D2.1 Requirements, Use Cases and Scenarios

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LIST OF ACRONYMS

Acronym	Definition
AI	Artificial Intelligence
API	Application Programme Interface
CAGR	Compound Annual Growth Rate
C3S	Copernicus Climate Change Service
DSO	Distributed System Operator
ECMWF	European Centre for Medium-Range Weather Forecast
EO	Earth Observation
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning System
IIoT	Industrial Internet of Things
LCoE	Levelized Cost of Electricity
LV	Low Voltage
ML	Machine Learning
MV	Medium Voltage
PDC	Phasor Data Concentrator
PMU	Phasor Measurement Unit
RES	Renewable Energy Sources
SCADA	Supervisory Control and Data Acquisition
TSO	Transmission System Operator
UC	Use Case
VLSBI	Voltage Stability Load Bus Index
WAMS	Wide Area Monitoring Systems
WP	Work Package

Executive Summary

This deliverable is part of the RESPONDENT project, which aims to develop a set of power generation and demand forecasting modules, and a power-grid timing and synchronisation module in order to address the challenge of renewable energy sources (RES) power generation forecasting, demand forecasting and smart power grid monitoring and supply/demand balancing. This document outlines the main outcome of Task 2.1 "Requirements Synthesis" and Task 2.2 "Use Cases and Scenarios Definition". Task 2.1 mainly focuses on the End Users Requirements, most of which stem from the Requirements Elicitation Workshop, which was conducted on the 14th of February 2023. Task 2.2 elaborates on the use cases and scenarios, which will be the basis upon which the project's modules will be tested and validated in Greece and Spain, through the two RESPONDENT pilots.

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1 Introduction

The RESPONDENT project, which stands for "Renewable Energy Sources Power fOrecasting and syNchronisation for smart griD nEtworks maNagemenT", aims to develop a set of forecasting and grid management modules to address the challenge of RES power generation forecasting, demand forecasting and smart power grid monitoring and supply/demand balancing.

An AI/ML RES power generation forecasting algorithm is proposed, exploiting both Copernicus EO and site-specific weather data, along with renewable energy power conversion models. Furthermore, an AI/ML – Multiphysics model for power demand of certain communities is also developed. Lastly, RESPONDENT will build a Galileo-enabled PMU and develop a monitoring module in order to test and verify the advantages offered from the Galileo timing and synchronisation services in smart grid monitoring, power balancing and overall operation.

The RESPONDENT solution and its individual modules were clearly defined at the proposal stage, and an overview of these was presented at an early stage to the users at the requirements elicitation workshop held in February. The relevant stakeholders were consulted to acquire their needs and preferences for the developed solutions. Finally, the validation criteria upon which the solutions will be validated at the pilot demonstrations will be defined here in close collaboration with the end users.

Relying on the outcomes of the Requirements Synthesis, the use cases and scenarios for testing the RESPONDENT modules and solution will be defined. The results of these definitions will be the basis upon which the two pilot demonstrations will be conducted.

1.1 Scope and Objectives

The objective of this deliverable is to compile the end user requirements collected in the workshop and the use cases (UCs) of the pilot sites.

The deliverable will further provide a set of recommendations to the technical work packages, which will be converted and mapped into system specifications in WP3, WP4, and WP5 for implementation and adoption.

1.2 Deliverable Structure

This deliverable is structured in the same order as Task 2.1 and Task 2.2 have been developed. After the introduction, a guide on the RESPONDENT concepts is presented as they were defined to introduce it to the external stakeholders of the project.

Following this, the way in which the external stakeholders were engaged to obtain their requirements is explained in the methodology section, and the subsequent results of that approach are explained in the requirements section.

After the objectives and results of the Task 2.1 are explained sections concerning activities belonging to Task 2.2 follow expanding on the project's use cases and the connection between the use cases and the requirements, as the use cases have been designed to match the stakeholders' comments and preferences.

In conclusion, to understand the deliverable and how WP2 has been addressed, an impression of what has been done chronologically in the Work Package 2 can be obtained by following the document point by point.

1.3 Relationship with other RESPONDENT Deliverables and Tasks

As stated in the proposal, the WP2 objectives are mainly related to setting the framework for both the technical Work Packages (WP3, WP4, WP5) and for the demonstration and validation at the pilot sites (WP6).

Work Package	Deliverable
WP2	D2.2
WP3	D3.1
WP3	D3.5
WP4	D4.1
WP4	D4.3
WP5	D5.1
WP5	D5.3
WP6	D6.1
WP6	D6.2
WP6	D6.3
WP6	D6.4

Table 1: Deliverable Beneficiaries

2 RESPONDENT Concepts

2.1 The RESPONDENT Solution

One of the main actions to be followed in efforts to achieve the targets of the European Green Deal is the greening of the energy production systems and the complete replacement of fossil fuels with renewable energy sources. In this regard, a complete and total adoption of renewable energy must take place; accompanied however, with an effective, efficient, and seamless integration to the existing and future power grids. For that to be accomplished, novel solutions addressing challenges in energy generation, energy transmission and distribution, and energy consumption must be developed.

Under these preconditions, RESPONDENT will develop a complete solution, incorporating renewable energy generation forecasting, power demand/consumption forecasting, and grid monitoring through effective timing and synchronisation techniques. Specifically, the project will provide a solution for solar energy generation forecasting and a novel demand forecasting solution based on Copernicus satellite weather data, along with an innovative grid monitoring technique based on Galileo timing and synchronisation services.

The solutions will be offered both as independent, stand-alone modules and as an integrated suite, with the latter covering the needs of the whole supply chain stakeholders. The project aims to provide innovative solutions that will equip the energy sector stakeholders with powerful tools in order to tackle the issues of the future, renewable energy composed, and power grids.

2.1.1 Power Generation Forecasting

The widespread adoption of weather dependent, intermittent renewable sources for energy production demands advanced solutions to secure seamless production, supply/demand equilibrium and grid stability. In that sense, the ability of predicting the power output of renewable energy sources plant installations with respect to the local microclimatic conditions is of critical importance. The so-called power generation forecasting offers the ability to relevant stakeholders to make the appropriate decisions regarding the total power production and the corresponding balancing to the power demand.

Working within this framework, RESPONDENT will develop a precise and low-cost power generation forecasting solution for solar power plants, based on the utilisation of AI/ML techniques, IoT ground-based sensors and COPERNICUS satellite weather data. The competitive cost of the module/service is achieved with, mostly, publicly available satellite data, and proprietary developed and low-cost IoT-based weather stations, that are already manufactured by FINT for commercial purposes.

The developed solution will be offered as a complete module, including both software and hardware parts, along with the corresponding user web dashboard. It intends to provide RES aggregators and power producers with a unique tool for accurate predictions of their production, allowing them to efficiently integrate the renewable energy to the grid and, moreover, provide the relevant data to the energy markets.

2.1.2 Demand Forecasting

Any power grid operator’s main goal is to maintain a continuous balance between power generation and demand. Any unbalance that occurs could potentially entail an additional cost for the users of the grid or, in the worst-case scenario, a reduction of the quality of the delivered power that result in outages and failure of the connected devices.

Numerous technologies have thus been developed and implemented to anticipate changes in the demand levels and allow for their management by influencing the generation. In RESPONDENT, a novel, state-of-the-art demand forecasting technique will be studied and implemented, merging different available data sources and algorithms that aim to enhance the accuracy of the forecasts. This will be achieved through the development of an enhanced weather prediction model, enabled by the use of Copernicus EO data, which will in turn be coupled with the data from ground-based weather stations. The obtained forecasted weather data will then be added to the historical power consumption data, together with other socio-economic and demographic data specific to the area under analysis, thus improving the accuracy of the aforementioned area's power demand forecasts.

2.1.3 Grid Timing & Synchronisation

The large-scale integration of RES in modern power grids introduces complex technical challenges to be tackled by TSOs and DSOs. Among others, these challenges include lower levels of inertia in the system, bidirectional flows at lower voltage levels, unintentional tripping of protections and stability issues.

Advanced grid monitoring is crucial in addressing these issues. For this reason, modern grids are increasingly incorporating Wide Area Monitoring Systems (WAMS), large-scale networks of advanced and synchronised sensors for real-time monitoring of the grid. WAMSs are based on Phasor Measurement Units (PMUs) which measure the synchrophasors, e.g., voltage and current phasors synchronised to the same time reference. The main advantages of PMUs with respect to legacy measurement systems, such as Supervisory Control and Data Acquisition systems (SCADAs) include:

- The ability to measure the phase angle of electric signals, thanks to the reference time that is common to all the PMUs and synchronised one to another. Measuring the phase angle can be crucial to assess the stability of the power grid.
- The higher rate of sampling is a necessary condition to detect fast dynamics on the grid.
- The timestamps: each measurement comes with a time tag representing the time at which each measurement has been taken. This feature can be very useful for bad data detection and for post-mortem analysis, especially when cause-effect relationships are not clear.

After measuring the synchrophasors, different PMUs send the collected data to a single Phasor Data Concentrator (PDC) where they are time-aligned and filtered and finally sent to the operation centre where they are used for different applications.

Potential applications enabled by WAMSs include:

- **State estimation**: a mathematical technique that allows the estimation of the most probable operative state of the network. PMUs enable the utilisation of a linear estimator which makes the computational process faster and more accurate than the one based on SCADA data.

- **Voltage stability control**: this involves the calculation of the Voltage Stability Load Bus Index (VLSBI) for every node to check the stability of the power grid.
- **Network Parameter Estimation**: network parameters can be estimated using PMU data from a line's ends with the support of new data-driven approaches, such as machine learning.
- **Congestion management**: the improved observability provided by PMUs can enhance the distribution of power flows in the grid in order to avoid congestions.
- **Fault Location**: PMUs spread in the power grid can help locate faults.
- **Others**: PMUs possess further additional applications, including interarea oscillations control, phase stability monitoring, system models validation and adaptive protections.

The main requirement for a PMU to work correctly is the presence of an accurate time synchronisation source with large-scale availability. This service is offered by the Global Navigation Satellite Systems (GNSSs) that are equipped with atomic clocks onboard. Currently, most PMUs exploit the Global Positioning System (GPS), but other alternatives are possible, such as the European GNSS, Galileo, that can provide more accurate and robust time synchronisation signals.

In this context, RESPONDENT's objectives are defined as follows:

- Development of a Galileo-enabled PMU to improve the accuracy of current commercial PMUs and enhance their robustness to cyber-attacks by employing the European GNSS.
- Definition of a planning framework to optimally locate PMUs in the grid in order to maximise grid observability while minimising the overall costs.
- Setup of a monitoring dashboard for the graphical view and analysis of the grid state and the monitoring of its dynamic behaviour using the data from the Galileo-enabled PMUs.

The resulting architecture is shown in Figure 1.

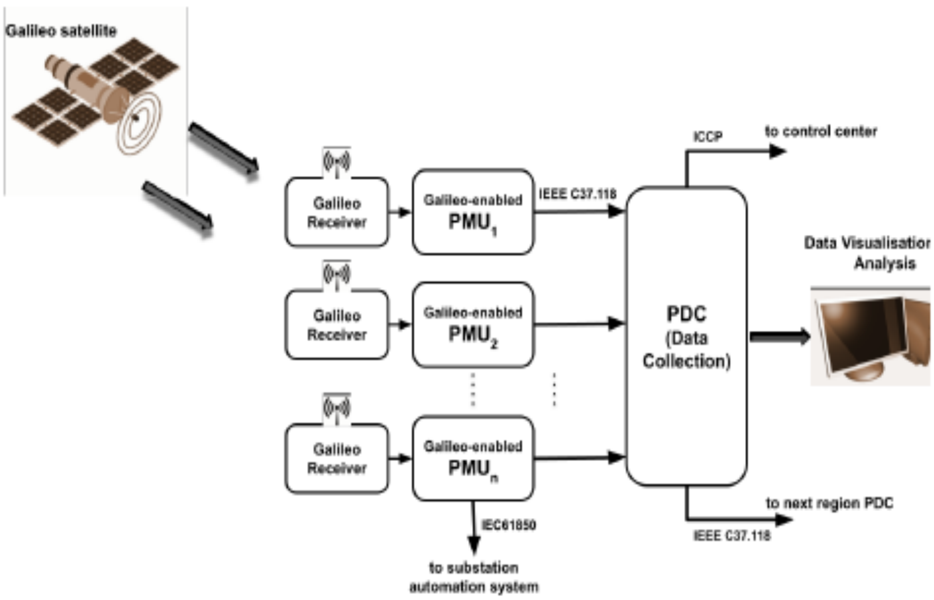

Figure 1: RESPONDENT Galileo-based T&S Architecture

2.2 Business Context

Recent reports [1] estimate that the RES market is currently valued at ~1B€ as of figures from 2021, with a projection to grow to ~2.23B€ by 2030 at a Compound Annual Growth Rate (CAGR) of 10.1%. Moreover, a Research and Markets report [2] defines the main factors that will drive the 2022-2032 renewable energy market in the following ways:

- Available technologies that rapidly improve their cost-performance
- Renewable energy Levelized Cost of Electricity (LCoE) is lower than fossil fuels LCoE
- Following Russia's invasion of Ukraine, the EU and individual european governments embarked on sweeping changes to planning laws and investments in renewable energy projects to improve their energy security
- China's mass investments in renewables
- The renewable market presents multi-trillion business opportunities
- Unprecedented public support
- Government subsidies and investments in renewable energy projects
- Investors' enthusiasm for financing renewable energy projects is substantial and growing
- Widespread and urgent replacement of fossil energy by renewable energies is crucial to control climate change
- Energy security needs for fossil fuel importing countries
- Cost reduction, driven by mass production, competition, and innovation

In the above context, the RESPONDENT solution intends to contribute to the continuous spread and growth of renewable energy through the provision of advanced digital tools and technologies to support renewable energy and power grid systems' efficiency, reliability, robustness, and energy supply security.

The RESPONDENT solution (either as a complete suite or as independent stand-alone modules) addresses a variety of challenges and relevant stakeholders in the (renewable) energy market sector and the energy supply value chains, respectively. A list of the most relevant stakeholders have been identified as follows:

- RES Aggregators/Producers
- Energy Retailers
- TSOs/DSOs
- Smart Power Grid Management and Operation companies
- Energy Holding Group
- ENTSO-E
- EU DSO Entity
- PMU (Synchrophasor) manufacturers
- Building/Energy management companies
- Powe utilities companies
- Research Institutes

RES Aggregators/Producers: Entities that produce and/or lead in full participation of RES assets in the electricity market. They also ensure the direct participation of RES assets to the Energy Exchange. These entities need advanced tools and algorithms to optimise power production prediction and minimise balancing costs. Thus, RES aggregators and energy producers are mostly interested in the RES Power Generation

Forecasting module, by which they will acquire an innovative, low cost, highly accurate and reliable tool to assist them in predicting the power output of the RES (solar) power plants in the short- and medium-terms.

Energy Retailers: Entities whose main activity consists of selling energy to the final users. Energy can be acquired through the energy market or, in some cases, with external agreements with the power generation companies. The main interest of energy retailers in the RESPONDENT project relies on the Power Demand Forecast Module, since it would help them prepare for the energy market and thus improve their participation.

TSOs/DSOs: Organisations responsible for the transmission and distribution of electricity. Since they develop and operate the power transmission and distribution network, these entities are interested in the complete RESPONDENT solution suite, addressing power generation, power transmission and distribution and power consumption/demand. Moreover, especially for the DSOs, there is an interest in the Power Generation and Demand Forecasting modules as a tool to support them in the prediction of energy consumption under different weather and socio-economic conditions, while also enabling them to design more effective demand response actions. Furthermore, since TSOs are responsible for the operation and maintenance of the grid and the power transmission network at large scales, they need a tool to effectively monitor the grid's health and the supply/demand balance. Therefore, the Galileo-enabled PMU signal monitoring module can offer them an efficient, robust and reliable solution for grid timing and synchronisation.

Smart Power Grid Management and Operation companies: Entities that are in charge of managing and/or operating power grids, similarly to TSOs. They are mostly interested in the Galileo-enabled PMU signal monitoring module and the complete solution suite, allowing them to acquire a grid monitoring tool and address the challenge of supply/demand equilibrium.

Energy Holding Group: Even though the energy sector determines by law that there needs to be different companies for each of the different roles in the sector (producer, retailer and DSO), there are some energy holding groups that might have companies present in more than one of such roles. The RESPONDENT solution can take advantage of being a complete solution with different scopes on the RES integrations and, by having a UX friendly interface and high interoperability, can be interesting for these different companies that are part of the same energy holding group.

ENTSO-E, EU DSO Entity: Organisations representing European TSOs and DSOs. Because of that dual role, both the complete RESPONDENT solution suite and the individual stand-alone modules are of interest to them.

PMU manufacturers: Industrial manufacturers of PMU (synchrophasor) devices and related accessories (such as monitoring dashboards). Currently, no Galileo-based PMU has been manufactured or prototyped. Timing and synchronisation of PMUs and grid monitoring is based on GPS or internet-based techniques. In this context, the Galileo-enabled PMU signal monitoring module constitutes an innovative software and hardware solution for advanced grid monitoring, that can exploit all of the Galileo differentiators.

Building/Energy management companies: Companies which are responsible for managing the energy consumption of residential, commercial, and industrial consumers. Having an estimation/prediction of the energy consumption/demand of their customers is therefore of significant importance. Thus, the Power Demand Forecasting module lies in the area of their interest, since it will provide them, even on a very local scale, with the needed information about customers' forthcoming energy consumption.

Power utilities companies: Companies that offer (smart) solutions for the demand/consumption side of the energy supply chain. Therefore, they are interested in the Power Demand Forecasting module, as it will enable them to contribute to the acquisition of power consumption data needed for the algorithm (e.g. by smart power meters), and also allow them to offer innovative solutions for consumption scheduling and demand response.

Research Institutes: There are many institutions dedicated to research of the energy sector. Often, these institutions need power demand or generation forecast modules to develop their studies or, even if the object of study is more specific on the subject, they could be interested in the Timing & Synchronisation module. It is interesting to have them as potential end-users since their needs and preferences may be slightly different to the business-related companies.

Looking at the global energy market sector in a more specific context, some of the key renewable energy sector players can be listed as follows [3] [4] [5]:

- Siemens AG
- GE Renewable Energy
- Green Energy Corp.
- Iberdrola SA
- Vestas Wind Systems A/S
- Orsted A/S
- Enel Spa
- Tata Power
- RWE AG
- JinkoSolar Holding
- Canadian Solar
- Tocardo BV

With respect to PMU manufacturers, the most important players are:

- Schweitzer Engineering Laboratories
- Fuji Electric France
- Siemens AG
- ERLPhase Power Technologies
- Arbiter Systems
- Toshiba Corporation
- General Electric
- Schneider Electric
- ABB Ltd.
- Intel
- Electric Power Group

In addition, there is a multiplicity of competitors and existing solutions in the market that possess their own advantages and disadvantages. With respect to RES power generation and demand forecasting, some of them (including their basic solution features) are:

- **Enercast**: Power forecasts for solar and wind power with AI-based weather forecasts

- **Vitecsoft**: Wind, solar PV and hydropower generation forecasts in one system, AI/ML-powered, multiple in-data weather forecasts, demand forecasting
- **Aleasoft**: Wind, solar PV, solar thermal and hydropower forecasting, demand forecasting
- **Steady Sun**: Solar power forecasting
- **ENFOR**: Wind and solar power forecasting, demand forecasting, ML self-learning and self-calibrating
- **IBM**: AI-based wind and solar power forecasting

Similarly, some of the existing solutions with respect to grid Timing & Synchronisation, include:

- **Nokia**: GPS and network based (PTP), microsecond accuracy
- **Qulsar**: GPS and network-based, microsecond accuracy
- **Siemens**: GPS-based
- **ABB**: GPS-based
- **Meinberg**: Network based (PTPv2)
- **Schweitzer Engineering**: GPS+Glonass and network-based
- **Qualitrol**: GPS-based
- **Hitachi**: GPS-based, microsecond accuracy
- **Valiant Com**: GPS+Glonass-based

Finally, a non-exhaustive list of complete grid monitoring tools has also been identified:

- **GE**: Diagnostic and data mining framework for grid monitoring
- **Siemens**: Automatic and configurable real-time PMU data analysis
- **Intel**: End-to-end smart grid monitoring, synchrophasor data management solution
- **Electric Power Group**: Synchrophasor based platform for grid event notifications

As can be observed from the previous listings, there are more than enough existing solutions competing with each one of the RESPONDENT individual stand-alone modules. However, to the authors' knowledge, there is no solution yet addressing power forecasting, demand forecasting and grid T&S as a complete package. Thus, there is no single solution, technological approach or even business model that has been established within this framework. The RESPONDENT complete solution suite, therefore, constitutes a unique and innovative solution that intends to offer a holistic tool for most of the energy sector stakeholders.

3 Methodology

The best way to engage with the external stakeholders and potential end users at the outset was to acquire their needs and preferences for the modules and collect those requirements for the technical work packages via the project's first Requirements Elicitation Workshop.

The workshop took place on the 14th of February both physically (in Granollers, Spain) and online, with a total of 21 companies in attendance. While contacting the companies for the workshop, the different target groups who stand to benefit from this project, as per the proposal, were taken into consideration.

To give the stakeholders participating in the workshop as much freedom as possible and in attempting to close the gap between the people attending online and those who attended physically, we employed the virtual tool "Mural" that enables groups to collaborate visually and brainstorm solutions and ideas by creating simple but comprehensive diagrams.

The format of the workshop was divided into four main blocks, each corresponding to one of the modules and a final one for the solution suite. Amongst other questions and topics of discussion, the main interest concerned finding out if the stakeholders were currently using similar services and, in case they were, what were their advantages and disadvantages in order to know what the needs and requirements would be to make RESPONDENT a useful and competitive solution. For each question, the participants were given some time to think and add their individual input to the Mural, after which they were invited to share their inputs and debate the different points of view among the attendees.

The day after the workshop, an in-person meeting took place among the Consortium Partners to discuss the inputs received during the workshop and to analyse and summarise them into the final requirements. For several of the inputs received in the Mural, some adjustments due to the availability of the requirements, were made.

A detailed description of the questions put forward in the workshop and the answers collected are shown at a later stage in this document (section 3. Methodology).

3.1 Stakeholder Groups

The respective stakeholders invited to the event had different roles in the energy sector. Some attended for their specific interests on their topics/expertise, while others came for the overall solution. The following paragraph contains a list of the different stakeholder groups that were in attendance:

A total of 43 people from 21 different companies attended the workshop, of which 14 companies were external stakeholders (potential end-users of the RESPONDENT solution) and the other 7 were partners of the consortium. Of the total attendees present at the workshop, there was a solid representation of the majority of potential stakeholders addressed in the Business Context as previously outlined. In addition, energy consultants were also invited as they possess a broad spectrum vision of the energy sector as well.

Below, the attendance on the workshop, and how the different target groups were represented can be found.

# of Attendees	Stakeholder Type	Country of Origin (Consortium Partner)
2	Communications Company	Ireland (CP)
2	Aggregator Producer	Greece (CP)
3	Power Utility Compan	Spain (CP)
2	Power Utility Company	Greece (CP)
2	Research Institution	Spain (CP)
2	Power Utility Company	Greece (CP)
4	DSO	Spain (CP)
1	Association of DSOs	Spain
1	Building Manager	Spain
2	DSO	Spain
2	DSO	Spain
6	DSO	Greece
2	DSO	Spain
2	Energy Business Group	Spain
1	Energy Business Group	Spain
2	Energy Consultants	Spain
1	PMU Manufacturer	Spain
1	Power Generation Support	Spain
1	Power Generation Support	Spain
1	Power Generation Support	Spain
3	Power Generation Support	Spain

Table 2: Requirements Elicitation Workshop Attendees

From the total number of participants, some were involved mainly in just the modules that were applicable to them and their work. Others, due to their experience and the wide vision of their respective companies/institutions, were involved in all discussions regarding the modules and the solution suite.

3.2 Questionnaires and Results

The Mural tool was also used to brainstorm, with various topics of discussion for each of the blocks proposed were provided. This Mural can be viewed in Annex 1 of the present document.

Several of the questions were generic in nature for all the modules, mainly to assist the project partners to certify if the external stakeholders were facing the issues that RESPONDENT intends to solve, if they were using something like the RESPONDENT solution, and what were the advantages or disadvantages of them. Moreover, some topics were discussed that related to specific functionalities of each module, such as the forecasting characteristics or the T&S accuracy.

A description of each of the topics discussed for the 4 main blocks and the feedback collected from them can be found in the following sections.

3.2.1 Power Generation Forecast – Topics and Feedback

For the Power Generation Forecast Module, several questions were put to the workshop participants, from which a vision of the needs and requirements for the module was obtained. The KPIs previously defined by the module developer were also presented and feedback was asked for.

Firstly, some questions to define our users' current situation were presented. Most of our users are currently using some form of power generation forecast, and some are already using data from C3S and ECMWF. Other providers were ESTG and Meteoblue. Overall, characteristics such as high accuracy, high spatial resolution, user friendliness and scalability were important. Of even more significance was having different ways you could interact with the software, so that it can be adapted and integrated with the user's needs, as well as to ensure interoperability.

Secondly, some technical questions about the forecast were asked. While the users were mostly interested in day-ahead or same-day forecasts, some also considered medium term forecasts interesting for planning purposes. The initial target of a 5 to 10% deviation on day-ahead forecasts was asked to be more demanding and changed to up to 5% deviation.

With interoperability in mind, we were asked to offer not only a graphical interface but also an API, and to follow standards.

When asked about the price they were willing to pay for such a service, our users commented that the price of the service had to be lower in order to save from using our service by reducing the cost of deviation.

3.2.2 Demand Forecast – Topics and Feedback

Similarly, to the previous module, the participants were asked about their current situation with regards to the demand forecast. Most of them use some form of demand forecast, mostly an in-house made tool, but also ECMWF. Some valued characteristics were scalability, interoperability, and considering the effect of weather in energy consumption. Most of them deal with different kinds of customers, including a mix of residential, business and shops, and industrial consumers.

On the forecast itself, once again our users were more interested in day-ahead forecasting, but also saw value in having medium term forecasts for planning purposes. They were mostly interested in receiving values for active power and energy consumption. VICOM was interested in knowing if the users were more interested in higher resolution power forecasting or in smaller resolution energy forecasting, with this last point assuming a constant power consumption throughout the forecasted period and with a higher accuracy. For this, the answer was both.

Once again, the participants think it is valuable to be able to interact with the software via an API, and their own savings on deviation costs from using a simpler algorithm to this one will reflect how much they are willing to pay for the service.

3.2.3 Timing & Synchronisation – Topics and Feedback

The main issues our users expect to solve with the T&S module are grid congestions and voltage volatility. Some challenges they foresee are adapting PMUs from different manufacturers, fitting the PMUs locations with different topologies, and using PMUs at medium voltage grid as, so far, it is commonly used only on transmission grids. Of most importance was the need for edge computing to pre-process some of the data and reduce the amount of data both sent and stored.

3.2.4 RESPONDENT Solution Suite – Topics and Feedback

The different possibilities for RESPONDENT's products business models were briefly discussed, and there was a preference from the participants for a software as a service approach. It was confirmed that there is an interest from energy holding groups in using the overall solution suite.

4 Requirements

4.1 Requirements Classification

The classification of requirement for the Modules is synthesised in the following categories:

- **Functional**: Requirements related to the functionalities of each module depends on each of the characteristics of the module to cover the needs and preferences of the end-users.
- **Interoperability**: Requirements related to the capacity of the modules to interact with different sources and devices.
- **User-Interface**: Requirements related to the interface displayed to the end-user, including user-friendliness and the information displayed.
- **Business**: Requirements related to the needs and preferences that would directly affect the competitiveness of the module in the market compared to other existing solutions.
- **Results**: Requirements related to the outcome expected of the end-users after employing the respondent solution.

4.2 Requirements for the RESPONDENT Solution

From the feedback provided by the stakeholders that participated in the workshop, a final list of requirements was created for each of the modules that included the needs and preferences of the potential end-users. As stated previously, the contents of the Mural were discussed among the consortium to match the final requirements with realistic scopes.

To describe each of the requirements for the modules in similar terms, a table of contents has been created with a set of key information that needs to be filled. A description of the contents required can be found below.

- **Requirement ID**: an ID tag that can easily identify a specific requirement, since it is composed by the initials of the module it belongs to and the type of requirement; e.g. PGF-F001, the first Forecast Functionality requirement from the Power Generation Forecast Module
- **Title**: Common name of the requirement that includes a small description about the contents.
- **Type**: The type of requirement amongst the classification described before in the document.
- **Description**: A complete description of the requirement.
- **Success Criteria**: The criteria to determine if the requirement has been fulfilled.
- **Dependencies**: Needs that the module might have to be able to complete the requirement.
- **Priorities**: States the importance of the requirement for the end-users. While some requirements might be *Highly Recommended*[1] or *Recommended* by the end-users, others might just be *Nice to Have*, depending on the importance that the end-users attributed to each one.

Among the specific dependencies for each requirement, there is an overall dependency on data availability and on using UX methodologies for the requirements for all three modules.

[1] Translates to *“Mandatory”*

4.2.1 Power Generation Forecast Module Requirements

A list of end-user requirements for the Power Generation Forecast Module is provided below.

Table 3 - Requirements for the Power Generation Forecast Module

Requirement ID	PGF-FF001
Title	Accuracy for day-ahead forecasts
Type	Forecast Functionality
Description	The PGF algorithm must have a minimum accuracy of 94% for day-ahead or same-day forecasts
Success Criteria	Accuracy of 94% for day-ahead and same-day forecasts
Dependencies	N/A
Priorities	Highly Recommended

Requirement ID	PGF-FF002
Title	Accuracy for intra same-day forecasts
Type	Forecast Functionality
Description	The PGF algorithm must have a minimum accuracy of 94% for intra-day forecasts.
Success Criteria	Accuracy of at least 94% for intra-day forecasts
Dependencies	N/A
Priorities	Highly Recommended

Requirement ID	PGF-FF003
Title	Accuracy for medium term forecast
Type	Forecast Functionality
Description	The PGF algorithm must have a minimum accuracy of 90% (medium) for medium-term forecasts
Success Criteria	Accuracy of 90% for 3 day-ahead to day-ahead forecasts
Dependencies	N/A
Priorities	Recommended

Requirement ID	PGF-FF004
Title	Spatial resolution
Type	Forecast Functionality
Description	The PGF algorithm must have a significant spatial resolution
Success Criteria	A spatial resolution sufficient to cover the micro-climatic differences of the area
Dependencies	Spatial resolution of the satellite data in conjunction with in-situ measurements
Priorities	Nice to have

Requirement ID	PGF-I001
Title	Interoperability with existent weather stations and/or other 3rd party weather data suppliers
Type	Interoperability
Description	The module must be able to receive data from different weather stations (in case the end user has their own weather stations and we do not need to install our own)
Success Criteria	Capacity to receive data from unaffiliated weather stations
Dependencies	Unaffiliated weather station capacity to share the data
Priorities	Highly Recommended

Requirement ID	PGF-I002
Title	Work within standards
Type	Interoperability
Description	The exchange of data of the module must conform to standards
Success Criteria	The module conforms to standards (if applicable)
Dependencies	Availability of existing defined standards
Priorities	Highly Recommended

Requirement ID	PGF-I003
Title	Data consistency

Type	Interoperability
Description	The data generated in the module must be consistent
Success Criteria	The format of all data generated should be consistent
Dependencies	Availability of standards
Priorities	Highly Recommended

Requirement ID	**PGF-I004**
Title	Access to the data
Type	Interoperability
Description	The modules must provide an API to allow the data to be accessible to the user on demand.
Success Criteria	The interaction is validated by the users
Dependencies	N/A
Priorities	Highly Recommended

Requirement ID	**PGF-UI001**
Title	User Interface information
Type	User Interface
Description	The user interface must display at least the following information: - Coordinates of the Power Generation installation - Total daily yield and the forecast - Accuracy of a given forecast - Power production ranking per site (in case multiple sites exist)
Success Criteria	The user interface is developed following UX methodologies
Dependencies	N/A
Priorities	Highly Recommended

Requirement ID	**PGF-B001**
Title	Competitive commercial use
Type	Business

Description	The module must contribute to the user reducing the imbalance cost when used for commercial purposes. The price of our product/service needs to be lower than the cost-saving it will provide.
Success Criteria	During the pilot, the savings/cost ratio observed is higher than the one in existing solutions
Dependencies	To have existing solutions to compare
Priorities	Highly Recommended

4.2.2 Demand Forecast Module Requirements

A list of end-user requirements for the Demand Forecast Module is provided below.

Table 4 - Requirements for the Demand Forecast Module

Requirement ID	**PDF-FF001**
Title	Accuracy for day-ahead forecast
Type	Forecast Functionality
Description	The DF algorithm must have an accuracy of 80-90% for day-ahead or same-day forecasts, both for active power and energy consumption
Success Criteria	80% of accuracy is achieved
Dependencies	N/A
Priorities	Highly Recommended

Requirement ID	**PDF-FF002**
Title	Accuracy for short time forecast
Type	Forecast Functionality
Description	The DF algorithm must have an accuracy of 85-95% for a resolution of 15 min., both for active power and energy consumption.
Success Criteria	85% of accuracy is achieved
Dependencies	N/A
Priorities	Highly Recommended

Requirement ID	**PDF-FF003**

Title	Temperature Consideration
Type	Forecast Functionality
Description	The DF algorithm must take temperature into account, and apply it to the comfort models
Success Criteria	Comfort models are considered inputs of the model
Dependencies	N/A
Priorities	Recommended

Requirement ID	**PDF-FF004**
Title	Distinct type users
Type	Forecast Functionality
Description	The DF algorithm must consider the differences between residential, commercial, and industrial users' energy consumption
Success Criteria	Consumers are clustered with a precision >75%
Dependencies	N/A
Priorities	Recommended

Requirement ID	**PDF-I001**
Title	Interoperability with different data providers
Type	Interoperability
Description	The programme must be able to receive data from different providers/sources
Success Criteria	Data from different providers/sources is operable by the pre-processing modules
Dependencies	Data received is incorrupt
Priorities	Highly Recommended

Requirement ID	**PDF-I002**
Title	Work Within standards
Type	Interoperability
Description	The exchange of data of the module must conform to standards

Success Criteria	The module conforms to standards (if applicable)
Dependencies	Availability of existing defined standards
Priorities	Highly Recommended

Requirement ID	**PDF-I003**
Title	Access to the data
Type	Interoperability
Description	The modules must provide an API to allow the data to be accessible to the user on demand.
Success Criteria	The interaction is validated by the users
Dependencies	N/A
Priorities	Highly Recommended

Requirement ID	**PDF-UI001**
Title	User Interface information
Type	Interoperability
Description	The user interface must display at least the following information: - Total daily yield and the forecast - Accuracy of a given forecast
Success Criteria	The accuracy is shown in the user interface following UX methodologies
Dependencies	N/A
Priorities	Recommended

Requirement ID	**PDF-B001**
Title	Competitive commercial use
Type	Business
Description	The module must contribute to the user reducing the imbalance cost when used for commercial purposes. The price of our product/service needs to be lower than the cost-saving it will provide.

Success Criteria	During the pilot, the savings/cost ratio observed is higher than the one in existing solutions
Dependencies	To have existing solutions to compare
Priorities	Recommended

4.2.3 Timing & Synchronisation Module Requirements

A list of end-user requirements for the Timing & Synchronisation Module is provided below.

Table 5 - Requirements for the Timing & Synchronisation Module

Requirement ID	TS-F001
Title	Normal Operation Timestamps
Type	Functional
Description	The DSO must receive information for SCADA with a timestamp of 1-5 min (Normal Operation)
Success Criteria	More than 90% of the data with the correct timestamp
Dependencies	N/A
Priorities	Highly Recommended

Requirement ID	TS-F002
Title	Fault Detection and Protection Tripping
Type	Functional
Description	The DSO can receive information for SCADA with a resolution under 1-2ms in case of alarm/fault
Success Criteria	More than 85% of the faults identified
Dependencies	N/A
Priorities	Highly Recommended

Requirement ID	TS-F003
Title	Work with limited communication and/or storage capacity
Type	Functional

Description	The module must be able to deal with limited communication and/or storage capacity
Success Criteria	Operating correctly under 3G connection (3Mbps)
Dependencies	N/A
Priorities	Highly Recommended

Requirement ID	TS-F004
Title	Adaptable to different topologies
Type	Functional
Description	The module must be able to adapt to different topologies and to cope with grid uncertainty
Success Criteria	State estimation accuracy >85% for any grid
Dependencies	N/A
Priorities	Highly Recommended

Requirement ID	TS-F005
Title	Module must work in MV & LV
Type	Functional
Description	The module must be implemented both in medium voltage and low voltage.
Success Criteria	State estimation accuracy > 85% for any grid
Dependencies	N/A
Priorities	Nice to Have

Requirement ID	TS-F006
Title	Different PMU models compatibility
Type	Functional
Description	The module must be compatible with different PMU manufacturers
Success Criteria	Easy to integrate with at least 2 different PMUs from different manufacturers
Dependencies	N/A

Priorities	Highly Recommended

Requirement ID	**TS-R001**
Title	Congestion reduction
Type	Results
Description	A DSO user must be able to reduce congestions by using the module
Success Criteria	A DSO must be able to reduce congestions by at least 15%
Dependencies	N/A
Priorities	Nice to Have

Requirement ID	**TS-R002**
Title	Increase Voltage Stability
Type	Results
Description	A DSO user must be able to increase its voltage stability by using the module
Success Criteria	A DSO must be able to increase its voltage stability at least by 10%
Dependencies	N/A
Priorities	Nice to Have

Requirement ID	**TS-R003**
Title	Improve Observability
Type	Results
Description	A DSO user must have a better grid reference/observability by using the module
Success Criteria	A DSO (for SCADA) has a better grid reference/observability (even in faraway areas)
Dependencies	N/A
Priorities	Nice to Have

5 Use Cases and Scenarios

In this section, the collected use cases are presented. As stated in the proposal, the definition of each use case has considered the potential end-users' requirements.

For the definition of use cases, a template of the IEC 62559 Standard [6] has been used. The template and complete information of each use case can be found in the annexes of this document.

5.1 Power Generation Forecasting Use Case

In the context of the European energy transition, an increase in the penetration of renewable energy sources into the energy mix has been observed. According to the EU target model, which is implemented in all the European countries, energy market participants, in order to sell their energy production to the local / national grids, have to participate in the respective spot markets (Day-Ahead Market (DAM) and Intra-Day (IDA)). The energy bids should be of high accuracy in order to avoid paying imbalance costs, for which having a power generation accurate forecasting brings value.

The objective of this use case is the evaluation and the optimization of a power generation forecasting algorithm in accordance with the user requirements as they have been defined in previous sections of this deliverable. In order to achieve the successful energy transition into the RES production, the grid operators must be assured of the availability of the hourly/daily energy production amounts, so that any grid faults and/or malfunctions (such as power outages), are mitigated and/or prevented. Thus, it is necessary to have an accurate and reliable power generation forecast.

Kiefer's solar PV park in Artemida (Figure 2), has a total capacity of 494.91kWp and is located within the administrative boundaries of the municipality of Spata, East Attica Region (Figure 3). It has been in operation since March 2021 and is connected to the local MV power grid. The park is a fixed structure PV system at a 15° tilt angle, with 1222 monofacial monocrystalline modules (type JKM405M-72H-V) manufactured by JinkoSolar. It includes 7 Huawei manufactured inverters, type HUAWEI-SUN 2000-60KTL-M0. It works at 1000V DC and 400V AC. The transformation to Medium Voltage at 20KV is done by a 500kVA oil transformer. The monitoring of the system is performed by the Huawei Smartlogger integrated monitoring device, which sends the data to the Huawei portal at 15-min intervals. For the needs of the RESPONDENT project, a weather station has been installed on top of the roof of the park's substation building.

Complete information of the Use Case can be found in Annex 3.

Figure 2 - Detailed satellite view of the park in Artemida

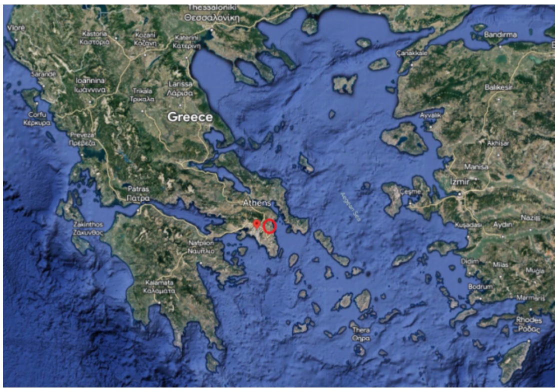

Figure 3 - Location of the park in the Attica region of Greece

5.2 Demand Forecasting Use Case

The electrical consumption measurements of > 100 customers, residential, commercial, and industrial are monitored every 5 minutes and stored in an IIOT Cloud. This data is then processed and stored in a time-series database, which has several advantages such as the interface for visualisations and data processing, alarm generation, real-time monitoring and, above all, it is serverless.

The industrial and commercial customers are from Gipuzkoa (Figure 4), a province of Spain and a historical territory of the autonomous community of the Basque Country, which has a GDP of 36281 € per capita. Gipuzkoa shares borders with France to its northeast, with the autonomous community of Navarre at its east, Biscay to its west, Alava at its southwest and the Bay of Biscay to its north. It has 66 kilometres of coastal land, with a total area of 1,980 km2. The oceanic climate gives the province an intense green colour with little thermic oscillation.

The residential customers are from Barcelona (Figure 5), a province of eastern Spain, in the centre of the autonomous community of Catalonia, with a GDP of 30.619 € per capita. It is bordered by the provinces of Tarragona, Lleida, and Girona, and by the Mediterranean Sea. Its area is 7,726 km2. The majority of the Province of Barcelona has a Mediterranean climate on the coast and an oceanic climate inland.

Complete information of the Use Case can be found in Annex 4.

Figure 4 - Gipuzkoa

Figure 5 - Barcelona

5.3 Time Synchronisation of Smart Grids through Galileo-Enabled Phasor Measurement Units

The grid integration of RES at the distribution system level can be technically challenging to address. RES are stochastic, intermittent and behave in a fundamentally different way than conventional generation from thermal and hydro power plants. A remarkable feature, affecting the stability of the power grid, is the lack of synchronous inertia of variable RES, such as solar and wind. As an increasing share of energy generation from conventional power plants is replaced by RES, faster and unexpected dynamic events are affecting the grid. These events cannot be tracked by conventional, low resolution SCADA systems.

WAMSs provide a solution to this problem: they consist of a network of advanced sensors, the PMUs, that support the identification of dangerous dynamic behaviour and risks of instability. The main feature of PMUs is that they are able to measure synchrophasors; e.g., time-stamped phasors whose reference for phase angle measurements is synchronised over a wide area. According to the IEEE C37.118 Standard [7] on synchrophasors the accuracy of time synchronisation between PMUs should be 1 μs, as a minimum, to guarantee correct time stamping and phase angle measurement.

Such time synchronisation accuracy requires the periodic adjustment of inaccurate clocks of PMUs to atomic clocks over large distances. This can be most practically achieved through GNSSs, the satellites of which contain atomic clocks onboard, although alternative solutions involving physical connections to atomic clocks on earth exist. Currently, most commercial PMUs are synchronised with GPS, which can guarantee the time accuracy required for PMU applications. However, a potential and more accurate alternative for time synchronisation of PMUs is Galileo, the European GNSS.

For this reason, the aim of this use case is to develop a Galileo-enabled PMU and test its application on a real grid (Figure 6), virtually connected to the IREC Energy Smartlab microgrid. After the development phase, the enhanced monitoring, control and resilience of the grid, thanks to the Galileo-enabled PMU, will be validated through specific experimental tests, involving Power Hardware-in-the-loop (PHIL). Additionally, the optimal location of the PMUs will be evaluated following the module developed. Finally, potential planning approaches such as applications for enhanced power grid observability and fault and stability analysis will be evaluated, and a signal monitoring dashboard will be developed.

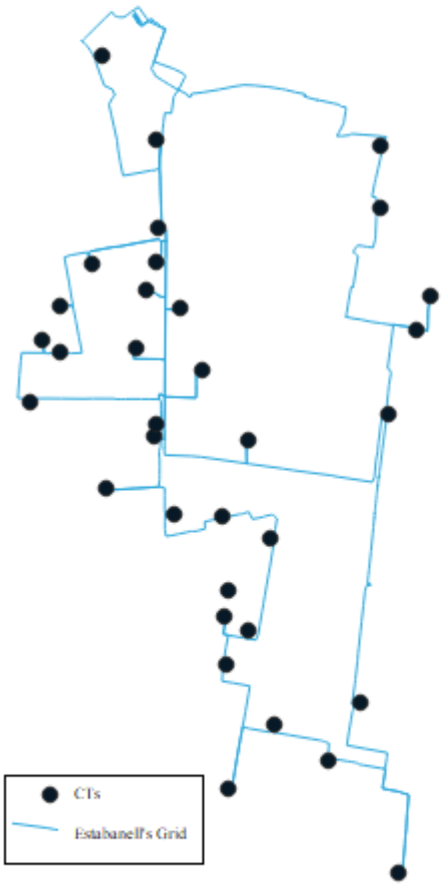

Figure 6 - Section of Estabanell's Low Voltage Grid (Blue line) showing Secondary Substations (Black dots)

6 Mapping Use Cases to Requirements

It is important that the requirements collected from the potential end-users are considered in the RESPONDENT solution. To ensure this is the case, a mapping has been created to reflect which of the use cases will be tested for each of the requirements collected. The mapping can be found in the following table (Table 7).

	Requirement ID	Use Cases and Scenarios
	PGF-FF001	Power Generation Forecast Use Case (Scenario 1.1)
	PGF-FF002	Power Generation Forecast Use Case (Scenario 1.3)
	PGF-FF003	Power Generation Forecast Use Case (Scenario 1.2)
	PGF-FF004	Power Generation Forecast Use Case (All Scenarios)
	PGF-I001	Power Generation Forecast Use Case (All Scenarios)
	PGF-I002	Power Generation Forecast Use Case (All Scenarios)
	PGF-I003	Power Generation Forecast Use Case (All Scenarios)
	PGF-I004	Power Generation Forecast Use Case (All Scenarios)
	PGF-UI001	Power Generation Forecast Use Case (All Scenarios)
	PGF-B001	Power Generation Forecast Use Case (All Scenarios)
	PDF-FF001	Power Demand Forecast Use Case (Scenarios 2.2; 3.2; 4.2)
	PDF-FF002	Power Demand Forecast Use Case (Scenarios 2.1; 3.1; 4.1)
	PDF-FF003	Power Demand Forecast Use Case (Scenarios 2; 3; 4)
	PDF-FF004	Power Demand Forecast Use Case (Scenario 1)
	PDF-I001	Power Demand Forecast Use Case (All Scenarios)
	PDF-I002	Power Demand Forecast Use Case (All Scenarios)
	PDF-I003	Power Demand Forecast Use Case (All Scenarios)
	PDF-UI001	Power Demand Forecast Use Case (All Scenarios)
	PDF-B001	Power Demand Forecast Use Case (All Scenarios)
	TS-F001	Time Synchronisation of Smart Grids through Galileo-enabled Phasor Measurement Units (Scenario 1)
	TS-F002	Time Synchronisation of Smart Grids through Galileo-enabled Phasor Measurement Units (Scenario 1)

	TS-F003	Time Synchronisation of Smart Grids through Galileo-enabled Phasor Measurement Units (Scenario 1)
	TS-F004	Time Synchronisation of Smart Grids through Galileo-enabled Phasor Measurement Units (Scenario 1)
	TS-F005	Time Synchronisation of Smart Grids through Galileo-enabled Phasor Measurement Units (Scenario 1)
	TS-F006	Time Synchronisation of Smart Grids through Galileo-enabled Phasor Measurement Units (Scenario 1)
	TS-R001	Time Synchronisation of Smart Grids through Galileo-enabled Phasor Measurement Units (Scenario 1)
	TS-R002	Time Synchronisation of Smart Grids through Galileo-enabled Phasor Measurement Units (Scenario 1)
	TS-R003	Time Synchronisation of Smart Grids through Galileo-enabled Phasor Measurement Units (Scenario 1)

Table 6 - Mapping of Use Cases to Requirements

7 Solution Integration Plan

Although the first steps for the solution integration plan have been defined within the works of Task 2.1 and Task 2.2 and are reflected in the definition of requirements and use cases, the main definition of the Plan for Integration is defined in Task 2.3 and, from that, the plan that specifies the integration of the modules and full solution suite can be found in Deliverable 2.2.

8 Conclusions

The collection of requirements provided in this document indicates the scope of the potential that end-users of the RESPONDENT solution can expect from the project. These sets of requirements can be functional or operational and might affect the final success of the RESPONDENT solution among others that offer similar services.

The main objective of collecting the potential end-users' requirements is to translate them into technical specifications, which will guide the developments in the technical work packages (WP3, WP4 and WP5). In order to do so, these requirements have been considered when developing the use cases in which the different modules developed will be tested. The project will then ensure that the requirements are being tested in the use case so that when obtaining the results of the RESPONDENT modules and solution suite, the potential end-users' needs and preferences will be evaluated.

The intention of this initial task in the beginning of the project was to apply and implement the foundation of the end users' needs and preferences and the impact on the modules which will set the framework for the technical work packages and the corresponding development of the solutions, rather than to document the use cases and requirements in the more technical detail.

To summarise, the forecasting modules of our end-users were mainly focused on its accuracy and reducing their imbalance costs, while for the T&S module, an important insight was the need to treat and share a large amount of data. Overall, there was a concern on interoperability and user-friendliness of the platforms. Each use case was built around one of the three modules and will consider the user requirements from the respective module.

The updates and improvements will be a "live" process to be updated and refined throughout the lifecycle of the project.

References

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[8] Dapeep, “Renewable Energy Sources Operator & Guarantees of Origin,” 24 08 2022. [En línia]. Available: https://www.dapeep.gr/wp-content/uploads/2022/08/2022.08.24%20%CE%9A%CF%8E%CE%B4%CE%B9%CE%BA%CE%B1%CF%82%20%CE%94%CE%91%CE%A0%CE%95%CE%95%CE%A0%20%28%CE%88%CE%BA%CE%B4%CE%BF%CF%83%CE%B7%203.3%29.pdf?_t=1661764905.

Annexes

1. Annex 1: Contents of the Mural after the workshop

The is following link is to the Mural page that was used for the Requirements Elicitation Workshop.

https://app.mural.co/t/estabanell4824/m/estabanell4824/1675954434418/17cfa6e6a30bb75081fca3cf095ac7b87bd469b4?sender=ud638f38568d3713754fb4196

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2. Annex 2: Use Case Template

Scope and objective of the Use Case

Scope	
Objective	
Related business cases	

Narrative of the Use Case

Short Description

Short description of the Use Case

Complete Description

Detailed description of the Use Case

Key Performance Indicators

ID	Name	Description
KP_1	….	….
KP_n		

Use Case conditions

Assumptions	Prerequisites

Diagram of the Use Case

Depending on the level of details, a diagram can be added

Actors

Actor name	Actor type	Actor description
Aggregator	System	…
DSO	Person	…

Analysis of the Use Case

Overview of scenarios

N.	Scenario name
1	Clusterisation of consumers

Scenario 1: Clusterization of consumers

Step N.	Name of Event	Description of event	Service	Information sender	Information receiver	Information exchanged
1	Data request	Requests weather data	GET	Weather data provider	Aggregator	Weather data
2	…					

3. Annex 3: Power Generation Forecasting Use Case

Scope and objective of the Use Case

Scope	Evaluation and training/optimization of the power generation forecasting algorithm
Objective	Maximising the power generation forecasting accuracy and reliability
Related business cases	Participation in the Energy Stock Exchange+-

Narrative of the Use Case

Short Description

Solar PV plant power generation with respect to the local microclimatic conditions.

Complete Description

In the context of the European energy transition, an increase in the penetration of renewable energy sources into the energy mix has been observed. According to the EU target model, which is implemented in all the European countries, energy market participants, in order to sell their energy production to the local / national grids, have to participate in the respective spot markets (Day-Ahead Market (DAM) and Intra-Day (IDA)). The energy bids should be of high accuracy in order to avoid paying imbalance costs, for which having a power generation accurate forecasting brings value.

The objective of this use case is the evaluation and the optimization of a power generation forecasting algorithm in accordance with the user requirements as they have been defined in previous sections of this deliverable. In order to achieve the successful energy transition into the RES production, the grid operators must be assured of the availability of the hourly/daily energy production amounts, so that any grid faults and/or malfunctions (such as power outages), are mitigated and/or prevented. Thus, it is necessary to have an accurate and reliable power generation forecast.

Kiefer's solar PV park in Artemida (Figure 2), has a total capacity of 494.91kWp and is located within the administrative boundaries of the municipality of Spata, East Attica Region (Figure 3). It has been in operation since March 2021 and is connected to the local MV power grid. The park is a fixed structure PV system at a 15° tilt angle, with 1222 monofacial monocrystalline modules (type JKM405M-72H-V) manufactured by JinkoSolar. It includes 7 Huawei manufactured inverters, type HUAWEI-SUN 2000-60KTL-M0. It works at 1000V DC and 400V AC. The transformation to Medium Voltage at 20KV is done by a 500kVA oil transformer. The monitoring of the system is performed by the Huawei Smartlogger integrated monitoring device, which sends the data to the Huawei portal at 15-min intervals. For the needs of the RESPONDENT project, a weather station has been installed on top of the roof of the park's substation building.

Key Performance Indicators

ID	Name	Description

KP_1	Weather Forecasting	<10% deviation
KP_2	Power Generation Forecasting: same-day	Deviation between Real generated power and forecasted (<6%)
KP_3	Power Generation Forecasting: day-ahead	Deviation between Real generated power and forecasted (<6%)

Use Case Conditions

Assumptions	Prerequisites
Reliable weather data (huge importance) // weather station technical availability	Weather data consistency
Grid and PV park availability	No grid faults, maintenance, extended black outs
Spatial resolution (depends on the resolution of the available satellite data)	1.000m^2 (33m X 33m)

Diagram of the Use Case

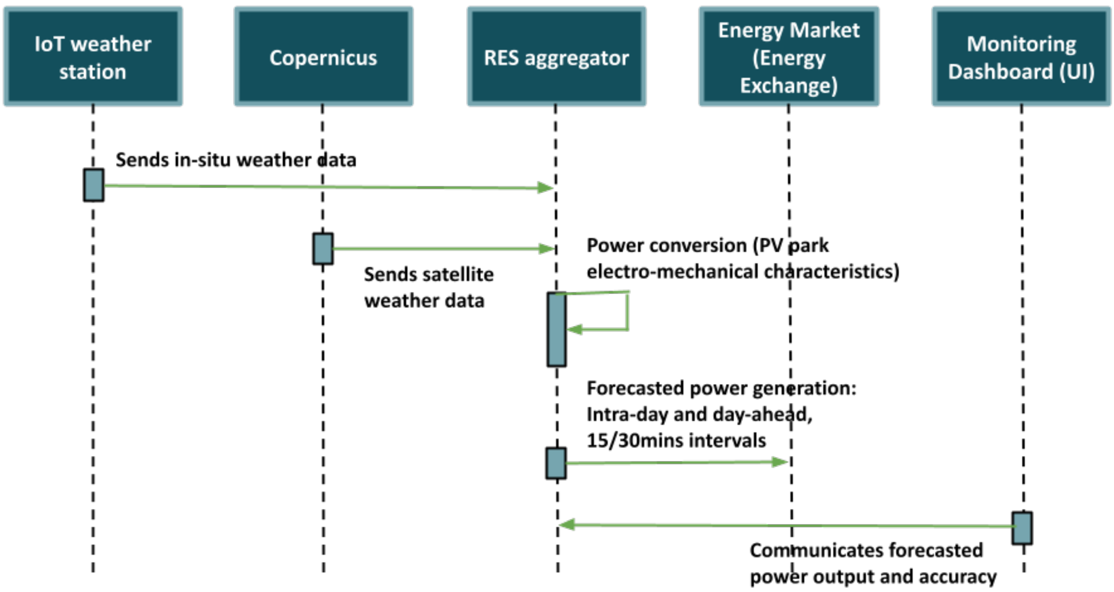

Figure 7 - Flow Diagram of the use case

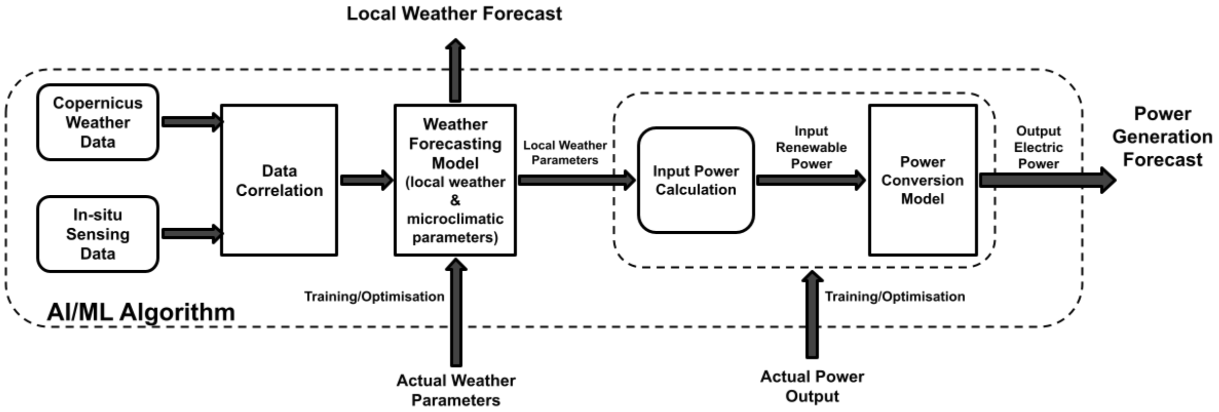

Figure 8 - Flow diagram of the use case

Actors

Actor name	Actor type	Actor description
IoT weather data provider	System	FINT's IoT data aggregation and management system
Satellite weather data provider	System	Copernicus EO programme
Aggregator	System	KIEFER: RES power producer and energy aggregator
Energy Exchange	Institution	Electric power and related commodities exchange

Analysis of the Use Case

Overview of the scenario

In this use case, the forecast functionality, the interoperability, the user interface and the competitiveness of the power generation forecasting module will be tested. In order to assess and validate the forecast functionality, the 3 day ahead, the day ahead and the intra-day forecasting accuracy will be independently tested. This will be done by comparing the absolute forecasted values to the actual power generation values. In case that the deviation is >6%, an examination of several external parameters that might have affected the algorithm's accuracy must take place. These parameters include:

a. the consistency of the weather data received by the local weather station (e.g., is the weather station working properly? Is there any data that has not been transmitted?)

b. the local grid availability (e.g., was the grid under maintenance? Did any extended blackout happen?)

Then the following cases must be examined:

i. If any or both above occurred, the algorithm's forecasting should not be considered as valid, and the forecasting results should not be considered for the PGF algorithm assessment.

ii. If none of the above faults occur and the forecasting deviation was beyond the limit set in the current deliverable (D2.1), the algorithm should be examined/tested in terms of its normal operation. This test will be done by running the algorithm repeatedly with the same input values and check if it produces the same results.

iii. If there are no faults and the algorithm works normally, we should check if by increasing the spatial resolution we get better results.

iv. If none of the above i, ii and iii occurs, the algorithm may require further training.

The KPIs regarding the interoperability and the user interface are qualitative and cannot be checked at this point of the project development.

Regarding the competitiveness of the commercial product, it is obvious that it could be calculated after the end of pilot 1 (Artemida Use Case). The total resulting imbalance costs will be calculated, considering the methodology described in the existing decisions of the Regulatory Authority of Energy the code Renewable Energy Sources Operator & Guarantees of Origin (DAPEEP SA) [8] and the imbalance market regulations.

An aggregator will be willing to pay a specific price (yearly / MW) for the product in the case that this price will be lower than its total revenues per year (Annual Revenues = Aggregator's charging – imbalance costs).

Scenario 1: Power Generation Forecast

Scenario 1.1: day ahead (hourly)

Step N.	Name of Event	Description of event	Service	Information sender	Information receiver	Information exchanged
1	Data request	Requests weather data	GET	Weather data provider	Aggregator	Weather data
2	Data request	Requests weather data	GET	Local weather station	Aggregator	Weather data
3	Data request	Requests generation data	GET	RES producer	Aggregator	Generation data
4	Forecasting	PGF day ahead	PROVIDE	Aggregator	EnEx	day ahead PGF
5	Evaluation	Evaluate accuracy	EVALUATE	Aggregator	EnEx	Accuracy

Scenario 1.2: 3 days ahead (hourly)

Step N.	Name of Event	Description of event	Service	Information sender	Information receiver	Information exchanged
1	Data request	Requests weather data	GET	Weather data provider	Aggregator	Weather data

2	Data request	Requests weather data	GET	Local weather station	Aggregator	Weather data
3	Data request	Requests generation data	GET	RES producer	Aggregator	Generation data
4	Forecasting	PGF 3 days ahead	PROVIDE	Aggregator	EnEx	3 day ahead PGF
5	Evaluation	Evaluate accuracy	EVALUATE	Aggregator	EnEx	Accuracy

Scenario 1.3: Intraday (half hourly)

Step N.	Name of Event	Description of event	Service	Information sender	Information receiver	Information exchanged
1	Data request	Requests weather data	GET	Weather data provider	Aggregator	Weather data
2	Data request	Requests weather data	GET	Local weather station	Aggregator	Weather data
3	Data request	Requests generation data	GET	RES producer	Aggregator	Generation data
4	Forecasting	PGF Intra day	PROVIDE	Aggregator	EnEx	Intraday PGF
5	Evaluation	Evaluate accuracy	EVALUATE	Aggregator	EnEx	Accuracy

4. Annex 4: Demand Forecasting Use Case

Scope and objective of the Use Case

Scope	Evaluation and training/optimization of the power demand algorithm
Objective	Maximising the power demand forecasting accuracy
Related business cases	Participation in the Energy Market

Narrative of the Use Case

Short Description

Power demand forecasting of residential, commercial and industrial customers.

Complete Description

The electrical consumption measurements of > 100 customers, residential, commercial, and industrial are monitored every 5 minutes and stored in an IIOT Cloud. This data is then processed and stored in a time-series database, which has several advantages such as the interface for visualisations and data processing, alarm generation, real-time monitoring and, above all, it is serverless.

The industrial and commercial customers are from Gipuzkoa (Figure 4), a province of Spain and a historical territory of the autonomous community of the Basque Country, which has a GDP of 36281 € per capita. Gipuzkoa shares borders with France to its northeast, with the autonomous community of Navarre at its east, Biscay to its west, Alava at its southwest and the Bay of Biscay to its north. It has 66 kilometres of coastal land, with a total area of 1,980 km2. The oceanic climate gives the province an intense green colour with little thermic oscillation.

The residential customers are from Barcelona (Figure 5), a province of eastern Spain, in the centre of the autonomous community of Catalonia, with a GDP of 30.619 € per capita. It is bordered by the provinces of Tarragona, Lleida, and Girona, and by the Mediterranean Sea. Its area is 7,726 km2. The majority of the Province of Barcelona has a Mediterranean climate on the coast and an oceanic climate inland.

Key Performance Indicators

ID	Name	Description
KP_1	Weather Forecasting	<10% deviation
KP_2	Clusterization of consumers	>75% accuracy
KP_3	Power Demand Forecasting: short time	Deviation between Real demanded power and forecasted (5-15%)
KP_4	Power Demand Forecasting: day-ahead	Deviation between Real demanded power and forecasted (10-20%)

Use Case conditions

Assumptions	Prerequisites
Weather data availability	Weather data consistency
Socio-economic data availability	Customers' location is known
Consumption data availability	No faults, maintenance, extended black outs

Diagram of the Use Case

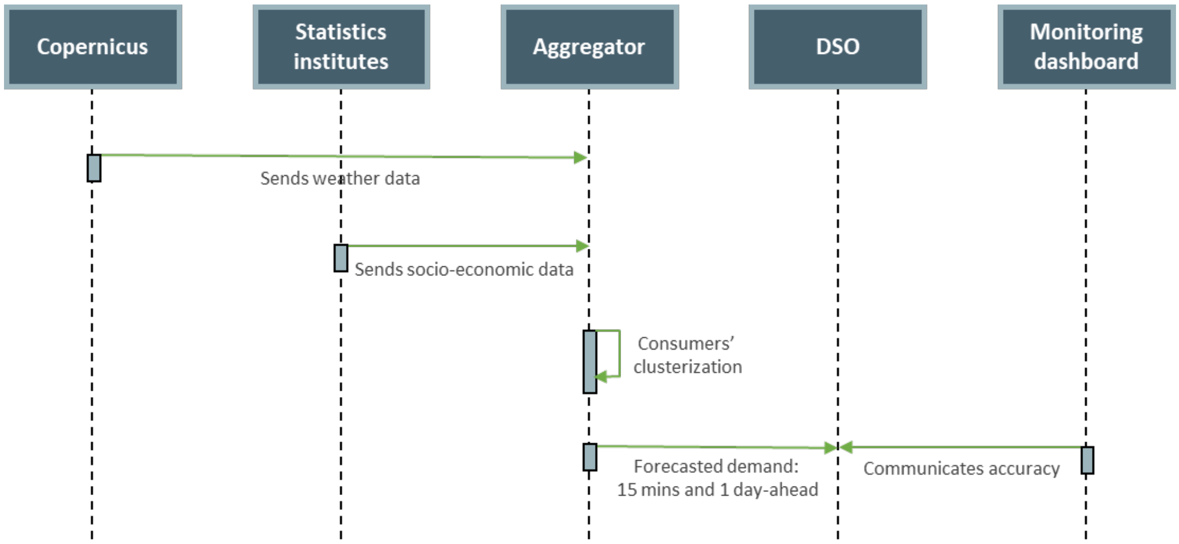

Figure 9 - DF Use case diagram

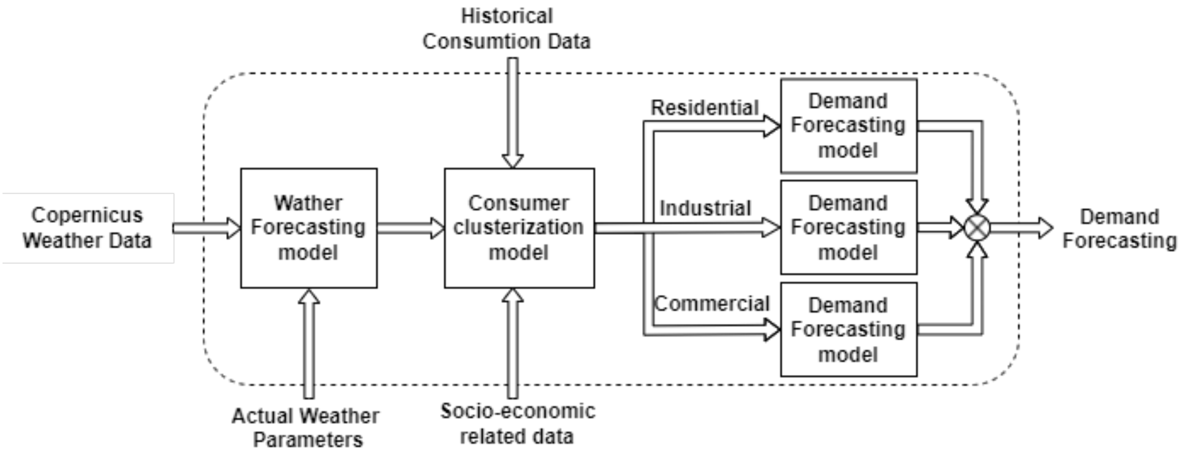

Figure 10 - Flow diagram of the use case

Actors

Actor name	Actor type	Actor description
Weather data provider	System	Provides the weather data

Socio economic data provider	System	Provides the socio-economic data
Aggregator	System	…
DSO	Person	Distributed System Operator

Analysis of the Use Case

Overview of scenarios

N.	**Scenario name**		
1	Clusterization of consumers		
2	Power demand forecast of industrial customer	2.1	15 min ahead
		2.2	Day-ahead
3	Power demand forecast of commercial customer	3.1	15 min ahead
		3.2	Day-ahead
4	Power demand forecast of residential customer	4.1	15 min ahead
		4.2	Day-ahead

Scenario 1: Clusterization of consumers

Step N.	**Name of Event**	**Description of event**	**Service**	**Information sender**	**Information receiver**	**Information exchanged**
1	Data request	Requests weather data	GET	Weather data provider	Aggregator	Weather data
2	Data request	Requests socio-economic data	GET	Statistic institutes	Aggregator	Socio-economic data
3	Data request	Requests consumption data	GET	Consumer	Aggregator	Consumption data
4	Clusterization	Cluster consumer	PROVIDE	Aggregator	Aggregator	Customer type
5	Evaluation	Evaluate accuracy	EVALUATE	Aggregator	Aggregator	Accuracy

Scenario 2: Energy demand forecast of industrial customers

a. **Scenario 2.1: 15 min ahead**

Step N.	Name of Event	Description of event	Service	Information sender	Information receiver	Information exchanged
1	Data request	Requests weather data	GET	Weather data provider	Aggregator	Weather data
2	Data request	Requests socio-economic data	GET	Statistic institutes	Aggregator	Socio-economic data
3	Data request	Requests consumption data	GET	Consumer	Aggregator	Consumption data
4	Forecasting	DF 15 min ahead	PROVIDE	Aggregator	DSO	15 min ahead DF
5	Evaluation	Evaluate accuracy	EVALUATE	Aggregator	DSO	Accuracy

b. **Scenario 2.2: day ahead**

Step N.	Name of Event	Description of event	Service	Information sender	Information receiver	Information exchanged
1	Data request	Requests weather data	GET	Weather data provider	Aggregator	Weather data
2	Data request	Requests socio-economic data	GET	Statistic institutes	Aggregator	Socio-economic data
3	Data request	Requests consumption data	GET	Consumer	Aggregator	Consumption data
4	Forecasting	DF day ahead	PROVIDE	Aggregator	DSO	Day ahead DF
5	Evaluation	Evaluate accuracy	EVALUATE	Aggregator	DSO	Accuracy

Scenario 3: Energy demand forecast of commercial customers

a. **Scenario 3.1: 15 min ahead**

Step N.	Name of Event	Description of event	Service	Information sender	Information receiver	Information exchanged
1	Data request	Requests weather data	GET	Weather data provider	Aggregator	Weather data

2	Data request	Requests socio-economic data	GET	Statistic institutes	Aggregator	Socio-economic data
3	Data request	Requests consumption data	GET	Consumer	Aggregator	Consumption data
4	Forecasting	Forecast power demand 15 min ahead	PROVIDE	Aggregator	DSO	15 min ahead demand forecasting
5	Evaluation	Evaluate accuracy	EVALUATE	Aggregator	DSO	Accuracy

b. Scenario 3.2: day ahead

Step N.	Name of Event	Description of event	Service	Information sender	Information receiver	Information exchanged
1	Data request	Requests weather data	GET	Weather data provider	Aggregator	Weather data
2	Data request	Requests socio-economic data	GET	Statistic institutes	Aggregator	Socio-economic data
3	Data request	Requests consumption data	GET	Consumer	Aggregator	Consumption data
4	Forecasting	Forecast power demand day ahead	PROVIDE	Aggregator	DSO	day ahead demand forecasting
5	Evaluation	Evaluate accuracy	EVALUATE	Aggregator	DSO	Accuracy

Scenario 4: Energy demand forecast of residential customers

a. Scenario 4.1: 15 min ahead

Step N.	Name of Event	Description of event	Service	Information sender	Information receiver	Information exchanged
1	Data request	Requests weather data	GET	Weather data provider	Aggregator	Weather data
2	Data request	Requests socio-economic data	GET	Statistic institutes	Aggregator	Socio-economic data

3	Data request	Requests consumption data	GET	Consumer	Aggregator	Consumption data
4	Forecasting	Forecast power demand 15 min ahead	PROVIDE	Aggregator	DSO	15 min ahead demand forecasting
5	Evaluation	Evaluate accuracy	EVALUATE	Aggregator	DSO	Accuracy

b. Scenario 4.2: day ahead

Step N.	Name of Event	Description of event	Service	Information sender	Information receiver	Information exchanged
1	Data request	Requests weather data	GET	Weather data provider	Aggregator	Weather data
2	Data request	Requests socio-economic data	GET	Statistic institutes	Aggregator	Socio-economic data
3	Data request	Requests consumption data	GET	Consumer	Aggregator	Consumption data
4	Forecasting	Forecast power demand day ahead	PROVIDE	Aggregator	DSO	day ahead demand forecasting
5	Evaluation	Evaluate accuracy	EVALUATE	Aggregator	DSO	Accuracy

5. Annex 5: Time Synchronisation of Smart Grids through Galileo-enabled Phasor Measurement Units

Scope and objectives of the Use Case

Scope	Precise time synchronisation of advanced sensor networks in power grids through the European GNSS (Galileo).
Objective	- Integration of Galileo receiver into commercial PMUs (Galileo-enabled PMU). - Test, demonstration, and validation of the Galileo-enabled PMU. - Development of a cloud-based PMU signal monitoring module and dashboard to remotely acquire, display and analyse time-stamped measurements from the Galileo-enabled PMU. - Improvement of power grid monitoring capabilities through the optimization of PMU locations and enhanced state estimation.
Related business cases	Commercialisation of Galileo-enabled PMUs. Installation of PMUs/µPMUs in power grids to enhance grid observability. Cross-sectorial transfer of the findings to other industries with similar time synchronisation needs

Narrative of the Use Case

Short Description

Precise time synchronisation of PMUs in power grids is crucial to enhance the observability of dynamic events on the grid and to improve their resilience. The proposed Galileo-enabled PMU aims at providing accurate and robust time synchronisation signals to PMUs. This technology will be tested on the Granollers power grid, connected to the IREC Energy Smartlab working as an interconnected microgrid.

Complete Description

The grid integration of RES at the distribution system level can be technically challenging to address. RES are stochastic, intermittent and behave in a fundamentally different way than conventional generation from thermal and hydro power plants. A remarkable feature, affecting the stability of the power grid, is the lack of synchronous inertia of variable RES, such as solar and wind. As an increasing share of energy generation from conventional power plants is replaced by RES, faster and unexpected dynamic events are affecting the grid. These events cannot be tracked by conventional, low resolution SCADA systems.

WAMSs provide a solution to this problem: they consist of a network of advanced sensors, the PMUs, that support the identification of dangerous dynamic behaviour and risks of instability. The main feature of PMUs is that they are able to measure synchrophasors; e.g., time-stamped phasors whose reference for phase angle measurements is synchronised over a wide area. According to the IEEE C37.118 Standard [7] on synchrophasors the accuracy of time synchronisation between PMUs should be 1 μs, as a minimum, to guarantee correct time stamping and phase angle measurement.

Such time synchronisation accuracy requires the periodic adjustment of inaccurate clocks of PMUs to atomic clocks over large distances. This can be most practically achieved through GNSSs, the satellites of which contain atomic clocks onboard, although alternative solutions involving physical connections to atomic clocks on earth exist. Currently, most commercial PMUs are synchronised with GPS, which can guarantee the time accuracy required for PMU applications. However, a potential and more accurate alternative for time synchronisation of PMUs is Galileo, the European GNSS.

For this reason, the aim of this use case is to develop a Galileo-enabled PMU and test its application on a real grid (Figure 6), virtually connected to the IREC Energy Smartlab microgrid. After the development phase, the enhanced monitoring, control and resilience of the grid, thanks to the Galileo-enabled PMU, will be validated through specific experimental tests, involving Power Hardware-in-the-loop (PHIL). Additionally, the optimal location of the PMUs will be evaluated following the module developed. Finally, potential planning approaches such as applications for enhanced power grid observability and fault and stability analysis will be evaluated, and a signal monitoring dashboard will be developed.

Key Performance Indicators

ID	Name	Description
KPI_1	Accuracy of timestamps	Synchrophasor measurements are associated with timestamps, whose accuracy depends on the availability of the time synchronisation source.
KPI_2	Fault Detection and Protection Tripping	PMUs should help detect faults and support grid protections.
KPI_3	Adaptability to different grid topologies	The accuracy of the state estimation should not be dependent on grid topology.

Use Case Conditions

Assumptions	Prerequisites
- The Galileo receiver can be integrated into the PMU. - Galileo time synchronisation service can guarantee an accurate and robust time synchronisation. - - Voltage phase angle difference between two distant nodes of the grid is larger than PMU measurement error.	Availability of Galileo time synchronisation service. Availability of a commercial PMU. Availability of Granollers grid data.

Diagram of the Use Case

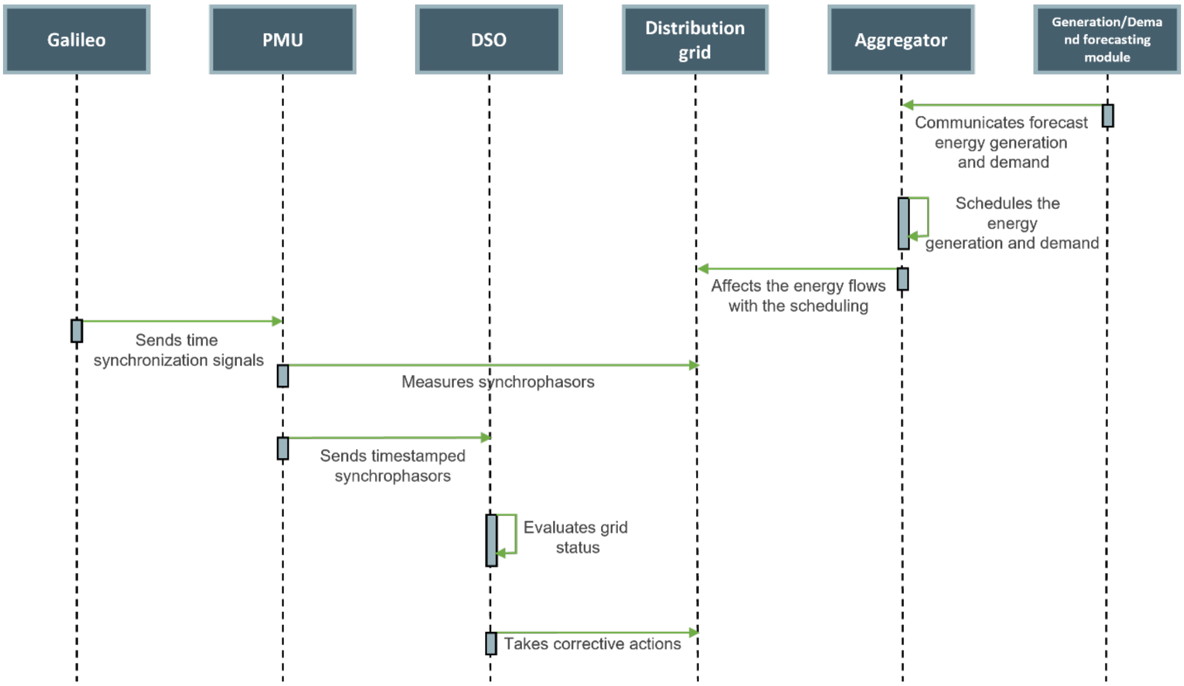

Figure 11 - Sequence Diagram of the T&S Use Case

Actors

Actor name	Actor type	Actor description
DSO	Organisation	Entity whose role includes management and planning of the distribution grid. The installation, utilisation, and maintenance of new sensors on the distribution grid, such as PMUs, is its responsibility.
PMU	Device	Device measuring the synchrophasors, e.g., synchronised and time-stamped phasors.
Distribution grid	System	System distributing power from the transmission grid and the DERs to the end users.
Galileo	System	System providing accurate and resilient time synchronisation services.
Generation/Demand forecasting modules	Software	Modules providing accurate generation and demand forecasts.
Aggregator	Organisation	Entity collecting prosumers for the optimal management of multiple energy assets.

Analysis of the Use Case

Overview of scenarios

N.	Scenario name	Actors involved
1	Enhanced grid observability in the presence of a high share of stochastic energy production from RESs	DSO, PMU, Distribution grid, Galileo,
2	Complete RESPONDENT suite demonstration	DSO, PMU, Distribution grid, Galileo, Demand forecasting module, Generation forecasting module

Scenario 1: Enhanced grid observability in the presence of a high share of stochastic energy production from RES

N.	Name of Event	Description of process	Service	Information sender	Informatio n receiver	Information exchanged
1	Grid Generation-Demand status	The DSO gathers energy generation and demand.	GET	DSO	Platform	Real energy generation and demand
2	Impact of generation and demand on the energy flows	The scheduling of energy generation and demand affects the energy flows	CHANGE	Aggregator	Distribution grid	Energy generation and demand of the assets owned by the aggregator
3	Time synchronisation signal exchange	Galileo sends the time synchronisation signal to the PMU	GET	Galileo	PMU	Time synchronisation signal
4	Synchrophasor measurement	The PMU measures the synchrophasors on the grid	GET	PMU	Distribution grid	Synchrophasor measurements
5	Data transfer	The PMU transfer the measured data to the DSO	GET	PMU	DSO	Measured data

6	Evaluation of grid status	The DSO evaluates the status of the grid	REPORT	DSO	Distribution grid	Grid status
7	Corrective actions	The DSO takes corrective actions, if needed	CHANGE	DSO	Distribution grid	Corrective actions

Scenario 2: Complete RESPONDENT suite demonstration

N.	Name of Event	Description of process	Service	Information sender	Information receiver	Information exchanged
1	Forecast communication	The forecasting modules send forecast data to the aggregator	GET	Forecasting modules	Aggregator	Generation and demand forecasts
2	Scheduling of aggregated assets	The aggregator schedules the energy generation and demand, based on the forecasts	EXECUTE	Aggregator	Aggregator	Scheduled energy generation and demand
3	Impact of generation and demand on the energy flows	The scheduling of energy generation and demand affects the energy flows	CHANGE	Aggregator	Distribution grid	Energy generation and demand of the assets owned by the aggregator
4	Time synchronisation signal exchange	Galileo sends the time synchronisation signal to the PMU	GET	Galileo	PMU	Time synchronisation signal
5	Synchrophasor measurement	The PMU measures the synchrophasors on the grid	GET	PMU	Distribution grid	Synchrophasor measurements
6	Data transfer	The PMU transfer the measured data to the DSO	GET	PMU	DSO	Measured data

7	Evaluation of grid status	The DSO evaluates the status of the grid	REPORT	DSO	Distribution grid	Grid status
8	Corrective actions	The DSO takes corrective actions, if needed	CHANGE	DSO	Distribution grid	Corrective actions