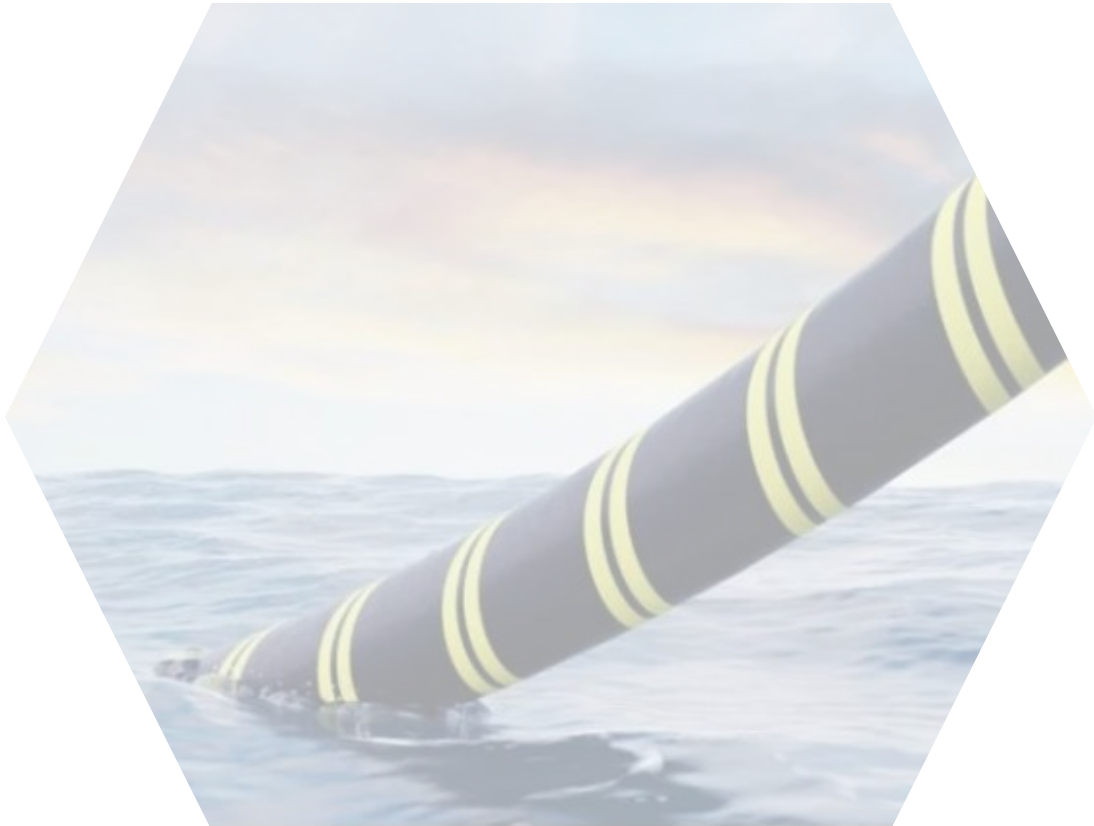




D1.5



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EasyDC-FOS

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EXECUTIVE SUMMARY

This deliverable outlines the technical progress of the EASYDC-FOS project from M1 through the mid-point of the reporting period (M9). The report presents a summary, able to be published, of the work performed across each WP. This first stage of the project has mainly focused on the development of key documentation to define the technical requirements for next developments and prototypes. These deliverables represent the main results of the initial project stage and provide the foundation for the upcoming implementation and demonstration activities.

As the project progresses, the consortium will move towards the execution and validation of these technical specifications. TSOs as the primary end users of the proposed innovations, have played a significant role in shaping the requirements, ensuring that the project's outcomes are aligned with their needs.

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ABBREVIATIONS AND ACRONYMS

Abbreviations / Acronyms	Description
WP	Work Package
PMO	Project Management Office
HVDC	High Voltage Direct Current
DAS	Distributed Acoustic System
DTS	Distributed Temperature Sensing
TSOs	Transmission System Operators
SAB	Stakeholder Advisory Board
EC	European Commission
GA	Grant Agreement
PO	Project Officer
DMP	Data Management Plan
GAP	Gender Action Plan
XLPE	Cross-Linked Polyethylene
LI	Lightning impulse
FAT	Factory acceptance testing
PEA	Pulsed Electro Acoustic
FEM	Finite Element Method
AI	Artificial Intelligence
PD	Partial Discharge
ML	Machine Learning
RTTR	Real Time Thermal Rating
KPIs	Key Performance Indicators
SLCA	Social Lie Cycle Assessment
FBG	Fibre Bragg Grating

1 Introduction

1.1 Overview of the progress: Summary of work performed and achievements

During the first nine months of the project, the consortium has made substantial progress across multiple Work packages (WPs), establishing a strong foundation for the technical, strategic, and operational objectives of the initiative. Currently, six WPs are in progress, one has been completed, and three have not yet started.

The project was successfully launched with the Kick-off Meeting and the establishment of the Project Management Office (PMO, WP1). Coordination mechanisms have been effectively implemented through regular technical and administrative meetings, ensuring alignment across partners and WPs. Risk management, financial oversight, and reporting procedures are in place, with no deviations reported.

Overall, the technical core of the project (WPs 3, 4, 5, 6, 7) is progressing in line with expectations, with all active WPs tasks either fully or partially implemented and no significant deviations reported. The results achieved to date highlight effective collaboration, technical excellence, and thoughtful planning, ensuring a strong foundation for EasyDC-FOS continued success.

Finally, WP9 has made strong progress in communication, dissemination, and exploitation. The project's strategic plan was formalized early with the submission of D9.1, and stakeholder engagement has been actively pursued through digital channels and international events. Although the formal establishment of the Stakeholder Advisory Board (SAB), initially planned for M6, was delayed due to efforts to engage high-impact Transmission System Operators (TSOs) members and internal decision-making processes, this has not significantly impacted project progress. The SAB constitution meeting is expected before M12. A wide range of communication materials has been developed, and the project has been showcased at several high-impact events across Europe and internationally. A preliminary exploitation roadmap has been drafted, and the consortium plans to leverage the Horizon Results Booster to enhance the impact and market readiness of key project outcomes.

2 Implementation: Work packages, activities, and timing

2.1 Work package 1

T1.1

Partially implemented

At M1, D1.1 "Project Management Plan" was successfully submitted. This document established key guidelines for financial reporting, deliverable standards, and reporting obligations to the European Commission (EC). It also outlined payment procedures and the project calendar, detailing the schedule of each task, the responsible partners for the related subtasks and deliverables, and the interdependencies among various project activities.

In terms of administrative, legal, and financial assistance, the pre-financing payment was successfully distributed among all partners at the start of the project. Ongoing financial control has been kept by providing timely responses to partner questions related to payments.

A procedure for the supervision of deliverables has been implemented to ensure the timely review and submission of progress and interim reports to the EC, in alignment with the deadlines established in the Grant Agreement (GA).

To maintain transparency and coordination, all partners have been kept informed of the project's progress through regular WP meetings. WP leaders have been invited to present updates on their respective WPs during TEAMS meetings. The minutes and presentations from these meetings have been collected in the project repository, ensuring full accessibility for all partners.

T1.2

Partially implemented

Monitoring meetings have been organized and carried out according to the project's coordination plan. The Kick-off Meeting was held in person in Madrid during M1 over the course of two days, successfully launching the project with the full participation of the consortium. Following this, a second consortium meeting was held online in M6. The next consortium meeting (in-person) is now scheduled for M14 instead of the initially planned M12 and will take place alongside the ENLIT event in Bilbao from November 18th to 20th, 2025. Attendance at this event was anticipated in the project as an ideal occasion for the dissemination of project results to relevant stakeholders. Aligning the consortium meeting with ENLIT will not only support dissemination efforts but also facilitate interaction between the SAB members and consortium partners, as many SAB members are expected to attend. This provides a convenient opportunity to hold the project's first SAB meeting. Although this change implies a two-month delay from the original plan, it does not affect the overall project timeline. The Project Officer (PO) has acknowledged and approved the rescheduling, considering the justification reasonable and the impact negligible.

In addition to the consortium meetings, regular technical meetings have been held every 2 months to ensure adherence to the work plan and monitor technical progress. These meetings, have been coordinated by the Technical Committee (TC), composed of WP leaders and the PMO. The meetings have served as a platform to review task progress, track deliverables, and prepare internal reports for ongoing monitoring and coordination.

Risk management activities have also progressed as planned. D1.2 "Risk Management Plan" was successfully submitted in M6, with only a minor delay of two days, which was duly

communicated to the PO. The plan outlines the methodology for identifying, evaluating, analysing, and mitigating risks throughout the project. It includes clearly defined risk categories, response strategies, monitoring procedures, and roles and responsibilities. Risk monitoring remains a continuous activity, with all project partners actively engaged and aware of their responsibilities in managing potential challenges as they arise.

T1.3

Partially implemented

D1.3 “Data Management Plan” (DMP) was successfully submitted in M6 with a minor delay of two days, communicated to the PO. This document outlines the procedures for the collection, storage, security, and sharing of research data throughout the project. It ensures compliance with the FAIR principles (Findable, Accessible, Interoperable, and Reusable), as well as adherence to legal and ethical standards and HE requirements. The plan is designed to guarantee the integrity, accessibility, and long-term preservation of all project-generated data.

D1.4 “Gender Action Plan” (GAP), was also successfully submitted in M8. This plan establishes the framework for promoting gender equality within the project, including measures to ensure balanced participation, raise awareness among partners, and integrate gender dimensions where relevant in research and innovation content.

Technical deviations

No deviations have occurred during the period reported.

No deviations are foreseen from M9 up to the rest of the reporting period (M18)

2.2 Work package 2

This WP has not started at M9 of the project

2.3 Work package 3

T3.1

Implemented

T3.1, led by NEX and with GD as a participant, culminated in the submission of D3.1 “*Cables systems requirements*”. The main objective of this work was to specify the requirements, the initial design, and the framework for the development of innovative HVDC cable systems, as well as to define the plans for their monitoring and validation. The work included the identification and summary of relevant standards and norms for extruded HVDC cable systems, such as CIGRE TB 852 and IEC 62895. Key aspects related to insulating materials, such as cross-linked polyethylene (XLPE) and its novel variant, DC grade XLPE, their electrical properties (conductivity, space charge), and how they are affected by crosslinking by-products (PDPs) were detailed. Manufacturing aspects of HVDC cables were reviewed, including conductor stranding, insulation extrusion, degassing, copper screening, aluminium sheathing, and PE sheathing. An initial design description of a 525 kV land cable system with a 3000 mm² conductor was presented as a base case, outlining the different layers and their relevant parameters. Thermal environmental scenarios were defined, and preliminary calculations for cable rating and loss estimation were performed for different design scenarios (varying nominal temperature, conductor size and material, and pole spacing).

Testing and validation plans were specified. These include the definition of:

- Screening tests, such as lightning impulse (LI) on samples, AC routine testing, and factory acceptance testing (FAT), establishing their conditions, standards, and pass/fail criteria (no breakdown).
- Small-scale measurements on peeled cable samples, such as space charge measurement using the Pulsed Electro Acoustic (PEA) method and electrical resistivity measurement, to evaluate the performance of the insulating material and provide data for modelling.
- The Key Performance Indicators (KPIs) for the full-size prototype and its type test (passing the test at 90 °C, $1.85 \cdot U_0$), the minimum prototype length (at least 100 m passing the screening tests), and the KPIs for the small-scale measurements.

A regulatory framework for eco-design and sustainability assessment was developed, defining a two-stage process (assessment at material/manufacturing level and at full system level), identifying key indicators (environmental, economic, circularity), and establishing thresholds (mandatory and preferable). A preliminary environmental impact assessment was performed comparing different cable design scenarios.

T3.1 and its deliverable are a requirements specification and initial design report, not a full implementation report, so it was not expected to include completed deliverables from later phases. However, some elements remain to be completed during WP4:

- The exact dimensional, electrical, and thermal parameters of the proposed cable were not fully specified, since the cable design was not finalised at the time of submission and is part of T4.1.
- The definition of social impact indicators, necessary for the sustainability framework, was not included, as it is scheduled for T4.4, in line with the project's work plan.

During T3.1, no issues arose for the definition of the new cable system requirements. However, fallback solutions (e.g., 400 kV operation, aluminium conductor, smaller cross-section) for the cable design were proposed as a planned mechanism to address the potential technical difficulty

of achieving the most ambitious design during the construction, testing and demonstration phases (WP4 and WP8) to ensure feasibility and schedule adherence in case the most ambitious $525\text{ kV} / 3000\text{ mm}^2$ design proves too complex to validate during testing. These alternatives were foreseen due to the high technical ambition and are part of the risk mitigation strategy.

In summary, no subtask was unexpectedly omitted. The deliverable met its intended scope, with specific elements planned for future stages.

T3.2

Implemented

T3.2 was completed with the successful submission of D3.2 “*Cable Modelling Specifications*”. This task was led by UCA with key contributions from LMK, RDT, APS, AMP, BAR, ENER, and STAT.

The objective of D3.2 was to define the specifications for models and prediction algorithms that will support the understanding and improvement of the performance, ageing, and reliability of HVDC cable systems. These models and algorithms will then be developed and implemented in WP5 and WP6:

- Development of frameworks and input/output parameters for both physical models and software-based predictive algorithms.
- The work was divided into two main groups: Models (based on physical principles such as Finite Element Methods (FEM)) and algorithms (using advanced software and Artificial Intelligence (AI) techniques).

Key components specified in the deliverable include

- Space charge modelling (by RDT): Methodology to simulate space charge accumulation within cable insulation using tools such as *COMSOL Multiphysics* software. Inputs (e.g., void characteristics, temperature gradient) and outputs (e.g., Partial Discharge (PD) frequency, energy) were defined along with validation strategies.
- Thermal modelling (by UCA): Specifications for thermal analysis of cables and connectors under real conditions, including relevant standards (IEC, CIGRE), case studies (e.g., systems from STAT, ENER, and NEXANS) and validation through integration of analytical, FEM models, and monitored data.
- Predictive algorithms:
 - Ageing algorithm (from LMK): Uses Machine Learning (ML) techniques with input from FEA models (RDT and UCA) and PD sensor data to predict remaining cable life or health status.
 - Real Time Thermal Rating (RTTR):
 - Cable RTTR (by APS): Combines 1D thermal networks and 2D FEM to estimate real-time ampacity and emergency ratings.
 - Connector RTTR (by LMK): Uses artificial neural networks (LSTM/GRU) with Bragg sensor data, cable current, and environmental conditions.
 - Fault location algorithm (by APS and LMK): A two-stage process combining vibration-based anomaly detection (LMK) and distributed acoustic sensing (APS) for accurate ($< 10\text{ m}$) fault location.

As D3.2 is a specification deliverable, it was not intended to include the full development or final validation of the models and algorithms described. Its primary objective was to provide the technical and methodological basis for these activities to be carried out in subsequent work packages (WP5 and WP6). This structure was explicitly defined in the project plan and does not reflect any delay or failure.

In addition, D3.2 provides comprehensive validation protocols for each model and algorithm, including comparisons with experimental and simulation data. These predefined strategies are designed to ensure the accuracy, reliability and traceability of results in future phases. Rather than reacting to a past problem, this approach proactively mitigates the risk of implementation challenges and supports the successful completion of WP5 and WP6.

T3.3

Implemented

T3.3 resulted in the submission of D3.3, the main objective of which was to define the specifications and requirements for the design of enhanced fibre-based monitoring and fault location systems. This task was led by APS with key contributions from LMK, UVA, AMP, BAR, ENER, and STAT.

The work involved gathering user requirements from TSOs, in particular ENER and STAT, based on the project's use cases (Øygarden 2 by STAT and COBRACable by ENER), as well as broader market needs. From this, detailed technical specifications were derived, which set performance benchmarks and functional targets for the monitoring system.

The deliverable includes specifications for key system components, including

- Distributed Temperature Sensing (DTS)
- Distributed Acoustic System (DAS)
- Point Vibration Sensors
- PD Analyser
- Edge Nodes

D3.3 provided the requirement criteria for monitoring > 125 km long HVDC cables on each individual element of the monitoring system (DTS, DAS, vibration sensors, PD analyser, edge node, fault location algorithms) that set benchmarks for the hardware and software development. The document defined performance metrics (e.g., spatial resolution, temperature range, PD detection bandwidth), operational, and installation parameters, environmental conditions and communication protocols for data exchange between the interrogators, the Edge Node, and the TSO systems.

As D3.3 is a specification and requirements document, it did not include the actual development, implementation or final validation of the monitoring and fault location systems. This was fully in line with the scope of T3.3, which was to define what needed to be developed and to establish the relevant performance benchmarks.

T3.3 provided the technical basis and a detailed roadmap for the subsequent development, implementation and validation activities planned in WP6, WP7, and WP8. It defined the methodology and criteria to be applied, ensuring consistency with end-user requirements, and overall project objectives.

Rather than reacting to a previous problem, the document takes a proactive approach to risk

mitigation. By rigorously specifying requirements at this stage, the project aimed to reduce the likelihood of future challenges, such as mismatch with stakeholder expectations or failure to meet technical objectives. In addition, the deliverable outlined the validation procedures to be applied in the use cases to support the accuracy and reliability of the systems once deployed.

T3.4

Implemented

T3.4 resulted in the production of D3.4, outlining the approach for the validation and testing of the DTS, DAS, PD and vibration monitoring systems developed in the EasyDC-FOS project. This task was led by ENER with key contributions from LMK, NEX, APS, AMP, BAR, RDT, STAT, ACE, GD, and ZAB.

The main objective of this plan was to demonstrate the effectiveness and reliability of these monitoring systems under real world conditions and to ensure that they meet the required performance standards.

The work carried out in T3.4 involved specifying and detailing the procedures for both laboratory and field validation. This included defining the overall scope and objectives of the validation plan, establishing KPIs to evaluate system effectiveness, and addressing anticipated challenges in calibration and field validation, along with strategies to overcome them.

The KPIs include specifically adapted measurement criteria for the following sensor types:

1. DTS
2. DAS
3. PD Sensor
4. Fault Localization Targets
5. RTTR Algorithms Targets

General and detailed calibration procedures for the different systems (DTS, DAS, PD) were defined and the methodology for data collection and analysis was described. The deliverable also specifies how the results of WP3, including D3.4, will feed into the validation activities of WP8, ensuring a coherent transition between the work packages.

In D3.4, the methodology and procedures were defined for later validation phases. The practical implementation of technical development, implementation and laboratory and field testing is planned for later phases of the project, mainly in WP8. This structure was planned from the outset and is consistent with the overall project schedule and work package distribution.

D3.4 has been developed to proactively minimise potential risks in future validation phases. By providing detailed specifications for laboratory and field testing, defining clear KPIs and setting out precise calibration procedures, the document lays the foundation for a robust and reliable validation process. It also addresses foreseeable challenges, such as the limited availability of real-world failures in the field, by proposing controlled simulations.

The COBRACable field/site test location has been presented in detail, including the actual test objects:

1. HVDC cable end termination
2. HVDC underground and submarine cable transition joint

Additionally, the physical locations of key components have been outlined, including:

- The actual HVDC cable route in relation to the optical fibre route
- The HVDC cable end termination in relation to the server/equipment rack
- The HVDC underground and submarine cable transition joint in relation to the link box and optical fibre house.

Potential issues have been addressed and discussed, and potential ideas for solutions have been presented and to be further discussed in the up-coming workshop, “Reflections on Verification and Validation of Monitoring Systems,” to be held at Energinet's offices near Copenhagen on September 9, 2025.

Technical deviations

There were no technical deviations from the DoA in the implementation of the WP3 tasks (T3.1 to T3.4). All deliverables were produced in line with the expected scope, which focused on specification, requirements definition, and validation planning.

2.4 Work package 4

T4.1

Partially implemented

NEX will start manufacturing this full-size cable as expected in the planning. All preparations have been executed internally in NEX to support this:

- Small scale compatibility testing
- risk assessment
- conductor trial
- technical documentation preparation
- pre-production meetings
- Representant from insulation system material supplier to be present during manufacturing.
- Nexans R&D engineers and process engineers to be present during manufacturing.

T4.2

Not implemented

At M9 of the project this task has not started

T4.3

Not implemented

At M9 of the project this task has not started

T4.4

Partially implemented

The work plan for the task was developed by GD, planning the assessments to be conducted iteratively. In this way, the first environmental impacts results (obtained by conducting life cycle assessment) are foreseen to be available at M11. These results will then be used to identify critical areas for the improvement of data quality on precision of the analytical approach. The economic impacts are planned to be assessed along with the environmental impacts, by applying the methodology of life cycle costing. The social impacts will be assessed through the methodology of Social Life Cycle Assessment (SLCA).

The analysis started with the definition of its goal and scope in collaboration between GD and NEX, expanding the methodology formulated in D3.1. The data collection process is ongoing within this task, being based on the communication between GD and NEX. A data collection template was created by GD to structure the data collection process. This template was then presented and explained to NEX. Meetings were organized to facilitate data collection, communicating and specifying the data requirements. Progressively, data on the material composition, manufacturing as well as other life cycle stages was collected for the newly developed cable. Based on this data, the cable system is currently being modelled in openLCA software by GD.

Technical deviations

From NEXANS: Before manufacturing starts, NEXANS do not see any blocking points or actions

prepared which have not been executed.

There are no technical deviations at moment in the sustainability assessment conducted by GD.

2.5 Work package 5

T5.1

Implemented

All T5.1 work was collected in D5.1 “*HVDC Cable Ageing Mechanisms Study*”, which was completed and submitted on schedule by RDT (T5.1 leader). This deliverable formed the scientific and technical foundation for all subsequent ageing modelling activities and sensor integration strategies within the project.

The document presented a comprehensive study of the key physical mechanisms responsible for the degradation of HVDC cable insulation during operational life. Specifically, it analysed:

- Space charge accumulation: Mechanisms of charge injection, transport, and trapping in cable insulation materials, particularly focusing on the influence of thermal and electric stress.
- PD: Identification of initiation factors and their evolution under DC conditions, including impact on insulation integrity.
- Electrical treeing: The role of local electric field enhancements and PD activity in initiating and growing tree-like degradation paths within the insulation.
- Thermal ageing: effects of elevated temperatures and thermal gradients on material structure and lifetime.
- Environmental ageing: Influence of moisture, contaminants, and mechanical stressors in real-world deployment conditions.

In parallel, the deliverable also explored fibre-optic sensor technologies that can detect and monitor variables linked to these ageing processes. The following sensor categories were thoroughly analysed:

- Electro-optic sensors (Pockels/Kerr effect) and interferometry-based sensors for electric field monitoring.
- Fibre Bragg Grating (FBG) and DTS for thermal ageing detection.
- DAS for PD and vibration monitoring.
- Humidity sensors for detecting moisture ingress and associated insulation degradation risks.

Each sensor type was described in terms of its operating principle, targeted ageing mechanism, integration potential in HVDC systems, and associated error sources with mitigation strategies.

This work established the scientific baseline for the development of advanced digital predictive models in subsequent deliverables (D5.2 to D5.7), also ensuring alignment with the sensor development activities in WP6 and support of the validation strategy to be implemented in WP8.

T5.2

Partially implemented

Currently, work with the COMSOL Multiphysics software is proceeding without issues, following the research conducted on the capabilities of other software (such as Ansys) for developing space charge and partial discharge models.

At present, a 1D model is being developed to simulate space charge within the insulation. This type of model will help us calibrate the model parameters (coefficients) that describe the transport, trapping, release, and recombination of charges, which may lead to charge accumulation in the insulation.

Since it is necessary to accurately model all the causes that can generate charge, the charge injection models from the electrodes are also being studied, as the default models in COMSOL (or any software), such as Schottky injection, are idealised models that do not perform well under low electric field conditions, such as in polarity reversal scenarios. Therefore, efforts are currently focused on modifying this condition or implementing alternative models. For this part, communication has begun with NEX, which provides support and data to help analyze EASYDC-FOS model.

T5.3

Not implemented

At M9 of the project this task has not started

T5.4

Not implemented

At M9 of the project this task has not started

T5.5

Not implemented

At M9 of the project this task has not started

Technical deviations

Given the early stage of these tasks, no deviations from the original plan have been observed to date

2.6 Work package 6

T6.1

Partially implemented

This task comprises the development of DAS and DTS interrogators with a minimum sensing distance range of 125 km and on-board data processing.

ST 6.1.1

Partially implemented

The current technologies and latest academic publications on measurement schemes and data processing algorithms for DAS and DTS have been studied extensively and compared with the requirements on the new products, especially given by the requirements of this project. The focus was on maximizing the sensing distance range while at the same time limiting the complexity of the fiber optic and electro-optic scheme and the data processing load. The selected schemes are a novel combination of polarization-diverse (coherent) detection and efficient data processing algorithms.

Based on the specified measurement scheme, components were sourced and two laboratory setups for Rayleigh phase-OTDR (for DAS) and Brillouin OTDR (for DTS and DSS) have been brought into operation. The data digitization is done with the full sampling speed that is required in the final receiver hardware to collect raw measurement data. Data processing is done offline to develop and optimize the processing using novel algorithms suited to DAS or Brillouin DTS/DSS.

The proof-of-concept laboratory setups successfully demonstrate acoustic and temperature sensing with the novel schemes based on the same of similar components that will be integrated in the prototype hardware. Results will be shown in D6.1.

The next steps to complete the proof-of-concept are performance testing on long ULL fibers for the demonstration of 125 km distance range as specified in D3.3.

ST 6.1.2

Partially implemented

Mechanical design and early prototyping of the housing and layout of fiber optical enclosures has been done using CAT simulations and 3D-printed prototypes.

The development of thermal management concept was done, including calculations of the expected power dissipation, heat transport, and thermal budgeting.

Ultra-low noise laser sources for DAS are being compared and qualified regarding their phase and intensity noise and stability over environmental temperature changes. Other required components for light modulation or amplification, fiber-optic components (e.g. splitters, couplers, circulators) and receiver optoelectronics are being sourced and qualified.

The design and simulation of multiple opto-electronic subsystems was done, including electronic circuit development and PCB design. Prototype boards have been ordered. This goes for the functional groups of

- Controlling and powering the laser source
- pulse shaping, modulation and amplification, which is required to form optical pulses with sufficient peak power for the OTDR-based measurement principles

- optical detection with photodiodes, followed by signal conditioning such as balancing, filtering, or electrical amplification.

Architecture comparisons and design of the integrated data processing hardware have started.

ST 6.1.3

Not implemented

At M9 of the project this subtask has not started. Prototypes are not available yet.

T6.2

Partially implemented

LMK has progressed in the development of a vibration sensing system based on an optical interferometric architecture. The project encompasses the design, implementation, and experimental validation of the sensing solution.

The initial phase focused on the definition of the system architecture and the development of a mathematical model that incorporates the physical behavior of light propagation in optical fibers. This model has supported key design decisions aimed at minimizing sensitivity to external perturbations and preserving signal integrity under varying environmental conditions.

Following component availability, the first version of the sensor was successfully assembled. Experimental testing has been initiated to characterize system performance in realistic operating environments. These tests are aimed at understanding the sensor response under external disturbances and verifying its robustness outside laboratory conditions.

Recent efforts have focused on mitigating oscillatory noise observed during operation. Physical adjustments and balancing are being implemented to address this, and further design alternatives are under consideration to optimize sensor performance.

T6.3

Not implemented

At M9 of the project this task has not started

T6.4

Partially implemented

LMK has developed a complete optical system for the detection of partial discharges (PD), using a high-frequency modulation approach. The project began with the definition of the system architecture and the development of a mathematical model to evaluate the physical feasibility of the solution.

To ensure reliable detection under varying operating conditions, special attention was given to the management of the polarization state of light within the system. A specific optical configuration was implemented to maintain consistent response, regardless of external perturbations.

An optical test setup was assembled in which a signal generator was used to replicate partial discharge pulses. This configuration enabled the characterization of the voltage levels required

for effective detection of these fast transients through modulation onto an optical carrier at around 1550nm wavelength.

To maintain a passive sensor architecture, a solution was developed allowing internal optical control of the operating point of the modulator. This was achieved by using two separate optical inputs at different wavelengths, enabling the adjustment of the sensor's response without the need for electrical tuning.

Almost the totality of the hardware for the PD interrogator is manufactured, establishing a solid foundation for continued development and integration into optical monitoring systems.

T6.5

Partially implemented

This task, led by AMP with LMK and UVA as participants, was started in M8 as initially scheduled. The task is divided in two subtasks, that are detailed below:

ST 6.5.1

Partially implemented

This subtask started in M8 and will finish in M16, with the delivery of D6.8, that contains three main parts: System Architecture (technical report), Test Plan (technical report), and Proof-of-Concept test setup (demonstrator – prototype)

As the date of reporting (M9), next activities have been done to achieve the expected results:

- Several meetings and technical agreements have been performed to define the detailed architecture and interfaces of the components being part of the enhanced PD analyzer. This also includes the definition of communication protocols between the Interrogator device (that connects to PD sensors developed in T6.4 via Fibre Optic) and the PD acquisition device (that collects the data).
- Conversations have been initiated with a potential subcontractor, that will work in the validation activities, defining the validation tests (Test Plan) in this task, and then performing test and evaluating results in ST6.5.2.
- Desing of the Proof-of-Concept setup and prototype has also been started.

ST 6.5.2

Not implemented

At M9 of the project this subtask has not started. Prototypes are not available yet.

Technical deviations

A minor technical deviation appeared during M1-M9 in T6.4 when compared to the technical specifications set in D3.3, related to the response bandwidth of the PD sensing system:

The limitation stems from the frequency response of a commercial passive component used to convert the current pulses generated by partial discharges into a signal that is subsequently used to modulate the optical system. While the optical system itself is capable of operating up to 2.5 GHz, the internal characteristics of this commercial front-end component limit the effective detection bandwidth to approximately 150 MHz.

This adjustment reflects the practical constraints of commercially available technology and ensures a sufficient output signal level for reliable detection. Since initial PD activity typically concentrates below this frequency range, the 150 MHz limit still supports early and effective detection.

The deviation does not affect the rest of the work packages, as the selected bandwidth aligns with the state of the art in passive PD monitoring. Moreover, this change has been communicated to the TSOs and does not compromise the development or operational goals of the monitoring system.

2.7 Work package 7

T7.1

Partially implemented

As part of WP3 focused on defining the technical specifications of the monitoring system, a questionnaire was distributed to gather input from TSOs. The objective was to identify their operational, cybersecurity, and regulatory requirements, which will directly inform the design and development activities of WP7 concerning the Edge Computing infrastructure.

In parallel with this data collection, a review of key security standards and implementation guidelines has been initiated. This includes the analysis of internationally recognised frameworks to extract relevant principles and requirements applicable to Edge Computing environments.

Based on the outcomes of this research, progress is being made in defining core functionalities to be developed in line with the IEC-62443 cybersecurity standard. These developments will consider both the Barbara Operating System and the Edge orchestration agent, which is responsible for managing and coordinating the deployment of services across distributed Edge nodes.

This foundational work in WP3 ensures that WP7's infrastructure design will not only be aligned with industry needs but will also meet high security and interoperability standards from the outset.

T7.2

Partially implemented

As part of the ongoing tasks within this work package, the Barbara Panel platform is being used as the cloud-based orchestration environment for managing microservices and Edge applications.

The platform enables two main areas of functionality:

- System configuration, including network settings.
- Node management and application deployment, covering the rollout of algorithms, services, and data models across Edge Nodes.

Based on the operational, cybersecurity, and regulatory requirements identified in WP3, this work package is focused on developing orchestration functionalities to support:

- Deployment of applications and communication services.
- Integration of field-level sensor data with TSO information.
- Real-time data acquisition and transmission using appropriate communication protocols.

These developments are essential for feeding real-time data into edge-deployed algorithms and ensuring full interoperability across the Edge computing infrastructure.

Additionally, the team has enabled the deployment of virtual machines both on Edge Nodes and on external servers. This supports operating systems such as Windows and Ubuntu, ensuring compatibility with legacy software used by TSOs and other consortium partners.

Barbara now offers full virtual machine deployment support on Edge Nodes, compatible with the following operating systems:

- Windows XP: Enables continued use of legacy industrial software through modern orchestration.
- Windows 10: Supports seamless execution of current Windows applications on Edge hardware.
- Ubuntu: Provides a stable and scalable Linux environment optimized for Edge computing workloads.

T7.3

Not implemented

At M9 of the project this task has not started

T7.4

Not implemented

At M9 of the project this task has not started

Technical deviations

No deviations have occurred during the period reported.

2.8 Work package 8

This WP has not started at M9 of the project

2.9 Work package 9

T9.1

Implemented

T9.1 was successfully completed with the submission of D9.1 “*Plan for Communication, Dissemination & Exploitation*” in M3 and the achievement of M1 “*DEC & Clustering Plan launch*” in M4 (both on schedule). The task was led by ACE with support from all project partners.

D9.1 is the cornerstone for WP9 and WP10 activities, as it sets the communication, dissemination and exploitation strategy for the project together with a detailed activity plan for the whole execution period. The plan outlined the main objectives and target groups to be addressed; defined suitable communication tools, channels and specific activities to reach them; sets KPIs and measurable target values for impact monitoring; established rules and procedures for internal coordination and suggested a methodology to assess the exploitation potential of the key project results, which were also identified.

T9.2

Partially implemented

Stakeholder engagement efforts have been addressed through three main lines of action:

Engagement through digital channels

A subscription link to the project newsletter is available at the project website. When a new issue is released, it is delivered by email to all the subscribers.

Reactions on project Social Media profiles (mainly LinkedIn and X) like commenting, liking, recommending are also monitored as an input for stakeholders following up the project.

Engagement through participation in sectoral events and conferences

The project team has been very active at international events linked to the project scope, which provided the opportunity to make strategic contacts and connections with key stakeholders, foster networking opportunities and increase the project visibility (*See events listed under section T9.4 "Implementation of the Communication & Dissemination Plan I"*).

Stakeholder Advisory Board (SAB)

The core of the engagement activity is the constitution of a SAB to provide the consortium with expert advice on the technical innovations and market uptake of the project outcomes. The methodology included the following steps:

- Identification and prioritization of key entities. An initial analysis was conducted to identify companies and organisations of strategic interest to the consortium. It was decided to focus primarily on TSOs regarded as end users and directly involved in the implementation of the project results. Target TSOs identified were: Amprion (Germany), TransnetBW (Germany), TenneT (Germany), Redeia (Spain), RTE (France), Elia Group (Belgium) and PSE (Poland).
- Formal contacts and outreach. Connections with the selected TSOs were established, leveraging both the existing networks of the project partners and participation at international events (e.g. meeting with RTE at FOWT 2025 conference in Montpellier, France; meeting with Polskie Sieci Elektroenergetyczne (PSE) at a business mission to

Poland). Additionally, a research organization (TUD, Denmark) and a DSO (EDP, Spain) expressed their interest in joining.

- Confirmation of SAB members. SAB members confirmed upon writing this report are: Amprion, Redeia, TenneT and TUD; Final decision still pending from RTE, TransnetBW and Elia Group.
- Constitution meeting. To be held (online) once all members are confirmed (before M12 in any case) to introduce the project, present the main outcomes from the specification phase, gather initial feedback and recommendations and plan the next steps for the coming months. After that, a face-to-face meeting with the SAB is planned co-located with the next consortium meeting at ENLIT Europe event in Bilbao (Nov 2025).

T9.3

Partially implemented

ACE has designed a wide portfolio of communication and dissemination materials to be used in the activities and events where the project team has been (and will be) involved.

The following items have been produced so far: project logo, graphical layout guidelines, presentation and document templates, overall project presentation, project infographic, website (up and running since M4), social media profiles and posts, press release, roll-up, first newsletter issue, motion graphics video (*work in progress*).

T9.4

Partially implemented

EasyDC-FOS has been already showcased at several high-impact international events, significantly contributing to raising awareness about the project, its objectives and expected outcomes, thus fostering stakeholder engagement.

- Enlit Europe 2024 (Milan, October 2024): EasyDC-FOS was officially disseminated for the first time at the “*Smart Grids Basque Country*” pavilion, coordinated by ACE, reaching a wide audience around the energy transition concept.
- Smart Grids Forum (Bilbao, November 2024): project presentation by LMK (Project Coordinator) at a sectoral event organised by ACE and hosted by Iberdrola, with 68 representatives from 34 companies from the smart grids ecosystem.
- WindEurope 2025 (Copenhagen, April 2025): dissemination at the “*Wind Energy Basque Country*” pavilion, coordinated by ACE. This event provided international exposure and fostered connections with stakeholders in offshore wind and HVDC transmission.
- openLCA.conf 2025 (Berlin, April 2025): event organized by Green Delta (GD) targeted to LCA and sustainability experts. The project environmental assessment approach was highlighted and also GD’s role in developing a regulatory framework for sustainable HVDC technologies.
- IPF Offshore Wind 2025 (Virginia Beach, April 2025): dissemination at the “*Offshore Wind Energy Basque Country*” pavilion, coordinated by ACE, reaching a global audience in the offshore wind sector and strengthening its international positioning and collaboration potential in this field.

T9.5

Partially implemented

In the framework of the Communication, Dissemination, and Exploitation Plan (D9.1), a first draft of a methodological approach for the project exploitation strategy has been developed, including a preliminary roadmap for the valorisation of project results and their potential transfer to the market. A preliminary list of Key Exploitable Results (KERs) has been identified with results that could generate value beyond the consortium, both technologically and in terms of economic and social impact. This initial approach served as a foundation to guide early result-tracking activities and to establish criteria for their prioritisation.

With the aim of strengthening and optimising this strategy, the project intends to leverage the services offered by the European Commission through the Horizon Results Booster (HRB) programme. HRB will significantly contribute to maximising the impact of the project outcomes by providing expert advice, supporting the development of more effective exploitation plans, facilitating the clustering of results with related projects (portfolio dissemination), and offering guidance for market or policy uptake. Specifically, the “Go-to-Market” service will enable a strategic redefinition of the exploitation approach, the identification of key actors for result valorisation, and an increased likelihood of effective adoption of project outcomes by relevant industrial or institutional sectors.

Technical deviations

The formal constitution of the SAB initially planned in M6 (Milestone M3), is taking longer than expected, thus causing a delay on the milestone achievement. This is mainly due to two reasons:

1. The decision made by the consortium to prioritize the TSO member profile to achieve a strong board that can perform a strongly rooted impact on the industry.
2. The internal decision-making processes at the TSOs and the difficulty identifying the appropriate (and available) contact people to get involved in the SAB, which led sometimes to response times much longer than desired.

Fortunately, this delay had no significant impact on the project progress so far, as the partners were engaged on the development of the technical specifications. The SAB constitution meeting will be held online once all pending answers from TSOs are received, and before M12 in any case.

2.10 Work package 10

This WP has not started at M9 of the project

2.11 Timetable

The gantt has not suffered any deviation and therefore it is expected to continue as described in the GA.

3 DEVIATIONS

3.1 DELIVERABLES

No deviations on the deliverables submission have occurred during the period M1-M9 of the project. On February 2025 3 deliverables were submitted with a delay of 3 days in order to finalise the review process. The PO was informed of the delay and granted permission to proceed with the uploading.

3.2 MILESTONES

During the M1-M9 period, 3 milestones are involved. MS1 was achieved without delay, MS2 was checked with a 3 days delay, of which the PO was informed and agreed. The most significant deviation is the delay of the constitution of the SAB, as the consortium has taken this risk to gather a meaningful and truly impactful advisory board composed mostly by TSOs (final end users of the EASYDC-FOS technology), with the intention of expediting the future reach of the solutions to true end-users.

3.3 RISKS

No expected or unexpected risks have occurred during the M1-M9 period. The consortium is constantly monitoring risks evolution as agreed and detailed in D1.1, through constant internal communication and dedicated meetings.

3.4 BUDGET

No significant deviations have occurred during the M1-M9 period on budget expenditure by all partners, nor have any significant deviation in efforts occurred. The consortium will continue to monitor budget VS technical deviations during the next project period.