D7.1: Baseline Analysis Report and 'BD-4-NET' Large Scale Pilots Preparation

WP7 – "BD-4-NET" Large Scale Pilots: Increasing the Efficiency and Reliability of the Electricity Network

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BD4 NRG
Big Data for Next Generation Energy

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Preface

BD4NRG focuses on addressing emerging challenges in big data management for energy sector with an innovative open holistic solution for smart grid-tailored, near real time, energy-specific and AI-based open Big Data Analytics modular framework. The vision is to deliver holistic services for techno-economic optimal management of Electric Power and Energy Systems value chain. Services range from optimal risk assessment for energy efficiency investments planning, to optimized management of grid and non-grid owned assets, improved efficiency, and reliability of electricity networks operation, while at the same time contributing to achieve fair energy prices to the consumers and laying the foundations for an EU-level energy-tailored data sharing economy. The BD4NRG Toolbox will be implemented and validated in real-life pilots in 12 large-scale demo sites across 10 countries for:

- Increasing the efficiency and reliability of the electricity network BD-4-NET
- Optimising the management of assets connected to the grid BD-4-DER
- De-risking investments in energy efficiency and increasing the efficiency and comfort of buildings BD-4-ENEF

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Abbreviation & Acronyms

Acronyms	Description
AMR	Automatic Meter Reading
BO	Business Objectives KPI
CB	Circuit Breakers
DAC	Diagnostics and Analytics Centre
DSO	Distribution System Operator
EI	Horizontal Expected KPI
EV	Electric vehicles
GA	Grant Agreement
HEI	Horizontal Expected Impacts KPI
HV	High voltage
KPI	Key Performance Indicator
LSP	Large Scale Pilots
OHL	Overhead Lines
P	Power
RoW	Right of Ways
REN	Renewable Energy
SCADA	Supervisory Control and Data Acquisition
TSO	Transmission System Operator
UC	Use Case
Vn1	Transformer Primary Voltage
Vn2	Transformer Secondary Voltage
WP	Work Package

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Executive Summary

D7.1 – "Baseline Analysis Report and 'BD-4-NET' Large Scale Pilots Preparation" provides a thorough description of four BD-4-NET pilots (two TSOs and two DSOs) in terms of LSP infrastructure, deployment of BD4NRG Platform and data analytics services implementation, establishing the baseline needed for the KPI calculation. It sets the foundation of the demonstration activities for increasing efficiency and reliability of the electricity network by means of the BD4NRG solutions developed under the project.

Evaluation criteria and KPIs already identified in D6.1 - "Pilot Operation, Engagement and M&V plan" were refined by each BD-4-NET pilot to enable the evaluation and validation of the BD4NRG developments and their utilisation in the specific use cases. General and pilot specific KPIs were thoroughly specified in terms of calculation and assumptions. The general KPIs Baseline was set for the four BD-4-NET LSPs together with the pilot specific KPIs Baseline; in the latter, values of 9 KPIs specific for LSP1 (Portuguese TSO), 4 for LSP2 (Slovenian TSO), 10 for LSP3 (Italian DSO) and 5 for LSP4 (Turkish DSO) were provided.

Moreover, D7.1 "Baseline Analysis Report and 'BD-4-NET' Large Scale Pilots Preparation" depicts a set of scenarios to be run during the demonstration phase based on the Use Cases already identified in D2.1 – "Big Data Value Chain and Requirements" as well as the test-cases to be executed by the end-users. The description of the trial sites and the test-scenarios allows for identification of BD4NRG developments that need to be implemented in the respective LSP and existing technologies that must be interfaced. The required adaptation and customisation of the trial infrastructure have been also considered for the further demonstration activities as well as the procedures needed to personalise BD4NRG in each pilot demonstrator.

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1 Introduction

1.1 Purpose of the document

The main purpose of D7.1 – "Baseline Analysis Report and 'BD-4-NET' Large Scale Pilots Preparation" is to lay the foundations for a smooth real case demonstration of the BD4NRG framework in four LSPs leaded by the electricity network operators (TSOs and DSOs). To reach this goal this deliverable provides a thorough description of the BD-4-NET pilots in terms of LSP infrastructure, deployment of BD4NRG Platform and data analytics services implementation, establishing the baseline needed for the KPI calculation. It sets the foundation of the demonstration activities for increasing efficiency and reliability of electricity network by means of the BD4NRG solutions developed under the project.

D7.1 describes and compiles all the results of the first task of WP7 – ""BD-4-NET" Large Scale Pilots: Increasing the Efficiency and Reliability of the Electricity Network", namely Task 7.1 - Pilots detailed specifications and preparation, which aims to plan the deployment and adoption of the BD4NRG technologies and services based on the current status of the four LSPs located respectively in Portugal (LSP1), Slovenia (LSP2), Italy (LSP3) and Turkey (LSP4). Evaluation criteria and KPIs already identified in D6.1 - "Pilot Operation, Engagement and M&V plan" have been refined to enable the evaluation and validation of the BD4NRG developments and their utilisation in the specific use cases.

To facilitate the preparation of the pilots, two main activities were carried out in this task: the first concerned the definition of the KPI baselines, and the second concerned the implementation of the pilot, consisting of the set-up, the technological integration with the BD4NRG project objectives and the collection and sharing of the dataset. Moreover, the purpose of this deliverable is to identify a set of scenarios to be run during the demonstration phase based on the use cases already identified in D2.1 – "Big Data Value Chain and Requirements" as well as the test-cases to be executed by the end-users. The description of the trial sites and the test-scenarios allows for identification of BD4NRG developments that need to be implemented in the respective LSP and existing technologies that must be interfaced. The required adaptation and customisation of the trial infrastructure have been also considered for the further demonstration activities as well as the procedures needed to personalise BD4NRG in each pilot demonstrator.

1.2 Relation to other documents

D7.1 plays a crucial role within the BD4NRG project, setting the baseline and giving the preparation plan to the four BD-4-NET pilots. It represents also a relevant document for the technology developers analysing the integration of BD4NRG solution with the local infrastructure.

The document gathers the information on the preparatory activities and information needed to start the deployment of BD4NRG tools as well as the trials described in T7.2 – "Integrating off-grid data with Condition based Monitoring for Enhanced Asset Maintenance (LSP1)", T7.3 - "Cross-functional Integration of Grid Operation with Predictive Asset Management (LSP2)", T7.4 - "Cross-Domain Cross-functional Integration of Predictive Asset Management for Grid Operation and coordination with flexible EVs charging (LSP3)" and T7.5 - "Cross-functional Predictive Asset Management for MV Grid Planning (LSP4)".

Besides, D7.1 is the result of a close collaboration and interdependence with WP6 - "Pilot Requirements and Assessment" and in particular with T6.1 - "Pilot planning, requirements and KPIs" and T6.2 - "Pilot monitoring and coordination". In fact, D6.1 - "Pilot Operation, Engagement and M&V plan" gathers together the selected KPIs as well as the main steps for the deployment of the BD4NRG tools in the real-life environment.

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1.3 Structure of the document

This deliverable is organised in five chapters as follows: Chapter 1 introduces the purpose of the document and the relationship with other WPs, tasks and deliverables of the project; in Chapter 2 the baseline is calculated for each pilot, refining KPIs and mapping each KPI against the LSP-specific Use Case; Chapter 3 provides for each BD-4-NET pilot thorough information about the infrastructure used in the trial, the deployment of BD4NRG platform and the data-analytics service implementation on the pilot; finally Chapter 4 draws the main conclusions of the document.

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2 Baseline Analysis

In order to identify the starting points for the demonstration activities planned in WP7 - ""BD-4-NET" Large Scale Pilots: Increasing the Efficiency and Reliability of the Electricity Network" and depict the current situation at the BD4-NET LSPs, a baseline study was carried out in T7.1 – "Pilots detailed specifications and preparation". This analysis was also relevant in terms of KPIs refinement and user scenarios definition.

As shown in Table 1, four LSPs are included in the BD4-NET category, specifically two TSOs (LSP1 and LSP2) and two DSOs (LSP3 and LSP4). As reported in D2.1 – "Big Data Value Chain and Requirements", each LSP will demonstrate one or two use cases as summarised below.

Table 1: BD-4-NET Pilots

BD-4-NET – Stakeholders and Use cases			
LSP	**Main beneficiary**	**Actors**	**Use cases**
LSP1: Integrating off-grid Data with Condition based Monitoring for Enhanced Predictive Asset Maintenance	TSO	Asset Management Division of TSO Protection Engineers	**UC1**: AI methods applied to Condition- based monitoring of Circuit Breakers (CB)
			UC2: Semi-Automatic Maintenance Plan for Right-of-Ways (RoW) in Overhead Lines (OHL)
LSP2: Cross-functional Integration of Grid Operation with Predictive Asset Management	TSO	Internal TSO departments: system operation, system maintenance, asset management DSOs HV-grid connected consumers and producers of electricity	**UC1**: Maintenance Plan Optimisation
LSP3: Cross-Domain Cross-functional Integration of Predictive Asset Management and Grid Operation while coordinating with EVs smart charging	DSO	EV managers; Technical providers; Manufacturers	**UC1**: Efficient management of flexibility resources for supporting grid operation
			UC2: Anticipated prediction of asset failures
LSP4: Cross-functional Predictive Asset Management for MV Grid Planning	DSO	DSO	**UC1**: Predictive maintenance and fault prediction for MV grid and cross functional predictive asset management

In this section, KPIs used by each LSP are presented, providing some definitions already reported in D6.1 - "Pilot Operation, Engagement and M&V plan", but going into more detail in order to refine the method of calculation, the assumptions behind the formula, in order to arrive to the reasonable figures used for the baseline assessment.

As regards the definition of the KPIs, this deliverable is linked to the work described in the D6.1 - "Pilot Operation, Engagement and M&V Plan", taking from it the list, numbering and explanation of the KPIs. In addition, the KPI baseline was calculated by the pilots in this task and showed in this deliverable.

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Contributions were added by the partners in Table 2 and Table 3, provided as templates. In the first table, the partners inserted the baseline of each KPI, showing also the definition, the unit of measurement and the related Use Case.

Table 2: First KPI template table

LSPX – Stakeholder				
KPI	**Definition**	**Unit**	**Baseline**	**Related Use Case**
KPI list, according to what has been done in T6.1	*KPI definition, according to what has been done in T6.1*	*Measurement unit*	*Baseline calculated for the first KPI*	*Use case for which the KPI is used*

The following table presents the process in which the formula calculation methods and the justification has been conducted in order to calculate the baseline value of the KPIs.

Table 3: Second KPI template table

LSPX – KPI Definition			
KPI	**Formula**	**Calculation methods in the pilot**	**Results justification**
KPI list, according to what has been done in T6.1	*Mathematical formulation*	*Method used to calculate the KPI, explaining what the constraints were and what data were used for the calculation*	*Justify the choice of target and the result obtained in the baseline calculation. If necessary, explain why zero was sometimes set as the baseline value.*

2.1 General KPIs

Within WP6 - "Pilot Requirements and Assessment", two types of indicators were defined, the general KPIs, common to all pilots within the BD4NRG project, and those specific to each LSP. General KPIs are indicators deriving from the GA. Table 4 below shows the definition of all General KPIs in the project and values for each pilot, whereas Table 5 presents the baseline value of the General KPIs for each LSP

Table 4: General KPIs definition

KPI	Definition
G01: Seamless and smooth data transition from different types of sensors	The different type of sensors that will be used to collect data.
G02: Seamless and smooth data transition from different types of data resources	The different type of data resources that will transmit data to the BD4NRG platform.

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G03: Resources	The number of resources used from the data sources.
G04: Type of data sources	The number of the different data sources to be used in BD4NRG.
G05: Identification and interoperability with well-known open data sources	The number of open-source data sources that will be used in BD4NRG.
G06: Datasets used	The number of datasets that will be used to develop the analytics services of BD4NRG.
G07: Digital Technologies integrated in the energy system	The number of digital technologies after the development of the analytics services that can be integrated in the energy system.
G08: Big data availability for real life research	The amount of data that will be used overall in BD4NRG.

Table 5: General KPIs baseline

General KPIs Baseline				
KPI	**LSP1**	**LSP2**	**LSP3**	**LSP4**
G01: Seamless and smooth data transition from different types of sensors	4 (Protection, automation and control system sensors, LiDAR inspection data sensors, image sensors of OHL, video sensors of OHL)	3 (operational sensors, sensors for gathering transformer diagnostic data, environmental sensors)	4 (Electrical smart meters, PMUs, environmental conditions sensors, acoustic sensors)	3 (Electrical meters AMR/AMI, power quality analysers, additional SCADA sensors)
G02: Seamless and smooth data transition from different types of data resources	3 (Circuit breaker events, OHL inspection related data, external level data such as satellite images of OHL RoW)	6 (Weather data, operational data, technical data, maintenance information, asset grid layout, external actor data)	7 (Weather, energy sensoring, energy production, energy consumption, charging stations, RES and acoustic sensors)	6 (Fault events, maintenance data, operational data, technical data, electrical grid asset data, energy consumption)
G03: Resources	5 (Voltage and current time series resources, spatial coordinates, temperature and satellite-based resources)	50 (Several type of resources, such as apparent power, active power, reactive power, manufacture year, inspection findings, inspection findings urgency categorisation, maintenance intervals)	6 (humidity, temperature, solar radiation, electricity generation, electricity consumption, noise emissions)	9 (Active and reactive power consumption, voltage, current, rates of transformers and its ages, maintenance and fault records, workforce management records)
G04: Type of data sources	4 (Event based-data of incidents, Point clouds of radar	7 (SCADA data, IBM MAXIMO, Microsoft Dynamics AX, OMT -	8 (secondary substation humidity, secondary substation	6 (Event based data of transformer faults, SCADA data, meter

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	inspection, images and videos of OHL aerial inspections)	Online Monitoring for Transformers, external actor input, PSA – mobile platform for maintenance activities, static outage plans)	temperature, solar irradiance, smart meters, RES production, PMUs, charging stations consumption, acoustic level in secondary substations)	data, power quality analyser data, workforce management system data, maintenance plans)
G05: Identification and interoperability with well-known open data sources	1 (Copernicus database)	0	0	0
G06: Datasets used	2000+ (Datasets regarding each individual incident with several oscillographies stored in COMTRADE format and LiDAR inspections)	120 (Datasets regarding operational sensors, sensors for gathering transformer diagnostic data such as oil and gas measurement and environmental sensors)	172 (Datasets regarding electrical measurements, phasor unit measurements, environmental measurements, audio measurements)	500 (Electrical measurements, Transformer meter data, voltage and current data, power quality data, fault and maintenance records etc.)
G07: Digital technologies integrated in the energy system	0	0	0	0
G08*: Big data availability for real life research	At least 1TB (Mainly from OHL inspections; then few GB are provided from event-based data for circuit breaker event records)	At least 2.3 TB (Which in terms of historical data consists of 4 years of operational data. 30 years of diagnostic data and 15 years of maintenance events data. The rest are static and real time data.)	3.75TB (consisting of 1 years of historical data and two years of real time monitoring. Data are provided mainly by PMUs, 550 GB/year from each of the 2 PMUs, and from smart meters, 1 GB/year from each of the 150 smart meters. The rest of the infrastructure produces negligible amount of data)	200 GB (from power quality analyser and other electrical sensors)

**The data reported in the baseline of KPI G08 concern the internal data that LSPs have available for use. The total amount of data that will be used in the project and provide the evaluation of the KPI G08, will be consisted of additional databases (such as open-source data, weather data), which will complement the LSP data and be reported in later deliverables of WPs 6-7.*

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2.2 Pilot Specific KPIs

The four pilots belonging to BD-4-NET: Large Scale Pilots: Increasing the Efficiency and Reliability of the Electricity Network identified a total of 23 different KPIs. A mapping by indicator type has been represented in the following table. With the acronyms taken from D6.1 – "Pilot Operation Engagement and M&V Plan" and whose description will also be found in the following paragraphs relating to each LSP.

Table 6: BD-4NET KPIs mapping among LSP

BD-4-NET KPIs Mapping					
	Typology	**LSP1**	**LSP2**	**LSP3**	**LSP4**
KPIs related to normal operations	**Grid parameters**	1203 1204 1205	2103	3104 3105 3201	
	Flexibility			3101 3102 3103	
	Operation performance	1201 1202			
KPIs related to special events	**Power outages**		2101 2102 2104	BO1 BO2 BO3	BO2 BO3
	Maintenance			EIO1	4102 4103
	Faults	1101			4101
	Intervention performance	1102 1103 1104			

A distinction is made between indicators relating to normal network operation activities, i.e., continuous operations, and indicators relating to special events, such as faults and maintenance activities. Depending on the objectives and the description of the use cases, each pilot identified the most suitable KPIs and it is noted that 12 KPIs were found that monitor normal operation activities and 14 KPIs related to special events.

Only two KPIs are common between pilots, namely BO2 and BO3, that are SAIDI and SAIFI, both used for LSP3 and LSP4. These were considered as global indicators, common for all BD-4-NET partners, but given the difficulty and lack of usefulness of using these indicators for TSOs, it was decided to adopt them exclusively for DSOs and to use similar, but more appropriate, indicators for TSOs.

The choice of KPIs gives an overview of what the pilots are going to validate. LSP1 mainly analyses activities related to reducing faults in the transmission network in UC 1 and identifying tower characteristics, again for maintenance purposes in UC2. LSP2 aims to reduce power outages and faults at TSO, through a series of maintenance strategies. Since LSP3 is a DSO, UC 1 focused on providing flexibility to the power grid, through tools such as demand response applied to the power grid, while UC 2 is focused on developing predictive maintenance mechanisms to reduce power outages. Finally, LSP4 will focus on increasing the integration of renewables and enhancing grid resilience. In the following sections KPIs specific to each LSP within BD-4-NET cluster are presented.

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2.2.1 LSP1: Integrating off-grid Data with Condition based Monitoring for Enhanced Predictive Asset Maintenance

Due to the ongoing digitalisation of power systems, the amount of data streams and sources available accessible by asset management departments of TSOs has greatly increased over the last years. This data opens up possibilities in novel predictive maintenance practices, based on data analytics and Machine Learning, which can be used to extend the lifetime of assets, optimise O&M costs and to increase the resilience of the electricity transmission system. LSP1 aims to implement these techniques in the context of two UCs, correspondent to two classes of assets: CB and OHL. LSP1 aims then to use ML techniques to define predictive maintenance or condition-based maintenance strategies for these two assets.

CB are critical assets that protect the system by eliminating possible faults and their capacity to eliminate such fault is linked to their operational condition. Thus, we aim to use the BD4NRG framework solution to investigate possible insights about the condition of the assets, by analysing historical data of incidents that occurred in the system and were eliminated by these assets. In this scope, this analysis is performed per circuit breaker (and not following an aggregated approach), which results in the need to identify each circuit breaker and the incidents in which it is involved as the main eliminating asset (i.e, the circuit breaker that eliminated a grid fault by opening the connection and disconnecting the faulty branch).

The second asset to be considered in this pilot are OHL, which are the main elements used to transport energy in the Portuguese Transmission System. The identification of possible obstacles in their RoW and the identification of possible faulty elements in the supporting elements (HV towers) is of extreme importance to the definition of maintenance plans. In this scope, the envisaged solution aims to create a semi-automated software tool to identify/cluster the different types of towers used in REN network, identify possible missing elements (e.g. missing structural element or insulators) and identify new obstacles in RoW. LSP1 is located in Portugal and is led by REN and RDN with UNINOVA, TS and UBIMET as contributing partners. Rede Electrica National (REN) is the TSO of Portugal and operates the HV grid (400 kV, 220 kV and 150 kV), taking care of its design, construction and maintenance. The Centro de investigação em Energia REN - State Grid (R&D NESTER) is a research center that belongs to REN. It focuses on developing innovative solutions for the energy system.

For UC1, the proposed KPIs will assess how well the COMTRADE incident data is analysed and how accurately the implemented system can report and automatically classify each CB tripping incident. Overall, these metrics will ensure that the insights derived from the system, as well as other predictive analytics, are robust and allow for the improvement of maintenance plans, at asset level.

For UC2, the goal is to evaluate how the implemented system uses 3D LiDAR point cloud data, originated from aerial scans, as well as data from other sources, to automatically classify tower models and components and potentially improve the monitoring and maintenance of these assets.

Table 7: LSP1 KPI Baseline values

LSP1 – Stakeholder: R&D Nester / REN				
KPI	**Definition**	**Unit**	**Baseline**	**Related Use Case**
1101: Percentage of switching operations identified	For a given asset, track number of switching operations over time and perform timespan analysis	%	0	UC1
1102: Fault categorisation accuracy	Accuracy in automatic classification of incident type based on COMTRADE file oscillography data.	%	0	UC1

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LSP1 – Stakeholder: R&D Nester / REN				
1103: Incident cause categorisation accuracy	Accuracy in relating CB tripping incidents with external causes.	%	0	UC1
1104: Accuracy of system circuit breaker incident reports	The analysis of CB tripping incidents results in accurate measurements (including faulted current, secondary arc extinguishing time), which are automatically extracted from COMTRADE files.	%	0	UC1
1201: Accuracy of the system identifying the tower type	Tower Types: Waist-type, double-circuit, Guyed-V, Tubular steel pole, Guyed cross-rope suspension, crossings	%	0	UC2
1202: Accuracy identifying the number of structural elements in the tower	Structural elements in the tower: Straight Elements, Main Leg, Diagonal bracing, Horizontal bracing	%	0	UC2
1203: Number of different types of tower and RoW features/entities identified	RoW: It is a legal agreement that allows electric power supplier access to the property directly beneath and to either side of an electric power line. Also called an easement, the RoW allows the supplier to enter the property at any time, to perform maintenance or repairs to our equipment.	#	3	UC2
1204: Meshed ground profile along the RoW	Define soil profile along RoW, in terms of the ground line and the categories of objects detected within it.	%	0	UC2
1205: Vegetation index mass	For each RoW segment, assess vegetation mass existent, for maintenance processes.	%	0	UC2

It is noted that compared to what was written on D6.1 - "Pilot Operation, Engagement and M&V plan", following an analysis on the Pilot and having defined in more detail the UCs, the pilot leaders have decided to remove 2 KPIs, previously named as "1102: Circuit breaker fault clearance time" and "1103: Circuit breaker closing/opening time", as they cannot be evaluated in the pilot and are therefore outside the scope of the UC. Specifically, these two KPIs are related to parameters resulting from the operational conditions of the asset (e.g., closing/opening times) and therefore the envisaged solution in this UC does not provide any possible improvement in these, but only a way of measuring them. This would imply a technical intervention in these assets, which is outside the scope of this pilot. Nonetheless, these parameters are measured and taken into account for the correct fulfilment of the pilot objectives and reported in KPI 1104 of the table above. It was therefore decided to assign the sequential numbers 1102 and 1103 to the subsequent KPIs, thus modifying the numbering of D6.1 - "Pilot Operation, Engagement and M&V plan" as seen in the table above.

The table below shows comments and notes on the calculation of the baseline and the choice of target, explaining in detail how it was calculated, where the data was taken from and justifying the assumptions and assumptions made.

Table 8: LSP1 KPI Baseline explanation

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LSP1 KPI definition			
KPI	**Formula**	**Calculation methods in the pilot**	**Results Justification**
1101: Percentage of switching operations identified	Number of faults detected / Total Faults * 100	Tracking of operation of individual circuit breaker asset over time in historical data	Zero was set as the baseline because without service intervention the baseline would have remained approximately constant, since no automatic solution has been developed in the past.
1102: Fault categorisation accuracy	Fault correctly identified / Total Faults *100	Measure the number of correctly classified incidents with respect to all incidents classified	Zero was set as the baseline because without service intervention the baseline would have remained approximately constant, since no automatic solution has been developed in the past.
1103: Incident cause categorisation accuracy (%)	Faults whose cause was correctly categorized / Total Faults * 100	Measure the number of incidents correctly linked with an external cause (e.g. Fire or lightning storms) in comparison to all incidents analyzed	Zero was set as the baseline because without service intervention the baseline would have remained approximately constant, since no automatic solution has been developed in the past.
1104: Accuracy of system circuit breaker incident reports	Fault information accurately extracted / Total Fault statistics * 100	For each fault statistic computed by the system, assess how well it corresponds to the real values measured by protection engineers	Zero was set as the baseline because without service intervention the baseline would have remained approximately constant, since no automatic solution has been developed in the past.
1201: Accuracy of the system identifying the tower type	OHL tower predicted class / Real tower class * 100	Measure the number of correctly classified overhead line tower models with respect to all towers classified	Zero was set as the baseline because without service intervention the baseline would have remained approximately constant.
1202: Accuracy identifying the number of structural elements in the tower	OHL tower structural elements correctly identified / Total tower elements * 100	Measure the number of correctly classified structural elements with respect to all tower elements identified	Zero was set as the baseline because without service intervention the baseline would have remained approximately constant.
1203: Number of different types of tower and RoW	Sum of RoW features identified	Sum the number of OHL RoW features automatically mapped by the system	The LiDAR services currently employed can provide a consistently accurate classification of approximately 3 features in the point clouds.

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features/entities identified			
1204: Meshed ground profile along the RoW	Ground profile measured / Real ground profile * 100	Validated by analyzing specific RoW segments and the correspondent automatic reports generated and measuring accuracy.	Zero was set as the baseline because without service intervention the baseline would have remained approximately constant, since no automatic solution has been developed in the past.
1205: Vegetation index mass	Vegetation index mass detected in RoW/ Vegetation index existent	Validated by analyzing specific RoW segments vegetation mass and the correspondent automatic reports generated and measuring accuracy.	Zero was set as the baseline because without service intervention the baseline would have remained approximately constant, since no automatic solution has been developed in the past.

UC1 KPIs are focused in the correct identification of faults that can stress the CB and contribute to their overall decrease of performance. In this scope, it is first necessary to identify real incidents from all switching operations present in the dataset (it is possible that different COMTRADE files correspond to a pre-fault condition but without a fault and a switching operation, which should not be considered in this work), which is performed in the first presented KPI. Currently there is no integrated strategy to calculate these values, hence the baseline values are set to zero. As a second step in this UC, it is necessary to identify (categorise) the fault type and extract all necessary parameters (e.g., fault clearance time and open time) to evaluate a possible degradation of the asset performance. This is represented by the other two KPIs in this UC.

UC2 KPIs correspond to two different categories: a first category (first three KPIs) is aimed at enabling the identification and automatic clustering of tower types, allowing to evaluate (in a second step) specific maintenance needs for each type. As this process do not currently exist (and there are three clusters of lines defined manually), the baseline values reflect this situation. In a second category, there is the need to identify possible obstacles (vegetation or other) in the RoW. These is represented by the last two KPIs related to UC2. As currently this activity is performed in a manual way, there is no current information about the baseline and it is still under investigation how these should be reflected in the target value, which will be updated accordingly.

2.2.2 LSP2: Cross-functional Integration of Grid Operation with Predictive Asset Management

Increasing share of renewables in the electricity production mix brings additional dynamics and uncertainties into power system operation, which already deals with stochastic consumption behaviour of the included actors. As a result, transmission power systems are required and expected to be highly flexible, not only on the operational aspect, but also on other related activities such as maintenance planning and associated equipment outages. Similarly, as in operation of the power system, maintenance outage planning is increasingly challenging

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because of transition from traditional time-based maintenance to condition based or predictive type of maintenance.

LSP2 is located in Slovenia, and is assigned to ELES, the Slovenian TSO. The network entrusted to ELES in 2020 consisted of the total 2,918 km of overhead transmission lines, with 30 km of cable conduits. It included also 59 stations, 42 of which were transmission system substations, 1 was a substation, 2 a transformer station, 2 were power supply substations and 12 were 110 kV switching substations at HPP/PSP/TPP.

As such is an important and solid backbone of the Slovenian electric power industry and a guardian of the Slovenian electric power system.

It interconnects all the main actors in the Slovenian electric power transmission network:

- Power plants providing electric power for the transmission network.
- Five distribution companies.
- Five larger consumers, the so-called direct customers, who offtake electricity from the transmission network, and four larger consumers with the status of a closed distribution system.

University of Ljubljana (UNILJ) is the oldest public higher education and scientific research and artistic organisation in Slovenia. At the Faculty of Electrical Engineering, University of Ljubljana, the research scope, and activities in Laboratory for Energy Policy (LEST) is involved in project activities. Laboratory is focused on challenges and issues connected to power system planning, operation and control as well as the energy policy development and electricity market control and regulation. Key research activities are focused on long-term security of supply forecasting, asset management in generation and transmission, forecasting the availability of renewable sources and support policies and power system economics.

The LSP2 demonstrates the transition within ELES the Slovenian TSO regarding the maintenance outage plan scheduling of the 400 kV, 220 kV and 110 kV transmission grid in Slovenia.

Existing maintenance outage planning is traditionally performed manually by the responsible planner. This also means that the signals from various internal or external actors are taken into account to a small extent, while automation, historic and predictive data are not fully utilised for preparing a cross-sector optimised maintenance plan. Traditionally, the planning process follows well established schedules, based on proven timelines and past intervals while considering operational security (N-1 criteria) and equipment type. Condition-based optimisation is used only to limited extent. In reference to system operation, the term maintenance planning usually considers equipment outage for maintenance purposes. The primary objective of the LSP2 is to develop a decision support tool for the TSO to assist in optimal scheduling process. It will serve as a guiding tool for the experienced planners within company and will bring:

- Reduction of the needed working hours for outage planner to create the maintenance outage plan.
- Improvement of established way of maintenance planning taking into account the wider data sets which will be processed in multi-criteria optimisation process.
- Scheduling tool will use data-driven descriptive and predictive analytics, based on the available data of the TSOs data centres. The developed methods could further be used for maintenance planning, where optimisation of the maintenance outage plan would be based not only on big data, available today, but also includes additional external parameters from several sources with new constraints and criterion algorithms. A coordinated plan will be prepared on a network-level for the considered transmission network elements, namely transformers and power lines.

The TSO will enhance its operation and maintenance planning of the network with the tool that will provide more analytical planning approach, where planning itself will be more flexible and digitalised. It will consider wider range of influencing parameters, increasingly involve available data of the assets, included in criteria functions, while reducing the effort for producing the maintenance outage plan. Reversible analytics and better process

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understanding can be used to trigger planning for purchasing equipment with higher capabilities than typically needed with a view to determine how timing of the predictive asset maintenance timing may linearly affect TSO grid operational capability and power market transaction prediction, and how predictive models for grid asset's maintenance may be affected by grid planning decisions. This complex and multidimensional challenge will also support TSO ambition towards fewer maintenance-related outages, reduced outage duration, better outage utilisation for maintenance purposes, increased system reliability, easier and faster outage rescheduling, better coordination with outside partners, possibility of dealing with more complex outages and therefore operation of the power system closer to the operational limits.

In the tables below the LSP2 KPIs are presented with baseline values during the LSP2 activities. Following the tables, a background for the values is described.

Table 9: LSP2 KPI Baseline values

LSP2 – Stakeholder: ELES				
KPI	**Definition**	**Unit**	**Baseline**	**Related Use Case**
2101: Planned outage duration	Total annual planned outage duration in hours.	hours/year	23,863.55 h/year	UC1
2102: Number of planned outages	The system total annual number of planned outages.	number/year	1,086/year	UC1
2103: AHI level (per asset and per fleet)	Asset health index.	-	78	UC1
2104: Faster maintenance outage plan proposal and optimisation	Person-hours needed for producing maintenance outage plan proposal.	Hours or days	128 h	UC1

The table below shows comments and notes on the calculation of the baseline and the choice of target, explaining in detail how it was calculated, where the data was taken from and justifying the assumptions and assumptions made.

Table 10: LSP2 KPI Baseline explanation

LSP2 – KPI Definition			
KPI	**Formula**	**Calculation methods in the pilot**	**Results justification**
2101: Planned outage duration	Total annual planned outage duration in hours.	There are several planned outages on lines and transformers. Each outage has a defined duration. This KPI gives information about sum of all planned outage durations of each the assets on an annual level.	

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LSP2 – KPI Definition			
2102: Number of planned outages	Number of planned outages.	Total number of planned outages on an annual yearly level.	With maintenance optimisation, UC1 aims to achieve with maintenance optimisation fewer outages due to combined maintenance activities on a broader sector.
2103: AHI level (per asset and per fleet)	Asset health index formula is complex and different for different asset types.	AHI value evaluates condition of the asset on multiple aspects, where the asset is evaluated both as a whole and on an individual component level. Asset health index is an aggregate score for the health of an asset and is calculated from the historical performance of the asset and the actual measured physical condition. The higher the value for the AHI, the less likely the asset will fail. Example factors that are used to calculate the health index are age, diagnostics measurements, etc. The AHI returns values in the range 0 to 100 where 100 is as new condition and 0 is very poor condition.	AHI values of the grid asset will be monitored during LSP2 to ensure that maintenance optimisation will not have negative impact on the asset.
2104: Faster maintenance outage plan proposal and optimisation	Time evaluation of maintenance outage plan proposal and optimisation process	Sum of the person-hours needed for producing annnual maintenance outage plan proposal.	UC1 aims to reduce the working hours needed

The values for Planned outage duration and Number of planned outages are based on of the annual operations report for lines and transformers in 2020 [1].

AHI KPI is proposed for the quality monitoring while performing the defined UC. With maintaining AHI values at the similar levels, we are proving that maintenance optimisation UC does not worsen the asset condition, which is evaluated through AHI. Formula for the Asset health index (AHI) is complex and unique for each asset type [2, 3, 4]. The AHI index calculation method is implemented for the following elements of substation: power transformer, circuit breakers, instrument transformer, disconnector, GIS circuit breaker, arrester and busbars. Asset Health Index (AHI) is applied as a method of managing assets and ranking of the TSO grid assets. It provides information about the equipment condition, level of weariness and aging process of the unit and status of the individual components of the assets. Through AHI the asset is evaluated based on field operation observations, field diagnostic and inspections together with laboratory testing. Based on the AHI evaluation, a managing strategy is prepared and more importantly, prioritised maintenance and investments plan are made.

The assets are evaluated based on the condition of individual components, stress tests and other aspects. Each aspect or parameter is numerically evaluated within defined range and weighted based on the importance of the parameter. The evaluated aspects, for example, of the power delivery transformer contains:

- Insulation resistance
- Visual appearance(inspection) of the oil tank, radiators, fans, bushing and other parts
- Infrared thermography DGA – Dissolved gas analysis

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- Oil quality tests, dissipation factor and capacitance measurements
- Tap changer stress test and inspection of oil, contact resistances, currents, etc.
- Bushing tests
- Excitation current measurements, core to ground measurements
- Turns ration test, winding resistance measurements, leakage reactance test
- Furan analysis, partial discharge measurement

Once the individual parameters are graded, the overall AHI can be calculated with following formula:

Equation 1: Asset health index formula

$$AHI = \frac{\sum_{j=1}^{i} S_j * W_j}{S_{Max} \sum_{j=1}^{i} W_j}$$

Where: AHI is the Asset health Index; J is the number of input parameters; S_j is the Score of the j-th parameter; W_j is the Weighted factor of the j-th parameter and S_{max} is the Highest Score parameter

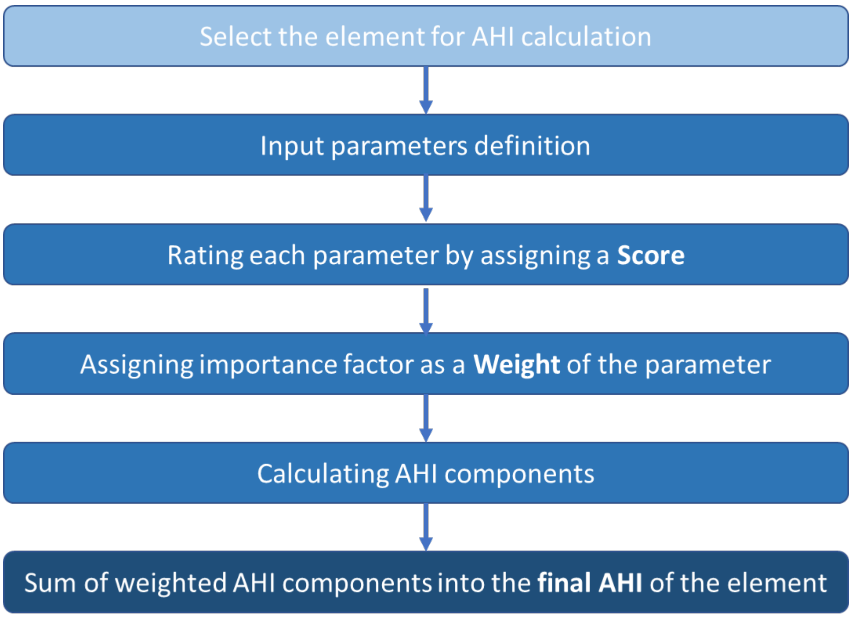

Figure 1: AHI calculation steps

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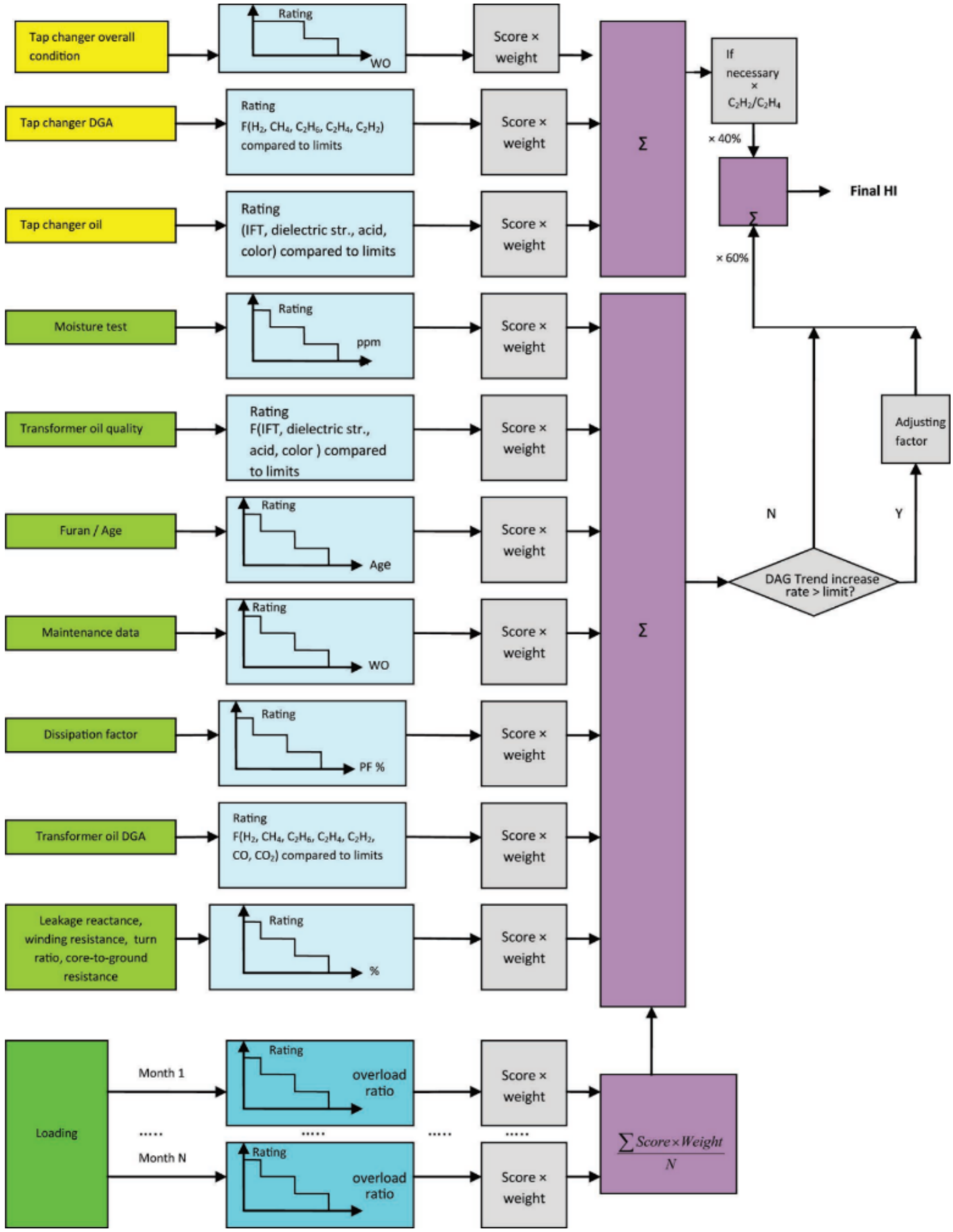

Figure 2: General AHI Model, proposed by Kinectics

AHI is an aggregate score for the health of an asset and is calculated from the historical performance of the asset and the measured physical condition. The higher the value for the AHI, the less likely the asset will fail. Example factors that are used to calculate the heath index are age, diagnostics measurements, etc. The AHI returns values in the range 0 to 100 where 100 is as new condition and 0 is very poor condition. For calculating AHI KPI we are going to consider only power transformers. The power transformers were chosen due to their importance and data availability, to test the proof of concept of asset management/maintenance planning methodology/process

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that can later be extended to other assets like power lines, CBs, etc. During the pilot the AHI calculation might also be upgraded with inclusion of new data or other findings of the project. Fleet AHI is calculated as an average AHI of all assets.

Due to the nature of Faster maintenance outage plan proposal and optimisation KPI it is very hard to get objective value. The stated value is based on expert opinion/judgement as currently we can only estimate the time needed time currently required for preparation of the maintenance outage plan proposal. With developed tool we will try to shorten it, but even methodological simplification and standardisation of the process will be a great improvement. It is estimated that today 128 hours in different organisational units are needed for preparing the annual maintenance outage plan, including numerous meetings that are held for preparation, supervision, external coordination, etc.

2.2.3 LSP3: Cross-Domain Cross-functional Integration of Predictive Asset Management and Grid Operation while coordinating with EVs smart charging

Over the last few years, the electricity grid has been subjected to increasing challenges due to the changing energy scenario on the one hand and the quest for greater resilience and reliability on the other. The energy strategies of the European countries foresee a high percentage of production from RES, which has a reduced impact on the environment and is extremely less polluting, but it is more complicated to manage and the availability in some cases is not-programmable.

From the DSO's point of view, this creates a number of grid management problems, as there are and will be more and more reverse power flow, leading to difficulties in managing the system and protections, and increasing power losses in the grid. At the same time, the electricity grid is affected to an increase in load, in particular due to the spread of EVs, which constitute an extremely important load for the grid, especially in large numbers. Over the last few years, both in the literature and in the experimental field, some discussions aroused about the demand response applied to EVs, acting on consumption and making it simultaneous with renewable generation. A further challenge for electricity grids, especially in developed countries, is the ageing of the infrastructure and the search for greater resilience to guarantee customers an optimal service. New strategies for maintaining network components are being tested, to minimise disruptions and also withstand increasingly frequent accidents (due to climate change, among other things). This is referred to as predictive maintenance, a maintenance strategy that involves replacing components when it is estimated that a fault is about to occur, based on data collected by sensors and using specific software.

The activities of Pilot 3, which is located in Terni and managed by ASM Terni and Emotion, address this challenging environment. ASM Terni is a multi-utility operating in the municipality of Terni and carries out various services such as water network management, environmental services, gas network management and assumes the role of distribution system operator (DSO) of the electricity network. Emotion is a charging station manufacturer and an electric mobility services provider, responsible for Terni pilot charging stations and EV fleet deployment, monitoring and management.

LSP3 is composed of two Use Cases, UC1: "Efficient management of flexibility resources for supporting grid operation", managed in collaboration between ASM, which plays the role of DSO, and Emotion, which plays the role of eMobility manager, and UC2: "Anticipated prediction of asset failures", carried out exclusively by ASM Terni as DSO. UC1 validates the tools developed by the project for demand response strategies applied to EVs, in order to guarantee benefits to the electricity grid, by reducing overcurrent, reverse power flow and increasing self-consumption of the distribution grid and the penetration rate of renewables The demand response

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mechanism applied to EVs will be realised taking into account the constant measurement of network parameters through distributed smart meters, forecasting of weather data and forecasting of electric vehicle consumption.

The ambitious aim of UC2 is to implement a predictive maintenance programme for electrical transformers, based on a large amount of data from various substations, which is then correlated by the technical partners to find a correlation between the data collected and the degradation of the machine, i.e., the presence of faults. Once the correlation has been found, predictive maintenance can be carried out on the transformer. The sensors used for this purpose are of different types, ranging from electrical sensors that measure current and voltage, environmental sensors for temperature and humidity, and acoustic sensors, which measure the noise level emitted by transformers. The aim of this trial is to find predictive maintenance strategies, thereby increasing the lifespan of transformers, reducing maintenance costs, increasing network resilience and minimising power outages for end customers.

The following table shows the KPIs identified for the two LSP3 use cases, showing the description, the measurement unit and the baseline value.

Table 11: LSP3 KPI Baseline values

LSP3 – Stakeholder: ASM				
KPI	**Definition**	**Unit**	**Baseline**	**Related Use Case**
3101: Reverse power flow	Reverse power flow energy of the distribution grid	GWh	24.9 GWh	UC 1
3102: Amount of flexibility energy exchanged	This indicator evaluates the energy that is shifted over time due to flexibility services (called flexibility energy), with respect to the total amount of energy exchanged.	%	0 %	UC 1
3103: Number of customers included in the local flexibility mechanism	Number of customers included in the local flexibility mechanism	#Customers	0	UC 1
3104: Self-consumption	Self-consumption ratio is a metric used for quantifying the amount of energy produced and consumed locally relative to the total production that is locally available from on-site generation units.	%	65 %	UC 1
3105: Power losses in the distribution grid	Indicator for the optimisation of the grid operation	%	4.50 %	UC 1
BO1: CAIDI	The Consumer Average Interruption Duration Index (CAIDI): Average interruption time per consumer affected by the interruption per year	Min/(customers *year)	20 min/(customers*years)	UC 2
BO2: SAIDI	The System Average Interruption Duration Index (SAIDI): the average time of interruptions per consumer per year	Min/(customers*year)	35 minutes/(customers*year)	UC 2

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LSP3 – Stakeholder: ASM				
BO3: SAIFI	The System Average Interruption Frequency Index (SAIFI): the number of interruptions per consumer per year	# interruption s/(customer s*year)	1.75 # interruption s/(customer *year)	UC 2
EIO1: Cost for asset maintenance and management reduc tion	The average annual cost that is spent on asset maintenance and management	€ / year	0 €/year	UC 2
3201: Asset lifetime	Asset lifetime	year	60 years	UC 2

Table 12 shows comments and notes on the calculation of the baseline and the choice of target, explaining in detail how it was calculated, where the data was taken from and justifying the assumptions and assumptions made.

Table 12: LSP3 KPI Baseline explanation

LSP3 – KPI Definition			
KPI	**Formula**	**Calculation methods in the pilot**	**Results justification**
3101: Reverse power flow	Sum of all the energy injected from the DSO to the National grid in primary substations	Annual reverse-flow energy calculated from the three primary substations of the distribution grid in 2020	This value takes into account all the reverse power flow energy of the entire distribution network, whereas the pilot will only focus on a portion of it, the specific value of which is not known. Appropriate scaling factors should be adopted.
3102: Amount of flexibility energy exchanged	100 * [Flexibility_energy / Total _energy_consumption]	The amount of flexible energy is the amount of energy that, being programmed to be used at a certain time, is shifted in time to meet demand response mechanisms, it's evaluated as the sum of energy used during demand response interventions over the total energy consumption in percentage	Zero was set as the baseline because without service intervention the baseline would have remained zero.
3103: Number of customers included in the local flexibility mechanism	#Customers engaged	It's the sum of customers engaged in demand response mechanism	Zero was set as the baseline because without service intervention the baseline would have remained zero
3104: Self-consumption	100 * (energy produced by on-site generation - energy injected in the distribution grid) / energy produced by on-site generation	The percentage of self-consumption was calculated in the tested area by taking into account the values provided by the energy meters of the secondary substations.	This baseline value refers to 2020 data

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LSP3 – KPI Definition			
3105: Power losses in the distribution grid	100*(1 – (energy consumed by all users) / (energy injected in the distribution grid from local power plants + energy injected in the distribution grid from national grid))	Energy losses in main conductors, mainly due to the Joule effect. It was obtained by 2020 data of the whole distribution grid	This value takes into account all the power losses of the entire distribution network, whereas the pilot will only focus on a portion of it, the specific value of which is not known. Appropriate scaling factors should be adopted.
BO1: CAIDI	CAIDI = SAIDI / SAIFI	The CAIDI was evaluated according to distribution grid data referring to 2020	This value takes into account all the whole DSO, whereas the pilot will only focus on a portion of it, the specific value of which is not known. Appropriate scaling factors should be adopted.
BO2: SAIDI	(Sum of all customer interruption durations) / (total number of customers served*year)	The SAIDI was evaluated according to distribution grid data referring to 2020	This value takes into account all the whole DSO, whereas the pilot will only focus on a portion of it, the specific value of which is not known. Appropriate scaling factors should be adopted.
BO3: SAIFI	(number of customer interruptions) / (number of customers served * year)	The SAIFI was evaluated according to distribution grid data referring to 2020	This value takes into account all the whole DSO, whereas the pilot will only focus on a portion of it, the specific value of which is not known. Appropriate scaling factors should be adopted.
EIO1: Cost for asset maintenance and management reduction	previous cost spent on outages and transformer maintenance - subsequent cost spent on outages and transformer maintenance	The measurement of maintenance costs is carried out through the analysis of historical invoices	Zero was set as the baseline because without service intervention the baseline would have remained approximately constant.
3201: Asset lifetime	-	This value represents the expected life of transformers and will be evaluated thought Arrhenius aging law.	Current average transformer life duration has been selected as baseline.

The calculation of the baseline has been carried out considering the historical data of the DSO, in UC1 it was decided to use KPIs strictly linked to flexibility, while for UC2 KPIs linked to the duration of power outages and related to maintenance were used.

As regards the SAIDI, SAIFI and CAIDI indicators, it is noted that ASM's distribution network already has high quality standards, so it was decided not to go beyond a 20% reduction in the current value. The same is true for self-consumption, which already assumes values of around 65% and a growth of 5% has been assumed as an effect of the technologies implemented in the project. The services introduced in these UCs and not yet used within the network have a baseline value of 0.

Finally, it should be noted that some parameters have been taken for the whole network and not only limited to the portion of the network under analysis in this pilot, as it is difficult to separate the effects on a single portion of the network from those made to the whole network.

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2.2.4 LSP4: Cross-functional Predictive Asset Management for MV Grid Planning

Nowadays for distribution companies the number of customers and energy demand are increasing day by day. The increased use of distributed generation sources, such as photovoltaics, is causing greater complexity in grid management, with power quality problems occurring more frequently. Thus, there is a need for optimal network operations and also a need for professional maintenance & asset management in order to reduce faults due to reasons mentioned before. As the digitalisation in distribution grids increases, the monitorability of the system also increases, which creates a large data pool. This is a situation that can be beneficial in preventing or predicting some problems in the distribution system. Having a data driven predictive maintenance process is more beneficial than having traditional inefficient methods. With these methods, maintenance processes become more professional, preventing of faults will increase customer satisfaction and also reduce supply interruptions. This will have also huge benefits from an economic and financial point of view reducing costs associated with maintenance. Through analytic approaches, investment planning will be more accurate.

LSP4 is located in Turkey and is managed by Osmangazi Electric Distribution Co. (OEDAS), the biggest Distribution Company in the country. It has 1.7 million of customers and has interests in various sectors, such as traditional and renewable generation plants, EVs, electric storage and smart cities.

Use case will be demonstrated through the implementation of maintenance and fault prediction operations. With predictive maintenance results, maintenance processes will become more professional and efficient and also with optimised maintenance and fault predictions, it is expected to have less MV faults on grid. The most suitable KPIs for demonstrating this UC are in the LSP4 opinion SAIDI&SAIFI, the reduction of faults, the productive maintenance/preventing unnecessary maintenance and last the number of components in replacements. Necessary datasets will be defined previously and according to data sets, historical and near real-time data gathering processes will be done with the MV equipment's on field.

Table 13: LSP4 KPI Baseline values

LSP4 – Stakeholder: ODEAS				
KPI	**Definition**	**Unit**	**Baseline**	**Related Use Case**
BO2: SAIDI	The System Average Interruption Duration Index (SAIDI): the number of interruptions per consumer per year	Min/customers*year	583.24 Min/customers*year	UC 1
BO3: SAIFI	The System Average Interruption Frequency Index (SAIFI): the average time of interruptions per consumer per year	Min/customers*year	5.21 Min/customers*year	UC 1
4101: Reduction of faults	Measuring the reduction of faults occurrence (inverters, cells, SF6 sensors etc.) after predictive fault monitoring is implemented	#faults/year - %	100%	UC 1
4102: Productive maintenance/preventing unnecessary maintenance	Measure the change in the number of maintenance interventions (e.g., cleaning, plant system resetting, string repairing, electric board) after predictive maintenance is implemented	#interventions/year - %	0%	UC 1
4103: Number of components replacements	Measure the reduction in components replacements (e.g., inverters, SF6 cells, etc.) after predictive fault monitoring is implemented	#components replaced/year - %	100%	UC 1

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The table below shows comments and notes on the calculation of the baseline and the choice of target, explaining in detail how it was calculated, where the data was taken from and justifying the assumptions and assumptions made.

Table 14: LSP4 KPI Baseline explanation

LSP4 – KPI Definition			
KPI	**Formula**	**Calculation methods in the pilot**	**Results justification**
BO2: SAIDI	number of interruptions/ numbers of all customers/year	Instead of the current SAIDI data calculated as a single value which is covering the entire distribution region, SAIDI data will be calculated again with some assumptions for the selected region.	With the outcomes of predictive maintenance activities, use case aims to reduce the number of faults and in this directive SAIDI index will also reduce. Comparison of SAIDI indexes(before&after) will be carried out for pilot network
BO3: SAIFI	duration of interruptions (min)/ number of all customers/year	Instead of the current SAIFI data calculated as a single value which is covering the entire distribution region, SAIFI data will be calculated again with some assumptions for the selected region.	With the outcomes of predictive maintenance activities, use case aims to reduce the number of faults and in this directive SAIFI index will also reduce. Comparison of SAIDI indexes(before&after) will be carried out for pilot network
4101: Reduction of faults	Calculate the total number of faults before and after implementing the services. The formula is: (1 - (Faults_After/Faults_Before))*100	It's referring the reduction of faults (especially for transformers) which occur in selected distribution network.	With the aim of fault prediction activities, it is planned to have less faults for selected network assets.
4102: Productive maintenance/preventing unnecessary maintenance	Calculate the total number of maintenance interventions before and after implementing the services. The formula is: (1 - (Interval_After/Interval_Before)) *100	It's referring the changing of total number of maintenance activities which is done in the selected region.	With the successful outcomes of predictive maintenance activities, it will be aimed to prevent unnecessary maintenance activities.The rate of this change will be tracked.
4103: Number of components replacements	Calculate the total number of components replacements before and after implementing the services. The formula is: (1 - (Replacement_After/Replacement_Before))*100	Total number of component/equipment replacement causing from fault events and maintenance outcomes for selected network will be collected.	With the successful outcomes of predictive maintenance and fault prediction, number of component replacements are aiming to be reduced and total numbers for before and after the demonstration of use case will be compared.

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3 Pilot Preparation

3.1 Approach step-by-step

Pilot preparation activities started already with the proposal in the pre-project phase and became increasingly clear and defined as the initial project tasks progressed. Each pilot proceeded both individually and within the common tasks in defining the characteristics of the pilot and practically preparing the suitable environment for experimentation. Among the other tasks, special reference is made to T2.1, where scenarios, use cases and requirements were defined for each pilot, and T6.1, where KPIs were set and a target was also set, as well as deciding in more detail the characteristics of each pilot.

At this moment, the tasks (T7.2, T7.3, T7.4 and T7.5) related to the pilots have not yet started, but the preparatory activities are almost completed, i.e., the infrastructure to be used has been chosen and identified, the type and quantity of data that will be collected and shared has been identified, and the KPIs have been set, the baseline has been calculated and the targets have been chosen. The pilots have identified which services they intend to validate in their LSPs, and collaboration with technical partners is underway to discuss these trials.

In the following we show the preparatory activities carried out by each pilot leader are expressed, divided into three types of interventions represented by three sub-sections.

- **The infrastructure**: it is explained in detail how the existing and planned infrastructure is composed, showing photos and pictures.
- **Deployment of BD4NRG Platform:** all the activities carried out in order to align the activities of the pilot with the tools carried out in the project are reported, such as the required services, the research areas and the customisation methods of the pilot.
- **Data-analytics service implementation**: it is shown which are the types of data collected, how they are to be managed and which are the analyses to be carried out with them, such as the scenarios that are going to be simulated and the test cases that are going to be used.

To collect this information pilots were asked to provide detailed data regarding the pilot's readiness obtained from the experience of the activities carried out, with the support also of what was done within the "Pilot Infrastructure Templates" and the "Data Analytics services Templates", shown in the appendix of D6.1.

In the paragraph "Data-Analysis service implementation" the test cases and the procedures to be followed in the experimentation are described. For reasons of uniformity and to facilitate the work of the partners, it was decided to use the following table as a template, to be filled in for each scenario to be tested. Inside each row there are described the contributions that are expected to be included.

Table 15: Scenario description template

Scenario Category	Description
Scenario Name	*Insert the name of the scenario*
Related UC	*Insert the name of the UC in which the scenario is included*
Data sources	*List all data sources used in this scenario*
Test cases description	*Enumerate the number of test cases you intend to study within this scenario and describe what they look like*
Assumptions	*What assumptions are made on the basis of the literature and the test case setting*
Tests object	*Describe the objectives of the test cases*

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Scenario Category	Description
Test procedures	*Describe step by step the procedures to be followed in order to carry out the experiment.*
Scenario success	*Write down the conditions under which the scenario can be considered successfully concluded (also refer to KPIs)*
Scenario requirements	*Report the requirements of the scenario, also referring to D2.1*
Replicability	*Describe to what extent the scenario is replicable and under what conditions*

3.2 LSP1: Integrating off-grid Data with Condition based Monitoring for Enhanced Predictive Asset Maintenance

3.2.1 Infrastructure

LSP1 focus on the application of data analytics to contribute to the current asset management strategies in the TSO environment. For this purpose, two critical assets were selected: CBs and OHL. RDN and REN will resort to data existing from REN infrastructures to create all necessary solutions, by selecting a representative set of data from heterogeneous sources.

REN owns and operates more than 80 substations and/or switching stations, with a total number of CBs close to 1500 (in operation). CBs are automatically operated assets designed to protect transmission system from damaged caused from short circuits or overloads, by breaking the flow of current. REN infrastructure contributing to the pilot execution includes a full set of event based COMTRADE files from reported faults in a period of up to 10 years, recorded by circuit breaker protection systems spread across the network.

Figure 1: Example of a circuit breaker

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With respect to the REN network, it is operated in three different voltage levels (400 kV, 220 kV and 150 kV), with a total line length of more than 9000 km - a vast majority of these represent OHL. In this context, a representative dataset will be used in order to demonstrate the applicability of the designed solutions. The dataset will be composed by aerial LiDAR scans of RoW corridors across the entire network, as well as the transmission towers themselves.

3.2.2 Deployment of BD4NRG Platform

The solutions to be developed in LSP1 follow the methodological approach and conceptual definitions of BD4NRG, employing big data related techniques to develop dedicated software tools for asset management purposes, improving current operation processes in an industrial player, the TSO.

An analytical methodology has been already put in place aiming at identifying all relevant data sets, the possible algorithmic solutions to solve the considered problem and its implementation/validation, including the creation of user-friendly reports.

The two envisaged technical solutions will be deployed locally and consider as main stakeholders internal REN teams as the System Operator and Asset Management departments. Namely:

- Automatic fault analysis and asset level predictive maintenance services: a set of software modules will be deployed in order to automatically generate on-event incident reports with key fault statistics (e.g. asset response times, fault classification and characterisation) based on state-of-the-art data science solutions. In addition, an analytics service will be deployed on top of this data in order to generate predictive maintenance insights at asset level based on the timespan analysis of response times and breakage effort performed by each asset. This set of modules will correspond to the predictive maintenance of CBs service component of the pilot
- Predictive maintenance of OHL: software modules designed to monitor and derive maintenance plans of overhead line infrastructures, based on RoW corridor and transmission tower LiDAR scan point cloud data. The datasets will be ingested, pre-processed, segmented and classified using computer vision based techniques. The implementation of these segmentation and classification will be done in order to detect tower models, identify structure and missing components on OHL and identify vegetation and obstacles within the corridors – all of which to be used as inputs to condition and predictive maintenance processes. These modules will correspond to the monitorisation and predictive maintenance of OHL service component of the pilot.

Achieved results by these services will contribute to the development of asset management processes using two different levels of magnitude: i) direct verification of current health and maintenance status of involved assets (OHL and CBs) and ii) definition of new predictive maintenance strategies which are a direct outcome of BD4NRG project.

3.2.3 Data-analytics services implementation

In order to execute this pilot, different sets of data from REN operation systems need to be gathered. Datasets are heterogeneous and come from different operational units (e.g. system operation and asset management). In order to allow REN and RDN teams involved in BD4NRG to have access to the required files, a single database will be created including all relevant data to cover the objectives of LSP1.

Data is gathered from the different operational units and internal processes of REN using a continuous methodological approach, ensuring that all sets of data are available for the execution of the pilot. This process

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is required as the required data consists of heterogeneous sources and formats (e.g. operational data as device level COMTRADE incident files or asset inspection data such as OHL inspection LiDAR point cloud data).

For the purpose of the envisaged predictive asset management strategies, all technical related solutions will be developed using Python programming language and all relevant libraries compatible with Python. The developed solutions will be deployed in a local server and external partners will have access to developed solutions through a REST API. Due to confidentiality issues, data belonging to REN will not be shared.

The implementation phase of LSP1 will contain a set of test scenarios, which describe the different usage alternatives of the developed services, mainly to TSO actors (e.g. asset managers and system operators) and other energy network end-users.

With respect to Use Case 1, several circuit breaker tripping incident scenarios will be taken into account throughout the development of the system services, reflected by the historical data available from REN own databases. Namely, the developed tool will be used to automatically fault typology and generate reports on key fault analysis metrics to asset managers (e.g. fault clearance time, I2T, maximum fault current). The tests for UC1 will ensure the system supports different types and formats of fault COMTRADE files, and accurately classifies them – as described in the KPIs. Furthermore, additional data analytics services will be developed downstream, using the automatically generated data attributes in order to derive suitable predictive/condition based monitoring strategies at asset level.

Table 16: Scenario description - Automatic fault analysis and asset state tracking

Scenario Category	Description
Scenario Name	Automatic fault analysis and asset state tracking
Related UC	UC1: AI methods applied to condition monitoring of circuit breakers
Data sources	COMTRADE recorded incident circuit breaker data from Portuguese TSO
Test cases description	○ System is able to read COMTRADE files in different formats (e.g. binary or ASCII) ○ System is capable of detecting and classifying different types of faults ○ Track reporting statistics from actuations of same asset across time ○ Generate predictive analysis of asset state
Assumptions	Data requirements: sufficient amount of COMTRADE format conformant data, with high variability of incident types and oscillographies
Test object	The objective of test cases is to assess if the system is able to correctly analyze and report incident data at asset level and hence fulfill the predictive maintenance oriented goals.
Test procedures	○ Parse several incident records in COMTRADE data and check for validity of outputs ○ For each incident/fault oscillography, performing detection, segmentation and classification of faults. Validate results

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Scenario Category	Description
	○ Generate automatic report with different incident statistics (e.g. maximum fault current, CB actuation time) ○ Use historic incident data to generate asset level predictions of key reporting statistics. Check accuracy and validity of results
Scenario success	The system is able to correctly perform the tasks described above, and the classification and prediction tasks yield results above the desired accuracy threshold described in the KPIs.
Scenario requirements	This scenario requires representative set of COMTRADE data and operational software modules – available through an API.
Replicability	This scenario is replicable, under the conditions above.

For Use Case 2, LiDAR scan data of overhead line corridors and towers from REN will be used to develop a ML based point cloud classification system. These aerial scans make up large amounts of data that must be automatically parsed and preprocessed before they can be effectively used as training data, which must be taken into account in the implementation and test process. The system will be used to group and identify tower models existent in the field by end-users and additionally to assess their condition by identifying and segmenting their components (e.g. cable, shield wires, insulators if possible).

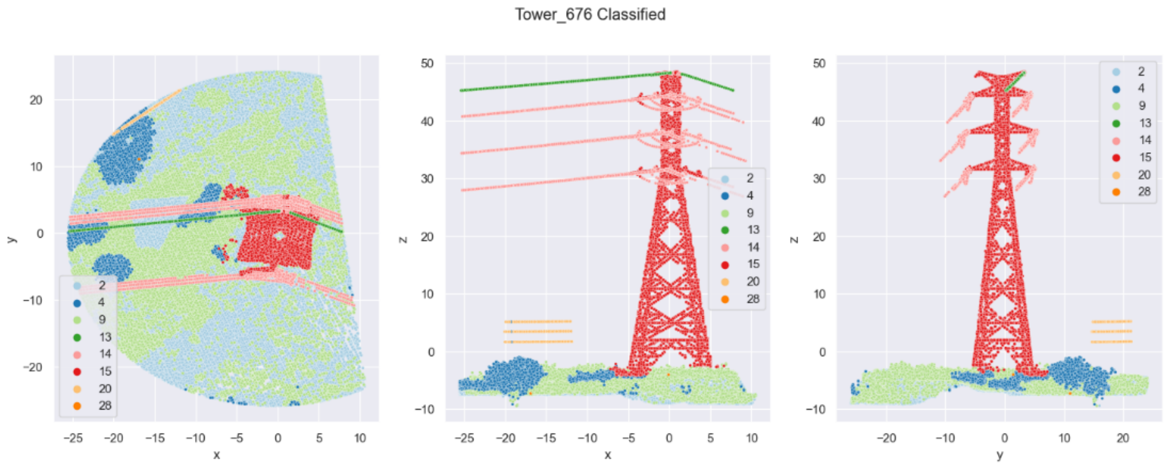

Figure 3: Example of a processed LiDAR transmission tower point cloud

For UC2, the implementation will be intercalated with a set of tests designed to assess the feasibility of the service, using different tower point cloud scans, with distinct models, resolutions and formats. These tests will be evaluated in the defined KPIs, by measuring accuracy scores or other equivalent classification metrics accordingly.

Table 17: Scenario description - Monitoring and predictive maintenance of OHL RoW

Scenario Category	Description
Scenario Name	Monitoring and predictive maintenance of overhead lines Right-of-Way
Related UC	UC2: Semi-automatic Maintenance Plan for Right-of-Ways in Overhead Lines

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Scenario Category	Description
Data sources	LiDAR scan point cloud data of RoW corridors, from the Portuguese TSO
Test cases description	○ System is able to process and visualise LiDAR point cloud data ○ Ensure that system is able to automatically group OHL towers into their respective families / models, with the usage of fitting AI models ○ For each point cloud representation, the tests will ensure that relevant features, both in terms of components (e.g. tower pole, shield wires or conductors) and obstacles (e.g. man-made or vegetation) can be accurately identified by the system ○ Assess how well vegetation state can be mapped in each RoW corridor – in terms of vegetation indexes (VIs)
Assumptions	Data requirements: large number of OHL towers and corridors is required to apply relevant algorithms for this use case
Tests object	The objectives of these test scenarios is to determine if the state of OHL lines can be automatically assessed and components and objects within the RoW can be accurately detected
Test procedures	○ Parse, read and visualise different point cloud files. Check for validity ○ Apply automatic pre-processing techniques to point cloud data. Check that output point-clouds are conformant in terms of spatial orientation and integrity ○ Apply classification techniques to point cloud data and measure accuracy in tower model classification, according to pre-defined supervised labels ○ Classify objects and vegetation state inside RoW corridors. Validate results for a subset of samples
Scenario success	The scenario is considered concluded if the procedures described above yield positive results for the test samples and the accuracy metrics match with the KPIs
Scenario requirements	For this scenario to be reproduced, it must be ensured that representative sets of point cloud data are provided and enough storage and computing power is available, in order to run the underlying computer vision algorithms of the use case
Replicability	Under the specified conditions, this scenario is fully reproducible.

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3.3 LSP2: Cross-functional Integration of Grid Operation with Predictive Asset Management

3.3.1 Infrastructure

The Diagnostics and Analytics Centre (DAC) [5] was established in 2019, with the aim of providing quality and up to date information for analytical support to asset management, analytical support to decision-makers, provision of reference data, research and development and promotion of the company's core business.

As mentioned, DAC main task is support of asset management of company infrastructure. Which in 2020 consisted of the total 2,918 km of overhead transmission lines, with 30 km of cable conduits. It included also 59 stations, 42 of which were transmission system substations, 1 was a substation, 2 a transformer station, 2 were power supply substations and 12 were 110 kV switching substations at HPP/PSP/TPP.

Each station incorporates multiple electrical components, which in 2020 amounted to more than 390 CBs, more than 2300 instrumental transformers, more than 1500 disconnectors and more than 800 surge arresters.

In terms of power transformation, the total output of power transformers between 110 kV, 220 kV and 400 kV voltage levels was 5,133 MVA, while the output of the phase shifting transformer was 1,200 MVA. In 2020 the fiber optic network was 1,717.9 km long.

Besides the development of maintenance plan optimisation tool prototype, any additional purchase of software or infrastructure is not foreseen.

Figure 4: The diagnostic and Analytics Centre (DAC) [6]

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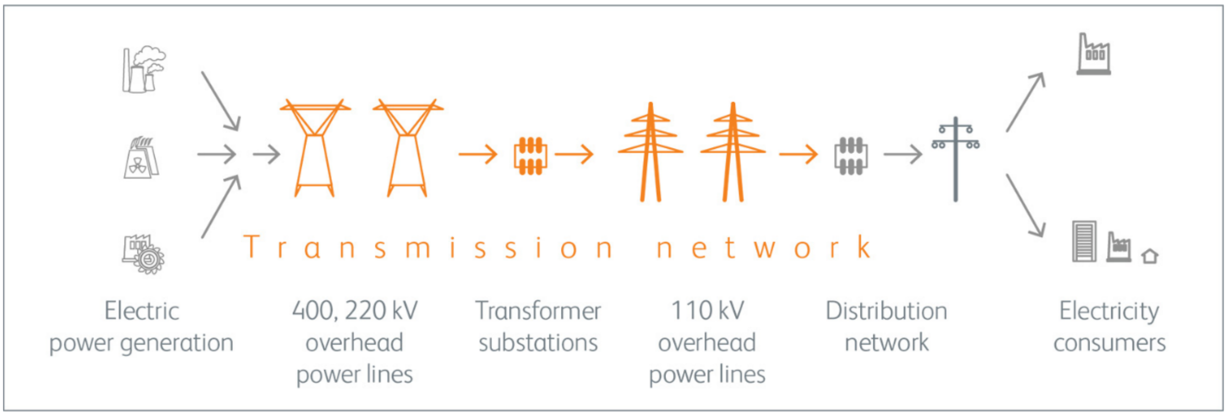

Figure 5: Transmission system [7]

3.3.2 Deployment of BD4NRG Platform

The software solutions developed within the LSP2 pilot case are a part of conceptual BD4NRG platform, so their deployment strategy follows the central tenets of the platform. By using big data approach and in-depth assessment of data requirements aligning the methods and the required data sources, the analytical methodology will be deployed to support internal stakeholders of ELES in optimisation and execution of asset management scheduling tasks that are now only semi-automated.

Technological development within the LSP2 pilot focuses on conception and implementation of clear and transparent methodology involving several new indices (e.g. Asset Health Index, Asset Utilisation Index, Asset Importance Index, Asset Estimated Probability of Failure, and Asset Maintenance Urgency Index) as well as the associated algorithms.

Maintenance Scheduling Tool overview

The developed Maintenance scheduling tool aims to assist the TSO in their maintenance planning of the grid assets. The methodology for deployment of the tool is defined based on the ELES needs. With validated, clear, and objectively defined methodology, the maintenance project scheduling will provide optimal schedule of maintenance activities of the assets.

The building block of the product are maintenance projects (MP), where a specific asset such as power transformer, power line and other equipment is connected to the special type of activity or process on that asset, such as check-up, service, monitoring equipment installation or replacement of the asset. In the final schedule, the maintenance projects are optimally organised for most efficient maintenance plan. They are rated with criteria such as Rank of the asset, optimal time for maintenance, impact on CO2 footprint, social welfare impact with the considering the boundaries such as time of use of assets and security impact of the scheduled project.

Maintenance scheduling tool includes three steps:

- Setup of a MP database
- Ranking of the defined MPs
- Optimal schedule creation of the ranked MP

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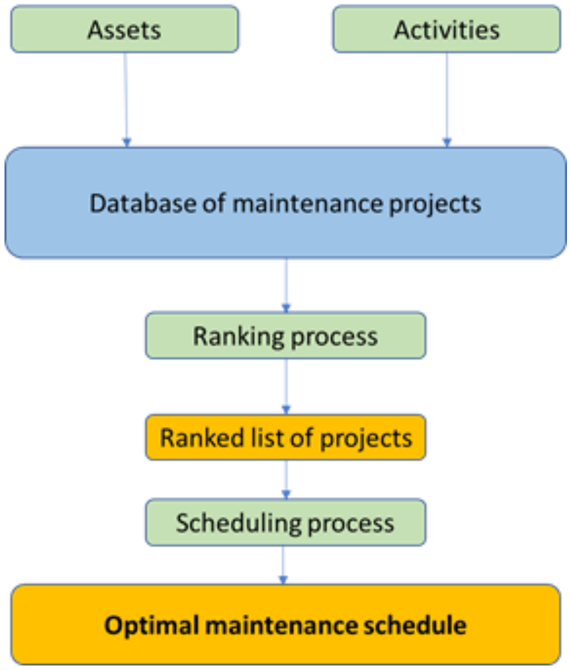

Figure 6: MST Process

In the first step the database of maintenance projects is prepared. It includes all the LSP2 targeted assets. For each of the asset, the activity that needs to be performed is selected. Afterwards a Maintenance Project (MP) database will be defined with all required maintenance activities. These projects are then evaluated in ranking process where MPs are ranked by priority, costs, and other criteria. Afterwards, a ranked list of MPs is complete and is ready for the optimal scheduling process, where final outage proposal is created.

The developed application is designed as an on-premises solution addressing specific case due to TSO-specific national regulatory conditions. Among the technologies, data from the online monitoring of transformers (IoT) will be used in the process. The result will be an integration with the existing systems or databases (asset management system, mobile system, SCADA etc.). The online-acquired data will be combined with the already available data sets, featuring big data in terms of data variety used instead of data volume.

While the main stakeholders involved in LSP2 are the internal transmission system operator (TSO) divisions such as System Operation, System Maintenance and Asset Management, the aim of the LSP2 is also to use the TSO deployment as an example to promote the digitalisation of the maintenance outage planning process with the external stakeholders (e.g., DSOs), HV-grid connected consumers and producers of electricity) and assist them to digitise the process of maintenance outage planning.

3.3.3 Data-analytics services implementation

The LSP2 implementation will rest on the concepts adopted from the IEC 62559-2:

To comprehensively capture the value of the demonstrated Optimal Maintenance Scheduling (OSM) methodology, a set of Business Requirements (Aims) of the LSP2 has been defined. Business Requirements are the functional aims of LSP2, describing the business needs and the required features of the OSM solution.

During the pilot implementation, several scenarios will be executed corresponding to various alternatives of the scheduling optimisation and needs. Each scenario corresponds to a Test Case, which are carried out under specified framework conditions. Each Test Case is associated with one Use Case, describing the typical ways each OSM is used based on the procedures of how the OSM methodology is implemented to achieve the goals stated in the Business Requirements. At the same time, a single Use Case can be tested in several Test Cases. This way, a set of scenarios for the LSP2 will be identified, including a set of Test Cases to be executed by the end- users.

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To determine whether the aims have been achieved or not, a set of quantitative Acceptance Criteria is defined for each Business Requirement. The Acceptance Criteria are expressed in terms of the Key Performance Indicators (KPIs), defined in WP6 - "Pilot Requirements and Assessment". As the KPIs, quantities are defined that are either directly measurable or that are calculated from the measured data. The Acceptance Criteria are defined as the acceptable level of the KPIs.

A short set-up period will be defined for the OSM methodology to be verified, validated and calibrated to achieve a well-designed operation of the LSP2. The aim here is for all actors to start using the OSM application and provide real-world feedback, so the necessary data and information can be incorporated that will reflect the current situation in the optimisation of the pilot operation.

In order to ensure the optimal data gathering, usage and later visualisation of identified data sources, including results that will be delivered by the maintenance plan optimisation tool, the data will be stored on a dedicated SQL server database, which runs on ELES data servers. The gathered data from different sensors, technical information systems and outside actors, will be managed by Diagnostics and Analytics Centre of ELES. The data will be available to all pilot partners via VPN, based on their needs and security clearance.

For the purpose of prototype development of maintenance plan optimisation tools, we primarily intend to use the programming and numeric computing platform Matlab and the programming language Python. After the development, the tool will be installed on a dedicated server at ELES for testing of different maintenance scenarios. In terms of visualisation, any needs from the prototype and overall pilot will be addressed with the use of big data analytics platform Power BI.

Table 18: Scenario Description - Transformer Outage Plan Proposal

Scenario Category	Description
Scenario Name	Transformer Maintenance Outage Plan Proposal
Related UC	UC1: Maintenance Plan Optimisation
Data sources	○ Internal and external outage requests ○ Maintenance history, maintenance intervals ○ Technical data ○ Inspection data ○ Diagnostics data ○ Operational data ○ Grid connected assets ○ Constrains
Test cases description	Maintenance Scheduling Tool (MST) will be triggered on demand. 2 Test Cases (TC) are envisioned to be completed during the LSP. **TC1:** MST will prepare maintenance schedule, based on internal and external outage requests. Outcome is a transformer maintenance outage plan for the transformer fleet of the TSO. **TC2:** Change due to unplanned outage event on one transformer. After the event MST calculates the optimal maintenance plan, an unexpected and unplanned outage of the transformer will occur in the dataset. As a result, MST will deliver new maintenance plan, with included new outage information.
Assumptions	Some boundary conditions will affect the rating of the maintenance projects. For Example, Transformers with higher priority, lower AHI

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Scenario Category	Description
	values, longer time since the last maintenance event and similar, will be prioritised.
Tests objectives	○ Automatic generation of Gantts chart for outage plan proposal. ○ Produced maintenance plan proposal for observed assets based on above defined data sources ○ Use of criteria function ○ Faster plan proposal generation ○ Reduction of effort for producing the plan ○ Outage aggregations for connected assets
Test procedures	○ Data pre-processing ○ List of main activities on targeted assets ○ Ranking of the maintenance projects ○ Use of the criterion and optimisation functions ○ Optimal scheduling of the ranked projects with the developed maintenance plan optimisation tool
Scenario success	○ Obtaining the indices: Asset utilisation index; Asset health index; Asset importance index ○ Maintenance project are ranked according to the criteria ○ Maintenance plan is obtained considering all targeting assets ○ Automated maintenance plan proposal considers more available data than traditional planning ○ One maintenance outage should cover as much as connected assets as reasonable. This means less outages.
Scenario requirements	Each of the scenarios needs pre-processing of the asset available data for the creation of the schedule. Outage plan proposal must be automated process, which can be reactivated on request, considering all updates on the asset's status. Each of the scenario's outcome must represent viable alternative to the current outage planning.
Replicability	The test case can be replicated. The data available at triggering will have influence on results, the outage plan gets updated when new data is available.

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3.4 LSP3: Cross-Domain Cross-functional Integration of Predictive Asset Management and Grid Operation while coordinating with EVs smart charging

3.4.1 Infrastructure

LSP3 is located in Italy and is comprised of part of the infrastructure of the DSO of the city of Terni. In this pilot two UCs will be demonstrated: the first concerning the demand response applied to EVs and the second concerning the implementation of mechanisms for predictive maintenance.

As to UC1, the infrastructure used and already available on site consists of IoT smart meters installed at different end users (schools, SMEs, householders, etc.), PMUs running in the secondary stations, charging stations for EVs and some EVs. Figures 7, 8 and 9 show pictures of this equipment. The portion of the network which will be tested is made up of 4 low voltage nodes and 2 medium voltage nodes, for a total of 8 branches. There are two secondary cabins in the network. Within the network there are 150 smart meters, distributed among various users, which measure the main electric parameters and collect and communicate them in real time to the LV SCADA. The newly registered smart meters measure a large number of electrical parameters, such as active and reactive power, current, voltage, amount of energy consumed and other parameters. Thanks to a two-way communication system, they send the data collected electronically through the 2G network, notifying the DSO in case of anomalies.

As for the phasor measurement units (PMUs) these are devices used to collect a large amount of data from the electrical network, such as the magnitude and phase angle of the voltage and current, the amount of harmonics and all the quantities to evaluate the power quality. PMUs can report measurements with a high granularity, equal to 120 measurements per second with an error of less than 1%. The data is then communicated via the MQTT protocol to the LV SCADA. There are 2 PMUs in the ASM Terni network under testing. In the UC1, 5 smart charging stations supplied by Emotion will be also used, able to remotely start&stop charging sessions and modulate charging power output according to real-time grid needs. Emotion smart charging stations exchange data through a Teltonika RUT230 modem connected to a single-board computer, a Raspberry Pi 3. Charging station protocols are OCPP (application protocol for communication between charging stations and EMOT central management system) and websocket (computer communications protocol, providing full-duplex communication channels over a single TCP connection); charging station data format is JSON and the sampling rate is one second. Finally, 10 EVs supplied by Emotion will be used for the experimentation. Regarding EV monitoring, Emotion use an on-board diagnostic (OBD) device to retrieve data from the EV; OBD is a IoT component, based on a Raspberry Pi 3 and Carberry; Carberry represents the link between car electronics and Raspberry Pi, which allows the development of end-user applications. OBD utilise a TCP/IP communication to a TCP/IP server.

The network connectivity of the OBD device is via data SIM (UMTS), thanks to a Raspberry module that works as a modem, and the server is a python software; OBD protocol is MQTT and the sampling rate is 2 seconds. The OBD connects to the diagnostic interface from which it is able to extract the information from the electric vehicle control unit using the CAN-bus protocol. The output data format of the OBD is an ASCII string; when the data is sent to the server, it is reorganised into a wrapper, thus obtaining a grouping of the data in JSON format.

As for the set up, it still needs to be completed together with the technical partners, but it is believed that through the available network model it will be possible to create a digital twin of the same and integrate the data from the LV SCADA, which collects all the data provided in real time. from sensors, to evaluate how to carry out demand response operations and how to optimise the network.

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Figure 7: ASM Smart meters

Figure 8: ASM Phasor Measurement Units

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Figure 9: Emotion's electric vehicle charging stations

As to UC 2, the infrastructure consists of 14 electrical transformer substations equipped with transformers with nominal power ranging from 250 to 600 kW, and all the protection and control instruments inside the secondary substations on both the medium voltage and low voltage sides. Table 19 lists the transformers used in the experiment, also indicating the type of installation and the protection panel used.

Table 19: Transformers list for use case 2, LSP3

Transformer data			
N	**Secondary substation name**	**Transformer type**	**MV Panel**
1	AS1021449	Prefab Substation	Protected panel
2	AS1021448	Building undergrounded substation	Protected panel
3	AS1021447	Prefab Substation	Protected panel
4	AS1021446	Tower substation	Protected panel
5	AS1021430	Building undergrounded substation	Protected panel
6	AS1021444	Prefab Substation	Protected panel
7	AS1021443	Prefab Substation	SF6 panel
8	AS1021440	Undergrounded Substation	SF6 panel
9	AS1021439	Prefab Substation	Protected panel
10	AS1021438	Building undergrounded substation	Protected panel

In the substations, sensors will be used to measure all the electrical characteristics, the electrical meters, already placed inside the substations, that detect the current, the voltage, the input and output power to the transformer. These data are collected in real time and sent via MQTT protocol to the internal LV SCADA of ASM,

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which manages and collects all data. In the cabins there are also some sensors for measuring environmental parameters, such as temperature and humidity, which are collected and sent to the LV SCADA on an hourly basis.

Finally, 10 noise detectors are going to be installed in already selected substations in order to provide the project with acoustic data for the predictive maintenance of the transformers. More in detail, data about the noise level emitted by the transformers will be sent via the MQTT protocol to the LV SCADA and shared with BD4NRG platform. The acoustic sensors have a resonance frequency of 100 Hz, a typical emission value of power transformers, and the sound emitted is distinguished in frequency bands by recording the sound levels emitted. The acoustic sensor assumed to be used is the Grove - Sound Sensor based on LM358 amplifier and electret microphone [8]. The sound produces analogue output signals. It is powered by a DC voltage of 4V - 12V, has a quiescent current drain of 4mA and a module has dimensions of 24mm x 20mm x 9.8mm and weight of 9g. It is compatible with Arduino or Raspberry PI. And it is quite cheaper. The voltage gain is 26 dB and the microphone sensitivity at a frequency of 1 kHz is 52-48 dB. The microphone monitors from a frequency of 16 Hz to 20 kHz. A figure of the sensor is available on Figure 10.

The setup of the infrastructure is almost completed and is ready for further integrations with the BD4NRG solutions by the technology providers.

Figure 10: Acoustic sensor for use case 2

3.4.2 Deployment of BD4NRG Platform

The pilot aims to investigate two key sectors within the BD4NRG project, the first concerns the implementation of demand response for the electricity sector, through the creation of digital twins of distribution grid, while the second concerns the implementation of predictive maintenance mechanisms for the inside the electrical distribution network, using machine learning models for the fault identification and health status. These two searches are carried out in UC1 and UC2 respectively.

As regards UC 1, the services that are expected to be used concern the forecast of the production of renewable sources, the forecast of buildings and electrical vehicle consumption, and mainly the optimisation of the operation of the network in order to take into account the sources flexibility and maximise renewable energy

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consumption. In order to achieve the expected results, a digital twin of the electricity grid will be created which integrates the results provided by the forecast study into the grid model. Part of these services is assumed to be carried out in collaboration with NTUA who, as task 4.3 leader, will implement the tools and validate them with the data provided by the pilot.

With regard to UC 2, data analysis services detected by the sensors are required, such as environmental and electrical data and in particular an analysis of acoustic data. Through the correlation of these data by means of instruments it is expected to obtain information on the health status of the component and to prepare predictive maintenance programs. The identification of the technical partners who will support the pilot in the validation of the technology is not yet finished. The customisation of the UC 2 will be carried out in use case II through the detailed analysis of the energy functioning within the ASM district, through the collection of production and consumption data. Whereas in UC 2 through the use of acoustic sensors for the evaluation of the state of health of transformers and electrical lines, which through research in the literature is still not investigated in depth.

In conclusion, the pilot is strictly aligned with the BD4NRG objectives and services and significant results are expected to be achieved by these two use cases for the innovation in the energy sector.

3.4.3 Data-analytics services Implementation

As expressed in paragraph 4.1.7, a large number of sensors are used inside the pilot and are briefly resumed. 150 IoT smart meters collect a large amount of data in JSON format and then transmit them via the MQTT communication protocol with a granularity of 5 seconds, the PMUs collect JSON data with granularity of seconds and transmit them via the MQTT protocol, the charging stations of EVs are equipped with smart meters for monitoring energy data with a granularity of 1 second, transmitted via MQTT in JSON format and the EVs are equipped with OBD to transmit real-time data via MQTT in JSON format with a granularity of 2 seconds. In total it is estimated that around 1.25 TB / year of data will be collected. All data is transmitted to the ASM LV SCADA System, which will receive and store them, and then make it possible to access the technical partners.

In UC 1, the demonstration, starting from the simulation realised, will have to consider different scenarios of use of electric cars, also to evaluate the impact on the electricity grid in the next years. The flexibility that charging stations can provide depends strongly on the number of vehicles involved. Additionally, EV charging can temporally and spatially be optimised, if the basic energy demand in a neighbourhood is known. Knowing the exact weather conditions for the next hours in the region allows to distribute the EV charging better over time and space and helps to relieve the grid. Scenarios will be carried out that integrate the electricity grid trend, with the increase of renewable production sources, with the consumption trends of electric cars, which are expected to increase significantly in the coming years.

Table 20: Scenario Description - Electric vehicle smart charging management

Scenario Category	Description
Scenario Name	Electric vehicles smart charging management
Related UC	UC1: Efficient management of flexibility resources for supporting grid operation
Data sources	○ 150 smart meters located in the distribution grid ○ 2 phasor measurement units ○ 5 EV charging stations ○ 10 EVs ○ Weather monitoring ○ Geographical images
Test cases description	There are three test cases related each with a different EV penetration:

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Scenario Category	Description
	○ The first test cases concern the deployed EV fleet in LSP3; ○ The second test case is a simulation that considers a tenfold increase in the EV fleet; ○ The third test case is a simulation that considers a hundredfold increase in the EV fleet.
Assumptions	Charging stations are supposed to be able to modulate power output based on DSO demand, without increasing energy losses or damaging components.
Tests' objective	○ Evaluate optimal charging sessions scheduling for local grid balancing among renewable energy generated by local PVs; ○ Evaluate economic incentive models for EV users by utilising BD4NRG framework.
Test procedures	○ Receiving weather data ○ Forecast of distributed generation for the next 24 hours ○ Forecast of demand consumption for the next 24 hours ○ Analysis of useful ancillary services for the distribution grid ○ Sending useful services for the distribution grid, related to energy consumption for the following hours, zone by zone ○ EV fleet state of charge assessment ○ BD4NRG central system sends commands to the charging stations, which modulate power outputs according to grid needs ○ EV users who participate in the grid balancing mechanism are rewarded with economic incentive
Scenario success	○ Realisation of an EV smart charging management system that provide benefits both to EV users and grid operators, based on BD4NRG big data smart grid service analytics toolbox; ○ Increase RES integration efficiency, reducing reverse power flow.
Scenario requirements	eMobility platform must be enabled for user registration, must allow charging station real-time monitoring and remote management, and must allow micro-payments and smart contracts.
Replicability	The service has to be replicable on a large scale, dealing with a large number of vehicles and charging stations.

Traditional and innovative sensors will be incorporated into UC 2 to perform predictive maintenance in the secondary substation. While standard sensors are able to measure transformer values, it is not easy to obtain information on the correlation with faults with the data collected in a short period of time, compared with the lifespan of the transformers. Several manoeuvres will be carried out with the disconnectors and the power of the transformer will be varied considerably, to see how the parameters, both electrical and acoustic, vary. As faults on transformers are quite rare, it is not expected to find decisive correlations on this aspect, but research will be carried out in this area, whereas faults in the compartments of the secondary cabin may be more frequent and easier to detect. The installation of the set up was done by contacting local sensor suppliers, experts in the design and manufacture of hardware components for measuring instruments.

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Table 21: Scenario Description - Transformer health status monitoring

Scenario Category	Description
Scenario Name	Transformer health status monitoring
Related UC	UC 2: Anticipated prediction of asset failures
Data sources	○ 10 electrical meters connected to secondary transformers ○ 10 acoustic sensors linked each with a transformer ○ 10 temperature and umidity sensors, one for each secondary substation ○ Geographical images data ○ Weather information
Test cases description	Data will be continuously monitored and there are 2 test cases: ○ The first concerns prefabricated electrical transformers ○ The second concerns undergrounded substation and tower substations
Assumptions	Transformer noise has a general noise level lower then 70 dB and a resonance frequency of 100 Hz.
Tests' objective	○ Evaluate measured parameters (noise, current, voltage, …) over time; ○ Check existing correlation between transformer acoustic emission and power flow; ○ Check existing correlation between transformer health based on how measured parameters vary over time
Test procedures	○ Installing acoustic, electric and environmental sensors in the secondary substations ○ Weather data are integrated ○ Geo-images data are integrated ○ Data sharing thought MQTT protocol ○ Data storing in the ASM LV SCADA System ○ Data analysis through BD4NRG Platform
Scenario success	○ Identification of acoustic and electrical threshold parameters indicating transformer degradation ○ Identification of a correlation between noise and electrical power of the transformer ○ Correlation between transformer degradation and measured parameters ○ Reduce maintenance cost ○ Reduce electrical supply interruptions
Scenario requirements	○ Installation of all sensors ○ Pre-processing of acoustic data
Replicability	The test case can be replicated in each secondary substation, just to monitor with similar sensors.

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3.5 LSP4: Cross-functional Predictive Asset Management for MV Grid Planning

3.5.1 Infrastructure

The Use Case demonstration under the LSP4, will include several distribution transformers which have different level of nominal power. Some of the transformers are connected to existing SCADA system and it is possible to collect real time active/reactive power and voltage values from this equipment. For the other transformers which are not connected to SCADA system, it is also possible to collect 15 min interval power and voltage data with Automatic Meter Reading (AMR) system. AMR meters have already placed inside the substations, that detect the current, the voltage, the input and output power to the transformer. Collected data is available in OEDAS system and it can be provided to related platforms or tools via API services.

In order to collect environmental data such as temperature and humidity, additional sensors may be needed and it can be planned to put this kind of sensors to selected transformers. If there is an additional sensor requirement for the tool to be developed within the scope of predictive maintenance activities, this will also be evaluated and additional sensors may be placed if necessary.

Figure 11: OEDAS Infrastructure

Table 22: Transformer features for use case 1, LSP4

Transformer Data		
	P [kVA]	**Vn1 [kV]**
TR1	400	34.5

3.5.2 Deployment of BD4NRG Platform

The UC takes place in medium voltage network distribution network of OEDAS. Pilot locations will be set after the final internal evaluation, but selection of an old network section with lots of MV faults in urban district will be considered. Since DSO does not have a professional maintenance plan and data evaluation processes, some

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unexpected faults on MV grid happen. In order to reduce faults and have more accurate predictive maintenance processes, the BD4NRG AI tools will initially work on long term historical data to analyse the accuracy of its short-term historical data. This fine-tuning process will serve as a continuous feedback loop for better prediction performance. Once the AI achieves a certain level of accuracy then the algorithm will be used to predict and analyse short term future maintenance and failure of the MV network assets, and hence failure along the grid.

Related data both for historical and 15 min/hourly interval or real time will be provided by REST API. According to plan created model will be trained on one asset (preferably for transformer or any other asset which has historical data) and then same pre-trained model is further trained on different asset. Electrical data collected from equipment's and also historical fault data will be used to train the fault prediction and predictive maintenance tools. Data analysis services will be required in this matter.

3.5.3 Data-analytics services implementation

Referring to the LSP, the processing should be the forecasts, the predictions or a corresponding maintenance optimisation take place in real time. We believe that the full analysis and data processing for a corresponding forecasting pattern, forecasting or offline can be done.

We collect the data of flexible assets from our SCADA system, AMR system, power quality analysers and other related infrastructures. The exact sensors and parameters measured vary among different types of assets and device manufacturers. Also, we can actually not say if all parameters available. More information will be provided in the further progress.

Table 23: Scenario Description - Predictive maintenance and long-term fault prediction for transformers

Scenario Category	Description
Scenario Name	Predictive maintenance and long-term fault prediction for transformers
Related UC	UC1: Predictive maintenance and fault prediction for MV grid and cross functional predictive asset management
Data sources	○ Several electrical meters via AMR system connected to secondary transformers in order to have power and voltage values ○ SCADA system is available for some of transformers in order to have power and voltage values ○ Historical fault and maintenance records are available ○ Additional sensors to collect environmental data may be installed for use case if need
Test cases description	Use case is aimed to be demonstrated on several transformers older than 20 years and which have high number of faults
Assumptions	-
Tests object	○ Data collection and evaluation process for electrical data such as current, voltage and also collection of historical data of fault records ○ Providing of necessary data to predictive tools and evaluating the outcomes of tools.
Test procedures	○ Collecting data from existing measurement units and installation of additional sensors if needed ○ Data integration and sharing with predictive tools which will be developed by other partners

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Scenario Category	Description
	○ Data analysis through BD4NRG Platform
Scenario success	○ Results from predictive maintenance tools and have more realistic maintenance plan ○ With the long-term fault prediction, reducing of some faults on distribution transformer ○ In line with above purposes, reducing of equipment/component replacement cost for selected transformers
Scenario requirements	Collecting of data from existing measurement systems Installation of necessary sensors if needed.
Replicability	The test case can be replicated in each distribution transformers.

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4 Conclusions

D7.1 – "Baseline Analysis Report and 'BD-4-NET' Large Scale Pilots Preparation" gathers information and data about four BD-4-NET LSPs, in compliance with the Description of Action (DoA) of the Grant Agreement. Each LSPs provided the values for setting its own baseline by using general and pilot specific KPIs. As to the former, 12 general KPIs that monitor normal operation activities and 14 related to special events were thoroughly depicted and calculated. Regarding the pilot specific KPIs, values of 9 KPIs for LSP1 (Portuguese TSO), 4 for LSP2 (Slovenian TSO), 10 for LSP3 (Italian DSO) and 5 for LSP4 (Turkish DSO) were accurately identified providing the related figures. All in all, almost 3000 sensors will be used for the demonstration activities and about 7.25 TB of data will be collected each year from BD-4-NET LSPs.

Each BD-4-NET pilot will rely on its own infrastructure assets, i.e. its own power lines and transformers to carry out the experiments, also involving electric vehicle charging stations and advanced metering devices. BD-4-NET pilots will test artificial intelligence and machine learning tools to optimise the operation of transmission and distribution networks and to implement predictive maintenance mechanisms. For each of the 6 use cases, a scenario with several test cases was identified as well as a procedure to be followed for testing.

The information and data gathered in this deliverable are fundamental for carrying out the demonstration activities foreseen in T7.2– "Integrating off-grid data with Condition based Monitoring for Enhanced Asset Maintenance (LSP1)", T7.3 – "Cross-functional Integration of Grid Operation with Predictive Asset Management (LSP2)", T7.4 – "Cross-Domain Cross-functional Integration of Predictive Asset Management for Grid Operation and coordination with flexible EVs charging (LSP3)" and T7.5 – "Cross-functional Predictive Asset Management for MV Grid Planning (LSP4)". The next step comprises the first technology release (from M10 to M13 - Pilot Cycle 1) based on the services provided by the BD4NRG technology providers to each specific pilot.

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