



6G Vertical trials for Sustainability

D5.2 – 6G trials validation and evaluation – Initial



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Abstract

This deliverable presents the initial validation and evaluation activities performed within the first trial phase of 6G-VERSUS. It provides an overview of the demonstrations executed across the six project clusters, covering pre-trial activities, trial execution, preliminary KPI analysis, and lessons learnt. The document highlights the integration and validation of advanced B5G/6G technologies within distinct vertical domains. Additionally, the deliverable summarises the validation and evaluation methodologies adopted for KPI and KVI assessment, including stakeholder engagement activities and data collection procedures. It establishes the baseline and key aspects identified by the clusters from the first-phase trials and supports the refinement of the trial activity planning and evaluation frameworks for the final large-scale trials and pilots.

Keywords

6G-VERSUS Trials; Key Performance and Value Indicators (KPIs/KVIs); Validation Framework; Trial Results; Lessons Learnt

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Executive Summary

This deliverable presents the results from the first trial phase of the 6G-VERSUS project. Building on the trial planning, KPI methodology, and KVI framework established in Deliverable D5.1, it consolidates the activities performed across the six project clusters in Bulgaria, Finland, France, Greece, Portugal, and Spain.

The first trial phase combined pre-trial preparation activities, field demonstrations, preliminary KPI measurements, and stakeholder-oriented trials. The trials addressed sustainability-oriented vertical domains including smart grids and renewable energy, energy-autonomous network sites, sustainable water management, wildfire response and public safety, smart ports, and precision agriculture. Across these domains, the trials assessed the impact of integrating B5G/6G capabilities with the 6G-VERSUS application triplet, comprising clusters' Vertical Applications (V-Apps), Network Applications (N-Apps), and AI-Apps.

Stakeholder engagement was an integral element of the validation activities. Showcasing, questionnaires, focus groups, and interviews enabled the clusters to collect early feedback from vertical-sector representatives, public authorities, citizen organisations, industry, research, and end users. This engagement confirmed the relevance of the selected use cases and highlighted the need for targeted communication, clear stakeholder segmentation, streamlined feedback instruments, and strong follow-up actions to ensure high participation and response rates.

The first trial phase produced important lessons on the preparation and execution of trials. The applied methodology, plans and roadmap were considered adequate, but several challenges were highlighted. The key cross-cluster challenges were the need for early identification and engagement of relevant stakeholders and the establishment of mitigation measures for diverse risks, including adverse weather, site access limitations, equipment availability, and last-minute changes to the trial setup. This phase also highlighted the need to communicate use cases and their technological impact in clear, non-technical language when engaging audiences with diverse backgrounds. It demonstrated the value of a well-structured approach to collecting stakeholder feedback, including sufficient time and support for questionnaire completion, as well as the early identification of suitable participants for focus group discussions and targeted interviews.

The deliverable also consolidates the KPI and KVI validation framework and details targeted updates to measurement, monitoring, and automation tools. The framework will guide the second trial phase, supporting more systematic, replicable, and comparable assessment of technical performance and stakeholder-perceived value.

Overall, the first phase has provided the necessary baseline for the second and final trial phase. Its results and lessons will feed across work packages into the refinement of the project architecture, testbeds, triplet applications, validation procedures, and impact-assessment instruments, enabling 6G-VERSUS to progress towards more mature, large-scale, and evidence-driven validation of sustainable 6G-enabled services.

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Acronyms and abbreviations

Term	Description
*-App	V/N/AI Application
3GPP	3rd Generation Partnership Project
5G	Fifth-generation mobile network
5G RedCap	5G Reduced Capability
5G SA	5G Standalone
5GTN	5G Terrestrial Network
6G	Sixth-generation mobile network
AI	Artificial Intelligence
AI-App	Artificial Intelligence Application
API	Application Programming Interface
B5G	Beyond 5G
BESS	Battery Energy Storage Systems
CAPIF	Common API Framework
CoE	Center of Excellence
CPE	Customer Premises Equipment
CU	Centralized Unit
DER	Distributed Energy Resources
DL	Download
DRX	Discontinuous Reception
DU	Distributed Unit
E2E	End to End
gNodeB	Next Generation Node B
INUS	INtelligentUxV Surveillance
IoT	Internet of Things
KPI	Key Performance Indicator
KVI	Key Value Indicator
MLOps	Machine Learning Operations
MV	Medium Voltage
N-App	Network Application
NEF	Network Exposure Function
NF	Network Function
OAI	OpenAirInterface
PDU	Protocol Data Unit
PMU	Phasor Measurement Unit
POI	Point of Interconnection,
Q&A	Question and Answer
QoS	Quality of Service
RACH	Random Access Channel
RAN	Radio Access Network

RBAC	Role-based access control
RC	Regional Controller
RC-Boat	Remote Controlled Boat
RES	Renewable Energy Sources
RTSP	Real-Time Streaming Protocol
RU	Radio Unit
rUAV	relay Unmanned Aerial Vehicle
SCADA	Supervisory Control and Data Acquisition
SDG	Sustainable Development Goals
UAV	Unmanned Aerial Vehicle
UE	User Equipment
UL	Uplink
UV	Ultraviolet
V-App	Vertical Application
WAC	Wide Area Control
WAM	Wide Area Monitoring
WWTP	Wastewater Treatment Plant

1 Introduction

This document presents the initial validation and evaluation activities carried out within the scope of WP5. Building upon the methodological framework and planning activities defined in deliverable D5.1, this document consolidates the first results obtained from the execution of the initial trial phase across the six project clusters' use cases and experimental platforms. The objective of this deliverable is to report the results of the initial trials, including assessments of the performance, feasibility, and impact of the proposed B5G/6G-enabled solutions, through a combination of technical validation and stakeholder engagement activities. The trials conducted during this phase address multiple vertical domains and sustainability-oriented scenarios. Through these trials, the project evaluates how advanced B5G/6G-enabled applications can impact society in environmental, societal, cultural, economic, and business aspects.

This deliverable focuses on the initial deployment and validation stage of the project trials, documenting the technical setups, execution procedures, preliminary KPI measurements, stakeholder involvement, and lessons learnt from the first trial phase. The reported activities include pre-trial and trial executions performed across the different cluster infrastructures, highlighting the integration of vertical applications (V-Apps), network applications (N-Apps), AI-enabled functionalities (AI-Apps), and testbed innovations aligned with the project's triplet architecture.

In addition to the technical evaluation, it emphasises the importance of stakeholder-oriented validation. The trials involved engagement with representatives from industry, public authorities, decision makers, citizens' associations, research organisations, technology providers, and end-users to assess the perceived value, applicability, and societal relevance of B5G/6G technologies. The feedback collected during the showcases and interactive sessions through questionnaires, focus groups, and interviews constitutes a key input to the project's KPI/KVI framework and supports the continuous refinement of the experimental activities, as further explored in WP6.

This initial version of Deliverable D5.2 assesses the first-phase trials and provides valuable insights to refine the preparation and execution of the second-phase trials, which will be reported in D5.3.

1.1 Project Overview

6G-VERSUS is a collaborative research project under the HORIZON-JU-SNS-2025 Work Programme. It focuses on advancing sustainable and inclusive 6G networks by integrating results from previous research into a shared experimental infrastructure. The project currently supports both the validation of emerging technologies and the evaluation of relevant use cases across six 6G testbeds in Europe. The work explores key technical directions, including AI-native orchestration, modular and open architectures, and energy-aware network functions. Emphasis is placed on the evolution of vertical applications and the role of machine learning in enabling intelligent and adaptive network behaviour.

Pilots across the project's testbeds address real-world challenges in sectors such as renewable energy, emergency response, and water and waste management. These trials also introduce a key innovation: the 6G Application triplet, which combines a Vertical App (V-App), a Network App (N-App), and an AI-assisted App (AI-App). Together, they deliver distributed, AI-enhanced services and represent a shift in how next-generation network services are structured and deployed. The project follows a three-step methodology: transforming use cases into 6G Applications, testing and validating them on the enhanced platforms, and assessing their impact from sustainability (environmental, societal, and economic) perspectives. Alongside the technical work, 6G-VERSUS engages with stakeholders from academia, industry, and policymaking to ensure outcomes are aligned with broader sustainability and innovation goals.

1.2 Scope and Intended Audience

This deliverable presents the initial validation and evaluation results of the 6G-VERSUS trials, focusing on the execution of the first trial phase across the project clusters. Its scope includes descriptions of the trial setups, execution activities, preliminary KPI assessments, stakeholder involvement, and lessons learnt from the demonstrations conducted. The document also provides an overview of the evaluation procedures adopted to assess the performance, sustainability impact, and operational feasibility of the proposed B5G/6G-enabled solutions in different vertical domains.

The intended audience for this deliverable includes the European Commission and project reviewers; project partners involved in technical development, integration, experimentation, and evaluation; and external stakeholders interested in the project outcomes. This includes representatives from industry, network operators, technology providers, vertical sectors, public authorities, research and academic communities, and standardisation or innovation initiatives related to B5G/6G technologies and sustainable digital infrastructures. It also aims to support further trials and pilot research activities by describing the applied methodology, plan, timeline, and highlighting the key risks and lessons learnt.

1.3 Relation to Milestones and Other Deliverables

This deliverable builds upon the methodologies, KPI/KVI framework, and trial planning activities defined in D5.1, while relying on the infrastructure, platform integration, and AI/ML developments performed in WP3 and WP4. It supports the validation of project milestone MS12. The results, lessons learnt, and preliminary assessments presented in this document will serve as input to refine future experimentation activities and to prepare the subsequent validation and evaluation deliverables.

1.4 Structure of the Document

The structure of this deliverable is designed to provide a coherent overview of the initial trial execution activities carried out within WP5. The document follows a progressive flow from the general context of the experimental activities to the cluster-specific execution results and to the refinement of the evaluation framework that supports the assessment of the trials.

- **Section 2 – Validation and Evaluation Framework** updates the framework previously presented in D5.1, based on the results of the first trials.
- **Section 3 – Trials Execution** presents the execution activities performed across the six project clusters (i.e., Bulgaria, Finland, France, Greece, Portugal, and Spain). For each cluster, the section provides an overview of the pre-trials conducted, the execution of trials and pilots, the initial KPI analysis, and the main lessons learnt during the first trial phase. The section highlights the deployment of technical infrastructure, the integration of triplet applications and testbed innovations, and the interaction with stakeholders and the collection of feedback during the trials.
- **Section 4 – Conclusions** summarises the main outcomes of the first trial phase, highlighting the lessons learned during this phase.

This structure ensures a clear separation between the practical execution of the trials and the overarching validation methodology, while providing a consolidated view of the initial trial results obtained across the project clusters.

2 Validation and Evaluation Framework

This chapter presents the final version of the KVI and KPI validation frameworks developed in the 6G-VERSUS project, building upon the methodology established in Deliverable D5.1. Together, they provide a unified framework for assessing system capabilities and societal impact through complementary KVI and KPI perspectives.

2.1 KVI Validation Framework

As described in D5.1, a structured and iterative framework for evaluating Key Value Indicators (KVIs) aligned with 6G use cases is developed in 6G-VERSUS, integrating both quantitative system-level measurements and qualitative stakeholder-driven assessments. The framework consists of six sequential yet interdependent stages.

Step 1. Identification of Key Values (KVs)

The KVI validation process begins with identifying KVs, which represent the overarching societal, environmental, and economic impacts the project aims to achieve. Unlike technical metrics, these values are inherently high-level and reflect the broader contribution of 6G technologies beyond system performance. The identification of KVs is therefore driven by strategic objectives, such as sustainability, resilience, and inclusiveness, ensuring alignment with European and global policy agendas. This step establishes the conceptual foundation of the framework, defining what kind of value the system is expected to generate.

Step 2. Alignment of KVs with Use Cases (UCs)

Following the identification of KVs, the framework emphasises their systematic alignment with specific use cases (UCs). This step ensures that abstract value dimensions are grounded in realistic deployment scenarios, thereby enhancing their operational relevance. Each KV is mapped to one or more UCs based on the expected impact of the technological solution within that context. This alignment process is critical to avoiding generic or non-actionable value definitions and to ensuring that each value is contextualised, measurable, and directly linked to real-world applications. In this way, the framework guarantees that value assessment is use-case-driven rather than purely theoretical.

Step 3. Definition of Key Value Indicators (KVIs)

Once KVs are aligned with use cases, they are translated into KVIs, which serve as measurable or assessable proxies of value realisation. This transformation involves defining both quantitative and qualitative indicators that can capture different dimensions of impact. Quantitative KVIs may be directly linked to technical Key Performance Indicators (KPIs), whereas qualitative KVIs often rely on stakeholder perceptions and experiences. The definition of KVIs requires careful consideration to ensure that each indicator remains interpretable, traceable to its corresponding KV, and meaningful within the context of the associated use case.

The full list of KVIs defined in 6G-VERSUS for each cluster can be found in Section 4 of D2.1, which covers various sustainability dimensions, including environmental, economic, and societal & cultural.

Step 4. Preparation of KVI Evaluation

The preparation phase constitutes the methodological core of the framework, where the evaluation strategy for KVIs is designed. This includes establishing quantitative evaluation methods by associating KVIs with relevant KPIs and defining appropriate measurement tools and data collection mechanisms. In parallel, qualitative evaluation instruments, such as questionnaires, structured interviews, and focus group protocols, are developed to capture stakeholder perceptions and experiential feedback. Furthermore, this step involves designing trial scenarios and test cases, identifying target stakeholder groups, and developing sampling strategies. The framework explicitly adopts a hybrid approach, integrating objective system-level measurements and subjective human-centred assessments to provide a comprehensive assessment of value.

Step 5. Execution of KVI Evaluation

The execution phase involves conducting trials in real-world environments, during which both quantitative and qualitative data are systematically collected. On the one hand, system-level data are gathered through KPI monitoring tools, capturing network performance, reliability, and efficiency metrics. On the other hand, stakeholder feedback is obtained through surveys, interviews, and focus groups conducted during or after the trials. This dual data collection process ensures that both technical performance and perceived value are assessed concurrently. The framework places strong emphasis on stakeholder engagement, recognising that meaningful KVI validation requires active participation from external users and domain experts. All data collection activities are conducted in accordance with predefined methodologies to ensure consistency and comparability across trials.

Step 6. Analysis, Monitoring, and Refinement

The final step involves the integrated analysis of collected data, combining quantitative KPI-based evidence with qualitative stakeholder insights to evaluate the extent to which the identified values have been realised. This analysis enables the identification of discrepancies between expected and observed values, as well as potential biases or limitations in the evaluation process. Based on these findings, the framework supports iterative refinement of KV definitions, KVI formulations, and evaluation methodologies. Importantly, this iterative process is not a one-time activity, but a continuous feedback loop embedded in the trial lifecycle, enabling progressive improvement across trial phases. This adaptive approach ensures that the KVI validation framework remains robust, context-aware, and responsive to emerging insights throughout the project.

In summary, the KVI validation framework provides a structured and iterative approach for assessing value realisation across 6G use cases through the integration of quantitative measurements and qualitative stakeholder feedback. The detailed definition, implementation, and methodological specifications of the framework are provided in Deliverable D5.1.

2.2 KPI Validation Framework

The KPI validation framework was established in Deliverable D5.1 as a structured methodology for evaluating system-level performance across heterogeneous 6G trial environments. The framework integrates key components including test cases, trial scenarios, measurement methodologies, monitoring tools, and automated execution pipelines, thereby enabling standardised, reproducible, and scalable performance assessment. The overall methodology is organised into a sequence of interrelated steps, as described below.

Step 1. KPI Identification and Use Case Alignment

The KPI validation process begins with identifying Key Performance Indicators (KPIs) that capture the system's technical performance. These KPIs are derived from both standardised metrics and project-specific requirements, ensuring comparability with existing frameworks and related projects. Crucially, KPI selection is tightly aligned with the defined use cases (UCs), such that each KPI directly reflects a measurable aspect of system behaviour within a specific operational context. This alignment guarantees that performance evaluation is not generic but instead tailored to the functional objectives and constraints of each trial scenario.

The list of KPIs defined in 6G-VERSUS for each cluster can be referenced in Section 4 of D2.1.

Step 2. Scenario and Test Case Design

Following KPI identification, the framework defines detailed trial scenarios and corresponding test cases. Scenarios represent high-level operational conditions or application contexts (e.g., normal operation, stress conditions, or specific vertical applications), while test cases provide concrete, reproducible experimental setups to evaluate KPIs under these conditions. Each test case specifies the system configuration, input parameters, expected behaviours, and associated KPIs to be measured. Importantly, a mapping between test cases and KPIs is established to ensure traceability and completeness of the evaluation process across different trials and clusters.

The detailed test cases identified for the trials for each cluster are defined in D5.1 annexes. The updated test cases from the Finnish cluster are specified in this document's annex. These test cases were not included in D5.1 due to previously ongoing architecture design and hardware & software selection. After MATLAB based simulation demo and multiple workshops on flow diagrams and API implementation, the Finnish use case final architecture was completed and test cases defined.

Step 3. Experimental Preparation and Measurement Setup

The preparation phase involves configuring the experimental environment and measurement infrastructure required to validate KPIs. This includes the deployment of testbeds, network components, user equipment, and application-level services, as well as the integration of measurement and monitoring tools. Standardised methodologies for end-to-end testing are adopted to ensure consistency, including traffic generation, latency measurement, and signal quality monitoring. This step also ensures interoperability across heterogeneous platforms and defines the procedures for data acquisition, storage, and synchronisation across different system components.

The specific measurement and monitoring tools deployed in each cluster are specified in Section 4.2 of D5.1, with minor changes recorded in Table 2-1.

Table 2-1: Changes of test and measurement tools with reference to D5.1

Cluster	Tool	Description	Changes to D5.1
Greek Cluster	Keysight N6705C DC Power Analyzer	A high-precision and modular DC power analyser to measure the power consumption of the device under test in real-time.	Added
Spanish Cluster	Keysight IxChariot	IxChariot can be installed in end devices connected to the network, enabling fine-granularity traffic generation and KPI collection	Added
Spanish and Greek Cluster	Keysight PathWave Test Automation	A web-based software suite designed to help test automation teams collaborate, deploy, and monitor test plans at scale across different geographies.	Added

Step 4. Execution and Automation of Trials

KPI evaluation is conducted through controlled trials, either in real-world environments or on realistic testbeds. The framework emphasises automation of experiment execution to ensure repeatability, scalability, and consistency across trials. Automation tools orchestrate test case deployment, control experimental conditions, and trigger data collection. This reduces human intervention, minimises variability, and enables systematic benchmarking across multiple scenarios and clusters. Real-time monitoring mechanisms are employed during execution to detect anomalies and ensure adherence to predefined experimental conditions.

Step 5. Results Collection and KPI Analysis

During and after trial execution, KPI data are systematically collected from measurement tools and monitoring platforms. These data include network-level metrics (e.g., latency, throughput, reliability) as well as end-to-end system performance indicators. The collected data are then processed and analysed using predefined methodologies to evaluate system performance against target values or baselines. Comparative analysis across test cases, scenarios, and clusters is performed to assess consistency and robustness. The results provide quantitative evidence of system capabilities and serve as input for further optimisation and reporting activities.

In summary, the KPI validation framework provides a structured and reproducible approach for evaluating system-level performance across diverse 6G trial environments through standardised measurement and analysis procedures. The detailed definition, implementation, and methodological specifications of the framework are provided in Deliverable D5.1.

3 Trials Execution

This section provides an overview of the execution activities conducted across the project clusters during the first trial phase. It consolidates the results of the trials, covering the preparation and execution of pre-trials, the deployment and demonstration of trials and pilots, the initial analysis of KPIs, and the lessons learnt from the activities conducted. The section highlights the validation of the proposed B5G/6G solutions and stakeholder interactions during the demonstrations. Additionally, it summarises the operational challenges encountered during the execution phase, the mitigation measures adopted, and the insights gathered to support the refinement and evolution of the next trial phase.

Table 3-1: Cluster activity overview

Cluster	In-Lab/ Pre-trial tests	T&P	Stakeholders	Questionnaire answers	Focus Groups	Interviews	News Articles	Videos	KPIs collected
Bulgarian	2	2	51	59	4	0	3	1	10
Finnish	0	2	31	9	0	0	3	0	5
French	2	1	31	0	2	0	1	1	8
Greek	2	2	29	29	2	1	9	2	13
Spanish	3	2	97	33	0	0	0	2	11
Portuguese	3	2	77	33	0	12	7	2	6

3.1 Bulgarian Cluster

The Bulgarian cluster focuses on a smart grid use-case for AI-data driven Wide Area Monitoring and Control of DERs through b5G communication. During this 1st phase of trials implementation, the Bulgarian cluster leveraged two end-to-end b5G infrastructures located in two European countries:

- the commercial network of A1 in Bulgaria which leverages its own edge/cloud orchestration, extended with CAPIF/NEF exposure, and which integrates X-Apps smart grid services with advanced power system sensors such as Phasor Measurement Units (PMU), SCADA, and power electronics invertors of the DERs assets of a remotely located wind farm of EE, and
- a pre-piloting end-to-end Beyond 5G (B5G) infrastructure in Cyprus which integrates OpenAirInterface (OAI) 5GSA, along with dedicated edge and cloud computing resources hosting the 6G-VERSUS X-Apps, extended with FlexRIC-based exposure of network KPIs, and commercial of virtual power system sensors and real-time grid digital-twins such that to replicate with high fidelity the pilot infrastructure in Bulgaria.

More specifically, the Bulgarian pilot involves a wind farm owned and operated by Entra Energy (EE), located in a remote area in Sliven Region in SE Bulgaria, the actual commercial telecommunication infrastructure of A1, and equipment deployed on several parts of Bulgaria, such as: a newly deployed radio base-station located close to the wind farm of EE in Sliven region, a data centre located in Varna, Bulgaria which serves as the edge cloud for the deployment of the V-App Regional, for monitoring of Distributed Energy Resources (DER), and another data centre located in Sofia, serving as central cloud for the deployment of the V-App Central Wide Area Monitoring (WAM).

The pilot is spread across multiple locations:

- X-Apps at the central cloud of A1 in Sofia

- V-App Regional at the edge cloud of A1 in Varna
- Power sensors and actuators of the wind farm of EE located in Sliven (including an advanced Phasor Measurement Unit (PMU) and power electronic inverters of DERs such as wind turbines and the digital twin of BESS).

These three locations are more than 300 km from each other, as depicted in the pilot map in Figure 3-1.



Figure 3-1: Map of the Bulgarian pilot physical components location

Besides the Pilot in Bulgaria, an advanced pre-piloting testbed located in Cyprus at the UCY (KIOS Center of Excellence) premises has been used for pre-trial sessions related to both Trials of the first phase, and for live demonstration of Trial 2. This pre-piloting testbed is briefly overviewed in the following sub-section, pre-trials, as well as in the 2nd Trial summary in the sub-section Trials and Pilots.

The Bulgarian Cluster organised two trials. The 1st Trial took place in Sofia, Bulgaria, on the 26th of March 2026, while the 2nd Trial took place in Nicosia, Cyprus, on the 11th of June. Both trials were supported by several pre-trial sessions held in Bulgaria and Cyprus. The defined test cases were applied to both trial events.

Table 3-2: Bulgarian cluster scenarios

Scenarios
1. 5G communication assessment for DERs – connectivity KPIs and baseline scenario for the vertical with no frequency support from DERs
2. 5G communication for DERs and no NApp
3. 5G communication for DERs +NApp & AI-App (partially).

Table 3-3: Bulgarian cluster test cases

Test Case ID	Title
1.1	Evaluate the Mobile Network Performance in remote areas of DERs using the A1 testbed
1.2	FFR service from synchronous generators and no DERs participation (baseline scenario) using the UCY testbed
2.1	PMU-to-V-APP communication (baseline eMBB setup) over the OAI 5G testbed and a commercial PMU at the UCY testbed
4.1	PMU-to-V-App Central (WAM-C) & ML-Ops framework for training of the ML models (AI-App) using the UCY testbed (partial tests, for the early version of the trained ML-model)

Table 3-4: Cluster summary table

Stakeholders	Questionnaires answers	Interviews	Focus groups	News Articles	Videos	KPI Collected
51	59	0	4	2 ⁴	1	10

3.1.1 Pre-trials

The preparations for the first-phase trials of the Bulgarian cluster required several pre-trial lab and field tests to be conducted by the cluster partners. Specifically, three pre-trial sessions were conducted in Cyprus by the UCY/KIOS⁵ CoE multi-disciplinary research teams with expertise in power systems, telecommunications, and IT. Also, in Bulgaria, the partners A1, EE and SCBG have conducted several pre-trial tests both at their research and development lab premises and in EE's wind farm. The scope of all these pre-trial sessions was to establish the ground truth for the baseline and to evolve the pilot and testbeds for the progressive implementation and testing of the use-case scenarios.

3.1.1.1 Cyprus pre-trial

The pre-trials run by the UCY team involved the development and integration of a pre-piloting testbed, which mirrors with high fidelity the actual pilot architecture of the Bulgarian use-case (Figure 3-2). It involved the integration of an advanced facility able to emulate in hard real time the operational behaviour of actual power grids based on OPAL-RT technology and actual power equipment (commercial PMUs, power electronics inverters for DERs, power amplifier) and a 5G-OpenAirInterface testbed for over-the-air connectivity between the power system testbed and the V-Apps, namely Wide Area Monitor (WAM), Wide Area Control (WAC), and Regional Controller (RC), deployed as containers on dedicated computing resources which replicate the central and edge cloud resources of the A1 testbed. The scope of the development and integration of this advanced pre-piloting set-up was to enable a highly realistic sandboxing environment for development and testing of newly created V-Apps (WAC and RC) using actual power sensors, and 5G over the air communication (rather than simulations), as well as for validation of several scenarios of the Bulgarian use-case which cannot be performed in the actual pilot due to grid operation restrictions (e.g., performing a broad range of artificially induced grid faults in order to test the robustness of the 6G-enabled WAC and RC services for DERs).

⁴ <https://news.nbu.bg/bg/events/seminar-sys-studenti-prepodavateli-i-doktoranti-ot-nov-bylgarski-universitet-i-firma-a1-na-tema-eksperimenti-v-razlichni-sektori-na-6-g-mrezha-za-po-golqma-ikonomicheska-ustojchivost-6-g-versus-vertical-trials-for-sustainability!93948>

⁵ https://www.linkedin.com/posts/kios-coe_6gversus-6g-smartgrids-activity-7471180140304101377-HMcN/

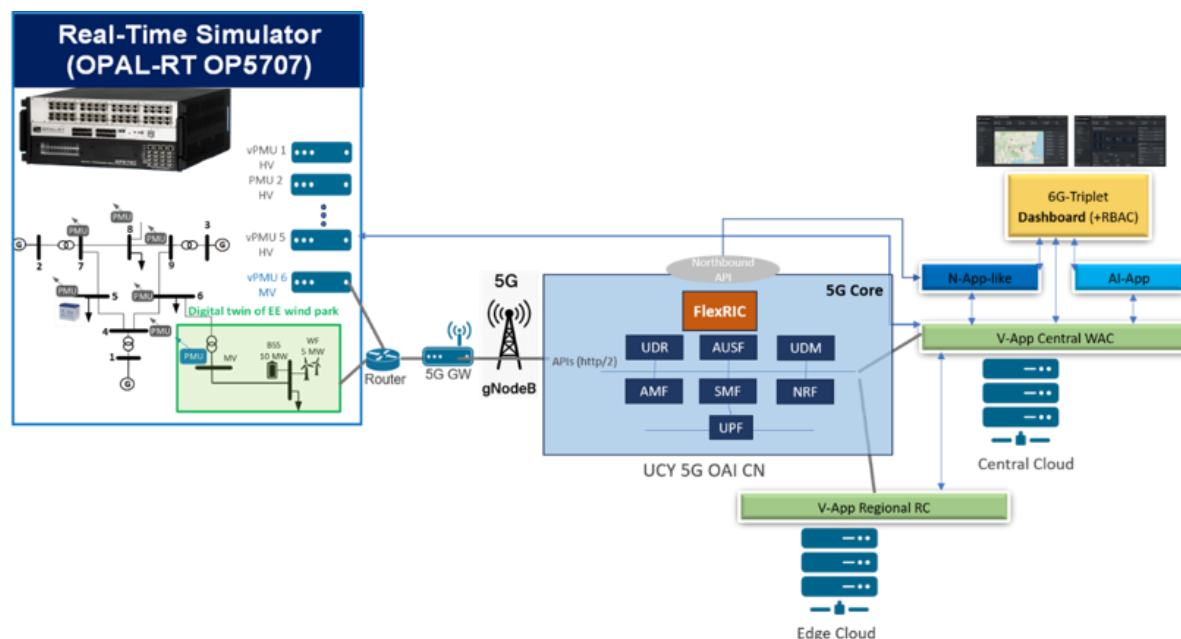


Figure 3-2: Blueprint of the UCY/KIOS Coe pre-piloting testbed of the Bulgarian cluster

Development and testing of a high-fidelity electromagnetic transient (EMT) model based on the IEEE 9-bus test system was developed in MATLAB/Simulink using Simscape Electrical library. The original benchmark network was modified to better represent modern power systems with high penetration of inverter-based distributed energy resources (DERs). In particular, a medium-voltage (MV) feeder was connected to one of the HV power substations through a 230/11-kV transformer. This feeder represents the digital-twin replica of Entra Energy's renewable energy park in Bulgaria and includes a 2-MW wind turbine (WT) together with a 1-MW/1-MWh battery energy storage system (MV-BESS). The inclusion of both transmission- and distribution-level DERs enables the investigation of coordinated control strategies and their interactions under a wide range of operating conditions.

The complete simulation platform was designed for execution on the OPAL-RT OP5707 real-time simulator using the RT-LAB environment. A fixed-step discrete solver with a microsecond-scale simulation step was adopted to accurately capture fast electromagnetic transients, switching dynamics, and inverter control behaviour while ensuring deterministic real-time execution. The platform is fully compatible with both Hardware-in-the-Loop (HIL) and Controller-Hardware-in-the-Loop (C-HIL) testing, facilitating the validation of real control hardware and communication architectures under realistic operating conditions.

Real-time communication with external applications was implemented through two industry-standard protocols, whose interfaces are provided by the RT-Lab software. Virtual PMU measurements are encapsulated according to the IEEE C37.118 standard and streamed over TCP/IP at a system frequency of 50 Hz and a reporting rate of 50 frames per second. Each virtual PMU is assigned a unique identifier and TCP port, enabling interoperability with Phasor Data Concentrators (PDCs) and Wide-Area Control (WAC) applications. In parallel, a Modbus TCP Slave interface exposes selected Simulink variables as read/write registers with an update period of 200 ms through the standard TCP port 502. This interface enables bidirectional communication between the real-time simulation and Regional Controllers (RCs), allowing supervisory control algorithms to monitor system states and dispatch active and reactive power set-points to the inverter-based DERs in real time.

During real-time execution, the WT is driven by active power set-points derived from historical measurements of an actual wind turbine, reproducing realistic generation variability. The HV-BESS and MV-BESS operate using constant active power references of 5 MW and 0.5 MW, respectively, while both units maintain zero reactive power set-points. A frequency event is initiated by the sudden connection of a constant 83 MW load near bus 4, introducing an active power imbalance that causes the system frequency to decrease.

This highly accurate digital-twin power grid replica was used to assess the baseline KPIs related to the smart grid service (the case when the frequency support is provided only by large synchronous machines and not by DERs, the current status-quo).

Deployment and validation of the local closed-loop interaction between the V-App Central WAC and the V-App RC and the OPAL-RT were developed from scratch as part of the 6G-VERSUS project. In critical infrastructures such as the power grids, it is mandatory for any software or hardware component to be tested and validated in relevant environments before they are deployed in the production environment.

The highly accurate digital-twin power grid replica was used to assess the baseline KPIs related to the smart grid service (KPI001 - Ultra-Fast Frequency response service time, and KPI002 - Improved grid stability) in the case when the frequency support ancillary service is provided only by large synchronous machines and not by DERs (the current status-quo). The results of these measurements are provided in Figure 3-3.

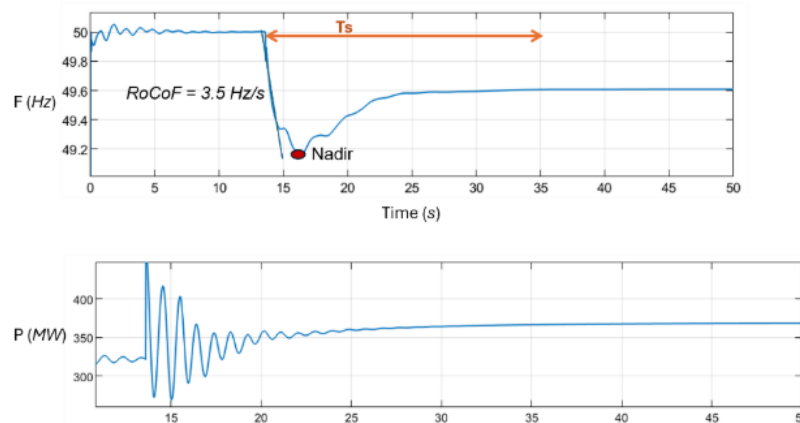


Figure 3-3: Baseline KPIs 001 and 002 for the Bulgarian Use Case

The pre-trial session, which took place during several days at the end of May and beginning of June 2025, prior to Trial 2, included the control-in-the-loop test case 4.1. This test case aimed to capture the improvement in the dynamic grid stability when coordinated control of DERs, facilitated by the b5G communication, is used for provision of ancillary services such as fast frequency support. The grid stability was assessed based on the measured values of the same KPIs 001 and 002 as a comparison between the case when DERs were providing ancillary services to the grid (ultra-fast frequency support) and the baseline scenario (DERs did not participate in the provision of this service). The recorded KPIs, as measured using the V-App Central WAC dashboard, are presented in Figure 3-4:

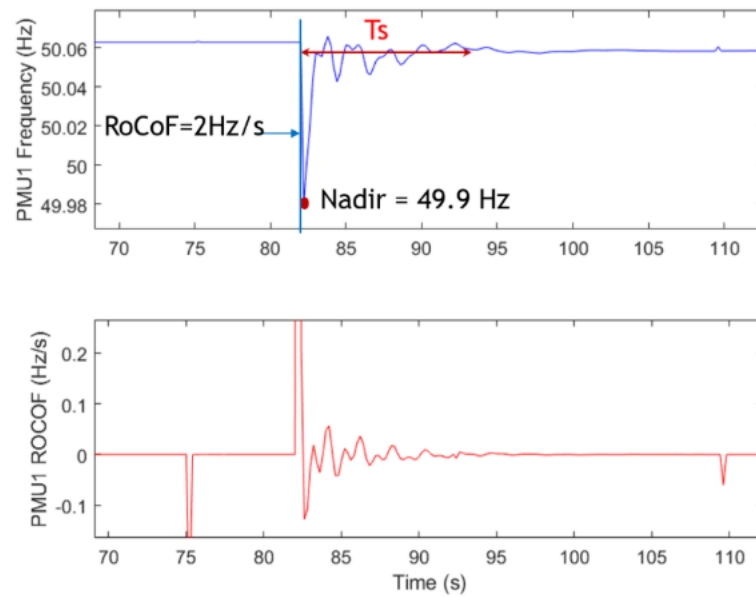


Figure 3-4: Measured KPIs 001 and 002 with WAC and RC for DERs activated in UCY testbed



Figure 3-5: Photos from the pre-trial sessions at the UCY lab using the pre-piloting testbed

Figure 3-5 shows the UCY team performing pre-piloting tests related to deployment and integration of the V-Apps into the UCY 5G-OAI testbed, performing connectivity verification between a commercial PMU and the V-App Central or collecting KPIs related to baseline scenarios and the closed-loop interaction between the V-App Central WAC and the V-App Regional Controller (RC), N-App like real-time monitoring of network QoS, and the alpha version of the AI-App. It should be noted that the V-App Central WAC and V-App Regional Controller, the N-App, and the AI-App were developed from scratch as part of the 6G-VERSUS project.

In summary, the pre-trial sessions run by the UCY team had a two-fold scope:

- To provide an integrated setup which is trusted by both energy utilities and telecommunication professionals as a pro-active, zero-trust cyber-physical orchestration setup able to de-risk millisecond PMU-based control loops, such as the 6G-enabled WAC service, before any field deployments.
- Validate the key functional requirements of the first stable versions of the newly developed V-Apps (V-App Central WAC and V-App Regional Controller/RC), N-App real-time monitoring of network QoS and the early release of the AI-App for grid frequency trajectory prediction. The V-Apps (WAC and RC) are software-only controllers. Thus, this solution addresses the scalability and replicability, enabling deployment on any hardware instead of the typical hardware-locked controllers (the current state of the art for power grids). Further, using a pre-piloting environment is not just "good practice"; it is a critical requirement for this type of use case.

3.1.1.2 Bulgarian pre-trials

Prior to the field deployment at the Wind Turbine Park, and while the A1 mast installation was being completed, a series of testing and pre-trial activities were conducted at the EE and A1 premises. This process was executed in two phases: first, via simulation configurations; then, by physically deploying all operational components into the A1 production environment.

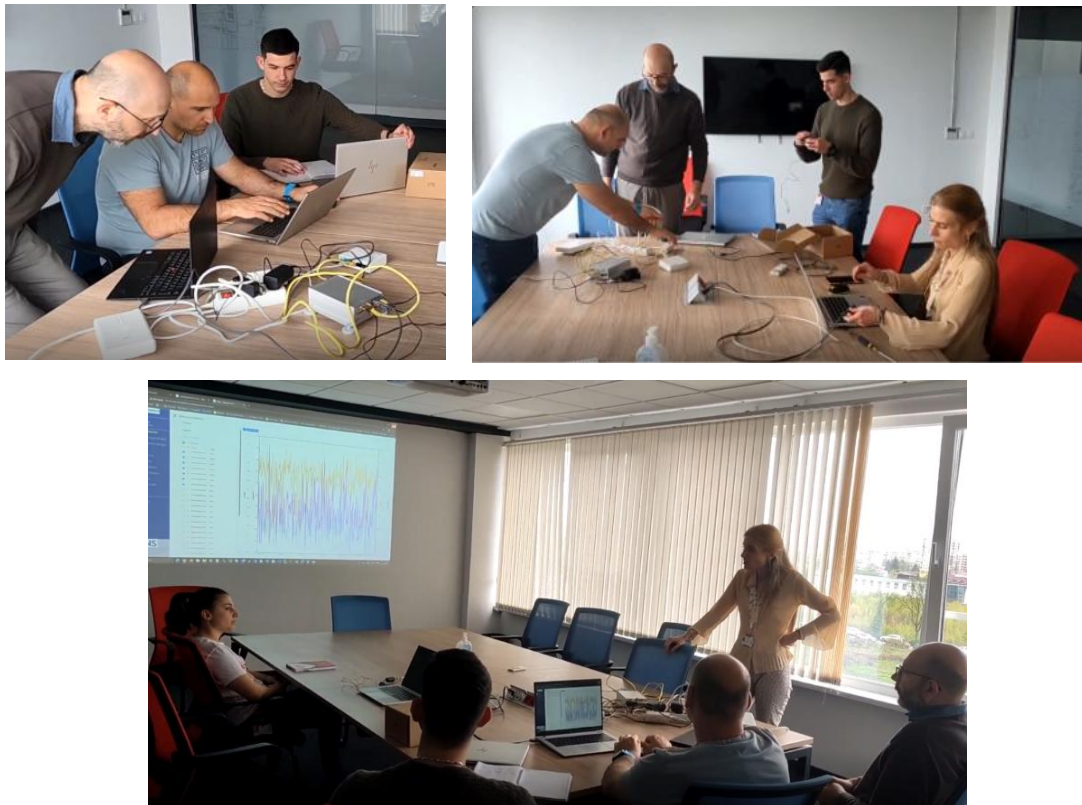


Figure 3-6: Pre-trial activities in EE and A1 premises

The core objective of these joint tests was to validate the connectivity matrix and verify the correct configuration and interaction between the Phasor Measurement Unit (PMU), the 5G router, and the CPE (Gateway) under the production network coverage of the gNodeB, located in Sofia

As part of the second phase (the physical pre-trial), the entire end-to-end setup was simulated in the A1 production reference network in Sofia, as shown in the diagram below:

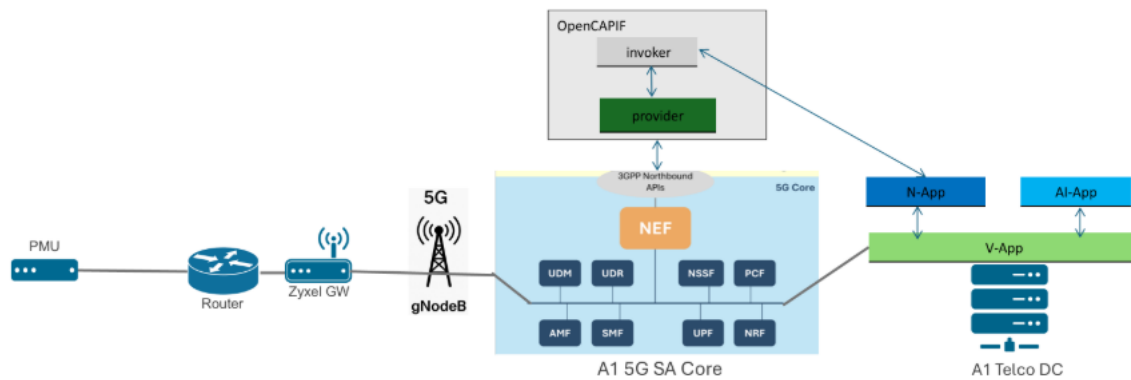


Figure 3-7: A1 reference network

The final execution yielded successful results:

- **Successful Hardware Integration:** The physical PMU device was successfully connected to the ZTE 5G Gateway in A1's 5G SA network, and a stable communication link to the V-App Central was established.
- **Live Data Visualisation:** The high-frequency electrical measurements generated by the PMU were correctly transmitted across the network, received without data loss, and successfully visualised live on the V-App Central dashboard.

3.1.2 Trials and Pilots

3.1.2.1 Trial 1: Bulgaria - Sofia

The first trial of the Bulgarian pilot and use case took place in Sofia, Bulgaria, on the 26th of March, on the premises of New Bulgarian University. The trial demonstration sequence lasted approximately 2 hours. The demonstration followed the agenda structure and was designed to present the 5G system's capabilities and its potential to support advanced smart grid applications, such as monitoring and control of DERs. The language and the style of the presentation were such that they engaged both specialists and non-specialist audiences. The event followed the agenda below.

Table 3-5: First Bulgarian trial agenda

Time (min)	Phase	Activity
5 min	Introduction & Project Overview	Welcome remarks and project introduction: Provided an overview of beyond-5G (B5G) technology's role in supporting smart grid applications within the Bulgarian use-case context. The presentation was supported by a short introductory video.
15 min	Bulgarian Cluster Walkthrough	Guided tour of cluster scope and progress: Outlined the pilot's motivation and current achievements. Explained the live data feeds originating from both Entra Energy's (EE) renewable power plant infrastructure (PMU measurements for the MV POI and DER units) and specific network metrics, as visualised via the vertical web apps.
45 min	Recorded Demonstrations from the pre-trial tests	Showcasing geographically distributed testbed results: Due to the wide distribution of the pilot – a remote Renewable Energy Sources (RES) plant, a new A1 5G base station, and data centres 400km apart – recorded pre-trial test results were presented to stakeholders in Sofia. Demonstrations included: • Live PMU data streaming visualised via V-App Central (WAM). • Live electrical Supervisory Control and Data Acquisition (SCADA) streaming from the actual EE wind turbine and a laboratory BESS digital twin via V-App Regional. Progress updates on connecting the power plant site to the A1 5G network.

25 min	Panel session discussion with experts and audience	Interactive discussion with domain experts: A panel recap highlighting the broader societal and industrial benefits of B5G technology evolution across domains. Concluded with an open Q&A session addressing audience inquiries.
30 min	Collection of feedback for the Kahoot questionnaires	The demo ended with collecting feedback from the audience, which included academics, students, researchers, and several industry stakeholders from the telecommunications, ICT, and energy domains. This feedback was collected using the Kahoot tool, in which initial consent was requested, and participants then answered questionnaires live. This collection was then used to analyse the KVis selected for the first trial.

The first Trial was promoted via a local news article⁴ and was attended by approximately 30 participants, primarily representing the scientific community alongside several industry professionals from the telecom and energy sectors. To evaluate the event's impact, a targeted questionnaire was designed to gather stakeholder feedback and address all KVis and Root KVs (R-KVs) defined for the pilot.

Table 3-6: Stakeholders' attendance per group: number of stakeholders/participants

Trial/Pilot (ID)	Government Bodies	Environmental Organizations	SME/Industry	Scientific Community	Other
1	0	0	5	25	0



26 march 2026
18:00

Workshop with students and teachers from New Bulgarian University and professionals from AI company on the topic “6G-VERSUS - Vertical Trials for Sustainability”.

Building 1, Room 210

Organisers:
Department of Informatics and Department of Telecommunications, New Bulgarian University

Figure 3-8: News publication promoting the 1st Bulgarian trial at NBU



Figure 3-9: Bulgarian trial venue



Figure 3-10: Demonstration slide outlining the Bulgarian pilot operational and logistical challenges



Figure 3-11: Presentation of the telecommunications layer and why connectivity is key

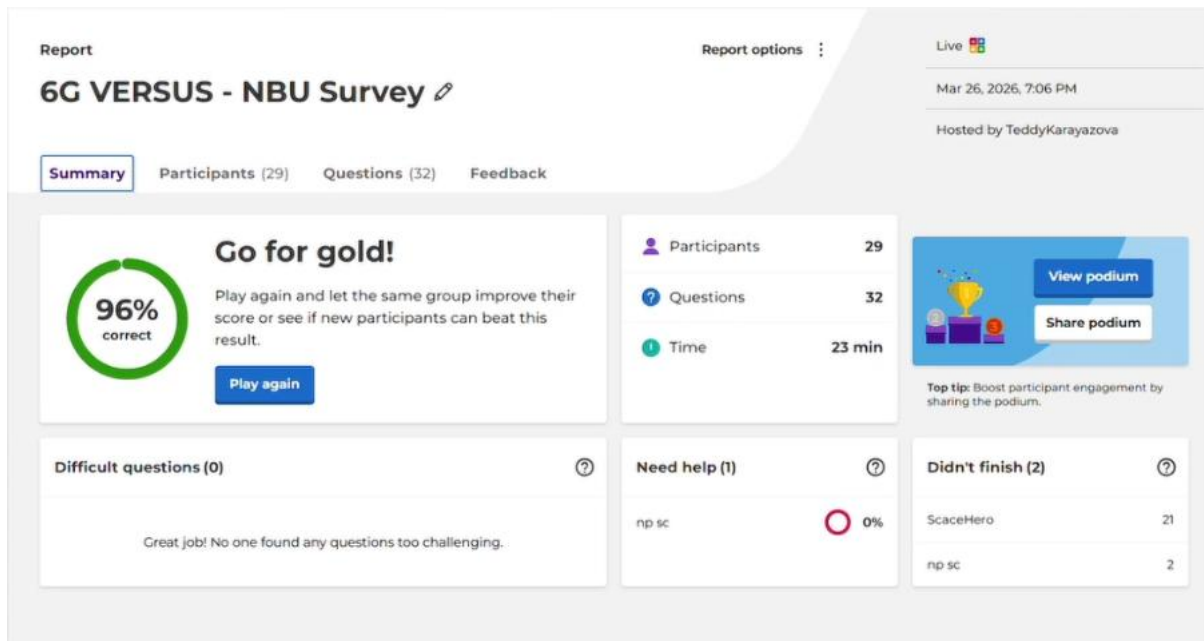


Figure 3-12: Live stakeholder feedback collection using the interactive Kahoot platform



Figure 3-13: Video summary produced for the 1st Bulgarian Trial event

Table 3-7: Collected KPIs

KPI Name/ID	Measured values	Comments
KPI_001	2 Hz/s/ 20s	Baseline, measured using the pre-piloting testbed of UCY and the V-App Central WAC dashboard
KPI_002	48.9 Hz	Baseline, measured using the pre-piloting testbed of UCY and the V-App Central WAC dashboard
KPI_003	100%	
KPI_004	100%	
KPI_005	5.9	
KPI_006	11.72	
KPI_007	0%	
KPI_008	3	

KPI_009	0%	
KPI_010	N/A	
KPI_011	15.5	
KPI_012	17	

Table 3-8: Collected KVI

Trial/Pilot	Questionnaire answers	Focus groups	Number of Interviews done	Comments
1	27	1	0	

3.1.2.2 Trial 2: Cyprus - Nicosia

The 2nd Trial of the Bulgarian Cluster took place on the 11th of June in Nicosia, Cyprus, at the premises of the KIOS CoE at the University of Cyprus. The primary objective of the second trial was to test and validate additional components of the 6G-Apps, such as V-App Central WAC, V-App Regional RC, N-App, like real-time monitoring of QoS KPIs and AI-App (alpha version), along with all their interfaces, ensuring enhanced interoperability and functionality for the 6G-enabled smart grid service for DERs. Unlike the first trial, which mainly focused on introducing the overall concept of the Bulgarian use case and to validate the basic connectivity and data flows for the V-App Central WAM and the V-App Regional Monitoring of DERs, the second trial was designed to demonstrate a more operational and dynamic deployment scenario under realistic operational conditions of the power grids with DERs able to provide ancillary services such as fast frequency support.

This second trial included an introductory presentation on the 6G-VERSUS project and the Bulgarian use case, and a live demonstration of the end-to-end flow of the alpha version of the 6G-enabled smart grid service (AI-data-driven wide-area monitoring and control of DERs) using the full functionality of the pre-piloting testbed. The Demo setup included both virtual and actual power sensors (PMUs and DERs inverters) monitoring the relevant nodes of the digital-twin of a power grid with DERs running in hard real-time in the OPAL-RT emulator. Part of the virtual PMU sensors were connected via fibre-optic links, and the PMU monitoring the digital twin of EE's MV feeder was connected via 5G. It should be noted that all these advanced power metering sensors sent GPS-synchronised measurements to the 6G-enabled WAM&C service. The rationale of this mixed communication approach (fibre optic and 5G communication) was to replicate the most realistic and practical implementation where high voltage (HV) power substations have PMUs connected via fibre optics (e.g., this is the real case of the power system of Cyprus) while MV critical DERs feeders are to be monitored by 5G connected micro-PMUs, due to their remote location and prohibitive costs for fibre optics in these locations. In the live demo session, the digital twin of a modified IEEE 9-bus system ran in hard real time on the OPAL-RT emulator using a Control-Hardware-In-the-Loop (C-HIL) setup, while all operational and control processes were monitored live via an integrated system dashboard. The *-App triplet dashboard included role-based access control (RBAC) functionality via KeyCloak technology, offering secure and personalised views and control actions for three types of service users: grid operators, DER operators, and communication network operators. Emphasis was placed on presenting the capabilities of the 5G-enabled environment, the integrated AI-based application (early developments), and the interactions among components within the power and B5G platform to shape the use case. To ensure the smooth execution of the activities and facilitate audience engagement, a structured agenda was designed and followed throughout the event and can be seen below (in the Cyprus time zone).

Table 3-9: Second Bulgarian trial agenda

Slot	Topic	Presenter
15:30	Welcome note from the PI	Prof. Georgios Ellinas (UCY)
15:35	Introduction to the 6G-VERSUS project	Dr. Irina Ciornei (KIOS/UCY)
15:40	Overview of the Bulgarian Use-case	Dr. Irina Ciornei (KIOS/UCY)
15:50	Pre-piloting infrastructure supporting the UC	Panagiotis Chrysanthou, Eleni Tekki, Kyriakos Karlettis (KIOS/UCY)
16:05	6G-Enabled AI data driven WAM&C – system dashboard	Kyriakos Karlettis (KIOS/UCY)

16:20	Coffee break	
16:30	Live Demo - Smart Grids and Networks Lab – KIOS CoE: • Showcase of infrastructure • Initiation of the 6G-enabled smart grid service and visualisation of the grid operator dashboard • Initiate the digital twin of the power grid operating in normal conditions • Switch the dashboard to DERs operator view and dive through the functionalities in normal operating conditions of the grid • Switch the dashboard to the Network Operator view for live monitoring and control of QoS • Initiate grid fault and monitor in hard real-time the behaviour of the grid monitored by PMUs (no WAC service activation for DERs participation) – baseline • Clear fault and back to normal operation condition • Activate 6G-enabled WAC service and initiate again a grid fault monitoring the grid dynamic behaviours with DERs participation	Panagiotis Chrysanthou, Eleni Tekki, Kyriakos Karlettis, Dr. Irina Ciornei (KIOS/UCY)
17:00	Questionnaire and Interview Session (Collection of Feedback)	All
17:30	Networking session (coffee and snacks)	All

The Trial was attended by the most relevant energy stakeholders in Cyprus, including representatives from the Transmission System Operator of Cyprus (TSOC), such as control room engineers; representatives from the management department of the Electricity Authority of Cyprus (EAC), the main power supplier of the country and also the Distribution System Operator (DSO); representatives from the Renewables Association in Cyprus, who are also owners and operators of RES (wind farms, PV farms and small storage systems); a representative from the Electricity Market of Cyprus (part of the TSOC); network engineers from EAC; and researchers and academics from UCY (not involved in the 6G-VERSUS project). Thus, the audience we attracted met the needs for the relevant, high-quality feedback we aimed to collect and analyse to achieve the best improvements in the next development and testing phase of the activities in the Bulgarian cluster.

In summary, the integrated operational setup of the pre-piloting testbed of UCY (Figure 3-14), enabled the validation of infrastructure connectivity, data flows, processing, and communication mechanisms within a highly realistic and dynamic environment. This trial captured key insights that will support future trial preparations, including the refinement of the next trial's workflow, the identification of remaining technical gaps and missing elements, and the assessment of organisational and logistical aspects requiring further improvement.



Figure 3-14: 6G-VERSUS project presentation during the informative session of the second trials



Figure 3-15: Presentation of the BG use-case



Figure 3-16: Presentation of the power system digital twin model

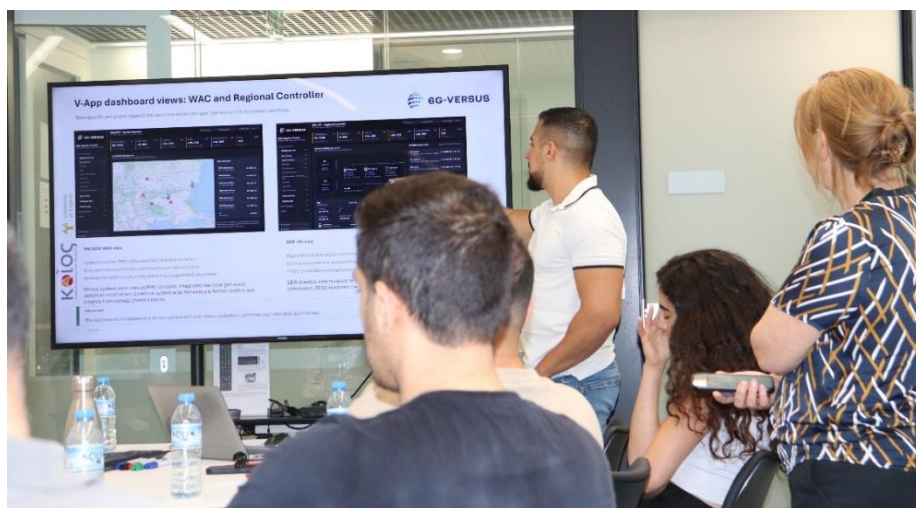


Figure 3-17: Presentation of the Dashboard of the 6G-enabled smart grid service

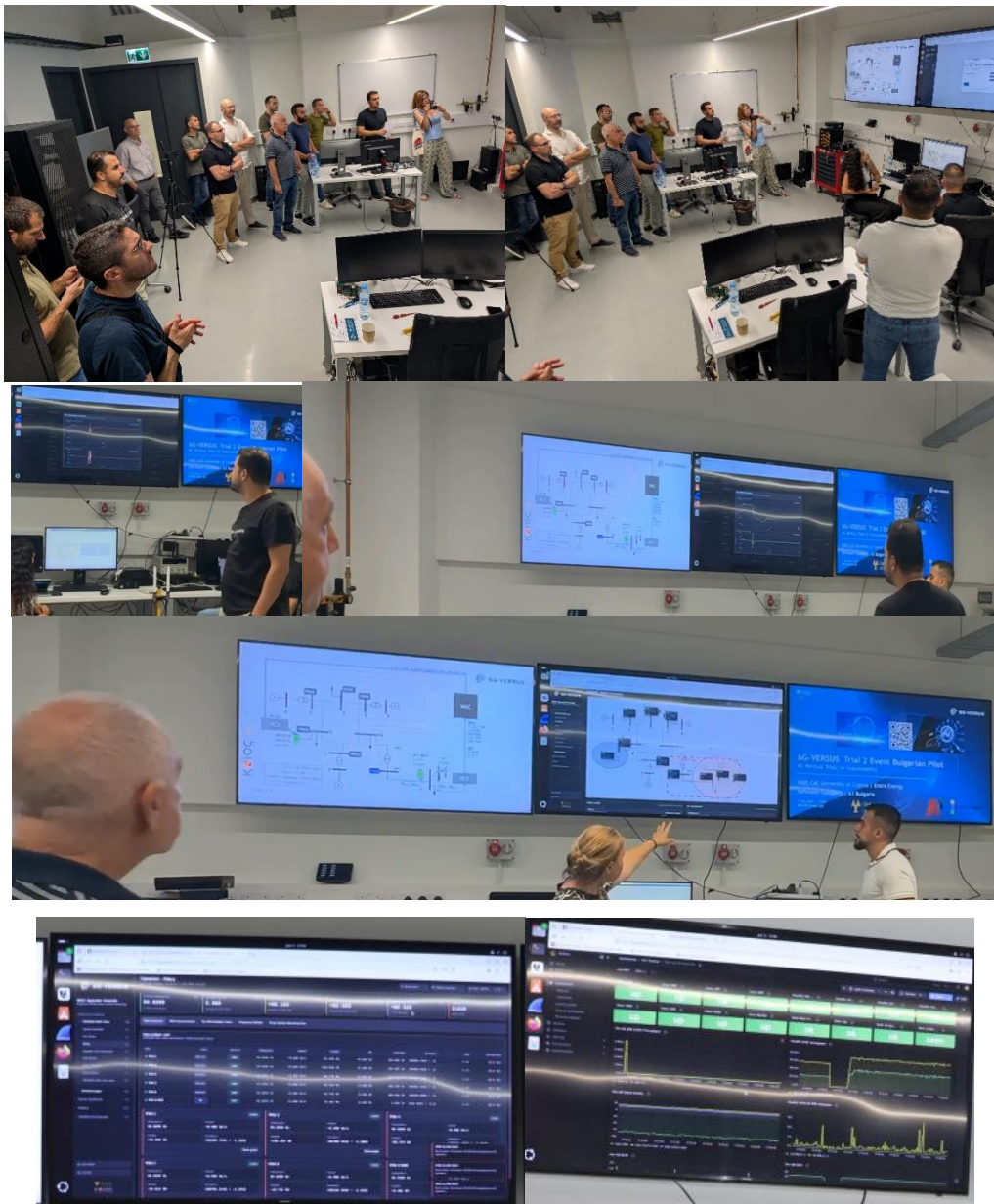


Figure 3-18: Live demonstration of the 6G-enabled WAC of DERs



Figure 3-19 Feedback collection through questionnaires and focus groups

Table 3-10: Stakeholders' attendance per group: number of stakeholders/participants

Trial/Pilot (ID)	Government Bodies	Environmental Organizations	SME/Industry	Scientific Community	Other
2- Cyprus	0	0	4/216	1/117	0

Table 3-11: Collected KVIs in Bulgarian trial 2

Trial/Pilot	Questionnaire answers	Focus groups	Number of Interviews done	Comments
2	32	4	0	

3.1.3 KPI analysis

The tests performed in the trial for the network-related KPIs are presented in Table 3-12 and overall considered successful against the expected thresholds. The overall conclusion from the trial is positive, as all measured KPI values met the predefined acceptance thresholds.

Table 3-12: KPI Analysis

KPI Name/ID	Title	Unit	Target Value	Baseline Value	Measured Values	Comments
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⁶ There were 21 representatives from 4 large energy stakeholders such as Transmission System Operator of Cyprus (TSOC), Electricity Authority of Cyprus (EAC) which integrates the Distribution System Operator of Cyprus and the main Power Supplier of Cyprus, Electricity Market Operator of Cyprus (which is an independent Division of TSOC) and from the Cyprus Association of Renewable Energy Enterprises (SEAPEK).

⁷ There were 11 representatives from the research and academic community of one academic institution in Cyprus, members which are not directly involved in the 6G-VERSUS project.

KPI_001	Ultra-Fast Frequency response service time (ROCOF_0.5/ Ts - settling time)	RoCoF[Hz/s]/ Ts[s]	<3 Hz/s/<30s	3.5 Hz/s /20s	2 Hz/s / 15s	Measured in the lab environment of UCY, it refers to both the baseline value and the control-in-loop
KPI_002	Improved grid stability with URLL Communication (frequency Nadir)	[Hz]	>49.5 Hz	48.9 Hz	49.9 Hz	Measured in the lab environment of UCY, it refers to both the baseline value and the control-in-loop
KPI_003	Network availability	(%)	99.9%	x	100%	Measured in the A1 network environment in Sofia
KPI_004	5G SA accessibility success ratio	(%)	99.9%	x	100%	Measured in the A1 network environment in Sofia
KPI_005	Average delay in downlink per slice	μs	<15 ms	x	5.9	Measured in the A1 network environment in Sofia
KPI_006	Average delay in uplink per slice	μs	<15 ms	x	11.72	Measured in the A1 network environment in Sofia
KPI_007	Packet loss rate	(%)	0.01%	x	0%	Measured in the A1 network environment in Sofia
KPI_008	Real-time environmental benefit indicator	Number of environmental indicators	To produce 2 new indicators	X	3	Water saving, CO2 saving and energy saving
KPI_008	Coverage	(%)	99%	x	N/A	Drive Tests are going to be performed at the Wind Turbine Park Location
KPI_009	5G SA active QoS flow drop ratio	(%)	0.10%	x	0%	Measured in the A1 network environment in Sofia
KPI_010	PDU session establishment failure ratio per slice and DNN	(%)	2 %	x	N/A	Planned to be measured
KPI_011	Network latency	ms	< 50 ms	x	15.5	Measured in the A1 network environment in Sofia
KPI_012	E2E latency	ms	< 25 ms	x	17	Measured in the A1 network environment in Sofia

3.1.4 Lessons Learnt

The execution of the Bulgarian cluster's first-phase trials provided critical technical and operational insights that will guide the deployment and enhancement of the upcoming trial phases. Below is a summary of what went well, the challenges encountered, and the roadmap for the next stages of the pilot.

3.1.4.1 What Went Well

- **Phased Integration Strategy:** The execution of the pre-trials in two distinct phases—progressing from virtual configurations to physical component aggregation within the A1 Lab environment—was highly effective. It successfully validated the connectivity matrix before field onboarding.
- **Core Network Stability and Performance:** The physical pre-trial setup in the A1 lab established an excellent performance baseline. Core 5G metrics measured in the Sofia network environment met or exceeded project goals, achieving 100% network availability, 0% packet loss, a network latency of 15.5 ms, and exceptionally low average downlink/uplink delays per slice (5.9 μ s and 11.72 μ s, respectively). Similar results were obtained at the UCY pre-piloting facility for network- and power-grid-related KPIs.
- **Cross-Sector Stakeholder Engagement:** The 1st Trial successfully engaged 36 total attendees, including 30 verified stakeholders representing both academia and industry (25 from the scientific community and 5 from the SME/industry sector). Utilising an interactive Kahoot questionnaire maximised feedback efficiency, yielding 27 completed responses for subsequent KVI and R-KVI analysis. The 2nd Trial focused primarily on relevant energy stakeholders across the entire energy chain (RES production, TSO, DSO, and the electricity market), as well as professionals from these stakeholders' network divisions. Feedback was collected using both questionnaires and interviews with focus group representatives (e.g., of the 21 industry participants, 4 from each stakeholder category listed above were selected to answer the interview-like questions).

3.1.4.2 Areas for Improvement

- **Lab-Restricted Data Flow:** Because the physical PMU was still operating from the Sofia lab or in the UCY lab rather than deployed at the site of the wind farm, a true wide-area network path routing from a remote endpoint could not be evaluated live during these two public events. Consequently, the team had to rely on a pre-recorded demonstration (trial 1) or a live demo at the UCY to showcase the evolution of the 6G-enabled smart grid service.
- One of the Bulgarian pilot's strengths—and at the same time its greatest challenges—is that it is implemented on A1 Bulgaria's live mobile network. On the one hand, deploying the project scope and validating the use cases in an operational network demonstrate their performance and feasibility under real-world operating conditions, making them readily transferable to other B5G networks. On the other hand, implementing and testing new functionalities in a live mobile network is highly dependent on the vendor's product roadmap and requires significant time, effort and investment, particularly for software licenses and professional services.
- **Pending Field Infrastructure:** As the A1 network mast installation near the wind farm was still being completed, specific localised field metrics could not be finalised. This reliance on lab environments left the boundaries of wireless coverage and local session establishment ratios unverified under real-world conditions during this phase.
- **Survey Fatigue and Questionnaire Complexity:** The feedback we gathered revealed that overly long or repetitive survey questions led to user fatigue, with some people even leaving the survey before completion. In a live, time-constrained demo event, complex phrasing reduces response precision and compromises stakeholder engagement.
- **The "Two-Language" Presentation Complexity:** Delivering a joint presentation that satisfies both the energy and telecommunications sectors proved to be highly complex. Because terminology from one sector was entirely unfamiliar to the other, presenters had to spend significant time on the agenda just building context and definitions to get everyone on the same

page. This naturally lengthened the presentations and made it challenging to maintain a high-paced, engaging narrative for a mixed audience.

- **Geographic Fragmentation and Dissemination Visuals ("The Wow Factor"):** Because the Bulgarian pilot is located in a highly remote area and heavily relies on software orchestration and cloud-to-edge data streams, it lacks the immediate visual "wow factor" of other pilots (such as those featuring physical drones or dynamic on-site tours). Relying on pre-recorded lab videos to explain backend 6G slicing and PMU data, particularly experienced during Trial 1, can come across as overly abstract or static to outside stakeholders and non-specialists.
- **Asymmetric On-Site Support due to Cross-Border Clustering:** While having a cross-border cluster (Bulgaria and Cyprus) brings immense technical expertise, it introduced a practical limitation for the live events. Due to language constraints and the physical distance between partners, teams could not provide adequate on-site operational support to one another. This was especially evident during the second trial, when UCY had to shoulder nearly the entire logistical and event-management burden alone.

3.1.4.3 Future Work & Next Steps in the Pilot

To progress into the next phase of the trials, the following concrete actions are required based on current testing gaps:

- **Finalise Infrastructure Onboarding:** Complete the remaining A1 radio base-station installation directly on-site near the Entra Energy wind farm in the Sliven Region to move past laboratory-only boundaries.
- **Transition to True Field Testing:** Execute full field measurements to capture the remaining critical parameters that are currently marked as Not Available (N/A).
- **Live Integration Verification:** Transition from showcasing recorded pre-trial simulations to establishing live, uninterrupted streaming from the physical wind turbine SCADA, PMU and the BESS digital twin models to the V-App platforms over the fully deployed regional 5G path.
- **Targeted Vertical Event Planning:** Future trial demonstrations should be segmented to target a single, specific audience vertical per session (e.g., holding an exclusive energy-sector workshop or a standalone telecom or academic session). This specialised approach allows the presentation content to match the audience's background exactly.
- **Optimisation of Stakeholder Survey Instruments:** Redesign the KVI assessment methodology to utilise concise and on-point question sets. Eliminating repetitive indicators will respect stakeholder time, ensure a professional delivery, and yield high-quality, actionable data without causing survey fatigue.
- **Implementation of Standardised, Proactive Reporting Templates:** To streamline future deliverable compilation, the project should adopt a rigid, uniform trial reporting template across all pilots. This template should be distributed months in advance so that clusters can pre-populate the fixed sections—such as the agenda, event structure, target stakeholder list, and invitation templates—long before the actual trial. This ensures rapid, uniform data entry even if a trial takes place just days before a deadline.

3.2 Finnish Cluster

The Finnish pilot focuses on developing a self-sufficient, remote energy base station capable of operating without grid connection under Arctic conditions. The University of Oulu is responsible for defining the use case and designing and implementing both the hardware and software architecture. The system combines a remote radio unit, microwave connectivity, solar and wind generation, battery storage, and a hydrogen fuel cell as a backup energy source. The complete system is planned to operate for one year, during which its technical performance, energy sustainability, and operational reliability will be evaluated.

The main objective of the pilot is to balance energy production and consumption while maintaining the required network performance. Real-time measurements, external energy meters, 48-hour weather forecasts, and predicted traffic information are used to estimate future energy availability. Based on this

information, the two AI-Apps (energy and traffic) can support decisions on the battery management system, RAN configurations, hydrogen fuel cell activation, and other energy-saving measures. The V-App provides a graphical interface for monitoring the system, visualising measurement data, and supporting interaction between the network, AI, and vertical applications.

The Finnish cluster focuses on validating the use case through trials to be conducted during 2026-2027. The first trial focused on energy budgeting simulations in MATLAB using real-time collected datasets to determine how much energy is consumed by the remote radio site, including the radio unit, microwave link, heating, control system, power electronics, and other electrical components. It also considered how much energy is produced by the renewable energy equipment, including the wind power plant, solar panels, and hydrogen fuel cell generator, all connected to a battery bank using the one-year (hourly) dataset collected in 2024.

The Finnish use case will be deployed at the University of Oulu, Finland. The first trial was conducted at the university campus. The second trial focused on validating selected KPIs for the Finnish use case “Energy-Aware Arctic Remote Site with AI-Enhanced Control”. The remaining KPIs will be validated during the next trials.

Table 3-13: Cluster summary table

Stakeholders	Questionnaires	Interviews	Focus groups	News Articles	Videos	KPI Collected
31	9	0	0	3	0	5

3.2.1 Pre-trials

The simulation for energy balancing of the Finnish pilot set-up was fed with data on consumption of all components and electricity generation by energy assets, and the required capacities for energy-generating assets, isolation, cooling, heating, and storage were produced. This simulation can be modified based on location, energy source selection, consumption profiles (network, base station, and energy asset setups), and weather forecasts.

Pre-trials for the second trial of the Finnish pilot focus on 5G Terrestrial Network (5GTN) system configuration and initial components-level integration:

- Deployment of the OAI-based 5G SA network, including Centralized Unit (CU), Distributed Unit (DU), remote-side Radio Unit (RU), and core components within 5GTN.
- Configuration and validation of the microwave link as a wireless fronthaul for remote-site connectivity.
- Integration of the energy measurement system at the network side to monitor CU, DU and server energy consumption.
- Initial deployment of the V-App, N-App, AI-Apps, database, and REST-based interfaces.
- Validation of multi-UE connectivity, throughput, latency, and data bandwidth capacity for a 5G cell.

3.2.2 Trials and Pilots

3.2.2.1 Trial 1

The first Finnish pilot trial was conducted at the University of Oulu, Finland, with additional online participation to maximise stakeholder engagement. The event combined a laboratory-based validation of the use case scenarios with a stakeholder workshop, providing an opportunity to present the pilot concept, discuss the proposed solution, and collect feedback from relevant stakeholders.

The laboratory activities focused on validating the defined use case scenarios and assessing the feasibility of the proposed architecture. The solution concept was introduced through presentations that described the overall system architecture and the energy-balancing simulation approach. Participants were subsequently invited to complete a structured questionnaire to evaluate the perceived usefulness

of the use case, its expected features, anticipated benefits, and key stakeholder requirements. The workshop also presented the objectives of the Finnish pilot and the current implementation status, fostering discussion and collaboration around the development of energy-self-sustainable mobile network infrastructures.

The demonstrated scenario addressed the Energy-Aware Arctic Remote Site with AI-Enhanced Control, comprising the following functional capabilities:

- Real-time monitoring of energy production and consumption;
- External metering for accurate energy budgeting;
- 48-hour energy weather forecasting;
- AI-based energy-aware decision-making enabling real-time adaptation to available energy and traffic conditions;
- Integrated operation of the network, AI platform, and vertical applications;
- Proactive optimisation of radio and network parameters.

The Finnish pilot focuses on the development of an energy self-sustainable, grid-independent base station designed to operate under Arctic environmental conditions. The University of Oulu is responsible for the definition, architecture, design, and implementation of both the hardware platform and software components. The complete system entered long-term operational testing in May 2026, with continuous evaluation planned over a one-year period. In total, four trial campaigns are scheduled during 2026–2027 to validate the technical feasibility, operational robustness, and performance of the proposed solution under representative Arctic conditions.

As this first trial primarily served to validate the system architecture, experimental setup, and stakeholder engagement activities, no quantitative KPIs were measured. Instead, the event focused on validating the use case concept, confirming stakeholder interest and requirements, and preparing the infrastructure and methodology for the subsequent measurement campaigns, during which the defined KPIs and KVI s will be assessed.

Table 3-14: Stakeholders' attendance per group: number of stakeholders/participants

Trial/Pilot (ID)	Government Bodies	Environmental Organizations	SME/Industry	Scientific Community	Other
1	2	0	4	22	3

Table 3-15 Collected KVI s

Trial/Pilot	Questionnaires answers	Focus Groups	Interviews	Comments
1	9	0	0	Online questionnaire for online and onsite participants

3.2.2.2 Trial 2

The second Finnish pilot trial was carried out on 10 June 2026 at the University of Oulu, Finland. The trial focused on the Finnish use case “Energy-Aware Arctic Remote Site with AI-Enhanced Control”. The main purpose of this trial was to validate the laboratory readiness of the selected 5G/O-RAN and energy measurement components prior to the 12-month long-term operational remote-site deployment. Figure 3-20 and Figure 3-21, depict the second trial, which focuses on the baseline energy consumption of the CU, DU, RU, and server under different operational and traffic conditions.



Figure 3-20: O-RAN CU, DU, Open5GS core and application server

The trial measured selected network and energy KPIs under laboratory conditions. The measurements covered per-user downlink and uplink data rates, microwave fronthaul latency, 5G cell bandwidth capacity, and energy consumption of the Central Unit (CU), Distributed Unit (DU), Radio Unit (RU), server, and microwave link. These values provide the first experimental baseline for later comparison with the complete renewable-energy-powered remote site, which is operational for 12 months.

Trial 2 validated the latency of the microwave link used as the wireless fronthaul in the Finnish use case. The latency and jitter of the microwave link were measured, and the target values were successfully achieved. In the next trials, latency will be measured over the complete end-to-end connection with the RU and UEs connected, and the KPI measured values will be updated accordingly.

In this trial, the full renewable energy system, long-term battery operation, hydrogen fuel cell triggering, and AI-based energy balancing were not yet fully validated. Therefore, the results should be interpreted as laboratory KPI validation and baseline measurements for the upcoming pilot trials.

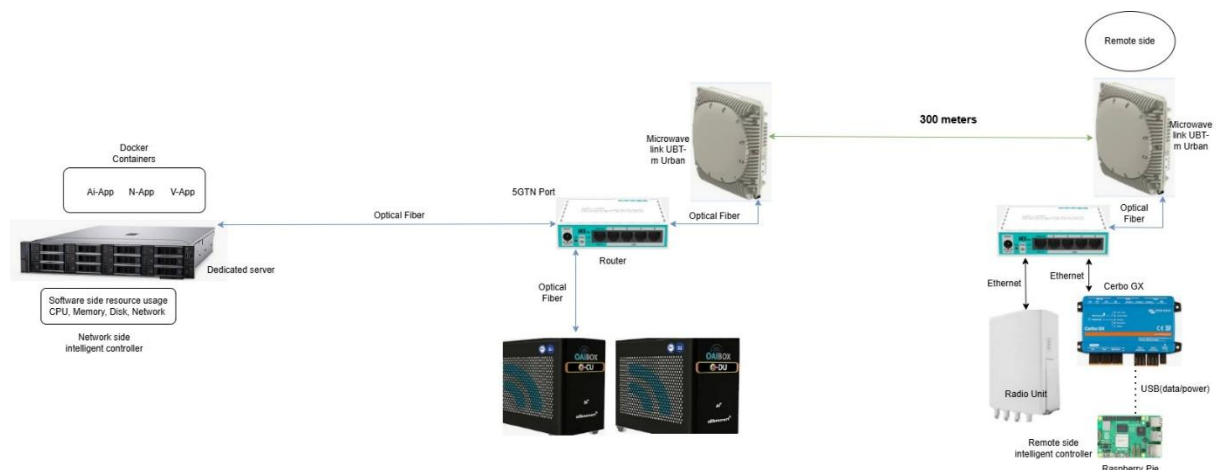


Figure 3-21: Network and remote site energy monitoring for Finnish Cluster

Table 3-16: Collected KPIs

KPI Name/ID	Measured values	Comments
Maximum data rates per user with energy balance awareness in DL and UL/ KPI_002	UE1: DL 100 Mbps, UL 10 Mbps; UE2: DL 100 Mbps, UL 10 Mbps; UE3: DL 100 Mbps, UL 10 Mbps	Downlink target of 50 Mbps per user was exceeded. Uplink measured value was 10 Mbps for each UE. Target values DL 50 Mbps, UL 30 Mbps
Achievable latency with microwave link in fronthaul/KPI_003	Microwave link delay: 0.5 ms; jitter: 0.1 ms	Target value: Downlink <10 ms, uplink <12 ms Link was healthy. The measured delay is well below the target values of DL <10 ms and UL <12 ms
Network side energy consumption /KPI_x1	116–112 Wh; DU non-operational state: 80–88 Wh; Server: 35–34 Wh	Energy baseline was collected for CU, DU, and server components. The server value can be used as a baseline for later comparison when AI-App, N-App, V-App, and additional processing loads are active.
Data Bandwidth capacity for 5G cell DL and UL/KPI_x2	Maximum DL: 600 Mbps at 100 MHz; Maximum UL: 60 Mbps	The measured cell capacity confirms sufficient bandwidth headroom for the Finnish use case scenarios and for serving multiple UEs during remote-site testing.
RU Energy Consumption /KPI_x3	No traffic: 72 Wh; Busy-hour traffic: 76 Wh	RU energy consumption remained stable, with an increase under traffic load. This indicates that RU baseline consumption is dominated by operational state rather than traffic variation in the tested configuration.

3.2.3 KPI analysis

Table 3-17: KPI Analysis

KPI Name/ID	Target Value	Baseline Value	Measured Values	Comments
KPI_002 Maximum data rates per user with energy balance awareness in DL and UL	50 DL 30 UL	N/A	UE1: DL 100 Mbps, UL 10 Mbps; UE2: DL 100 Mbps, UL 10 Mbps; UE3: DL 100 Mbps, UL 10 Mbps	Downlink target of 50 Mbps per user was exceeded. Uplink measured value was 10 Mbps for each UE.
KPI_003 Achievable latency with microwave link in fronthaul	DL <10 ms, UL <12 ms	N/A	Microwave link delay: 0.5 ms; jitter: 0.1 ms	Link was healthy. The measured delay is well below the target values of DL <10 ms and UL <12 ms
KPI_x1 Network side energy consumption	N/A	N/A	116–112 Wh; DU non-operational state: 80–88 Wh; Server: 35–34 Wh	Energy baseline was collected for CU, DU, and server components. The server value can be used as a baseline for later comparison when AI-App, N-App, V-App, and additional processing loads are active.
KPI_x2 Data Bandwidth capacity for 5G cell DL and UL	N/A	N/A	Maximum DL: 600 Mbps at 100 MHz; Maximum UL: 60 Mbps	The measured cell capacity confirms sufficient bandwidth headroom for the Finnish use case scenarios and for serving multiple UEs during remote-site testing.
KPI_x3 RU Energy Consumption	N/A	N/A	No traffic: 72 Wh; Busy-hour traffic: 76 Wh	RU energy consumption remained stable, with an increase under traffic load. This indicates that RU baseline consumption is dominated by operational state rather than traffic variation in the tested configuration.

3.2.4 Lessons Learnt

The measured CU and DU energy consumption showed only a limited range of fluctuations during normal operation, making these values suitable as baseline references. The measured server consumption can also serve as a baseline for quantifying the additional energy overhead introduced by AI-App, N-App, V-App, database, and orchestration workloads in future trials. The microwave latency will also be measured when the E2E data path is enabled, including RU, UEs and traffic profiles. The final trials will include completed datasets for KPI validation and test cases after the use case enters the operational phase.

What went well:

- Simulation on the energy balancing demonstrated how a variety of combinations of energy assets may be selected to power a 5G BTS in any kind of location and weather conditions. The simulation can be adapted for diverse conditions and power supply requirements.
- The audience showed great interest. There was a vivid discussion at the end of the trial, and the 6G-VERSUS Oulu pilot and simulation received very positive feedback.

Areas for improvement:

Although more than 70 invitations to the trial were sent to a variety of stakeholders, including remote-area SMEs, development companies, policymakers, and the telecom industry, the participants were mostly researchers from the university and other research organisations, with only a few industry participants. Engaging representatives of local communities, decision makers and other stakeholder groups is challenging.

Most participants started the feedback questionnaire, but fewer than half finished and submitted it. Either the questions or the questionnaire length needs to be reduced, or other means of collecting feedback need to be considered.

Future work and next steps in the pilot:

Set-up and integration of the network with the energy site in August 2026, and the whole pilot running from September 2026 for a one-year test period to assess the system operation in all weather conditions. The next trial will be in October 2026 in a real pilot setting.

3.3 French Cluster

The French cluster focuses on sustainable water management through two complementary Use Cases (UCs): UC1: Sewer Network Monitoring and UC2: Smart Irrigation for Preserving Green Spaces. The trials leverage an end-to-end Beyond 5G (B5G) infrastructure integrating OpenAirInterface (OAI) 5GSA, edge/cloud orchestration, AI-assisted optimisation, CAPIF/NEF exposure, and IoT environmental sensors.

The French cluster involves collaboration between EURECOM as the testbed leader, GreenCityzen as the use-case leader, and Thales Six GTS France as the AI-App leader for RAN optimisation and battery-lifetime extension.

The first French cluster trial focused on validating UC2: Smart Irrigation for Preserving Green Spaces. This trial was mainly conducted in Sophia Antipolis, France, where humidity sensors were deployed, and essential APIs related to ML-Ops, NEF, CAPIF, and monitoring services were exposed (see Figure 3-22). In addition, several large-scale features were validated on the vertical side using field-deployed sensors.



Figure 3-22: Two GREEN Soil Moisture Sensors Deployed in the Testbed

From a technical perspective, the trials validated:

- Real-time environmental monitoring over 5G SA infrastructure.
- Integration of 3GPP Release-17 RedCap devices.
- AI-assisted battery optimisation mechanisms and ML-Ops training.
- CAPIF/NEF-enabled service exposure for monitoring events, including localisation, Protocol Data Unit (PDU) session connectivity, and RedCap UE connection status.
- OAI Software UE support for advanced 2-step RACH experimentation, including payload transmission to cloud-based V-Apps.
- Integration of V-App soil sensors at the extreme edge, closer to the deployed sensors.
- Sustainable water-management analytics and dashboards.

The first pilot demonstrated the successful integration of environmental sensors, RedCap connectivity, AI-driven optimisation, and low-latency communication within the French B5G infrastructure, including the integration of V-, N-, and AI-Apps.

Videos and dissemination material were produced during the trial demonstrations. A first demonstration video is available online⁸, while further technical details and experimental results can be found in the corresponding trial report.

During the first-phase trials, two focus groups were conducted. The first was set up in February, with the participation of CITEO, a public waste management funding organisation. The second focus group took place in mid-March and involved the municipalities of Istres, Marseille, Martigues, and Toulouse.

Table 3-18: French cluster summary table

Stakeholders	Questionnaire answers	Interviews	Focus groups	News Articles	Videos	KPI Collected
31	0 ⁹	0	2	1 Article	1	8

3.3.1 Pre-trials

Pre-trial activities focused on baseline system configuration, stabilisation, and initial component integration:

⁸ https://www.youtube.com/watch?v=_FXwV6bZaYA

⁹ Due to seasonal climate and KVI constraints, this will be redeployed during the summer period to formally validate KVI_3: Cooling through green space watering

- Deployment and stabilisation of the core OAI 5G SA infrastructure.
- Integration and onboarding of heterogeneous environmental IoT sensors into the application layer.
- Configuration of the Common API Framework (CAPIF) and Network Exposure Function (NEF) to ensure secure Northbound API exposure.
- Functional validation of Release-17 RedCap UE connectivity over the OAI RAN and Core network.
- Preparation for AI-assisted Discontinuous Reception (DRX) optimisation and the exposure of dedicated MLOps training APIs.
- Deployment and integration of cloud and edge monitoring/telemetry services.
- Initial testing of the OAI Software UE supporting experimental 2-step RACH procedures.

Additionally, the French cluster prepared the underlying environmental monitoring dashboards, compiled the specialised datasets required for AI-App training activities, and formally validated end-to-end interoperability across all distinct architectural components prior to executing live demonstrations.

3.3.2 Trials and Pilots

The first French cluster pilot demonstrated the second use case of the cluster about sustainable irrigation over the B5G infrastructure. More specifically, the trial validated:

- Real-time sensor-data collection.
- RedCap-enabled low-power communications.
- CAPIF/NEF-enabled API exposure.
- AI-assisted battery optimisation.
- Low-latency communications.
- Environmental-benefit analytics.
- Experimental 2-step RACH connectivity using OAI Software UE.

The demonstrations involved participants from academia (EUR), industry (Green, TSGF), and public stakeholders (Municipalities, and organisations).

Table 3-19: Stakeholders' attendance per group

Trial/Pilot (ID)	Government Bodies	Environmental Organizations	SME/Industry	Scientific Community	Other
1	8	6	8	5	4

Table 3-20: Collected KPIs

KPI Name/ID	Measured values	Comments
KPI_001 Battery lifetime	87%	Percentage increase of battery lifetime by tuning 3GPP Release 17 parameters of the Radio Access Network (sleep times in DRX, fixed Bandwidth). Baseline: no DRX
KPI_002 Battery lifetime	~16%	Percentage increase of battery lifetime by using AI-configured DRX. Baseline: DRX without AI
KPI_003 Battery lifetime: Optimal network resource usage	~104%	Percentage increase of battery lifetime by using AI-configured DRX and spectrum resources (bandwidth limitation). Reference: baseline RAN configuration (no DRX, no AI and no spectrum optimization)
KPI_004 Latency / wake-up delay with DRX	1-26s	Additional time delay is introduced when a UE must wait for the next scheduled ON period for transmission
KPI_008 Real-time environmental benefit indicator	-	To produce and display in real-time at least 2 environmental benefit indicators
KPI_009 Hardware footprint reduction	-	Reduce the number of deployed sensors on the rainwater network by 2 using AI-based predictions.

KPI_010 Latency	~62.028 ms	Latency in data transmission with RedCap (RAN + CN).
KPI_010 Latency	8.94 ms	2-step RACH connectivity latency test using OAI Software UE.
KPI_011 Energy Efficiency	42% (16.68 Wh)	Energy-efficiency gain with 5G RedCap compared to traditional full 5G modules.

Table 3-21: Collected KVIs

Trial/Pilot	Questionnaire answers	Focus groups	Interviews	Comments
1	1	2	-	Online questionnaire for online and onsite participants

3.3.3 KPI analysis

Table 3-22: KPI Analysis

KPI Name/ID	Target Value	Baseline Value	Measured Values	Comments
KPI_001 Battery lifetime	10%	Nonapplicable (the Baseline is no DRX)	87%	Percentage increase of battery lifetime by tuning 3GPP Release 17 parameters of the Radio Access Network (sleep times in DRX, fixed Bandwidth). Baseline: no DRX
KPI_002 Battery lifetime	15%	Nonapplicable (the Baseline is DRX without IA)	~16%	Percentage increase of battery lifetime by using AI-configured DRX. Baseline: DRX without AI
KPI_003 Battery lifetime: Optimal network resource usage	25%	Nonapplicable (the Baseline is no DRX, no IA)	~104%	Percentage increase of battery lifetime by using AI-configured DRX and spectrum resources (bandwidth limitation). Reference: baseline RAN configuration (no DRX, no AI and no spectrum optimisation)
KPI_004 Latency / wake-up delay with DRX	< 10s	~0.4 seconds (Baseline no DRX)	1-26 seconds	Response time to data
KPI_008 Real-time environmental benefit indicator	2	-	-	To produce and display in real-time at least 2 environmental benefit indicators
KPI_009 Hardware footprint reduction	/2	-	-	Reduce the number of deployed sensors on the rainwater network by 2 using AI-based predictions.
KPI_010 Latency	<=100 ms 10 ms	<=150 ms 13.94 ms	~ 62.028 ms 8.94 ms	Latency in data transmission with RedCap (RAN + CN) 2-step RACH connectivity latency test
KPI_011 Energy Efficiency	≥ 25% (<=30 Wh)	40 Wh	42.75% (22.90 Wh)	Energy Efficiency Gain with 5G RedCap device compared to traditional full 5G modules under similar usage conditions.

In conclusion, the current results highlight promising progress in network optimisation and efficiency. Further improvements are expected in the upcoming trial, particularly as the AI model is refined and enhanced. This continuous development will contribute to more reliable and sustainable outcomes in future evaluations.

3.3.4 Lessons Learnt

The French cluster trials highlighted several important technical and operational lessons:

- OAI-based 5G SA infrastructures provide sufficient flexibility for advanced sustainable IoT experimentation.
- RedCap devices significantly improve energy efficiency for environmental monitoring applications, which can reduce the cost of energy at large-scale deployment.
- CAPIF and NEF facilitate modular and interoperable service exposure between provider and vertical applications.
- AI-assisted DRX optimisation shows strong potential for extending IoT battery lifetime.
- Edge/cloud orchestration improves the scalability and responsiveness of environmental-monitoring services.
- Integration of heterogeneous IoT, AI, and telecom components remains complex and requires careful orchestration.
- Experimental 2-step RACH procedures using OAI Software UE demonstrated promising latency reductions for future massive IoT scenarios.
- Future trials will investigate interoperability using commercial 2-step RACH-capable UEs when such devices become commercially available.
- Future trial will focus mainly on the UC1 sewer networking but also on the other V-N-AI-Apps and KPIs, KVIIs remaining.

3.4 Greek Cluster

The primary objective of the initial trial round is to test and validate key components of the 6G-App interfaces, ensuring interoperability and baseline functionality among the N-App, the AI-App for wildfire monitoring, and the AI-App and V-Apps within the INtelligentUxV Surveillance (INUS) system. The setup for this first round (**Round 1**) adopts a static component configuration to minimise complexity while still enabling meaningful validation of connectivity with the infrastructure, as well as the associated data flow and processing mechanisms. The first official trial is also aimed at capturing key insights to inform upcoming trial activities, including the design of the trial workflow, the identification of missing elements and technical gaps, and the assessment of organisational and logistical aspects requiring improvement.

Round 2 was performed during the first week of May, defining a clear delta from the initial setup by introducing multi-cell support for the Location reporting event API, triplet interaction (AI-App location awareness, V-App wildfire monitoring and N-App location) and controlled mobility of the robotic dog while also utilising an active relay UAV (rUAV) acting as a side-link relay node to the robotic dog.

Table 3-23: Greek cluster summary table

Stakeholders	Questionnaires	Interviews	Focus groups	News Articles	Videos	KPI Collected
29	29	1 ¹⁰	2	9	2	13

3.4.1 Pre-trials

For the first round, the pre-trial activities were conducted three days prior to the main testing phase to ensure that all system components were properly integrated and functioning as expected. These pretrials focused on validating the end-to-end connectivity between modules, confirming data exchange across interfaces, and verifying that the overall infrastructure was stable and operational. This step helped identify and resolve potential issues in advance, ensuring a smooth and reliable execution of the main trials. Moreover, since the setup and integration were completed smoothly without any major issues, the

¹⁰ Representative of a public body

final day served as a full rehearsal aimed at validating the complete trial workflow and identifying any technical shortcomings, but mostly organisational issues that needed to be addressed prior to the official trial execution.



Figure 3-23: Pre-trial 1 preparation activities

For the second round, the same approach has been followed, maintaining the additional days for integration testing and proper preparations to effectively support the additional functionalities that were introduced compared to round one.



Figure 3-24: Pre-trial 2 preparation activities



Figure 3-25: Pre-trial 2 preparation activities at the field



Figure 3-26: Pre-trial 2 preparation activities for the UAV with the relay link

3.4.2 Trials and Pilots

3.4.2.1 Trial 1

Before the trials and demonstration presentations, an introductory session was held to present the project's overall concept. This session then focused specifically on the Greek use case and the technologies to be demonstrated. A second session focused on the actual demonstration, during which all components were presented following the sequence of the operational scenario that will be delivered end-to-end during the final round of trials in 2027. A structured agenda was designed to facilitate the entire process. The trials took place at the NCSRDC campus, with the setup and location illustrated in the figure below.



Figure 3-27: 6G-VERSUS project presentation during the informative session of the first trials

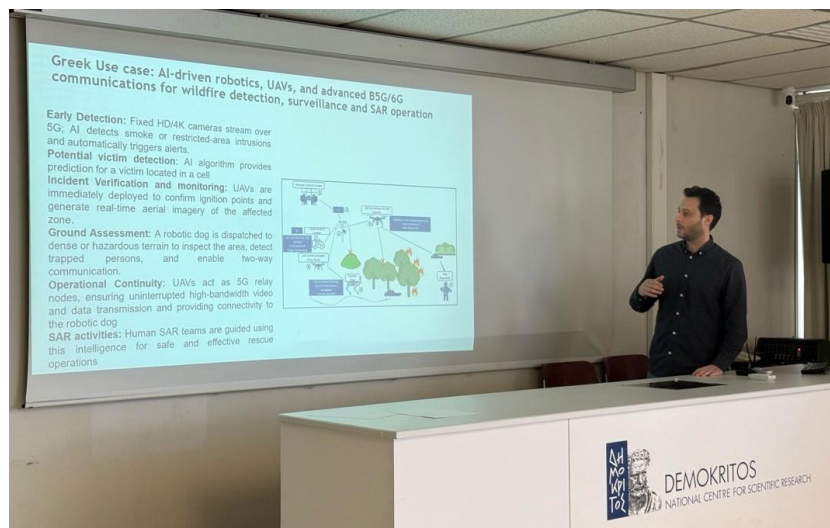


Figure 3-28: Presentation of the Greek use case during the informative session of the first trial



Figure 3-29: Introductory and Informative session of the first trials



Figure 3-30: Attendees and partners of the Greek cluster in the first trials

For the execution of the trials, the area next to the Informatics and Telecommunications (IIT) building (orange oval) for device placement and execution was selected. In the figure, the orange dot indicates the fixed RAN position, the yellow dot indicates the camera location, and the red dot marks the “fire” area on the rooftop of the building (in this first round, the test was performed using a smoke canister to simulate fire smoke).

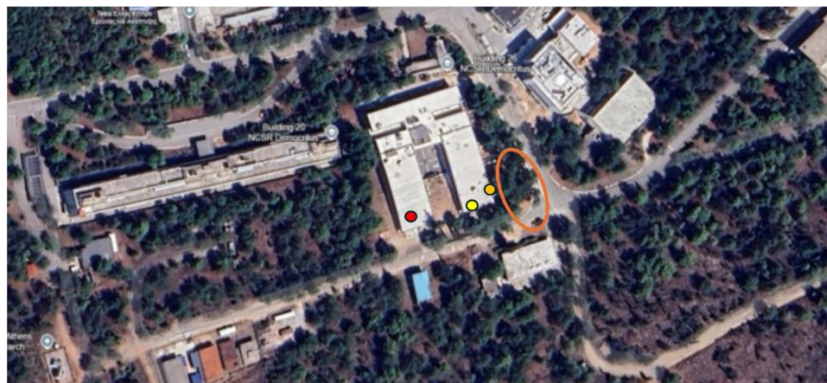


Figure 3-31: Area of Greek trial execution at the NCSRDCampus

The scenario began with smoke detection captured by the camera, triggering the backend process of the AI-based wildfire monitoring application and generating an event indicating a potential fire (smoke probability). In the next step, the AI-App for Location Awareness was evaluated using a UE connected to the 5G infrastructure. The 5G Core, via the N-App for location services, sent API notifications regarding the UE connection. Based on this data, the AI application estimated the probability that the user would remain in a specific cell for an extended period. Subsequently, the INUS Asset Management Platform and its AI-powered microservices supporting object detection were demonstrated. This included both integration with the connectivity infrastructure and AI capabilities for detecting and tracking objects and individuals within the monitored area. It is important to note that during Trial 1, the INUS assets were static, as the objective was to test overall connectivity and integration with the infrastructure.

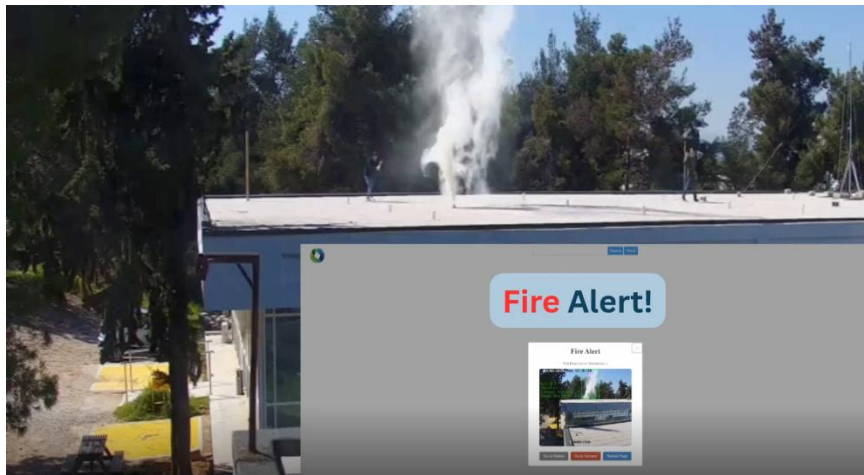


Figure 3-32: Fire detection and alert during the first trials

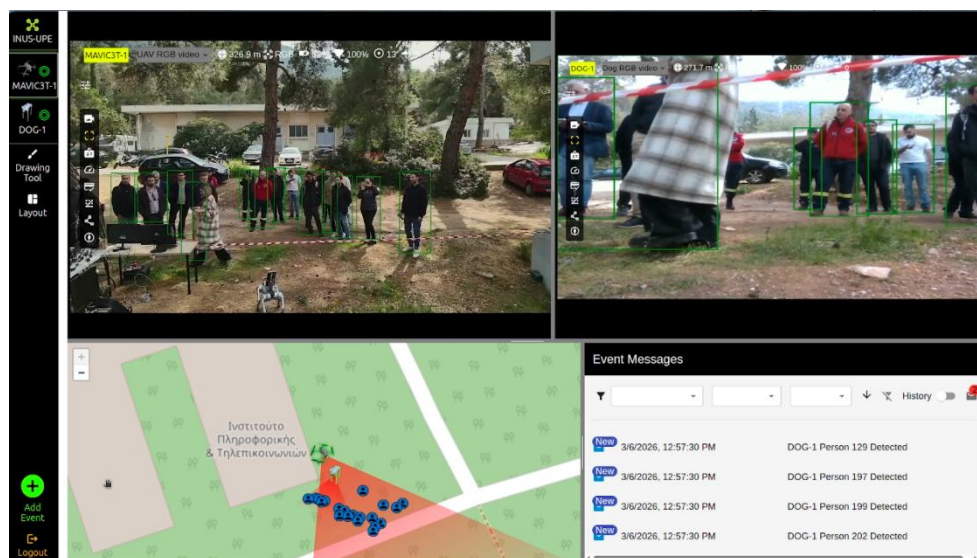


Figure 3-33: INUS v-App (object detection from the robotic dog and the UAV) during the first trials



Figure 3-34: Presentation and demonstration of the Greek use case during the first trials



Figure 3-35: Demonstration of the Greek use case during the first trials

3.4.2.2 Trial 2

The primary objective of the second trial was to test and validate additional components of the *-App interfaces, ensuring enhanced interoperability and functionality among the N-App, the AI-App for wildfire monitoring, and the AI-App and V-Apps within the INUS system. Unlike the first trial, which adopted a static configuration to minimise complexity and validate basic connectivity and data flows, the second trial was designed to demonstrate a more operational and dynamic deployment scenario under realistic conditions. Conducted during the first week of May, the second round of trials introduced several enhancements to the initial setup, including multi-cell support for the Location Reporting Event API and triplet interaction among the AI-App for location awareness, the V-App for wildfire monitoring, and the N-App for location services. In parallel, the trial showcased the robotic dog's controlled mobility, while an active rUAV served as a side-link relay node to support communication and connectivity throughout the exercise. This integrated operational setup enabled validation of infrastructure connectivity, data flows, processing, and communication mechanisms in a realistic, dynamic environment. As the second official trial, the activity also aimed to capture key insights to support future trial preparations, including the refinement of the trial workflow, the identification of remaining technical gaps and missing elements, and the assessment of organisational and logistical aspects requiring further improvement. Before the trials and demonstration presentations, an introductory session was organised to provide the audience with a comprehensive overview of the project's vision, objectives, and expected outcomes. The session introduced the project's overall architecture and explained the Greek use case, describing the wildfire monitoring and location-awareness scenario to be demonstrated during the trial. The participating technologies, AI applications, network functions, robotic platforms, and monitoring systems were introduced in detail, allowing the audience to better understand the operational flow and the objectives of the demonstration activities. Emphasis was placed on presenting the capabilities of the 5G-enabled environment, the integrated AI-based applications, and the interactions among components within the platform to shape the use case. To ensure the smooth execution of activities and facilitate audience engagement, a structured agenda was designed and followed throughout the event; it is shown below.

Slot (Greek Time)	Topic	Partner
11:00 – 11:05	Welcome	NCSRD
11:05-11:15	Athens B5G Testbed	NCSRD/OTE
11:15 – 11:25	6G-VERSUS Project Overview	ICCS
11:35– 11:35	Use Case Overview & Trial 2 Scenario	NCSRD
11:35-11:45	Greek Cluster Activities Overview	ICCS
11:50 – 11:55	Q&A	ALL
12:00 – 12:15	Break / Preparation for Technical Demos	
12:20 – 13:30	Technical Demonstrations outside of Building 26 • Narrator introduction • Athens B5G Testbed (10) • Wildfire Detection (15 min) • AI Location Awareness (15 min) • Energy Efficiency as a Service: fine-grained measurements dashboard (10 min) • INUS AI-Powered Tracking application, with live video stream over direct 5G D2D connection (20 min)	NCSRD, OTE, INF, ICCS

Figure 3-36: Agenda for the Greek trial



Figure 3-37: Athens UC and B5G testbed presentation in the informative session of the second trials

The second session focused on the live demonstration itself, during which all components were presented in the operational sequence as part of the end-to-end scenario planned for the second trial phase in 2027. The conceptual architecture of the second trial is depicted in Figure 3-38 below. The deployment of the components spans the two sites comprising the Athens B5G testbed. More specifically, from left to right, the INUS Management System, together with its associated AI-App and V-App functionalities are deployed in the field environment at the NCSRD campus, where the trials are conducted. In addition, the NCSRD cloud infrastructure hosts the N-App, the AI-App for location services, and the V-App for wildfire monitoring, including the RTSP camera integration. On the other hand, the backend components of the wildfire monitoring service, including the corresponding AI-App and the V-App responsible for monitoring functionalities, are deployed at the OTE premises.

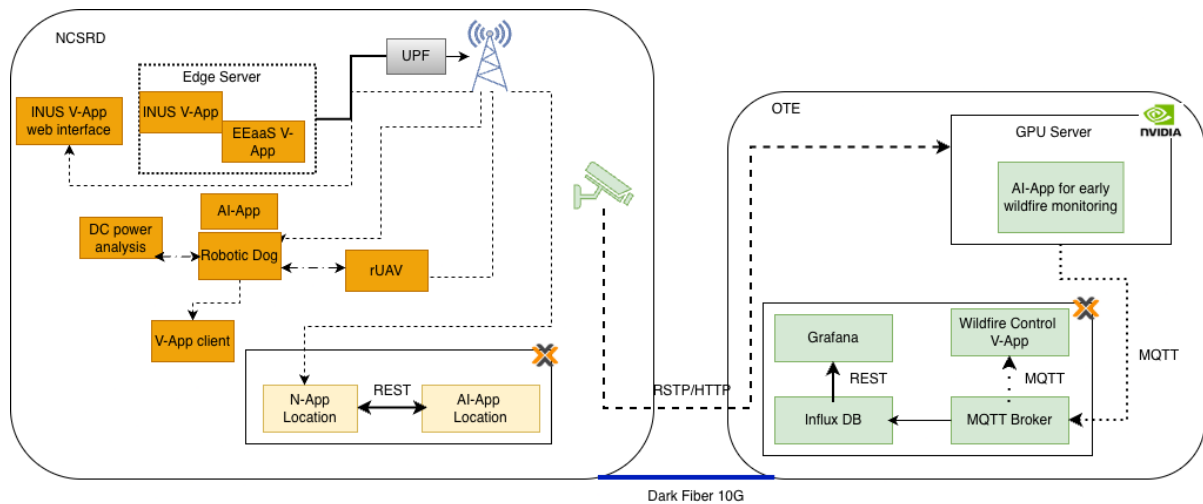


Figure 3-38: Component-level architecture demonstrated during the second trials

For the second trial, the same area as the first round, next to the IIT building (orange oval), was selected for the placement and execution of the activities. The campus environment provided a realistic outdoor setting for the wildfire monitoring scenario, including vegetation, trees, open spaces, and natural obstacles, enabling validation of the activities under representative field conditions. In the figure, the orange and blue dots indicate the fixed RAN positions for the two cells, the red dot indicates the camera location, and the light green dot indicates the location where the fire was ignited.



Figure 3-39: Second trial execution area and infrastructure components during the second trials

The scenario remained the same. However, the trial was structured into sequential operational logic as presented in Figure 3-40 below, to facilitate a clear end-to-end execution approach. The second trial phase will focus on integrating human intervention by rescue personnel to support decision-making and coordinate the emergency response. The steps that shape the scenario and define the operational workflow are illustrated in Figure 3-40.

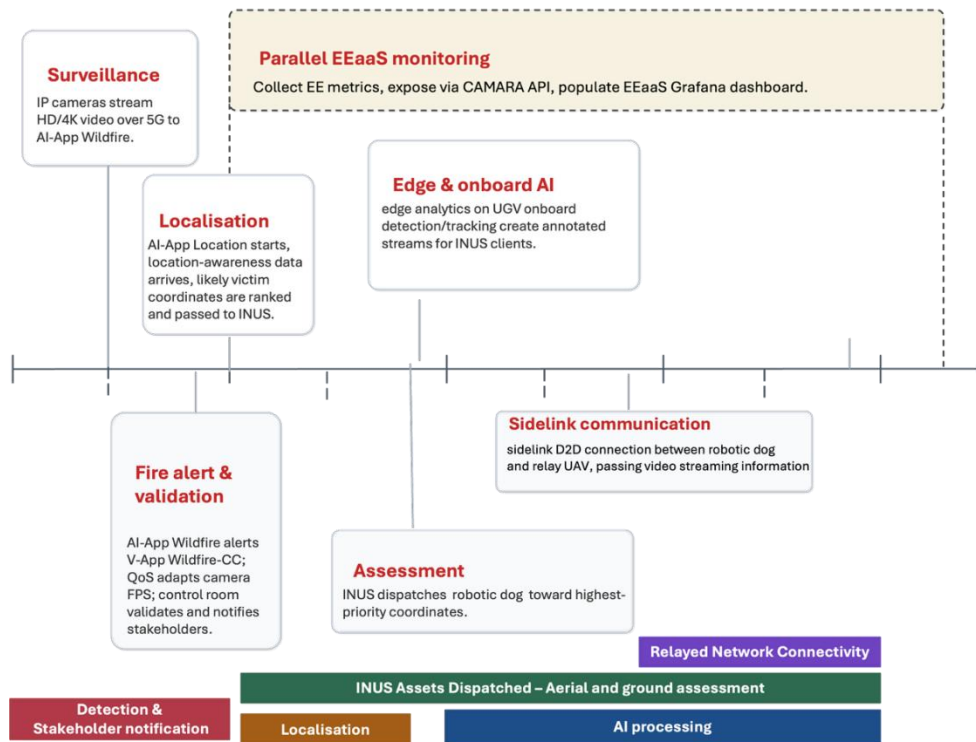


Figure 3-40: Sequence of steps for the operational scenario of the Greek use case



Figure 3-41: AI-App wildfire detection and monitoring setup

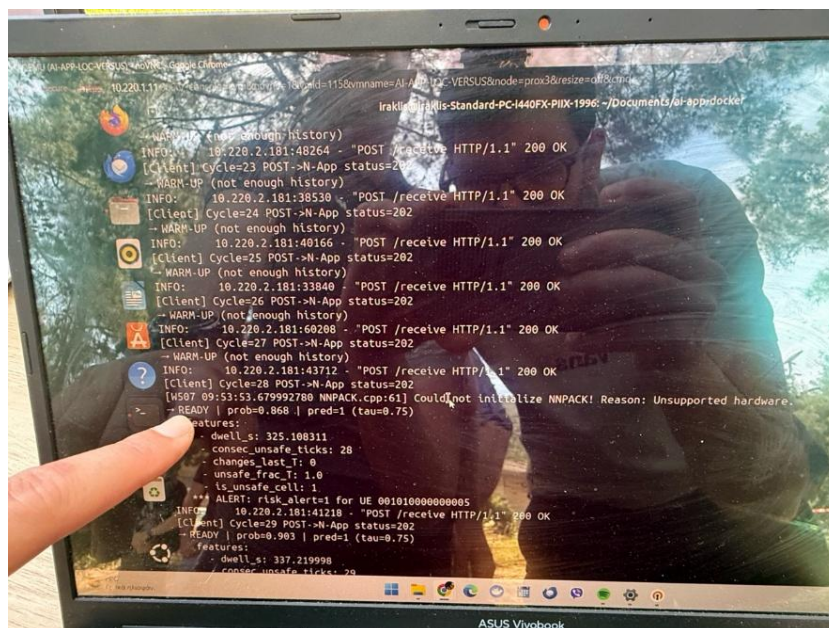


Figure 3-42: AI-App location calculating the probability of UE being long time in a cell

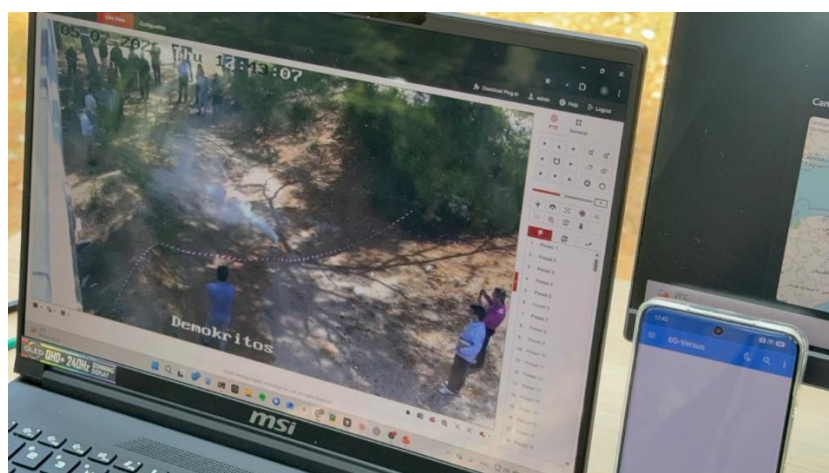


Figure 3-43: View from the RTSP camera at NCSR D campus and the detection of fire



Figure 3-44: Second trials at NCSR D campus



Figure 3-45: Demonstration of the AI-App wildfire monitoring during the second trials

As far as the audience is concerned, the approach followed by the Greek cluster has been an incremental engagement of audiences representing different entities. Given that the Greek use case includes an operational search and rescue scenario and considering that at this stage the main focus is on testing the technologies while the operational approach will be added later on, the decision was to initially involve the scientific community, which would be primarily interested in the technological aspects, and then gradually add SMEs and municipalities, which was the case for the second round. The table below lists the entities invited in the two trial rounds.

Table 3-24: Stakeholders' attendance per group (number of stakeholders) in Greek trials

Trial/Pilot (ID)	Government Bodies	Environmental Organizations	SME/Industry	Scientific Community	Other
1	0	0	0	13	0
2	1 ¹¹	0	4	12	0

3.4.3 KPI analysis

During the first trials, a subset of KPIs was measured, and the following table provides information on the initial set measured in the first phase (early March). Additional material and details are available in the trial reports.

Table 3-25: Collected KPIs in Greek trial 1

KPI Name/ID	Measured values	Comments
KPI 01	69 DL, 20 UL	Peak User data rate
KPI_03	30ms	U-plane latency
KPI_04	10ms	Delay deviation/jitter
KPI_014	Average inference time was measured at approximately 47.58 ms	The inference time of the Wildfire Detection AI-App
KPI_015	Detection delay of approximately 1 second	The difference between the timestamp of the first visible smoke in the video stream and the timestamp of the first AI detection

¹¹ Municipality of Egaleo

KPI_016	Alert delay of approximately 20 seconds	First visible smoke timestamp and the timestamp of the first alert notification received by the operator
KPI_09	Baseline usage of ~4–6 W at idle and ~7–8 W during GPU-based AI processing (object detection), with transient peaks up to 14 W	Power consumption of the system (edge hardware) is measured across idle and active states
KPI_024	Runtime logs showed 50–56 ms processing time per frame.	AI processing pipeline
KPI_025	Runtime logs showed 50–55 ms processing time per frame.	AI video processing pipeline

During the second trials, the initial set of KPIs plus some additional ones were measured, and the following table provides information on the relevant metrics.

Table 3-26: Collected KPIs in Greek trial 2

KPI Name/ID	Measured values	Comments
KPI 01	72.1 DL, 22 UL	Peak User data rate
KPI 03	27,4 ms	U-plane latency
KPI 04	8ms	Delay deviation/jitter
KPI_05	RSRP of -110 dBm RSRQ of -12 dB SINR approximately 9 dB	Measure coverage through radio signal parameters (SINR, RSRP/RSRQ)
KPI 11	0.957 and macro F1 0,949	Accuracy score for the AI-App for location
KPI_12	80.7% across the 47 consecutive smoke-positive frames that led to event confirmation.	Wildfire Detection AI (Average) confidence score
KPI_14	47.46 ms, with minimum and maximum values observed at 46.86 ms and 52.49 ms, respectively.	The inference time of the Wildfire Detection AI-App. These values are significantly below the target threshold of 100 ms,
KPI_15	7 secs	The time to detect smoke. The smoke became visible at 12:47:40, while the first AI-detected frame occurred at 12:47:47
KPI_16	15 seconds	First visible smoke timestamp and the timestamp of the first alert notification received by the operator. The smoke became visible at 12:47:40, while the alert was received via Pushover at 12:47:55,
KPI_09	MAPE w/o 27.703% , w/m 2.830%	With power model prediction and without model
KPI_09	MAE w/m 0,364 W	With power model prediction and without model

3.4.4 Lessons Learnt

The first two rounds of trials successfully demonstrated the feasibility of the envisioned scenarios and validated the overall technical setup. The integration and interoperability of the different components were achieved without major technical issues, while several infrastructure optimisations were identified and implemented to enhance flexibility and support future activities during the second trial phase.

The trials also highlighted opportunities for improvement in the operational workflow and in the way the scenarios are structured and presented to facilitate better understanding and engagement among the audience and stakeholders. Furthermore, stakeholder engagement remained challenging despite dedicated and proactive outreach efforts, indicating the need for enhanced participation mechanisms and additional interaction strategies in future trial phases to collect more meaningful feedback. Beyond validating the technical setup and operational procedures, the trials underscored the importance of testing in a relevant operational environment under realistic conditions. Thus, a key lesson learned is that future trial phases should incorporate dedicated early testing activities before the main demonstrations. Such preliminary testing can help identify and address technical challenges and operational constraints at an early stage, reducing the risk of disruptions during the trials and enabling timely refinements to both the technical infrastructure and operational planning.

3.5 Portuguese Cluster

The Portuguese Cluster performed 3 trials related to the monitoring of Smart Ports. Trial 1 presented the V-Apps developed to manage the port environmental awareness. During Trial 2, the V-App, AI-App and N-App were showcased to enhance the port safety levels. In this trial, the concept of the V-App, destined for the port infrastructure energy awareness, was also presented. Finally, Trial 3 started with the showcase of the V-App, N-App and UE Devices dedicated to managing the port environmental awareness, followed by the showcase of the V-App, AI-App and N-App developed to enhance the port safety levels, and then concluding with the demonstration of the first version of the V-App destined for the port infrastructure energy awareness.

Table 3-27: Cluster summary table

Stakeholders	Questionnaires	Interviews	Focus groups	News Articles	Videos	KPI Collected
38	25	12	0	9	2 ^{12, 13}	11

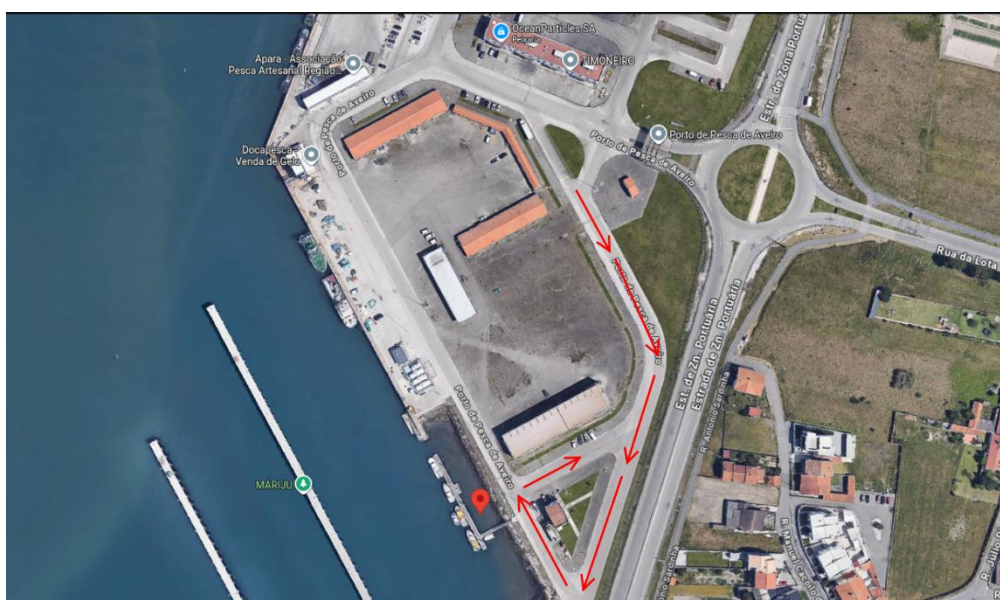


Figure 3-46: Portuguese trials site at the Port of Aveiro

3.5.1 Pre-trials

For the Portuguese cluster, five pre-trials were conducted in the same geographical and operational environment as the full cluster trials, namely the Port of Aveiro facilities.

Pre-trial 1.1 (1st pre-trial for Trial 1) - 10/12/2025: Leveraging the Mobitrust V-App, the trial focused on on-site device validation, end-to-end data collection from water quality monitoring sensors, and preliminary integration with the first version of the AI-App. The remote-controlled boat (RC-Boat) was deployed and evaluated, including its 5G-based remote-control functionality and onboard environmental sensing capabilities. Collected data included water temperature, pH, and real-time video streams. In parallel, initial integration tests with the Mobitrust AI-App assessed video data ingestion and basic object detection functionality. These activities aimed to identify technical issues early, mitigate risks before the main trial phase, and verify the alignment of all components with the operational requirements of the Portuguese Cluster use case.

¹² 1st video - <https://www.youtube.com/watch?v=aoEPpDocBvM>

¹³ 2nd video - <https://www.youtube.com/watch?v=9Ov1ZRmkBzM>

Pre-trials 1.2 - 14/01/2026 and 1.3 - 27/01/2026: These activities served as trial rehearsals to validate the overall workflow and identify technical, organisational, or procedural gaps that required adjustment before the official trial. The rehearsal simulated the planned trial conditions as closely as possible, involving key technical components, stakeholders, and evaluation instruments. Both Trial 1 V-Apps—the Mobitrust V-App and the Port Environmental Monitoring V-App—were demonstrated to assess application readiness, infrastructure interoperability, and suitability for presentation to external stakeholders. In addition, integration tests were performed to further validate V-/AI-/N-App interoperability, including verification of the Port Environmental Monitoring V-App–QoS N-App interface. Finally, the questionnaire completion and post-trial interview procedures were rehearsed to identify and address language and communication issues.

Pre-trial 2.1 - 11/03/2026: The goal was to rehearse the operational workflow of the Portuguese Cluster’s second trial while conducting technical validation activities. During the session, partners tested system component integration, end-to-end connectivity, and application functionality. Operational data was also collected to support scenario evaluation and further refine AI-based processing and platform capabilities. This pre-trial activity enabled the cluster to identify final technical adjustments, refine the demonstration workflow, and confirm operational readiness ahead of the full stakeholder trial.

Pre-trial 3.1 - 15/05/2026: In order to prepare the Portuguese Cluster Trial 3, particularly scenario 2, planned to take place on 20/5/2026, work was carried out at the trial site, mainly focused on: a) verification of the end-to-end integration of all hardware, software and network components used in scenario 2; b) Fine-tuning system configurations to optimize the overall performance and the quality of the trial results; c) Testing software updates implemented since trial 2; d) Collecting relevant KPIs.

Below are presented pictures illustrating the pre-trials performed.



Figure 3-47: Pre-trial 1.1 testing activities for the 1st Trial of the Portuguese Cluster

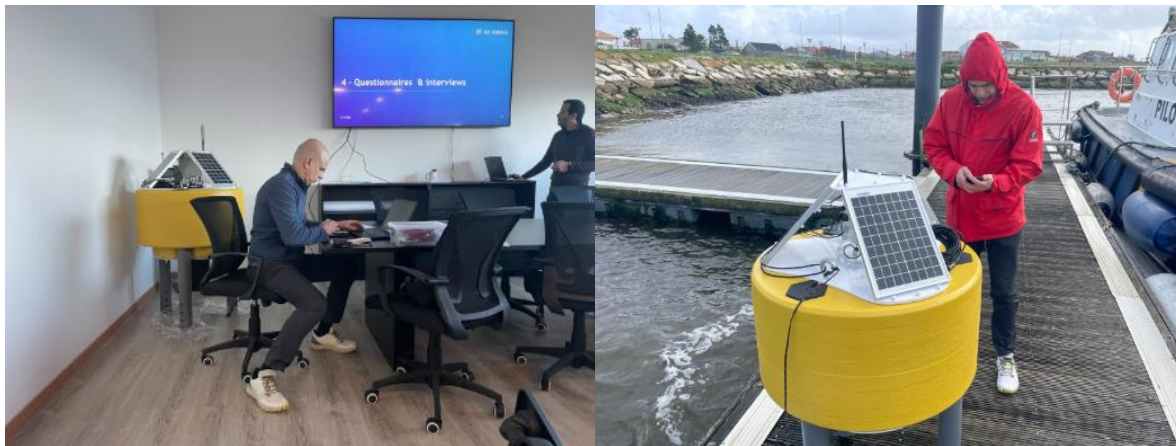


Figure 3-48: Pre-trial 1.3 testing activities for the 1st Trial of the Portuguese Cluster

3.5.2 Trials and Pilots

This section provides a description of each trial performed.

3.5.2.1 Trial 1

The trial aimed to validate and demonstrate the triadic capabilities of the 6G-App within the scope of Scenario 1 and to collect feedback primarily from stakeholders representing local port entities, academic and R&D communities, and the port. This scenario addresses the need for more timely, reliable, and energy-efficient environmental monitoring in maritime port environments, particularly to support water-quality monitoring and the reporting of relevant findings to environmental authorities. The trial focused on two main solution components. The first was a custom smart buoy system equipped with a water-quality sensor, a solar energy-harvesting module, and a data logger using 5G NR RedCap communications. The second was the Mobitrust platform, presented as a modular situational-awareness solution for real-time monitoring, supervision, and operational management. The conceptual view for the Trial 1 setup is depicted in Figure 3-49.

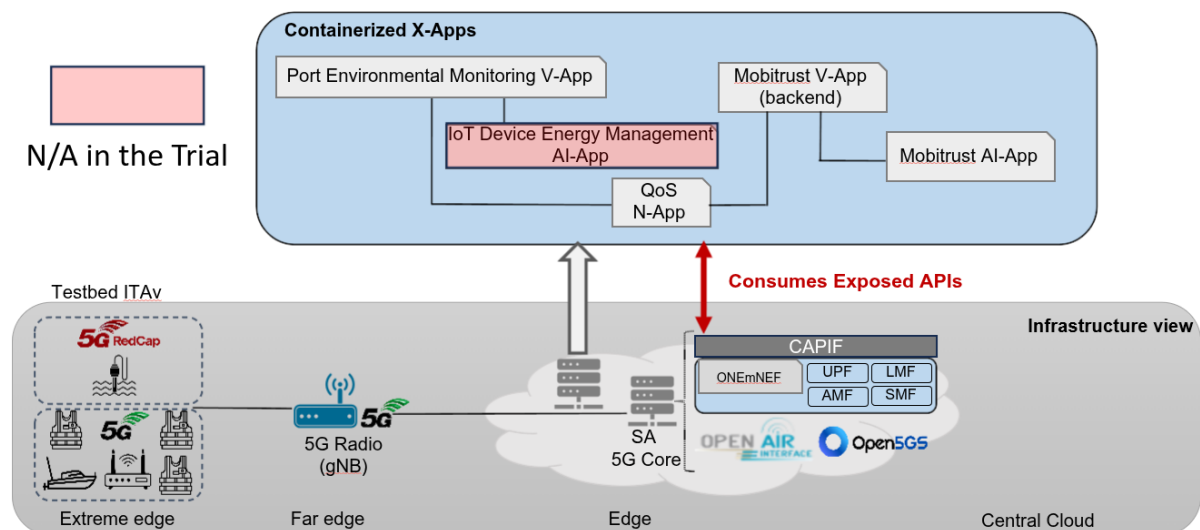


Figure 3-49: Portuguese Trial 1 architectural view and setup

To provide standard 5G connectivity, the trial leveraged ITAV's outdoor network infrastructure deployed at the port, consisting of three antennas. This access network segment was connected to the 5G Standalone Core located at the University of Aveiro campus. In addition, a portable, battery-powered system was used to provide 5G NR RedCap connectivity and Open5GS-based 5G Core capabilities, with the core functions deployed through a virtual machine.

The technical setup included integrating several 6G Application components, namely the Port Environmental Monitoring and Mobitrust V-Apps, as well as the QoS N-App. Multiple UE devices were interconnected through the ITAV 5G and battery-powered network infrastructure. These included the 5G NR RedCap-connected smart buoy; the Mobitrust Edge node, connected through 5G; an RC boat, also connected through 5G; a VR headset connected to the Mobitrust Edge node for visualisation of the port's 3D map; and a drone connected to the Mobitrust Edge node.

The deployment was designed to demonstrate the end-to-end triplet architecture and to show how OpenCAPIF can support the secure discovery and consumption of network capabilities. In the environmental monitoring scenario, the QoS Network Application interacts with ONEmNEF through OpenCAPIF, enabling the selection of energy profiles for IoT devices such as the smart buoy. This approach simplifies the use of exposed network interfaces while supporting more efficient and context-aware operation of connected sensing devices.

Table 3-28: Stakeholders' attendance per group (number of stakeholders) in Portuguese trial 1

Trial/Pilot (ID)	Government Bodies	Environmental Organizations	SME/Industry	Scientific Community	Other
1	0	0	3	3	7

Table 3-29: Collected KPIs in Portuguese trial 1

KPI Name/ID	Measured values	Comments
Datalogger energy consumption - KPI_009	4.5mW	Total system idle average. Assuming the modem is powered off.
Energy harvesting efficiency - KPI_010	84%	$\eta = (P_{load} + P_{battery})/P_{panel}$

Table 3-30: Collected KVI in Portuguese trial 1

Trial/Pilot (ID)	Questionnaire answers	Number of focus groups	Number of Interviews done	Comments
1	10	0	5	

The first Portuguese trial was considered successful by clearly presenting the motivation/need (i.e. continuous environmental quality monitoring in the Port), demonstrating the multiple solutions and their benefits, e.g., V-Apps advantages from integration with N-Apps and AI-Apps in terms of context-enablement and complexity reduction, energy-aware operation. Photos from Trial 1 are shown in Figure 3-50 and Figure 3-51.



Figure 3-50: Scenario 1 presentation during the 1st Trial of the Portuguese Cluster



Figure 3-51: Mobitrust presentation during the 1st Trial of the Portuguese Cluster

3.5.2.2 Trial 2

The trial aimed to demonstrate the value of key B5G/6G capabilities for port safety and logistics within the scope of Scenario 2 (whose conceptual setup is depicted in Figure 3-52). In particular, the scenario addressed the identification of HazMat trucks crossing forbidden “civil-only” roads using energy-efficient image collection and processing systems that benefit from on-the-fly dynamic resource management, activating and deactivating network and compute (AI processing) resources on demand. This behaviour is quantitatively supported by the collected network energy-efficiency KPI, which reports a 44.17% improvement in RAN energy efficiency. In addition, it aimed to present the approach and benefits of energy optimisation for port campus infrastructure within the scope of Scenario 3.

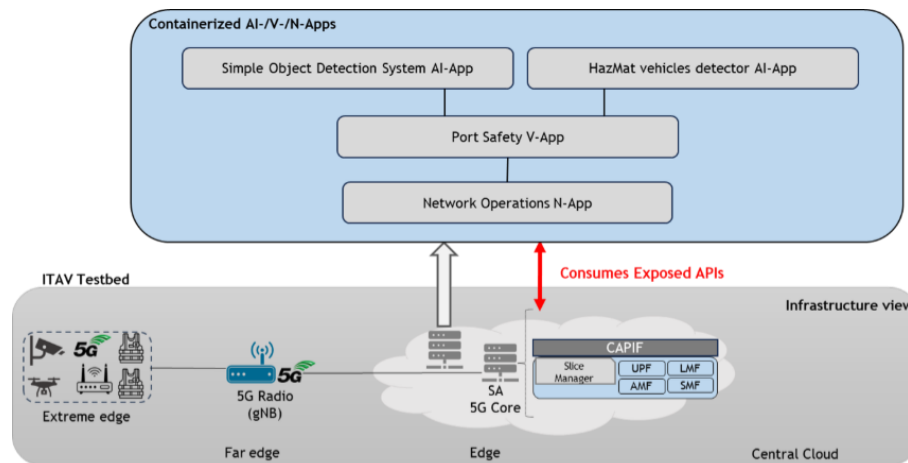


Figure 3-52: Portuguese Trial 2 architectural view and setup

The technical setup included the integration of V-Apps, N-Apps, AI-Apps, and multiple UE devices interconnected through the ITAV Standard 5G connectivity (as described for Trial 1). The deployment was designed to demonstrate the end-to-end triplet architecture and to show how application-level, AI-based, and network-level capabilities can be combined to support port safety and logistics, as well as infrastructure energy optimization.

The demonstrated components included the Port Safety and Mobitrust V-Apps; the Simple Object Detection System and HazMat Vehicles Detector AI-Apps; and the Network Operations N-App. The user equipment integrated in the trial included two ASECAM 4K MP IP surveillance cameras, a Mobitrust Edge node connected through 5G, and a drone connected to the Mobitrust Edge node.

Table 3-31: Stakeholders attendance per group (number of stakeholders) in Portuguese Trial 2

Trial/Pilot (ID)	Government Bodies	Environmental Organizations	SME/Industry	Scientific Community	Other
2	0	0	6	1	6

Table 3-32: Collected KPIs in Portuguese Trial 2

KPI Name/ID	Measured values	Comments
Throughput - KPI_003	53.4 / 10.5 Mbps (DL / UL median values)	20 MHz is the channel bandwidth available to the 5G infrastructure at the port.
Slice provisioning time KPI_004	4.12 seconds	-
Service provisioning time - KPI_005	1 to 103 s (median 27 s)	73% of the containers that comprise the whole service take less than 30 seconds to deploy.
Network energy efficiency - KPI_006	RAN energy efficiency: improvement of 44.17%	Energy efficiency in full power mode: 28634.74 bit/J Energy efficiency in low power mode: 41282.53 bit/J

Table 3-33: Collected KVis in Portuguese Trial 2

Trial/Pilot (ID)	Questionnaire answers	Number of focus groups	Number of Interviews done	Comments
2	8	0	5	

For the second scenario, the technical objectives planned for Trial 2 were fully accomplished, namely (1) the demonstration of the B5G/6G-based 6G-VERSUS system as an efficient solution to support monitoring of heavy truck traffic flow and enhance safety in the port and adjacent areas, and (2) the demonstration of the capabilities of 6G-VERSUS to optimize energy efficiency through the smart

allocation of network resources according to varying needs. The figures below show the execution of the second trial.

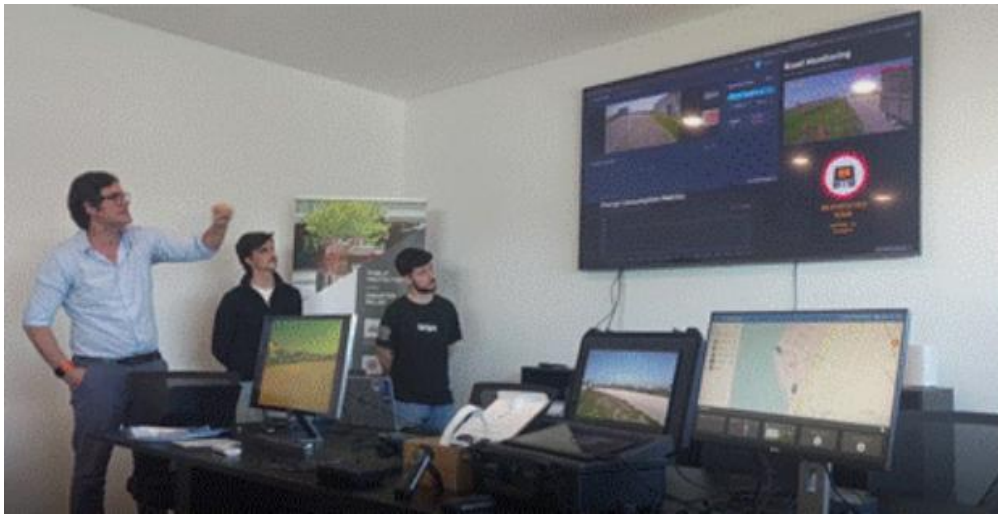


Figure 3-53: Port Safety V-App dashboard presentation during the Portuguese cluster's second trial



Figure 3-54: Equipment used for the setup of the Portuguese second trial

Regarding the third scenario, the technical objectives for Trial 2 were successfully accomplished, namely (1) the demonstration of the Infrastructure Energy Tracking V-App as a solution for collecting, aggregating, and visualizing energy-related data from solar panels and EV charging infrastructure deployed in the Altice Labs campus, and (2) the validation of the initial application architecture supporting energy-aware infrastructure management through the integration of the V-App with the N-App and the ingestion of real-time operational data.

3.5.2.3 Trial 3

The trial aimed to perform the first integrated demonstration covering all three port scenarios. Its main objective was to demonstrate the potential of the proposed solutions to enable 360-degree port monitoring across the environmental, safety, and energy dimensions. The trial was also designed to present these capabilities to business stakeholders and to collect feedback from relevant entities, including regional and public authorities. The conceptual view for the Trial 3 setup consists of the combination of the setups depicted below in Figure 3-56, Figure 3-57, and Figure 3-58.

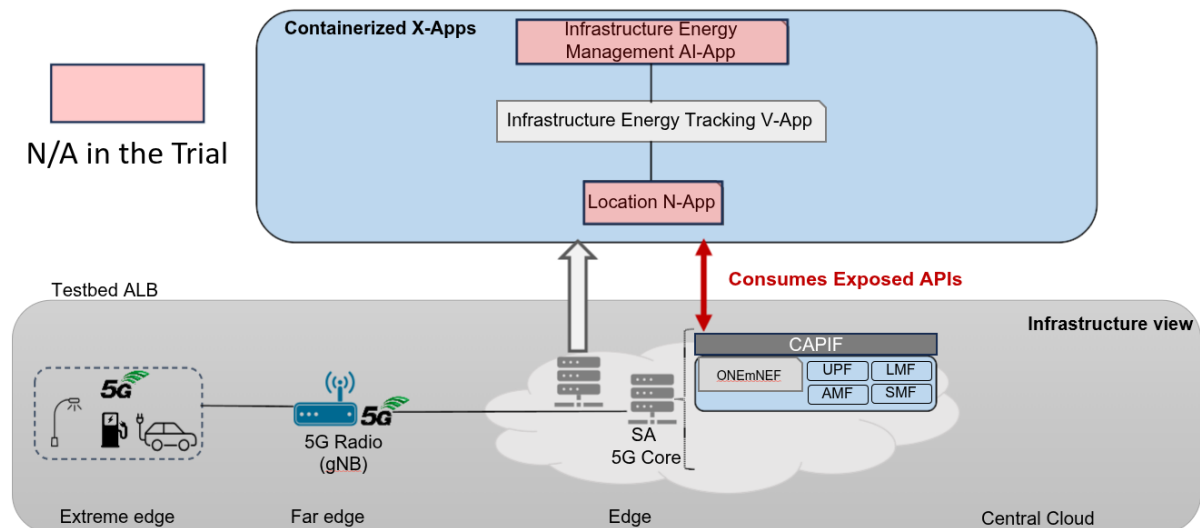


Figure 3-55: Architectural view and setup of scenario 3 in the Portuguese trial 3

The technical setup integrates vertical, network, and AI applications, as well as multiple UE devices interconnected via the ITAV 5G infrastructure (5G and mobile 5G RedCap site) used for trials 1 and 2.

The components demonstrated included the Port Environmental Monitoring, Mobitrust, Port Safety, and Infrastructure Energy Tracking Vertical Applications; the QoS and Network Operations Network Applications; and the Simple Object Detection System, HazMat Vehicles Detector, and Mobitrust AI Applications. The user equipment integrated in the trial included the smart buoy connected through 5G NR RedCap, the 5G-connected Mobitrust Edge node, a boat connected to the Mobitrust Edge node, and two ASECAM 4K MP IP surveillance cameras.

Table 3-34: Stakeholders' attendance per group (number of stakeholders) in Portuguese Trial 3

Trial/Pilot (ID)	Government Bodies	Environmental Organizations	SME/Industry	Scientific Community	Other
3	3	3	3	NA	3 (Maritime Port sector)

Table 3-35: Collected KPIs in Portuguese Trial 3

KPI Name/ID	Measured values	Comments
Object detection accuracy (water) - KPI 016	100%	RC-boat object detection
Water surface pollution detection - KPI 019	80% for RC-boat	KPI values with video streams from RC-boat and UAV mounted cameras
Water surface minimum object detection size - KPI 020	9cm for RC-boat	KPI values with video streams from RC-boat mounted cameras
Near-time real-time AI processing - KPI 021	727 ms	RC-boat object detection
Stable AI detection performance KPI 022	8%	RC-boat object detection

Table 3-36: Collected KVs in Portuguese Trial 3

Trial/Pilot (ID)	Questionnaire answers	Number of focus groups	Number of Interviews done	Comments
3	7	0	2	

The trial showcased a more mature version of the 6G applications in scenarios 1 (environmental monitoring) and 2 (safety/HazMat truck monitoring), and the partial implementation of scenario 3, focused on infrastructure energy tracking and visualisation, with AI-driven optimisation planned for the second trial phase. Together with feedback collected from relevant stakeholders, such as ports, the port industry, and regional authorities, these results represent the successful achievement of the Trial goals. Figure 3-56 and Figure 3-57 show the execution of trial 3.



Figure 3-56: Demonstration of scenario 1 in the 3rd Trial of the Portuguese cluster



Figure 3-57: Demonstration of scenario 2 in the 3rd Trial of the Portuguese cluster

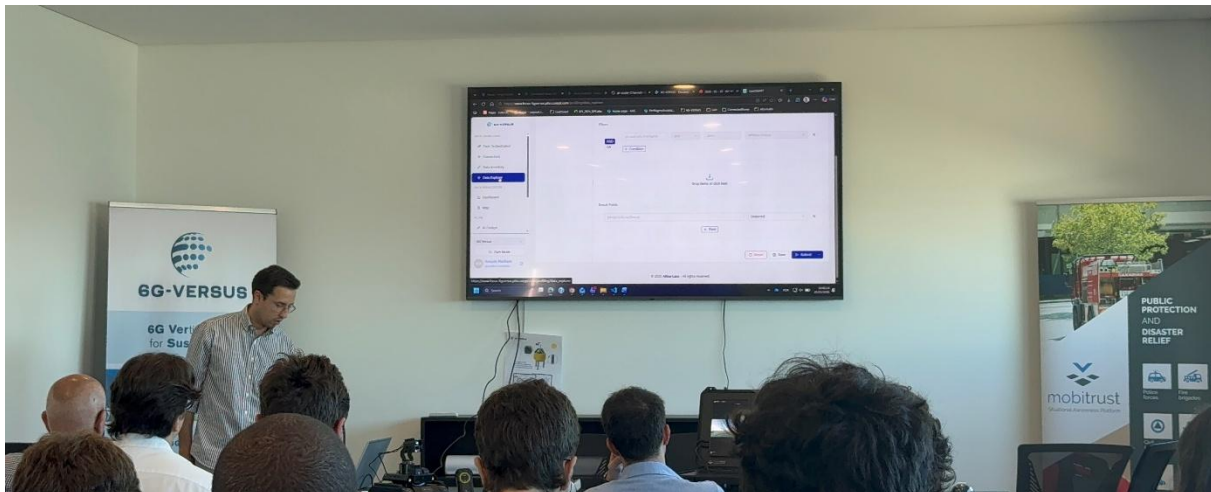


Figure 3-58: Demonstration of scenario 3 V-App in the 3rd Trial of the Portuguese Cluster

3.5.3 KPI analysis

The KPIs which have been addressed during the first trial phase of the Portuguese cluster activities are listed below.

Table 3-37: KPI Analysis

KPI Name/ID	Target Value	Baseline Value	Measured Values	Comments
Throughput - KPI_003	25 Mbps	N.A.	53.4 / 10.5 Mbps (Downlink / Uplink median values)	20 MHz is the channel bandwidth available to the 5G infrastructure at the port.
Slice provisioning time KPI_004	<180s	N.A. - service-dependent	4.12 seconds	-
Service provisioning time - KPI_005	<100s	N.A. - service-dependent	1 to 103 s (median 27 s)	73% of the containers that comprise the whole service take less than 30 seconds to deploy.
Network energy efficiency - KPI_006	25% improvement in network energy efficiency	Energy efficiency in full power mode: 28634.74 bit/J	RAN energy efficiency: improvement of 44.17%	Energy efficiency in low power mode: 41282.53 bit/J ¹⁴
Datalogger energy consumption - KPI_009	<50 mW	N.A.	4.5mW	Total system idle average. Assuming the modem is powered off.
Energy harvesting efficiency - KPI_010	>80%	N.A.	84%	$\eta = (P_{load} + P_{battery})/P_{panel}$
Object detection accuracy (water) - KPI_016	>80%	N.A.	80% for RC-boat 100% for UAV	Collected across several sets of objects (glass bottles, snack wrappers, cardboard, carton bottles, and water bottles)
Water surface pollution detection - KPI_019	>80%	N.A.	80% for RC-boat 100% for UAV	KPI values with video streams from RC-boat and UAV-mounted cameras
Water surface minimum object detection size - KPI_020	>10cm ²	9 cm ²	9 cm ²	KPI values with video streams from RC-boat mounted cameras
Near-time real-time AI processing - KPI_021 ¹⁵	≤ 1000 ms	661	727 ms	RC-boat based detection
Stable AI detection performance - KPI_022 ¹⁵	≤15 %	14%	8%	Variability in frame processing time to ensure a perceived consistent and coherent stream visualisation

3.5.4 Lessons Learnt

The lessons learned from the three trials conducted to date can be grouped into four main areas:

1. Trial planning and logistics: The execution of three trials within a four-month period proved to be highly demanding. For the second trial phase, trial planning should ensure a better balance between ambition and available planning effort. A higher number of trials, stakeholders, and engagement activities requires a proportional increase in coordination and logistical effort. This includes the preparation of invitations, stakeholder-specific message customisation, engagement follow-up, and feedback collection activities.

¹⁴ It should be noted that the measured energy efficiency improvement is related to the RAN segment only, therefore a direct comparison with the target value (25%) is inadequate. This 6G-VERSUS global target value (specified in the DoA) was not considered in D2.1 in relation to this KPI.

¹⁵ This KPI has been identified during the execution of the first phase trials, and it will be reflected in deliverable D2.2

2. Stakeholder engagement: A key challenge identified across the trials was the need to strengthen stakeholder participation in trial activities. Although Trial 3 involved a larger number of invited entities and achieved a higher number of registrations, the number of actual participants remained broadly similar to previous trials. Future trials should therefore include more targeted engagement actions before and during the trial period, with the aim of converting registrations into effective participation.

3. Impact-centric communication: Another key lesson learned concerns the importance of impact-centric communication. Communication with non-technical stakeholders, particularly end users, should be simplified while still clearly conveying the technical value of B5G/6G technologies. Expected value and Key Value Indicators should be integrated throughout the presentation and discussion, rather than being concentrated in a dedicated slide or isolated section. This approach can help stakeholders better understand the relevance and practical benefits of the trial outcomes.

4. Feedback collection and survey design: Lessons were also identified regarding the design of surveys and questionnaires. Further clarity is needed on how to distinguish between “end users” and “other stakeholders” when defining survey questions and feedback mechanisms. Improving stakeholder engagement in the feedback collection process is also necessary. In later trials, the number of survey responses represented only a subset of the actual participants, limiting the amount of feedback available for analysis. Future trials should therefore consider more streamlined feedback mechanisms, clearer stakeholder segmentation, and stronger follow-up actions to increase response rates.

3.6 Spanish Cluster

Table 3-38: Cluster summary table

Stakeholders	Questionnaires answers	Interviews	Focus groups	News Articles	Videos	KPI Collected
38	25	0	0	0	2	11

3.6.1 Pre-trials and lab-testing

Pre-trial #1 – 06/2025: Study of E-Coli sensor at the Roquetas de Mar wastewater treatment plant

An online E. coli sensor, ColiMinder, was installed at the Roquetas de Mar wastewater treatment plant (WWTP) water reclamation plant to assess its suitability as an early-warning system for microbiological risk and to support compliance with the quality requirements of RD 1085/2024 prior to the supply of reclaimed water to irrigators. The assessment included preliminary laboratory testing and two pre-validation trials at the outlet of the reclaimed water tank to evaluate disinfection efficiency and identify potential installation points.

Overall, no reliable correlation could be established between ColiMinder readings and Colilert-18 results, as shown in Figure 3-59. This lack of correlation is attributed to the different measurement principles of the two methods: Colilert-18 quantifies viable E. coli bacteria, whereas ColiMinder detects enzymatic activity associated with metabolically active E. coli after UV treatment. Due to decay and physiological stress induced by UV disinfection, the relationship between culturable E. coli and enzymatic activity was not sufficiently consistent under the conditions tested.

Consequently, the study concluded that the sensor should not be deployed at the reclaimed water tank as an early-warning system under current operating conditions. However, ColiMinder may still be considered as a supporting monitoring tool upstream of disinfection or in further controlled validation tests.

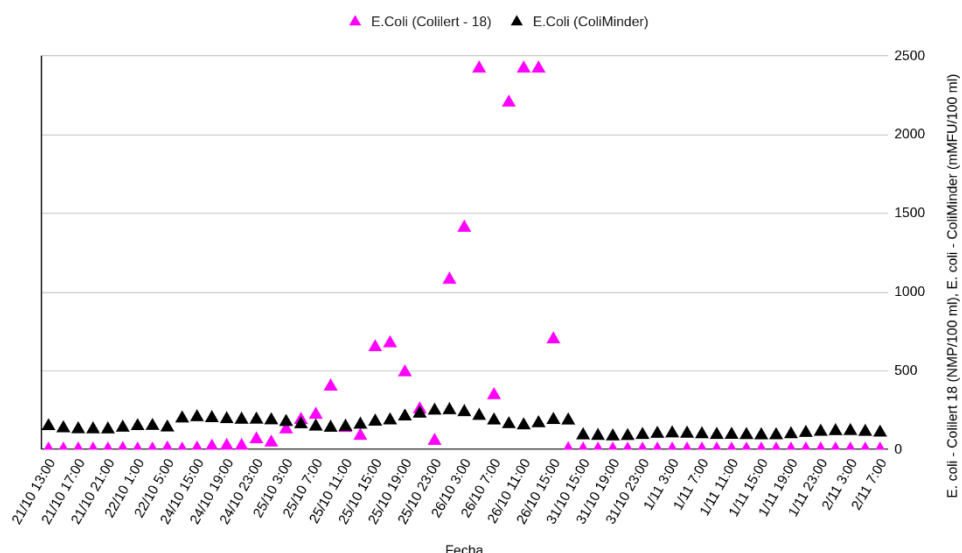


Figure 3-59: ColiMinder and Colilert-18 laboratory measurements comparison

Pre-trial #2 – 11/12/2025: Drone-based network coverage mapping at La Mayora

As part of the pre-trial activities, a series of drone-based coverage collection flights was conducted at the La Mayora experimental farm, as part of scenario 1 of the Spanish cluster activities. The primary objective of this phase was to gather baseline measurements to inform and refine the preparation for subsequent, more complex trial deployments. To achieve this, a mobile device equipped with the Keysight Nemo Handy measurement software was integrated onboard a drone. This setup enabled the dynamic, continuous collection of KPIs related to cellular network coverage, signal quality, and overall network performance throughout the targeted operational area.

Due to the irregular terrain, profiling the network at different altitudes is essential for this preliminary phase. Conducting these systematic flights at varying heights allows us to assess network quality and identify potential coverage blind spots or areas of signal degradation caused by irregular terrain. Furthermore, obtaining KPIs such as throughput and latency provides a complete view of the site. Figure 3-60 shows an example of the results obtained for network coverage at the test site, clearly demonstrating that coverage is significantly better at higher altitudes, as a direct line of sight is available to the 5G base station.



Figure 3-60: Drone-assisted mapping of network coverage at La Mayora

Pre-trial #3 – 26/02/2026: Algarrobo Irrigation Community visit

UMA and Cetaqua carried out a visit to the Algarrobo Irrigation Community, where representatives explained their infrastructure and operating conditions in detail. During the visit, the irrigation

community presented the layout of their network, the components that make it up, such as the mesh filters used for tertiary treatment, as shown in Figure 3-61, and the overall functioning of the system. The visit also included a small tertiary treatment plant for wastewater, using mesh filters to polish secondary effluent and remove remaining nutrients, bacteria, and suspended solids. This provided a clearer understanding of their operational context and enabled consideration of these conditions in the applications to be developed.



Figure 3-61: Mesh filters for tertiary treatment at Algarrobo irrigation association

Pre-trial #4 – 03/2026: La Mayora site assessment and network validation

Before conducting the immersive remote driving trial at La Mayora, a pre-trial assessment was performed to evaluate the communication conditions within the intended test area. The objective was to verify that the available 5G network could provide sufficient performance to support a safe and reliable remote driving operation. A series of network coverage measurements and signal quality tests was carried out across the planned driving area. In addition, throughput measurements were performed to assess the communication capacity available at different locations. An example of these measurements is depicted in Figure 3-62. The collected data enabled the identification of areas with adequate network performance and locations where communication quality did not meet the trial requirements. Based on the coverage and throughput results, the operational area for the trial was defined and limited to the zones where stable connectivity and sufficient communication performance could be guaranteed. This assessment ensured that the immersive remote driving demonstration would be conducted under suitable network conditions, reducing communication risks and increasing the reliability of the overall trial.



Figure 3-62: Network performance measurements

Lab-testing #1 – 12/2025: Testbeds for core network and UE energy measurements in Ada Byron

In the UMA lab at Ada Byron, KEYS, UMA, and HPE built a joint testbed for core network energy measurements, comprising network and emulation components and the necessary measurement tools. This testbed enables accurate energy measurement, and the results are presented during the first trial.

Moreover, UMA and KEYS developed the testbed for UE energy profiling in the lab, which is presented as a live demo during the first trial. The details of these two testbeds and the corresponding measurement methodologies will be described in more detail in deliverable D3.2.

Lab-testing #2 – 01/2026: Hexa-drone & RoArm-M2-S integration

UMA conducted another lab test at the Ada Byron building, focusing on the technical integration and validation of the unmanned vehicle (in particular, a hexa-drone) and the RoArm-M2-S robotic arm. The main objectives of this activity are to achieve seamless hardware-software integration between the drone and the robotic arm and to perform operational testing of the unmanned vehicle control V-App.

The experimental setup, illustrated in Figure 3-63, demonstrates the end-to-end workflow featuring three distinct operational modes for the robotic arm:

- **H16 Skydroid Remote Controller:** Movement commands are transmitted directly utilising MAVLink channels.
- **Laptop-Based Remote Control:** Operational commands are issued from a laptop keyboard and sent over the 5G network.
- **Vision-Based Gesture Control:** Hand movements are captured by a camera and translated in real time into robotic arm trajectories.

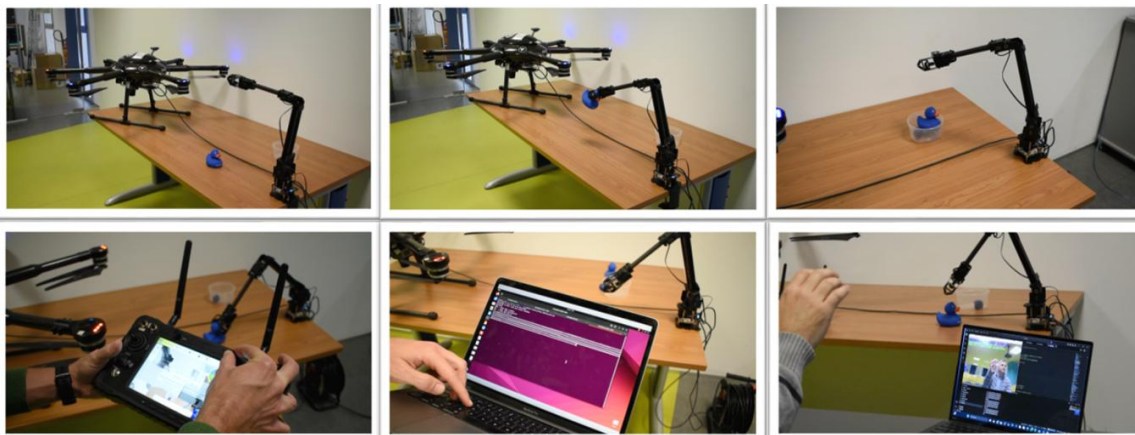


Figure 3-63: Hexa-drone and RoArm-M2-S integration setup

Lab-testing #3 – 05/2026: Unitree go2 and D1 arm integration

The last lab test carried out during this phase at the Ada Byron building by UMA was similar to the previous one. In this case, the focus was on the technical integration and validation of the unmanned vehicle (specifically, a Unitree Go2 quadruped robot) and the Unitree D1 robotic arm. Similarly, the main objectives are to achieve seamless integration between the hardware and software of the quadruped robot and the robotic arm, and to carry out operational tests of the V-App application for controlling the unmanned vehicle. The experimental setup, illustrated in Figure 3-49, shows the simultaneous remote control of both the unmanned vehicle and the robotic arm.



Figure 3-64: Unitree go2 and D1 arm integration setup

3.6.2 Trials and Pilots

The Spanish Pilot was executed across sequential trials, beginning with a first trial split into two primary activities: technical validation and stakeholder engagement. These initial activities established the baseline for a second trial dedicated to live field validation and international cross-project collaboration.

3.6.2.1 Trial 1: Activity 1 (Ada Byron – scenario 3)

Conducted on February 2, 2026, at the University of Malaga's Ada Byron Building, corresponding to scenario 3 of the Spanish pilot. This session engaged researchers and students, as illustrated in Figure 3-65, with technical demonstrations of key 6G enabling technologies, including energy profiling, P4 UPF SDN, Integrated Sensing and Communication (ISAC), drone multi-connectivity, and robotic arm integration.



Figure 3-65: Demonstration of activity 1 in the 1st Trial (scenario 3 – Ada Byron)

3.6.2.2 Trial 1: Activity 2 (La Mayora – scenario 1)

Held on March 19, 2026, at La Mayora, which is scenario 1 of the Spanish pilot, during an ASAJA Málaga conference. Figure 3-66 shows this event, which showcased 6G applications for precision agriculture and smart water management—such as immersive telepresence and continuous sensor-based monitoring—directly to farmers, researchers, and policymakers.



Figure 3-66: Demonstration of activity 2 in the 1st Trial (scenario 1- La Mayora)

We had public government attendees, including:

- Ramiro Angulo, General Secretary for Water in the Andalusian regional government (Junta de Andalucía).
- Miguel Briones, Provincial Delegate for Education, Universities, Research and Innovation in Malaga (Junta de Andalucía).
- Natacha Rivas, Mayor of Algarrobo, where La Mayora farm is located.
- Francisco Moreno, General Manager of AXARAGUA, for the public water utility in the Eastern Costa del Sol (Axarquía).

We were joined by several members of the Interprofessional Organisation for Avocado and Mango, including representatives from ASAJA, among them its president in Málaga, Baldomero Bellido; the president of the Spanish Association of Tropical Fruit Producers, José María López; the president of TROPS, David Sarmiento; and the CEO of Reyes Gutiérrez S.L., Juan Antonio Reyes. In addition, representatives from the irrigation communities of Algarrobo and the area's central irrigation boards attended, along with researchers from the Spanish National Research Council (CSIC) and the University of Málaga. Most of the audience were farmers, mainly members of ASAJA.

Trial 2 (La Mayora – scenario 1): Conducted on June 2, 2026, at La Mayora, corresponding to scenario 1 of the Spanish pilot. Organised by partners UMA, NOKIA, and CET as part of the EuCNC 2026 social program, this event hosted more than 20 international participants from research and industry for a dedicated Smart Agriculture use case visit, as pictured in Figure 3-67. The activity successfully gathered valuable ecosystem feedback, promoted co-location and cross-pollination with the 6G-PATH project, and achieved field validation and integration of the Unitree Go 2 quadruped robot and the D1 robotic arm.



Figure 3-67: Demonstration of the 2nd Trial (scenario 1- La Mayora)

Table 3-39 describes the entities that have been invited during the two activities of Trial 1.

Table 3-39: Stakeholders' attendance per group: number of stakeholders/participants

Trial/Pilot	Government Bodies	Environmental/Farming Organizations	SME/ Industry	Scientific Community	Other
1.1 (Ada Byron)	0	5	0	3	5
1.2 (La Mayora)	4	39	6	15	0
2 (La Mayora)	0	0	4	20	0

3.6.3 KPI analysis

Table 3-40: KPI Analysis

KPI Name/ID	Target Value	Baseline Value	Measured Values	Comments
KPI_01 User Experienced Data Rate	10-25 Mbps	25-30 Mbps	10 Mbps	During the trial run, lower values were obtained than those previously measured. This limited performance was reflected in latency, the application's most critical KPI.
KPI_02 Latency	<200ms	Because it is measured during application execution, there is no baseline value.	300-500ms (Trial 1 location) 100-200ms (original location)	RTT measure in the application. Measured every time we interact with the AGV (100ms). The values measured during trial 1 are very high due to the change of location required by the event. In a suitable location, the target value is met.
KPI_03 Coverage	100% of the experimental field with sufficient signal strength	Because it is a previous measurement, the baseline value coincides with the measured value. 80%	80%	Measured before the trial started to ensure a good performance. The measured value is smaller than the target value because the trial was organised differently, the location was different, and there was no full view of the antenna.
KPI_17 Sustainability. UE Energy	N.A.	0.128 W (UE in airplane mode)	Depending on different parameter values (like screen state), the measured power ranges from 0.422 to 2.28 W	Conducted in Test Case #3.1: Trial/Lab-based validation of modem energy consumption features, a clear correlation between energy consumption and some parameters has been observed
KPI_018 Sustainability. Core Network Energy	N.A.	91.56 W (idle server, without any UE connected to the core network)	Depending on different parameter values, the measured power consumption ranges from 90 to 120 W	Conducted in Test Case #3.3: Core network energy profiling, the effects on energy of different network parameters have been clearly demonstrated g

In this stage, a contextual assessment was conducted based on perceptions of water scarcity and drought. Questions have also been designed to assess the suitability of the proposed technologies for the needs of the attending audience. Questions were tailored to the different audiences in both trials/activities, as in the Ada Byron trial 0 (as explained earlier), the attendees/stakeholders had a more research-oriented profile. On the other hand, in trial 1 in Mayora, the audience was mostly farmers, so the questions were adapted accordingly.

Table 3-41: Collected KVIs

Trial/Pilot	Questionnaire answers	Number of focus groups	Number of interviews	Comments
1.1	13	0	0	Two volunteers were identified for interviews. Follow-up is ongoing
1.2	20	0	0	Only a fraction of attendees populated the questionnaires
2	-	-	-	

3.6.4 Lessons Learnt

This section describes the operational challenges faced and the tactical lessons learnt during the evaluation of the first phase of the Spanish pilot, in which the main technical and logistical lessons learnt from the first trial (activities 1 and 2) were used to refine the planning and execution of the second trial. Furthermore, all this information will, in turn, improve the planning, execution, and results of the second trial phase.

Trial 1 - Activity 1 (Ada Byron – scenario 3)

During the first activity in Ada Byron, it was found that an issue with the preparation of the online questionnaires caused the questionnaire collection to be less than expected. Although we had conceived a smarter reactive itinerary with multiple sections, the logic didn't behave as we anticipated, and all questionnaires went through the same sequence. For this reason, it included explicit checkpoints to further verify questionnaires (particularly if including multiple itineraries). This learning helped redefine the questionnaires for later activities and allowed us to identify some benefits of manual/written questionnaire completion, as it would be easier to check for sound completion (for example, in the event of optional questions).

Trial 1 - Activity 2 (La Mayora – scenario 1)

During the second activity at La Mayora, the analysis of the trial execution highlighted several relevant observations about the system's performance under real operating conditions. While the overall communication performance was sufficient for remote operation, the RTT measurements revealed occasional latency peaks. These peaks are attributed to potential interference affecting the wireless communication link within the deployment environment.

Despite these fluctuations, the system demonstrated robust behaviour, with AGV control maintained throughout the trial without critical failures. The operator was able to continue navigation, indicating that the implemented architecture can tolerate temporary degradations in network performance.

These findings underscore the importance of accounting for interference and variability in network conditions when deploying remote operation use cases over wireless infrastructure. Future iterations of the system could benefit from additional mechanisms for latency mitigation, such as improved network configuration, prioritisation of control traffic, or the incorporation of predictive control strategies to compensate for communication delays.

Overall, the trial provided valuable insights into the system's behaviour under non-ideal conditions, contributing to the validation of the proposed solution and identifying areas for further improvement. This learning was relevant in identifying the need for actions to confirm that the questionnaires are effectively completed. Including the use of written questionnaires and assigning roles to explicitly verify which attendee has completed or not. Because the event was collocated with another activity (from the regional farmers organisation ASAJA), we didn't have full control over the attendees. So, there are pros and cons in combined events. Maybe if we have a dedicated event, we could be in a better position to set an expectation on all attendees to populate the questionnaires.

Trial 2 (La Mayora – scenario 1)

The execution of Trial 2 provided critical organisational and logistical insights, particularly regarding stakeholder management when co-locating project trials with major international events. Although the event initially attracted considerable interest, with 50 participants registered and various reconfirmation emails sent in advance, the final number of attendees fell considerably.

As the event was organised as part of the 2026 EuCNC & 6G Summit social programme, attendance remained highly vulnerable to last-minute external issues. Several registered stakeholders faced unforeseen problems that prevented them from attending, including flight disruptions, visa processing delays, and operational commitments that conflicted with the conference, such as managing exhibition stands.

Key Takeaway for Future Phases: Building on the combined findings from Trials 1 and 2 regarding combined events, these results demonstrate a clear trade-off: linking pilot trials to high-impact events

(such as international conferences) significantly maximises project visibility but introduces a high degree of attendance volatility. This requires highly flexible scheduling, shorter evaluation formats, and dedicated backup target audiences in future testing editions to guarantee stable results.

Beyond the live trial execution, the first trial phase encountered several critical operational, procurement, and environmental difficulties that impacted the planned timeline and technical scope:

- **Cancelled activities:** Roquetas de Mar (scenario 2): A key lesson learnt was that trials involving critical infrastructure such as water treatment plants are highly dependent on the operational status and availability of the facility. In Roquetas de Mar, severe weather conditions affected the water treatment plant, making it impossible to host the planned stakeholder event within the original timeframe. Future planning should therefore include contingency options for cases where external events compromise access to critical sites.
- **Delays in hardware provisioning for applications development:** The development of applications dependent on specific hardware, such as cameras, water sensors, or other devices, required the timely availability of these components from the early stages of the project. Delays in provisioning water sensors intended for installation in La Mayora affected the availability of this capability for the early trials and delayed the development of the DSS for water quality. The same occurred for the cameras planned for installation in Roquetas de Mar, meaning that the computer vision component of the DSS for reliable water quality could not start as planned due to supplier-related issues, including delivery delays, stock shortages, and problems with the original manufacturer. This highlighted the need to identify hardware dependencies early, prioritise the procurement of third-party components, monitor supplier-related risks closely, and define contingency measures, such as alternative suppliers, substitute devices, or temporary testing equipment.
- **Microbiological sensor evaluation:** One of the inputs to the DSS for reliable water treatment was an E. coli sensor installed at the Roquetas de Mar water reclamation plant. To assess the reliability of the measurements from this sensor, a dedicated validation study was conducted. The microbiological assessment showed that, under the current operating conditions, the E.coli sensor (ColiMinder) did not demonstrate a reliable correlation with the reference Colilert-18 method, mainly because post-disinfection E. coli levels were too low and variable to establish robust alarm thresholds; consequently, its deployment as an early-warning sensor in the reclaimed water tank was not recommended. Further review of the study is required before deciding on an alternative. A key lesson learned is that sensor selection must be aligned with the expected concentration range and treatment conditions, and that alternative monitoring technologies should be considered from the outset whenever there are indications that this limitation may arise. In this respect, opting for a rental arrangement rather than a direct purchase was an appropriate and prudent decision, as it effectively mitigated the risk associated with a potential lack of technical suitability.

4 Conclusions

The first trial phase of 6G-VERSUS has achieved its main objective: moving the project from trial planning and component integration towards trial and pilot showcasing and stakeholder engagement. The activities reported in this deliverable confirmed the feasibility of deploying and interconnecting the 6G-VERSUS application triplet across diverse 5G/6G experimental environments in a trial setting and established an initial basis for evaluating stakeholder-perceived value and impact.

The trials showcased capabilities for sustainable and resilient vertical applications, including distributed monitoring and control of energy systems, energy-aware network operation, environmental and water management applications, wildfire detection and emergency response support, smart port monitoring, and agricultural applications. The collected KPI results provide useful baselines for the next phase and show that several cluster-specific technical targets were achieved under the trial conditions. At the same time, the results should be interpreted as preliminary to be refined in the second trial phase.

A key outcome of this phase is the preliminary evaluation of the stakeholder-oriented impact assessment. The trials enable relevant stakeholders to observe and interact with 6G applications in real-world contexts and to provide early feedback on their perceived value. However, trials also showed that stakeholder engagement, communication, questionnaire completion, and feedback collection require further refinement. Future trials in the second phase should use more targeted engagement strategies, simpler and more impact-oriented communication, clearer stakeholder categories, and feedback mechanisms designed to maximise completion rates and data quality.

The first phase also exposed practical constraints that are intrinsic to real-world showcasing. These include adverse weather conditions, limited site availability, hardware provisioning delays, field coverage variability, interference, dependencies on external infrastructure, and additional coordination effort required when multiple demonstrations and stakeholder activities are organised in parallel within a cluster. These findings are valuable as they identify the technical and operational conditions that must be addressed before the final trial phase.

The results will now feed into coordinated refinements across the project. WP2 will benefit from the identified architecture and integration requirements; WP3 from testbed, infrastructure, and measurement-tool improvements; WP4 from the evolution of V-App, N-App, and AI-App components; and WP5 and WP6 from the refinement of KPI/KVI methodologies and stakeholder-impact assessment instruments. Through this iterative process, 6G-VERSUS will be positioned to deliver final insights on the sustainability value of its 6G-enabled vertical services.

Annex: Test Case Details

This annex provides a detailed description of the Finnish cluster test cases that were not included in D5.1. The test cases were not included in D5.1 due to the previously ongoing architecture design and hardware & software selection. After a MATLAB-based simulation demo and multiple workshops on flow diagrams and API implementation, the final architecture for the Finnish use case was completed, and test cases were defined.

Finnish Cluster

Test Case #1: Reliability testing

Leading Partner: UOULU	Test Case #1: Reliability testing					
Test Case Objective	Measure the achievable 5G network availability YoY					
Test Case Target Layer or Application	Full stack					
Test Environment	Field					
Test Deployment Setup	Full system					
Network Setup	Finnish Cluster O-RAN setup with remote BTS					
Test Configuration	End Device Density	As in traffic profile	Mobility Level	N/A	Has Background Traffic	As in traffic profile
Initial Conditions / Prerequisites						
Full (configuration needed to start 12-month test period) Finnish Cluster Remote BTS system implemented and integrated						
Test Scenario						
Ensure the system runs for the entire duration of this test without interruptions and functions as specified						
Test Variables						
• SoC limit 80% • Generate double busy hour traffic profiling • Max amount of active UEs • Duration of test: 24 hours						
Expected Behaviour / Target KPIs / Values						
• System runs without interruption for 24 hours • KPI 1: Achievable network availability Year-on-Year (YoY) with renewable energy sources						

Table 8: Finnish Cluster Test Case #1

Test Case #2: Performance testing

Leading Partner: UOULU	Test Case #2: Performance testing					
Test Case Objective	Measure the technical 5G performance parameters of the End-to-End System					
Test Case Target Layer or Application	End to End					
Test Environment	Field					
Test Deployment Setup	Full system					
Network Setup	Finnish Cluster O-RAN setup with remote BTS					
Test Configuration	End Device Density	As in traffic profile	Mobility Level	N/A	Has Background Traffic	As in traffic profile

Initial Conditions / Prerequisites
Full (configuration needed to start 12 month test period) Finnish Cluster Remote BTS system implemented and integrated
Test Scenario
Test critical performance parameters for the system functionality
Test Variables
• SoC limit: 80% to 100% • All traffic profile used • Duration of test: 6 hours
Expected Behaviour / Target KPIs / Values
• Performance target met • KPI 2: Maximum data rates per user with energy balance awareness in DL and UL • KPI 3: Achievable latency with microwave link in fronthaul

Table 9: Finnish Cluster Test Case #2

Test Case #3: Energy efficiency

Leading Partner: UOULU	Test Case #3: Energy efficiency					
Test Case Objective	Measures the energy efficiency of the system of three different KPIs, includes coverage energy efficiency, data energy efficiency and energy efficiency of power supply unit.					
Test Case Target Layer or Application	End to End					
Test Environment	Field					
Test Deployment Setup	Full system					
Network Setup	Finnish Cluster O-RAN setup with remote BTS					
Test Configuration	End Device Density	As in traffic profile	Mobility Level	N/A	Has Background Traffic	As in traffic profile
Initial Conditions / Prerequisites	Full (configuration needed to start 12 month test period) Finnish Cluster Remote BTS system implemented and integrated					
Test Scenario	Ensure the system meets all the energy efficiency targets					
Test Variables	Default system configuration (automated)					
Expected Behaviour / Target KPIs / Values	• KPI 5: Coverage energy efficiency • KPI 6: Data energy efficiency • KPI 7: Energy efficiency of power supply unit					

Table 10: Finnish Cluster Test Case #3

Test Case #4: Energy capacity

Leading Partner: UOULU	Test Case #4: Energy capacity
Test Case Objective	Measures the energy production, storage and charging/discharging capability, includes KPIs battery status, hydrogen fuel cell usage control and remote site energy sufficiency.

Test Case Target Layer or Application	End to End and all Applications					
Test Environment	Field					
Test Deployment Setup	Full system					
Network Setup	Finnish Cluster O-RAN setup with remote BTS					
Test Configuration	End Device Density	As in traffic profile	Mobility Level	N/A	Has Background Traffic	As in traffic profile
Initial Conditions / Prerequisites						
Full (configuration needed to start 12 month test period) Finnish Cluster Remote BTS system implemented and integrated						
Test Scenario						
Evaluate the energy capacity of the remote BTS system in 4 stages (June 2026, October 2026, February 2027, May 2027)						
Test Variables						
Default system configuration (automated)						
Expected Behaviour / Target KPIs / Values						
KPI 8: Battery status SoH KPI 9: Battery status SoC KPI 13: Hydrogen fuel cell usage control KPI 14: Remote site energy sufficiency						

Table 11: Finnish Cluster Test Case #4

Test Case #5: Energy profiling

Leading Partner: UOULU	Test Case #5: Energy profiling					
Test Case Objective	1-year operation under dynamic photovoltaic (PV)-WIND- DESS and Hydrogen fuel cell vs baseline cost of electricity using nordpool (simulated RU), includes KPI: Cost counter/Energy savings (€)					
Test Case Target Layer or Application	End to End and all Applications.					
Test Environment	Field and Lab (simulations)					
Test Deployment Setup	Full system					
Network Setup	Finnish Cluster O-RAN setup with remote BTS					
Test Configuration	End Device Density	As in traffic profile	Mobility Level	N/A	Has Background Traffic	As in traffic profile
Initial Conditions / Prerequisites						
Full (configuration needed to start 12 month test period) Finnish Cluster Remote BTS system implemented and integrated						
Test Scenario						
1-year operational energy consumption for the Finnish cluster compared to grid-linked cost for the same system. - Calculate the energy savings						
Test Variables						
Default system configuration (automated) vs grid linked system						
Expected Behaviour / Target KPIs / Values						
KPI 10: Cost counter/Energy savings (€)						

Table 12: Finnish Cluster Test Case #5

Test Case #6: Sustainability assessment

Leading Partner: UOULU	Test Case #6: Sustainability assessment					
Test Case Objective	This test measures how much carbon emissions can be avoided compared to the legacy commercial solutions.					
Test Case Target Layer or Application	End to End and all applications					
Test Environment	Field and Lab (simulations)					
Test Deployment Setup	Full system					
Network Setup	Finnish Cluster O-RAN setup with remote BTS					
Test Configuration	End Device Density	As in traffic profile	Mobility Level	N/A	Has Background Traffic	As in traffic profile
Initial Conditions / Prerequisites						
Full (configuration needed to start 12 month test period) Finnish Cluster Remote BTS system implemented and integrated						
Test Scenario						
1-year operational energy consumption for the Finnish cluster compared with grid-linked CO2 emission estimates for the same system.						
Test Variables						
Legacy commercial solution energy consumption gathered from 6GXR project (similar environment)						
Expected Behaviour / Target KPIs / Values						
- Calculate measured CO2 emission savings in Kilogram - KPI 11: Reduction of CO2 emissions						

Table 13: Finnish Cluster Test Case #6

Test Case #7: AI forecast accuracy assessment

Leading Partner: UOULU	Test Case #7: AI forecast accuracy assessment					
Test Case Objective	This test case measures the accuracy of the deployed AI models used for energy weather forecasting and traffic forecasting. It provides the percentage based analysis of model accuracy.					
Test Case Target Layer or Application	End to End and all applications					
Test Environment	Field					
Test Deployment Setup	Full system					
Network Setup	Finnish Cluster O-RAN setup with remote BTS					
Test Configuration	End Device Density	As in traffic profile	Mobility Level	N/A	Has Background Traffic	As in traffic profile
Initial Conditions / Prerequisites						
Full (configuration needed to start 12 month test period) Finnish Cluster Remote BTS system implemented and integrated						
Test Scenario						
In this scenario the weather and traffic forecasting efficiency is evaluated for the 12 month test period						
Test Variables						
Default system configuration (automated)						
Expected Behaviour / Target KPIs / Values						

- | |
|--|
| <ul style="list-style-type: none">• Accuracy measured as percentage• KPI 12: AI algorithms accuracy |
|--|

Table 14: Finnish Cluster Test Case #7