with a nominal power of 1 MWe each, on the other hand inert liquid digested residue which is separated into the liquid and solid fractions through a mechanical separation installed within the plant. Both fractions of the digested residue, rich in inorganic nutrients N, P, K and trace elements, after storage in appropriately licensed areas within the unit, are applied directly as soil conditioners to local crops. PREVEZA BIOGAS has been certified by TÜV NORD with ISO 9001:2015 – Quality Management System and ISO 14001:2015 – Environmental Management System, confirming the strong commitment to creating a better and more sustainable future, through improving the company's performance in quality management and environmental issues. The Preveza Biogas plant is equipped with advanced infrastructure that provides a robust foundation for implementing the proposed project. Key components include:

- **Biogas Production Facility:** The plant features biomass digesters that utilize organic waste to produce biogas, with a capacity to generate 2 MW of electricity. These digesters operate with high efficiency and are equipped with modern control systems.
- **Sensors:** The facility includes sensors for monitoring key parameters, such as temperature, pH, and methane concentration. In the context of the pilot, the plant will install an AwiFLEX gas analyzer and a CPS11E Ph sensos, enabling real-time measurement of critical process stability indicators.
- **Cogeneration equipment:** The plant integrates a cogeneration system for converting biogas into electricity and heat, ensuring optimal energy utilization and providing real-time data for system efficiency analysis.
- **Data acquisition system**: The plant has established data collection and storage systems, capable of handling real-time data streams from various sensors. This infrastructure supports the integration of advanced ML-based analytics.
- **SCADA Systems**: A Supervisory Control and Data Acquisition (SCADA) system monitors and controls the biogas production processes.

Main actors and roles

Table 8.23 Main actors and roles

Actor name	Actor type	Actor Description	Actor role in Use case
BPO	Industrial plant owner and operator	Manages the daily operation and performance of the anaerobic digestion system	Facilitates deployment of monitoring systems, acts on insights and alerts from predictive analytics
Awite AwiFLEX Gas Analyzer	Process Instrumentation	Online gas measurement system for monitoring CH_4, CO_2, H_2S, O_2, and H_2 levels	Provides continuous gas composition data critical for assessing digestion efficiency
Memosens CPS11E Sensor	Process Instrumentation	Digital pH sensor used in industrial environments with harsh process conditions	Continuously monitors digester pH levels to ensure biological stability
Ewon Flexy 205	Edge Communication Gateway	Industrial gateway supporting Modbus and IIoT protocols for remote data collection	Collects and transmits sensor data to the edge analytics server
Edge Server	Edge Computing Node	Local processing unit running analytics and predictive models on real-time sensor data	Performs fault prediction, process monitoring, and provides actionable feedback to the plant operator
COP-PILOT Platform	Digital Orchestration Layer	Project-wide integration platform linking field assets to centralized analytics	Manages data flows, service deployment, and remote dashboard access

ENIC	Technology provider	Offers domain-specific analytics services with direct added value to the operator	Offers the edge computing infrastructure and analytics services for the use case.
pNET	Testbed provider	Provider of 5G telco infrastructure for application validation	Offers connectivity of the real pilot to the COP-PILOT platform

Ambition, Motivation and Objectives

Motivation behind UC#3E.3: The operation of biogas plants relies on the complex and sensitive process of AD, where microbial activity transforms organic waste into methane-rich biogas. This biochemical process is highly dependent on maintaining strict environmental conditions—such as pH, temperature, and feedstock composition—within optimal ranges. Prior to the project, the monitoring and control of these parameters at the Preveza biogas plant were conducted through manual sampling and experience-based assessment, leaving the facility vulnerable to undetected anomalies, unplanned outages, and efficiency loss. Operators were ***often left reacting*** to issues rather than anticipating them, which limited the ability of the plant to function as a reliable, high-performance energy asset in the renewable energy mix.

Furthermore, the increasing emphasis on renewable energy in Europe, coupled with the push to decarbonize power systems, demands greater reliability and integration of biogas into smart grids. The motivation behind this use case is to ***enable the plant to become a digitally enabled, proactive contributor to the grid***. This transformation is critical not only for operational excellence but also for increasing the share of dispatchable, renewable power in the energy ecosystem. Predictive maintenance and real-time process monitoring are essential to turning biogas plants from static producers into smart, responsive grid-supporting assets.

Ambition behind UC#3E.3: UC#3E.3 aims to modernize biogas plant operations by shifting from reactive to predictive and data-driven maintenance approaches. By embedding real-time monitoring and edge-based analytics into the BPO's plant, the use case seeks to ensure stable biogas production, early anomaly detection, and accurate electricity generation forecasting. This directly contributes to operational resilience, reduces unplanned downtime, and maximizes energy output. ***A key ambition is to transform the plant into a model for digitalized biomass energy production***, capable of integrating smoothly into flexible, renewable-rich distribution grids.

Another ambition is to demonstrate how legacy or semi-modern biogas facilities can be retrofitted with cutting-edge industrial IoT technologies and AI-driven analytics to dramatically enhance performance without requiring full system overhauls. Through this deployment***, UC#3E.3 contributes to broader EU-level goals around sustainability***, circular economy, and grid flexibility. It seeks to prove that biomass-based energy, particularly from waste streams, can be a high-value, reliable, and intelligent component of the future decentralized energy landscape.

UC#3E.3 mapping with project objectives:

Obj#1: Open Orchestration Platform across IoT-Edge-Core Continuum: UC#3E.3 directly contributes by demonstrating the integration of heterogeneous devices (gas analyzers, pH sensors, edge gateways) and orchestrating data flow and analytics over an edge-core-cloud continuum. This includes deployment of local services (edge analytics) and their orchestration through a unified platform to ensure continuous operation and smart control of the anaerobic digestion process.

Obj#5: Demonstrate the value of hyper-distributed intelligent services across real-world industrial use cases: This use case showcases a concrete industrial environment (biogas plant) where predictive maintenance services and real-time analytics are deployed at the edge. It validates the project's ambition of pushing intelligence closer to data sources, particularly in a high-value renewable energy setting

UC#3E.3 mapping with project innovations:

Hierarchical and Federated Data Management: UC#3E.3 implements local data management and processing at the edge while enabling upward communication to cloud orchestration layers. This layered approach focuses on federated data flow across swarm → domain → cluster levels, allowing decentralized intelligence while retaining cross-layer coordination.

Proactive SLA Preservation through AI-based Closed-Loop Services: The predictive analytics and condition monitoring applied to critical assets at the Preveza Biogas Plant align with this innovation, demonstrating how AI-based services can ensure system uptime and prevent SLA violations by anticipating maintenance needs before they escalate into faults.

Secure One-Touch Domain Expansion: The deployment of secure, low-latency, programmable edge interfaces at the plant supports this innovation by proving how the platform can be expanded securely to new operational environments, offering a replicable model for other biogas or industrial plants

Rationale for using the COP-PILOT platform:

Integrated Orchestration: COP-PILOT provides a unified platform for deploying microservices, managing connectivity, and coordinating between edge devices, sensors, and operator interfaces—all critical for continuous monitoring of complex biogas processes.

Fail-safe, Scalable Architecture: The platform enables local analytics processing at the edge while maintaining seamless cloud connectivity and providing fallback mechanisms during connectivity loss, ensuring uninterrupted monitoring and decision-making in mission-critical plant operations.

Challenges addressed

From manual to automated monitoring:

Current state: Operators rely on manual sampling and experience to assess the digestion process.

Final ambition: Full automation through real-time sensor integration, edge-based data processing, and predictive analytics to detect process anomalies early.

From Reactive To Predictive Maintenance:

Current state: Maintenance is triggered only after faults occur, often causing downtime and reduced biogas output.

Final ambition: Predictive models proactively identify wear and degradation in the digester and generator components, enabling timely, planned interventions.

Expected outcomes

- **Outcome:** Improved operational reliability and biogas yield.
  → **Mapping:** The system will ensure stable electricity generation by minimizing downtime and maximizing process efficiency—directly contributing to COP-PILOT's goal of supporting grid resilience with reliable RES sources.

- **Outcome:** Demonstration of edge-cloud orchestration for industrial predictive maintenance.
  → **Mapping:** This UC proves the real-world value of COP-PILOT's architecture by deploying microservices and real-time intelligence at the edge, fulfilling the project's key technical ambition of end-to-end orchestration across the edge-core continuum.

Key pain points

- **Lack of continuous visibility into critical process parameters:** Currently, decisions are made based on delayed and intermittent data, which increases the risk of sudden failures in the anaerobic digestion system.

- **No automation for anomaly detection or forecasting:** There is no system in place to predict deviations in microbial activity, gas composition, or component health. COP-PILOT introduces AI-driven models that eliminate this blind spot and support resilient plant operations.

UC Diagrams

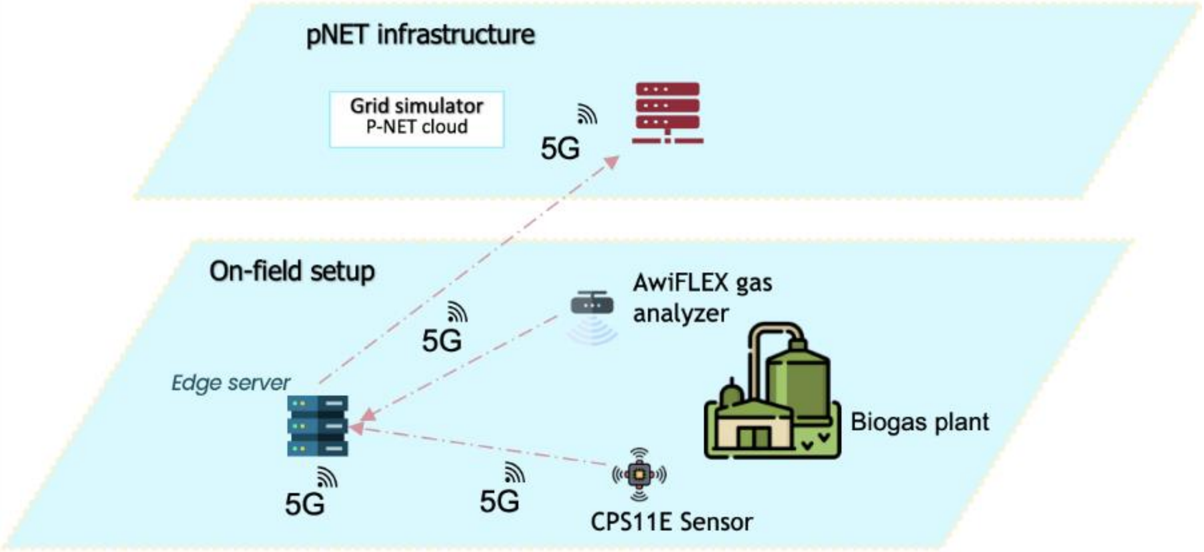

Figure 8.7 UC#3E.3 diagram

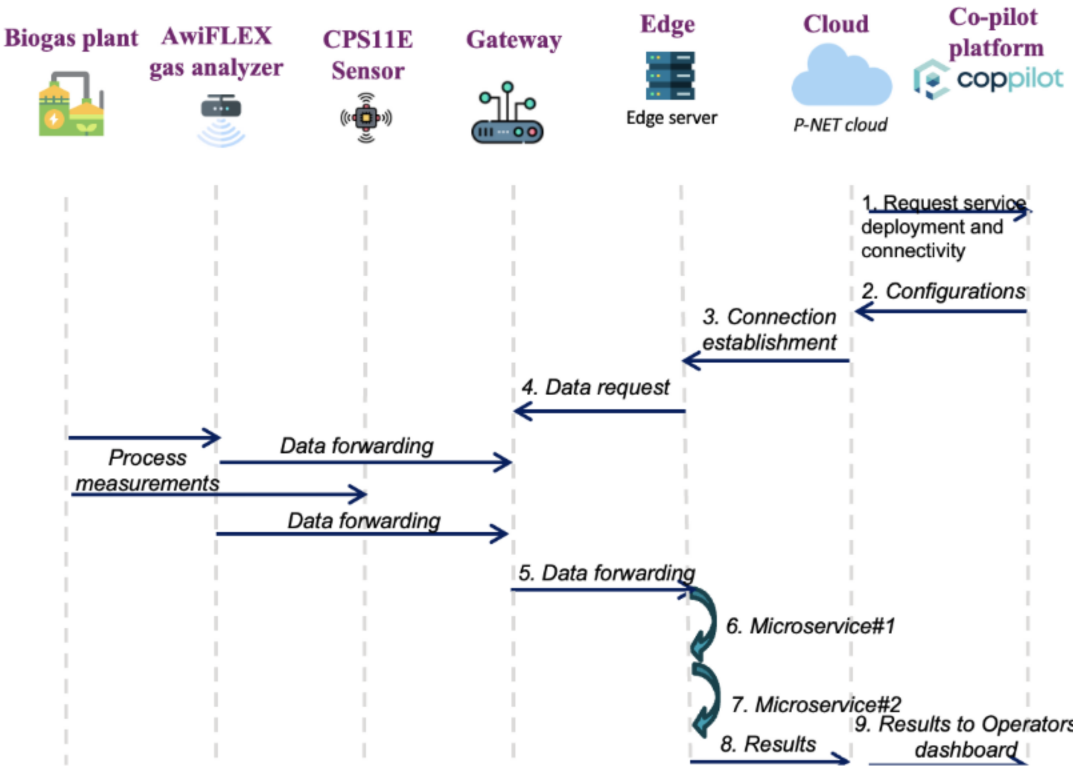

Figure 8.8 UC#3E.3 technical diagram

Step-by-step analysis of the flowchart for UC#3E.3:

1. **Request service deployment and connectivity**: The Co-pilot platform initiates the use case by requesting the deployment of services (such as predictive maintenance and real-time monitoring) and establishing connectivity with the cloud-based infrastructure that supports data orchestration and analytics.

2. **Configurations**: In response, the P-NET cloud sends back configuration parameters, detailing the data structure, device mapping, communication protocols (e.g., Modbus), and microservice workflows needed for the system to operate.

3. **Connection establishment**: A connection is established between the cloud and the edge server. This connection enables service orchestration, remote deployment of analytics tasks, and secure data routing.

   Process measurements: The biogas plant begins its routine operation, during which:

   - The **AwiFLEX analyzer** collects gas composition data (CH_4, CO_2, O_2, H_2S, H_2).

   - The **CPS11E pH sensor** measures and monitors pH levels in the digester.

   Data forwarding (Sensors to Gateway): The process measurement data is forwarded from the sensors to the Ewon Flexy 205 gateway using the Modbus protocol. The gateway serves as the far-edge device responsible for aggregating sensor data locally

4. **Data request**: The edge server requests sensor data from the gateway to initiate local analytics and predictive maintenance processes.

5. **Data forwarding (Gateway to Edge Server)**: The gateway responds by sending the requested sensor data to the edge server. This step marks the start of edge-based data analytics.

6. **Microservice #1 execution**: The first microservice is triggered on the edge server. It refers to the forecasting process of the anaerobic digestion parameters.

7. **Microservice #2 execution**: A second microservice performs predictive maintenance analytics—detecting anomalies and forecasting potential system faults.

8. **Results**: The outcome of the microservices—diagnostics, forecasts, and maintenance recommendations—are packaged into a results set ready for operator access.

9. **Results to Operator Dashboard**: The final results are forwarded to the operator's dashboard in the biogas plant, enabling real-time visibility into plant health, early fault warnings, and optimization opportunities.

Scenarios description

Scenario name:
Anomaly Identified – Signal for Action Sent
Step No.:
#1
Step Event:
Service requested
Name of process/activity:
Request service deployment and connectivity
Description of process/activity:
COP-PILOT platform initiates orchestration request
Service:
CREATE
Information producer (actor):
COP-PILOT Platform
Information receiver (actor):
Cloud (P-NET)
Information exchanged (IDs):
Deployment request
Step No.:
#2
Step Event:
Cloud configuration

Name of process/activity:
System configuration
Description of process/activity:
Cloud responds with configuration settings
Service:
CONFIGURE
Information producer (actor):
Cloud
Information receiver (actor):
COP-PILOT Platform
Information exchanged (IDs):
Configuration parameters
Step No.:
#3
Step Event:
Connection established
Name of process/activity:
Establish data connection
Description of process/activity:
Cloud sets up connections with biogas sensors and edge gateway
Service:
CONNECT
Information producer (actor):
Cloud
Information receiver (actor):
Sensors / Gateway
Information exchanged (IDs):
Secure channel setup
Step No.:
#4
Step Event:
Process data collected
Name of process/activity:
Sensor data acquisition
Description of process/activity:
AwiFLEX and CPS11E sensors collect gas composition and pH readings
Service:
REPORT
Information producer (actor):
Sensors

Information receiver (actor):
Gateway
Information exchanged (IDs):
Process telemetry
Step No.:
#5
Step Event:
Data forwarded
Name of process/activity:
Send telemetry to Edge
Description of process/activity:
Gateway forwards real-time process data to Edge server
Service:
FORWARD
Information producer (actor):
Gateway
Information receiver (actor):
Edge
Information exchanged (IDs):
Process values
Step No.:
#6
Step Event:
Analytics triggered
Name of process/activity:
Run Microservice #1
Description of process/activity:
Edge uses ML model to predict stability/risks
Service:
EXECUTE
Information producer (actor):
Edge
Information receiver (actor):
Internal
Information exchanged (IDs):
Stability analysis, sensor patterns
Step No.:
#7
Step Event:

Risk threshold exceeded
Name of process/activity:
Run Microservice #2
Description of process/activity:
Control logic classifies pattern as anomaly
Service:
EXECUTE
Information producer (actor):
Edge
Information receiver (actor):
Internal
Information exchanged (IDs):
Error classification
Step No.:
#8
Step Event:
Alarm triggered
Name of process/activity:
Report to COP-PILOT
Description of process/activity:
Edge reports anomaly to COP-PILOT with action flag
Service:
REPORT
Information producer (actor):
Edge
Information receiver (actor):
COP-PILOT Platform / Operator
Information exchanged (IDs):
Anomaly detected, trigger maintenance
Scenario name:
No Anomaly Identified – No Action Required [Same steps #1-#6 as Scenario#1]
Step No.:
#7
Step Event:
Process within normal range
Name of process/activity:
Run Microservice #2
Description of process/activity:
Control logic confirms process stability
Service:

EXECUTE
Information producer (actor):
Edge
Information receiver (actor):
Internal
Information exchanged (IDs):
Normal operation log
Step No.:
#8
Step Event:
No action required
Name of process/activity:
Passive logging
Description of process/activity:
COP-PILOT receives confirmation of normal operation
Service:
REPORT
Information producer (actor):
Edge
Information receiver (actor):
COP-PILOT Platform
Information exchanged (IDs):

Requirements

Functional requirements

Table 8.24 Use Case functional requirements

Req. ID	Subject (+ Condition)	Commitment	Action + Object + {Constraint and/or Value}
FR3.1	Real-time process monitoring	Must	Continuously collect and process biogas production data (CH_4, CO_2, O_2, H_2S, pH)
FR3.2	Predictive maintenance	Must	Analyse operational parameters to forecast equipment faults and wear (lead time ≥ 24h)
FR3.3	Data acquisition integration	Must	Interface sensors (e.g., AwiFLEX analyzer, CPS11E sensor) with edge gateway via Modbus
FR3.4	Edge analytics execution	Must	Execute microservices on local edge server for fault detection and forecasting
FR3.5	Alert generation	Must	Generate automated alerts and forward to operator dashboards when anomalies are detected
FR3.6	Dashboard visualization	Must	Display real-time trends and insights in a user-friendly web interface

FR3.7	Secure data handling	Must	Encrypt all data transfers between sensors, edge gateway, and local edge server

Non-functional requirements

Table 8.25 Use Case non-functional requirements

Req. ID	Subject (+ Condition)	Commitment	Action + Object + {Constraint and/or Value}
NFR3.1	System availability	Must	Ensure predictive maintenance and monitoring system uptime ≥ 99.5%
NFR3.2	Latency of edge analytics	Must	Complete data processing and alert generation within ≤ 2 seconds from data ingestion
NFR3.3	Data accuracy	Must	Maintain sensor reading and analytics result accuracy ≥ 95%
NFR3.4	Cybersecurity	Must	Protect against unauthorized access and apply encryption protocols (TLS/HTTPS)
NFR3.5	Scalability	Could	Support future addition of more digesters or monitoring points with minimal reconfiguration
NFR3.6	Operator usability	Must	Ensure dashboard interface is intuitive and requires <1 hour training for new operators
NFR3.7	Fault tolerance	Must	Maintain analytics function during network interruptions using local data caching

KPIs and KVIs

UC/vertical Specific

Table 8.26 UC#3E.3 vertical specific requirements

KPI/KVI	Description
KPI#E.3.1	% of unplanned downtime reduction achieved due to predictive maintenance [more than 5%]
KPI#E.3.2	Accuracy of failure prediction algorithms (e.g. >90% precision)
KVI#E.3.1	Edge-enabled analytics increase equipment lifetime by enabling timely interventions [more than 5%]

Sustainability

Table 8.27 UC#E.3 sustainability requirements

KPI/KVI	Description
KPI#E.3.3	% increase in system energy efficiency due to improved digestion control [more than 10%]
KVI#E.3.2	COP-PILOT supports sustainable biogas-based grid integration, reducing reliance on fossil backup

Environmental

Table 8.28 UC#E.3 environmental requirements

KPI/KVI	Description
KPI#E.3.4	Reduction in methane leakage due to real-time process corrections

KVI#E.3.3	Greater control of biogas production reduces environmental impact of organic waste processing

Societal

Table 8.29 UC#E.3 societal requirements

KPI/KVI	Description
KPI#E.3.5	Increase in availability of renewable power for rural areas from the biogas plant
KVI#E.3.4	Enhancing biogas reliability contributes to local energy autonomy and resilience

Operational and Efficiency

Table 8.30 UC#E.3 operational and efficiency related requirements

KPI/KVI	Description
KPI#E.3.6	Time to detect anomalies via edge analytics (target <2s)
KPI#E.3.7	% of alerts correctly triggering preventive actions
KVI#E.3.5	Real-time monitoring replaces manual sampling, increasing operator efficiency

Economic and Business

Table 8.31 UC#3E.3 economic and business requirements

KPI/KVI	Description
KPI#E.3.8	Reduction in maintenance costs compared to baseline operation [by 5%]
KPI#E.3.9	Avoided revenue loss from downtime [5% recovered production hours]
KVI#E.3.6	Predictive analytics business model validated for replication in other biogas plants

Scalability and EU Sovereignty

Table 8.32 UC#E.3 scalability and EU sovereignty requirements

KPI/KVI	Description
KVI#E.3.7	Local analytics and sovereignty-preserving architecture align with EU digital autonomy goals

Legal and Ethics Requirements

Data Related Activities

Datasets for the execution of UC#3e.3: Several operational and environmental datasets will be collected, including: (i) gas composition data: ch_4, co_2, h_2s, o_2, h_2 (via awiflex gas analyzer), (ii) ph levels: measured using cps11e ph sensor, (iii) temperature and feedstock data, (iv) electrical output performance, (v) maintenance logs and event histories, and (vi) Synthetic data generated from digital twin simulations for performance forecasting and model validation

Data collected, shared, and stored:

- collected: real-time sensor data, system events, and metadata

- shared: internally within the COP-PILOT platform, between the edge analytics server, operator dashboards, and cloud coordination layer
- stored: on local edge servers and backed up in project-designated secure cloud environments

Purpose of data collection the data is collected to: (i) monitor and optimize the anaerobic digestion process in real-time, (ii) enable predictive maintenance to prevent failures, (iii) forecast biogas-based electricity generation, and (iv) improve grid integration of renewable energy these activities are central to the use case's objective of increasing system reliability, energy efficiency, and operational resilience.

Data availability and access: (i) internal access: limited to authorized project partners (BPO, ENIC, UoP, PNET) via role-based access controls, (ii) external availability: aggregated or anonymized datasets may be made available for future research or replication studies, subject to the Data Management Plan (D1.2) and consortium agreement

Data re-use: Data may be reused for algorithm training, performance benchmarking, and replication in other biogas plants or similar industrial environments. Synthetic datasets from the digital twin environment may also simulate edge cases or rare failure modes.

Data sharing with third parties: Data sharing with third parties (e.g., research institutions, regulators) will be governed by D1.2 and performed under strict licensing, anonymization, and compliance frameworks.

Transparency of processing:

- all data handling workflows are documented and traceable through the COP-PILOT orchestration platform
- data provenance, processing logic, and access logs are maintained
- operator dashboards offer explainable analytics and allow for human oversight

Data security measures:

- End-to-end encryption (TLS/HTTPS) for data in transit
- Secure Modbus protocols for sensor communication
- Role-based authentication and firewalled edge servers
- Offline data caching to ensure resilience in case of connectivity loss

Data retention: Data will be retained for at least 5 years after project completion, in alignment with HORIZON EUROPE guidelines and the Data Management Plan (D1.2). Regular data backups and secure archival processes will be enforced.

AI Systems

The AI system implemented in UC#3E.3 is machine-based and deployed as containerized microservices on an industrial edge computing platform (e.g., Jetson Orin Nano). It consists of:

- Anomaly detection algorithms for biogas process monitoring
- Predictive maintenance models to forecast equipment degradation
- Electricity production forecasting models using historical and real-time data

Level of Autonomy: The AI system operates at a moderate level of autonomy. It autonomously detects anomalies and predicts maintenance needs but does not trigger control actions without operator confirmation. Decisions and recommendations are visualised through dashboards for human review and intervention.

Adaptability Capabilities: The system supports adaptability after deployment. AI models can be re-trained periodically using updated process data, enabling them to adapt to evolving plant conditions or operational changes. Retraining occurs in a controlled environment, and models are redeployed to the edge via secure orchestration mechanisms.

Input sources: The AI receives input from: (i) Real-time sensor data (e.g., pH, gas composition, temperature), (ii) Historical process logs and performance metrics, and (iii) Synthetic data generated through simulations (digital twin). Data is ingested through the edge gateway (Ewon Flexy 205) and processed locally on the edge server.

Objective and utilisation: The AI is used to:

- Monitor critical process variables of the anaerobic digestion system
- Predict equipment wear and schedule maintenance proactively
- Improve plant uptime and optimize energy yield
- Provide early warnings to reduce unplanned downtime

These objectives support the overall project goals of enhancing operational resilience and integrating dispatchable renewable energy into the grid.

Automated decisions and transparency:

- The AI system generates automated alerts and maintenance recommendations, but does not autonomously execute operational changes
- All outputs are logged and visualized via an operator dashboard with clear diagnostics and historical traceability
- A human-in-the-loop approach is maintained throughout, ensuring operator oversight

Algorithmic transparency measures:

- Decision thresholds and model logic are documented and made available to operators
- Dashboards offer intuitive access to both raw sensor trends and AI-generated insights

Risk assessments and fundamental rights: A preliminary AI risk assessment is planned to

- Ensure robustness and prevent misclassification or false positives
- Evaluate fail-safe mechanisms during sensor or connectivity failures
- Ensure compliance with ethical AI principles and safety requirements

Since the system operates in an industrial context with no personal data or human profiling, fundamental rights risks are minimal, but traceability and accountability are enforced.

AI Act risk category: The AI system likely falls under “high-risk” AI as per Annex III, Section 2 of the EU AI Act, since it is used to operate critical infrastructure (i.e., a biogas plant integrated into the electricity grid). Even though it does not directly control physical actuators, its role in process reliability and safety justifies this classification.

Training data and fairness

- The models are trained using historical operational data from the biogas plant and an open-source repository.
- No personal or demographic data is involved, eliminating the risks of gender or social bias
- Data diversity is ensured by including various seasonal and operational scenarios to improve generalisation and prevent overfitting.

Risk identification and assessment

Table 8.33 Use Case risk assessment

Risks	Likelihood (L / M / H)	Impact (L / M / H)	Mitigation
1. Sensor failure or drift affects monitoring accuracy	M	H	Implement redundancy and calibration routines
2. Discrepancies between simulated conditions and real plant behavior	L	M	Validate models in real conditions and include uncertainty margins
3. Edge analytics model misclassifies anomalies	M	H	Continuously retrain models using updated datasets and verify via alerts
4. Limited computational capacity at the edge	L	M	Prioritize critical tasks and optimize ML pipelines
5. Unauthorized access to biogas plant data	M	H	Enforce encrypted communication, firewall, and role-based access control
6. Operator misinterpretation of alerts	M	M	Develop clear dashboard indicators and action recommendations