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RENEWABLE INTEGRATION & SUSTAINABILITY IN ENERGY COMMUNITIES

D4.2 – ENERGY NODES INTEGRATION REPORT

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RENAISSANCE Consortium

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Executive summary

The deliverable aims to present in detail the Energy Nodes design and development, as part of the RENAISSANCE Platform. It is the prime outcome of the work that has been carried out within Task 4.2 (RENAISSANCE Energy Node Integration), the backbone of which is based on the Fog Ready Devices (FRDs); cutting-edge technology smart devices that will be used for monitoring and control of facilities that belong to a Local Energy Community (LEC).

The document covers all hardware and software specifications of the aforementioned devices. Novel forecasting modules have been developed, in order to assist the decision support mechanisms that will guide the participation of LEC members in the Blockchain-based Smart Contract Marketplaces. Significant mention, the electricity price forecasting tool developed within the RENAISSANCE project, which takes into consideration both day ahead and intraday markets.

The FRDs, also, support Demand Side Management (DSM) signals exchanging based on OpenADR protocol. Specific entities were developed to facilitate the communication in both ends, Virtual Top Node (VTN) and Virtual End Node (VEN).

Also, the needed communication between the FRDs and external sources is achieved using a Unified API component.

All the functionalities are accessible to the different entities of a LEC (prosumers, consumers, installation technicians, etc.) via the User Interface (UI) that has been developed and presented in the deliverable.

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Table of Contents

Horizon 2020
European Union Funding
for Research & Innovation

Horizon 2020
European Union Funding
for Research & Innovation

Horizon 2020
European Union Funding
for Research & Innovation

Horizon 2020
European Union Funding
for Research & Innovation

Horizon 2020
European Union Funding
for Research & Innovation

Horizon 2020
European Union Funding
for Research & Innovation

Horizon 2020
European Union Funding
for Research & Innovation

Horizon 2020
European Union Funding
for Research & Innovation

Horizon 2020
European Union Funding
for Research & Innovation

Horizon 2020
European Union Funding
for Research & Innovation

Horizon 2020
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for Research & Innovation

Horizon 2020
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List of figures

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Horizon 2020
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List of Tables

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Definitions and acronyms

ACRONYM	DEFINITION
AI	Artificial Intelligence
ANN	Artificial Neural Network
API	Application Programming Interface
ARIMA	Autoregressive Integrated Moving Average
BMS	Building Management System
CIM	Common Information Model
CNN	Convolutional Neural Networks
CPU	Central Processing Unit
DL	Deep Learning
DNN	Deep Neural Network
DR	Demand Response
DSM	Demand Side Management
DSO	Distribution System Operator
DSS	Decision Support System
EB	Energy Box
ESS	Energy Storage System
EV	Electric Vehicle
FFT	Fast Fourier Transformation
FRD	Fog Ready Devices
GBT	Gradient Boosted Tree
GUI	Graphic User Interface
IoT	Internet of Things
LEC	Local Energy Community
LSTM	Long Short Term Memory
M2M	Machine To Machine
MAE	Mean Absolut Error
MAPE	Mean Absolut Percentage Error
MILP	Mixed Integer Linear Programming
ML	Machine Learning
MLP	Multilayer Perceptron

Horizon 2020
European Union Funding
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NGSI	Next Generation Safeguards Initiative
OS	Operative System
PAA	Piecewise Aggregate Approximation
PCB	Printed Circuit Board
PV	Photovoltaic
RES	Renewable Energy Sources
RMSE	Root Mean Squared Error
RNN	Recursive Neural Network
RP	RENAISSANCE Platform
SAX	Symbolic Aggregate approximation
SMAPE	Symmetrical Mean Absolut Percentage Error
SVM	Support Vector Machines
TSS	Trading Supervision System
URL	Uniform Resource Locators
VEN	Virtual End Node
VTN	Virtual Top Node
WP	Work Package
WPSE	Weighted Relative Squared Error
WSGI	Web Server Gateway Interface

Table 1 – List of acronyms

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1. Introduction

1.1. Scope and objectives of the deliverable

This document aims to present the effort of ATOS, CERTH and CIRCE related to the RENAISSANCE Fog Ready Devices (FRD) as occurred within Task 4.2. Covering both hardware and software aspects, the goal of these activities is to deliver a cutting edge technology that can provide a technological advantage to Local Energy Communities in automated monitoring and control of members' assets, while facilitating permission based peer-to-peer interaction at energy exchange level. Every submodule developed for that cause, is depicted in the following chapters, giving a complete overview of the task activities and results.

1.2. Structure of the deliverable

The work presented in this deliverable is structured as follows.

- **Chapter 2** presents the hardware design of FRD and Energy Box, providing the technical and operational requirements and the supported communication protocols.
- **Chapter 3** presents the software architecture of FRD's submodules. A thorough description of its functionalities regarding the asset monitoring and control, the four (4)-fold forecasting engine and Demand Side Management (DSM) signal handling.
- **Chapter 4** presents the User Interface through which each Marketplace's actor interacts with the FRD(s).
- **Chapter 5** presents the capability of FRD to communicate with external sources based on edge-technology protocols.
- **Chapter 6** concludes the report.

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1.3. Relation to other tasks and deliverables

The present deliverable is closely related to all WP4[1] tasks as well as the project's third objective - Deliver a platform for integrated management and value delivery across all actors. Especially, outcomes of Task 4.1 are highly connected to the Energy Nodes functionalities and purpose. Also, part of Task 4.6, is the testing of all RP components, so end -to-end testing scenarios will be widely analysed in the scope of its activities. In addition, the report is connected to WP5 activities that concern the demo sites integration and validation, as well as to WP7 regarding the dissemination material.

[1] AMENDMENT Reference No AMD-824342-12 Grant Agreement number: 824342 — RENewAble Integration and SuStainAbility iN energy CommunitiEs (RENAISSANCE)

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2. Description of hardware design & implementation

Two different hardware solutions were tested during Task 4.2 FRD from CERTH and Energy Box from CIRCE. Both are presented in the following paragraphs.

Figure 1 – FRD final version

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Figure 2 – Energy Box

2.1. FRD

2.1.1. Hardware specification

The aforementioned hardware solution is the result of a thorough literature review and continuous testing of different implementations. The designed solution meets the minimum criteria and requirements of FRD, hence, any further research was targeted towards improving the solution so that it can support RENAISSANCE' different use cases and support informed decision-making for cost effectiveness of local energy systems.

The general requirements of the FRD are the following:

- Support BMS communication
- Lightweight processing node
- OpenADR-compliant
- Direct communication with assets and smart meters

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Hardware Requirements				
Wired connection	Ethernet	RS-232 / UART	RS-485 / Modbus RTU	
Wireless connection	WiFi	Bluetooth	LoRa	NB-IoT
Load connection	Relay	I/O	PWM	Analog

Table 2 – FRD Hardware Requirements

2.1.2. Implementation of the core system

The implementation of the core system is depicted in the diagram below:

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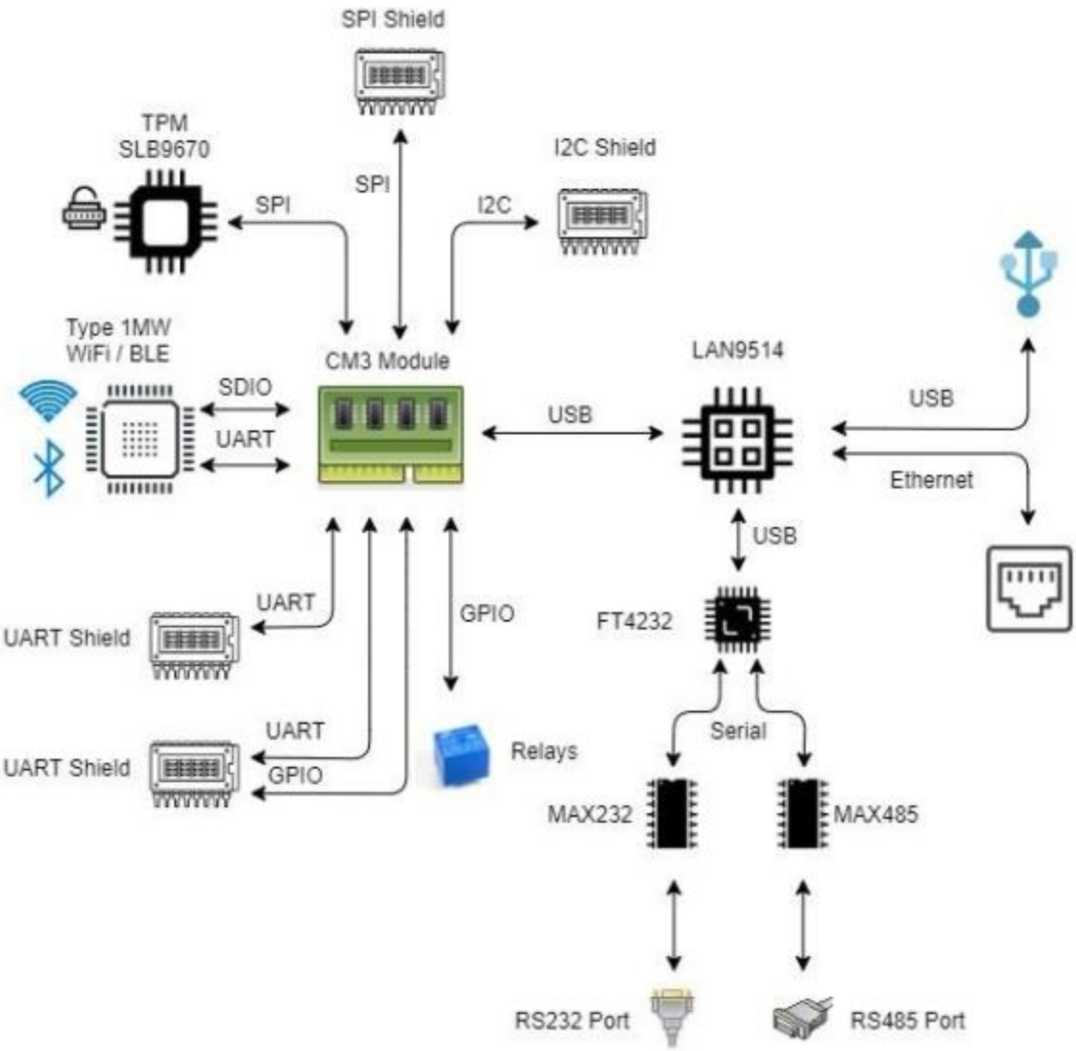

Figure 3 – FRD core system

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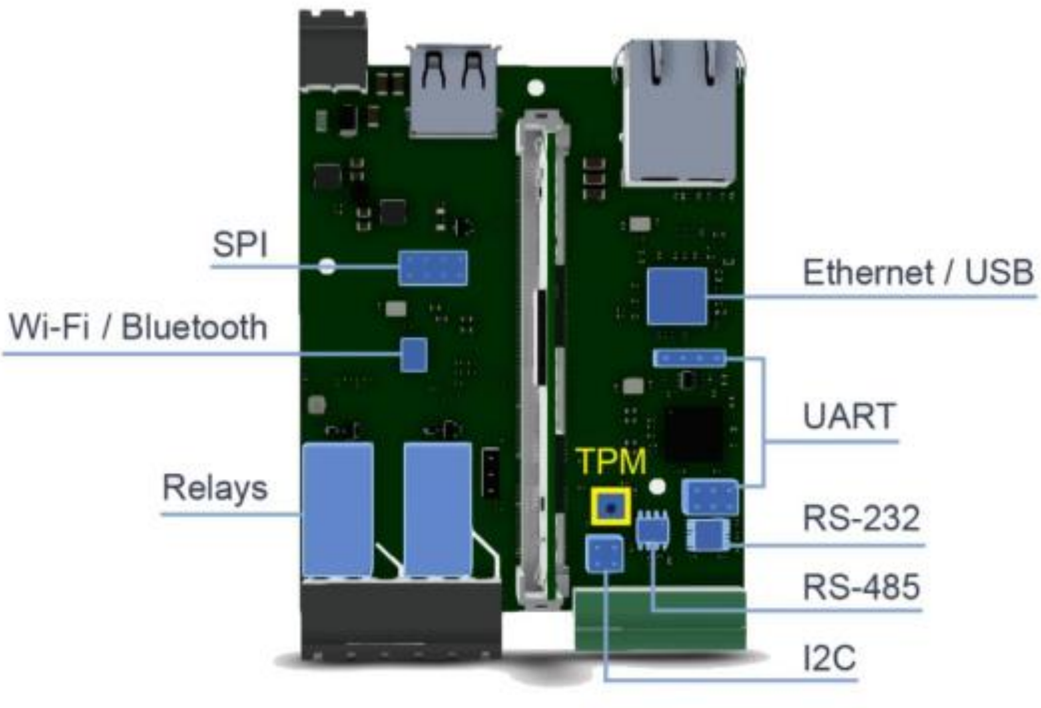

Figure 4 – Schematics of the final hardware components

2.2. Energy Box

2.2.1. Hardware specifications

CIRCE Energy Boxes (EB) are next-generation smart controllers. It was developed under the H2020 project “energy services demonstration of demand response, FLEXIbility and energy effiCIENCY based on metering data” (FLEXICIENCY). Since that project, new features and functionalities have been added and a new version of PCB was developed.

The EB reduces equipment and deployment costs via the integration of several communication technologies. Furthermore, it relies on a multi-core CPU architecture and non-blocking switching structure to provide industry-leading system capabilities, meeting not only home requirements but also

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other more complex control requirements needed for more demanding environments.

Thus, the Energy Box provides a compact and embedded solution for controlling real smart devices. The key features of this system are:

- Compact and modern design (see Figure 2 – Energy Box)
- Fan-less design that ensures quite operation in small office spaces and living rooms
- High-level services and monitoring can be performed remotely whereas local services can be processed locally, which improves service quality, security and efficiency
- Low power consumption
- Debian-based computer operating system
- Reduced form factor and light weight

The Energy Box requires an ad-hoc hardware design that complies the project requirements regarding the communication capabilities, the algorithm process, and the size and enclosure suitable for the smart home application. This versatile development includes 5 communication standards:

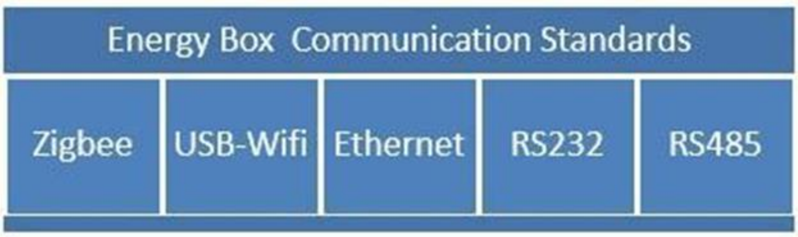

Figure 5 – EB Communication standards

The PCB can be divided in 6 blocks. Every block has different layout restrictions which are critical in order to get the hardware to operate correctly and, in consequence, their position on the layout is clearly defined. In this way, possible operational issues interferences are prevented.

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The core of the solution is the Raspberry Pi Compute Module 3, where the main functionalities of the system are located. The rest of the modules are connected to it, providing the communication interfaces necessary to achieve the integration purposes of the different protocols. In Figure 6 – Functionalities of the PCB A schematic view of the modules and their interactions are presented, and in Figure 7 – General view of the PCB components A general view of the PCB, with the main elements emphasized, is presented.

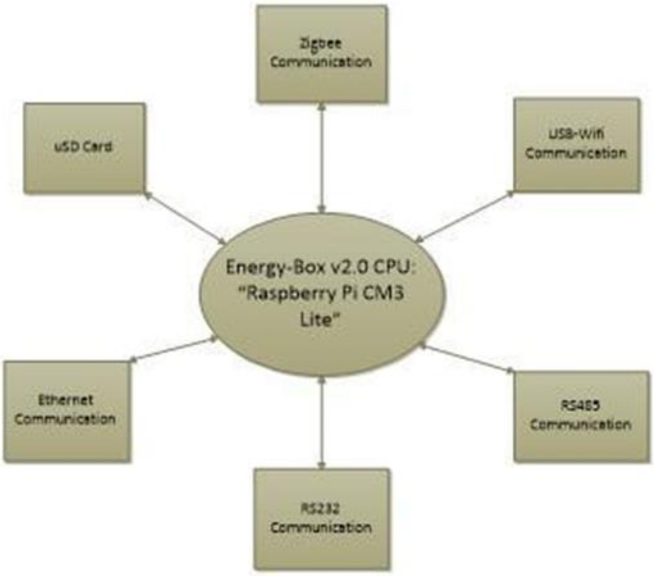

Figure 6 – Functionalities of the PCB

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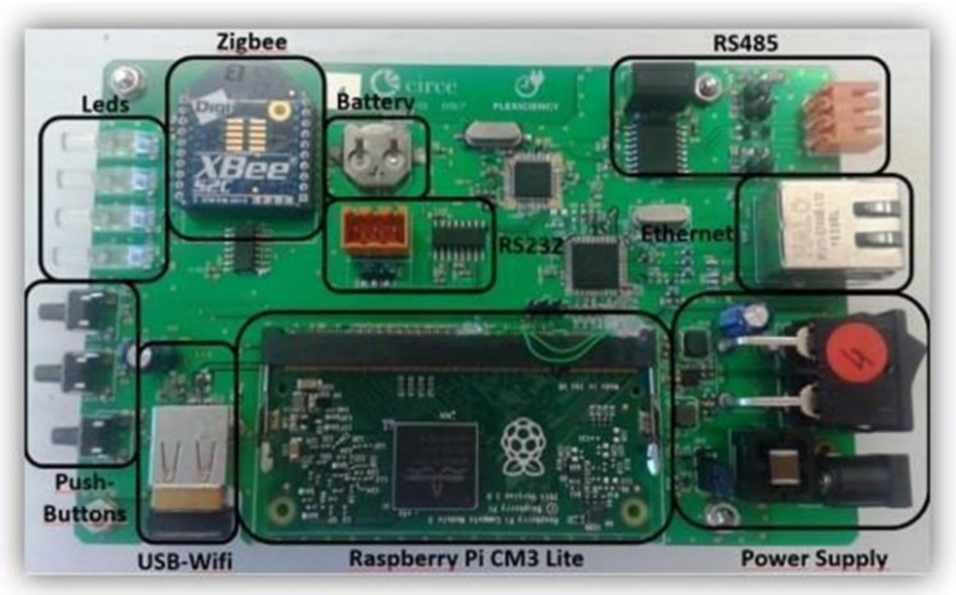

Figure 7 – General view of the PCB components

As a summary, the most relevant hardware specifications are explained below.

Energy Box Hardware Specifications	
External supply of 5 V	The Energy-Box has an external power source with +5 V output to power-up the PCB. This voltage is adapted to +3.3 V and to +1.8 V to supply the power to the rest of the PCB components.
Raspberry Pi CM3 Lite	This plug-in card is the energy box CPU.
Battery	This battery of 3 V powers up the real time clock (RTC) DS1307, which keeps track of the current time. In this way, the RTC can continue to keep timing while the primary source of power of the Raspberry is off or unavailable.

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uSD card	This card allows to storage and load the operating system in the Raspberry Pi CM3 Lite.
External LEDs	Another design consideration are the LEDs indicators that shows: • Wifi connectivity. • ZigBee connectivity. • RS485 communication. • Power indication. These 4 LEDs are shown in the exterior of the enclosure light extensors.
External push buttons	The PCB includes 3 external push-buttons to allow the user to set up the communication and to reset the system: • Wifi connection • ZigBee connection • Raspberry reset and set default values
External connectors	There are 3 connectors: • RS485 port • Ethernet Connector • 5 V Power Supply Jack
Jumpers	There are 3 types of jumpers: JP1: It enables and disables “auto-MDIX” mode for Ethernet wire. When this characteristic is enabled, the type of connection of required wire is detected, and if not, direct wires must be used. The installer can manage it according to the needs. JP2: It is for Raspberry boost. The installer does not need to move it from default position.

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	JP5, JP6 and JP7: They offer the possibility of putting a pull-up line or pull-down resistor depending on the RS485 connection. The installer can manage them according to the needs.

Table 3 – EB hardware description

2.2.2. Communication capabilities

About the communication layer, the Energy Box has two levels of communications, external and internal.

The internal communications include the communication between the auxiliary modules that provides the external communications, with the Raspberry Pi 3 module that contains the main operative system and the main functionalities. These communications are based in serial communications using dedicated ports of the Raspberry to avoid problems derived from port sharing. It includes communications with the ZigBee module, WiFi module, Ethernet connector and RS485/RS232 modules. For each one of the modules a development of their protocols has been performed between the core and the drivers of each module.

The field devices and the upstream agents (as an Energy Management System, or any kind of cloud platform) comprise the external communications. Field devices comprehend the ZigBee devices, power analyzers connected using Modbus or Ethernet, and other equipment as solar and wind converters or electric vehicles chargers. Their respective modules implement ZigBee and WiFi, but the rest of the protocols, like Modbus and the specific protocols of the rest of the equipment, have been programmed in the core module of the Energy Box.

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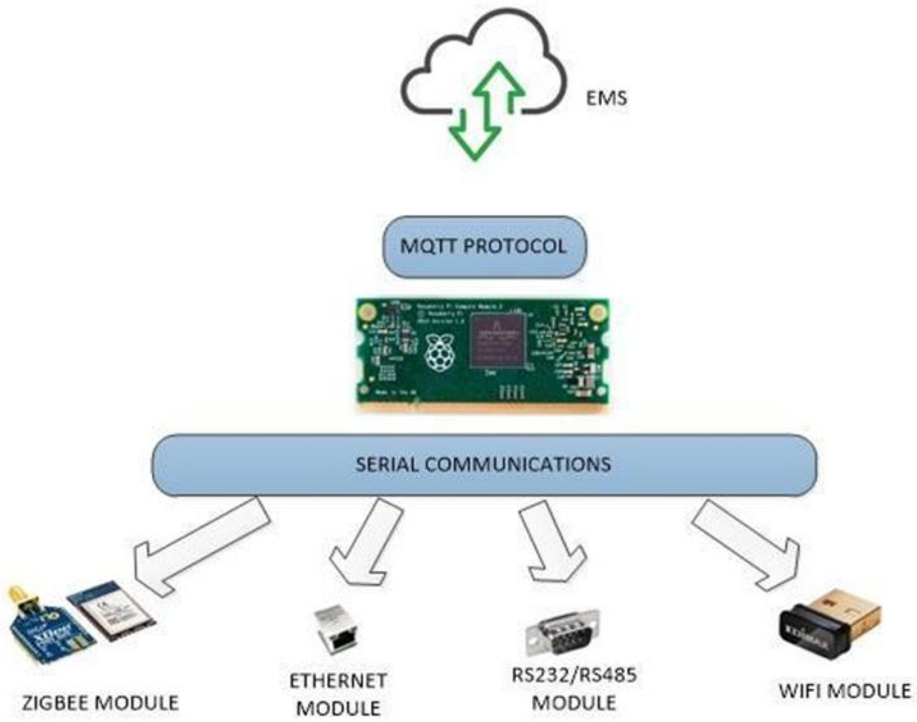

Figure 8 – Communication architecture of the Energy Box

For the communication between EB and platforms, the final solution implemented has been the MQTT protocol.

The MQTT protocol is based on the principle of publishing messages and subscribing to topics, or "pub/sub". Multiple clients connect to a broker and subscribe to topics that they are interested in. Clients also connect to the broker and publish messages to topics. Many clients may subscribe to the same topics and do with the information as they please. The broker and MQTT act as a simple common interface for everything to connect to.

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3. Description of software design & implementation

FRD follows a modular software architecture, which consists of lightweight components including the monitoring and control of the available assets, a forecasting suite, an interconnection with smart meters as well as direct or indirect connection with the assets and a DSM signals handling capability. Hence, the FRD is equipped with a robust backend system surrounded by an intelligent lightweight toolkit, enabling small and medium customers to participate in current and future marketplaces.

The EB is also a modular software solution that provides communication capabilities, both upstream and downstream, with a wide variety of field devices supporting the main standard communication protocols, but also with different cloud platforms where advanced functionalities are implemented. Taking advantage of this advanced communication capabilities, it is able to perform device control policies and provide flexibility and scalability for the control architecture. It also provides a database and GUI layers for SCADA capabilities. The orchestration of the operating system (OS) with the backend software, using Yocto technology and repositories for OS deployment and VPN remote access, allows an easy deployment of third-parties software solutions to take advantage of its functionalities.

For RENAISSANCE purposes, the EB ease of including external software solutions has been useful for deploying CERTH software modules within the EB, providing the required communication capabilities and improving its performance.

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3.1. Architecture description

All FRD's core functionalities are developed in Python3.7. The core module of the backend system is the Agent that is responsible for managing all the submodules.

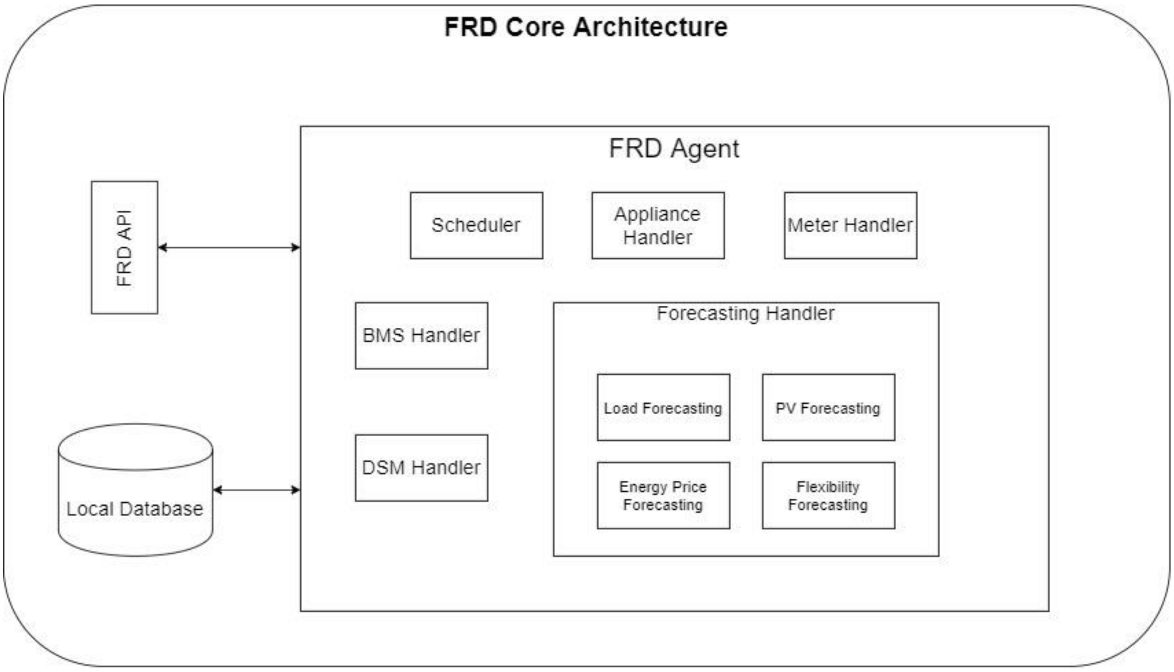

Figure 9 – FRD Core Architecture

Initially, a Web-App server was installed to provide access to and from the FRD, as well as a variety of web services (i.e. RESTful endpoints). The Flask framework for Python is used to create the Web-App server. Flask is a lightweight WSGI web application framework designed for quick and easy startup, with the ability to scale to complex applications. It has become one of the most popular Python web application frameworks.

Furthermore, FRD contains a Forecasting algorithm suite, which consists of a Load Forecaster, PV/Generation Forecaster, Flexibility Forecaster and Energy Price Forecaster which will be described more thoroughly in Chapter 3.3. They utilize input generated from the grid's assets and combines them

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with information from 3rd parties Web Services, such as weather data and Renewable Energy Systems (RES). There are modules for a variety of assets that can be connected to the FRD with different communication protocols in order to be monitored and controlled. The overall class diagram of the FRD's Agent module is presented below:

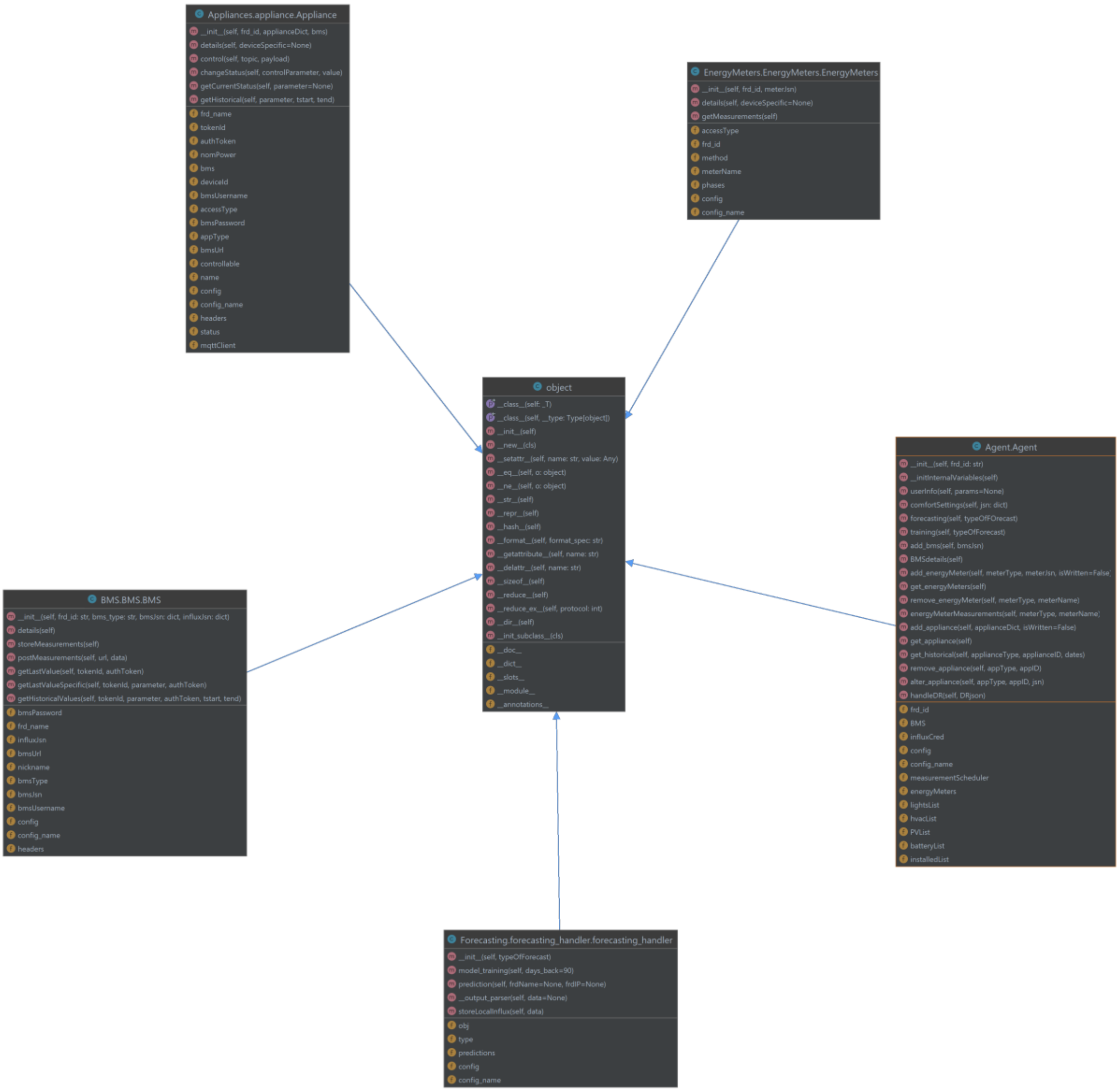

Figure 10 – FRD Agent module class diagram

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A more detailed schema of the classes is presented below:

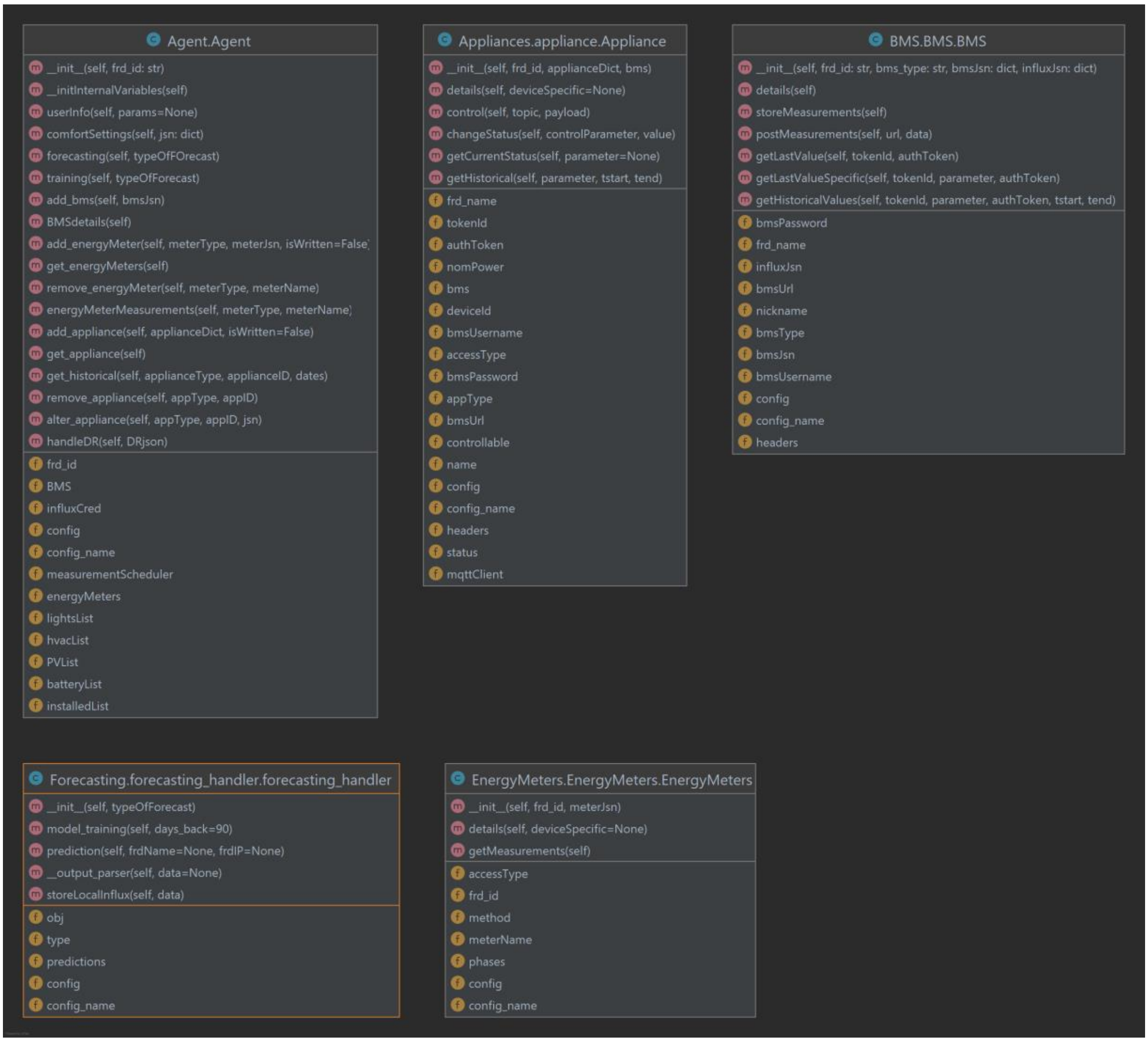

Figure 11 – Classes detailed depiction

Finally, FRD can operate as a decentralized intelligence node, as it can acquire and store time-series information from the grid into a local database, where measurements and exchanged messages can be stored. Data storage is also described in the following chapters (3.1.1.1).

3.1.1. Course of actions

The interaction of the consumer or the DSO with the FRD is supported through the User Interface (UI) (Chapter 3.3.4) developed explicitly for the

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needs of RENAISSANCE. Below, a series of sequence diagrams are provided that depict vital functionalities of the device as well as some Use Cases.

3.1.1.1. Fetching User's information/comfort settings

In order to display FRD owner's information, a specific field in the UI was created, as well as the respective endpoint in the FRDs. The User can see his personal information as well as with comfort settings.

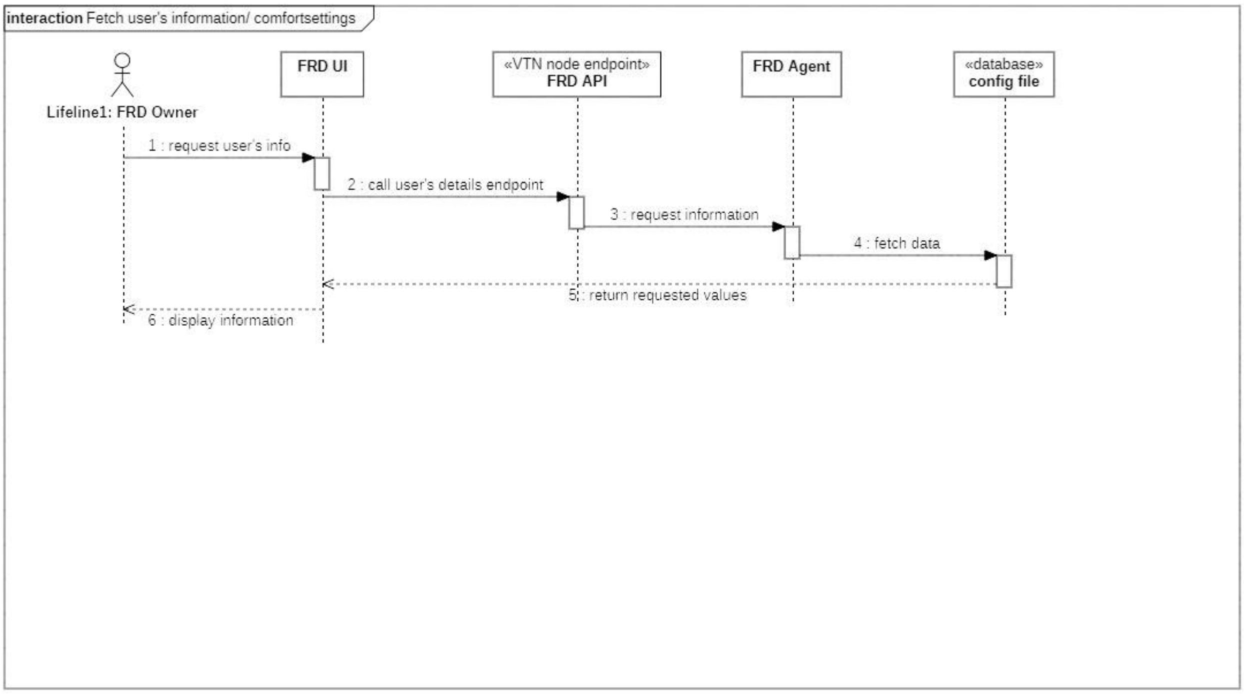

Figure 12 – Fetch user's information Sequence diagram

3.1.1.2. Alter user information/comfort settings

FRD owner can change the information stored in the FRD and re-set his comfort settings.

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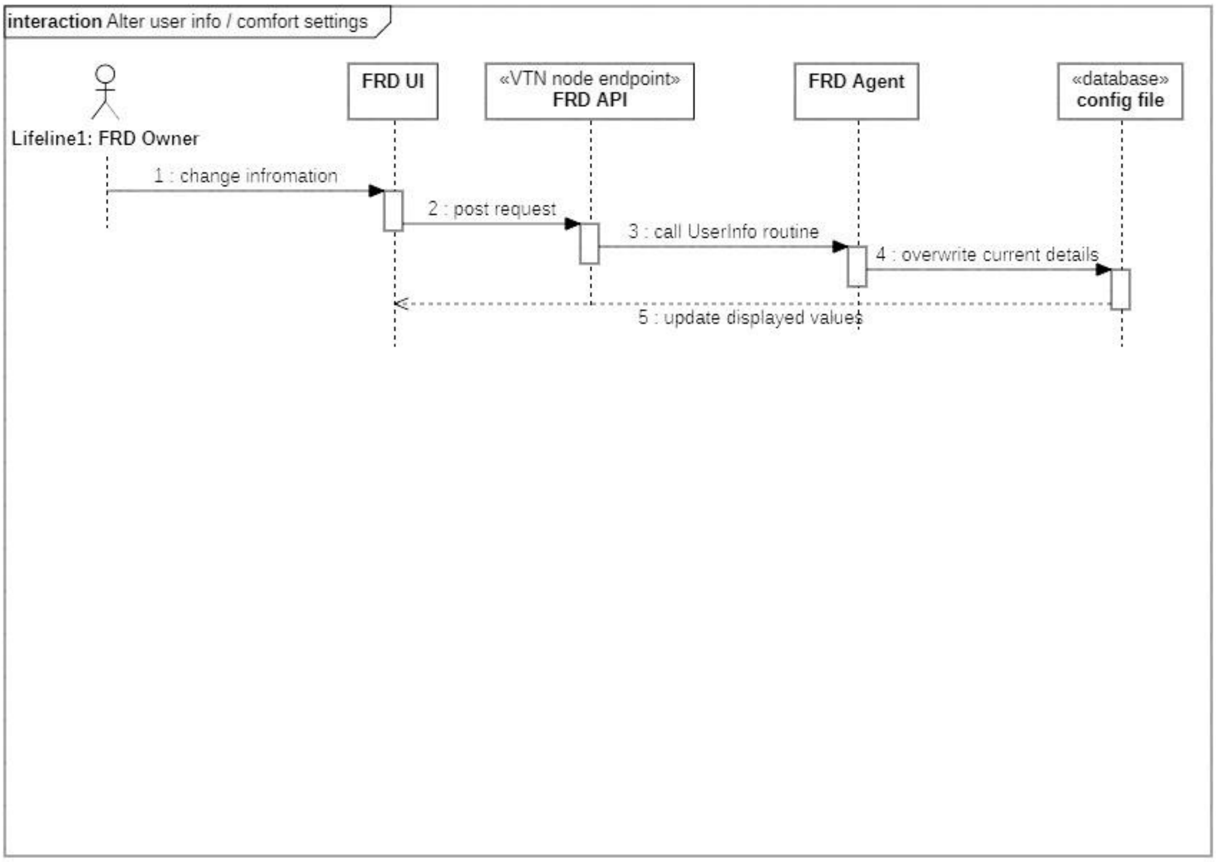

Figure 13 – Alter user's information Sequence diagram

3.1.1.3. Train forecasting models

Each one of the four (4) forecasting models described in Chapter 3.3, can be retrained either based on an internal scheduler or upon request of the user.

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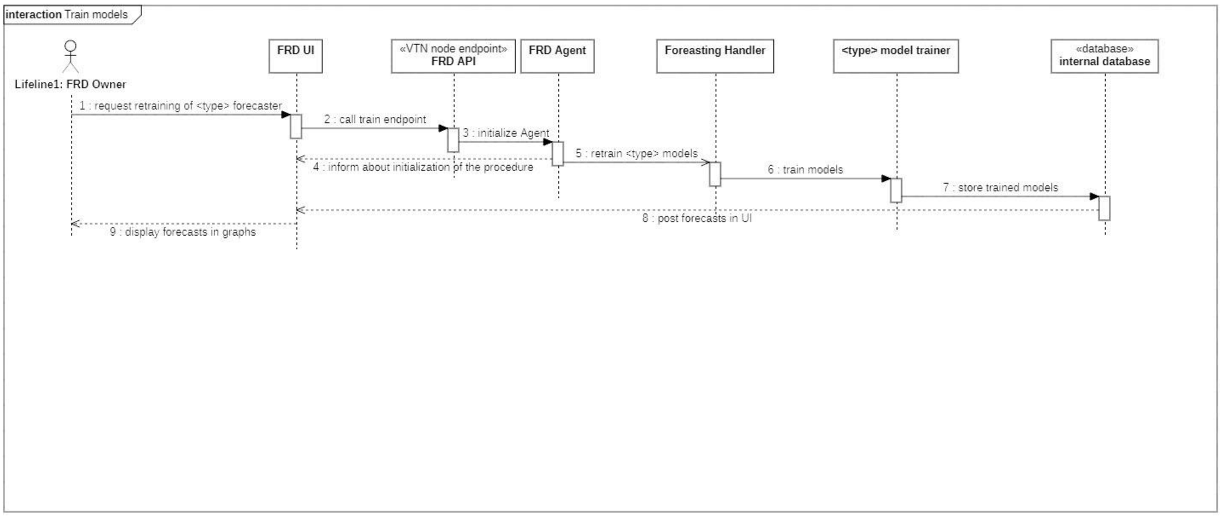

Figure 14 – Train forecasting module Sequence diagram

3.1.1.4. Request forecast

Each one of the four (4) forecasting models described in Chapter 3.3, provides forecasts either based on an internal scheduler or upon request of the user.

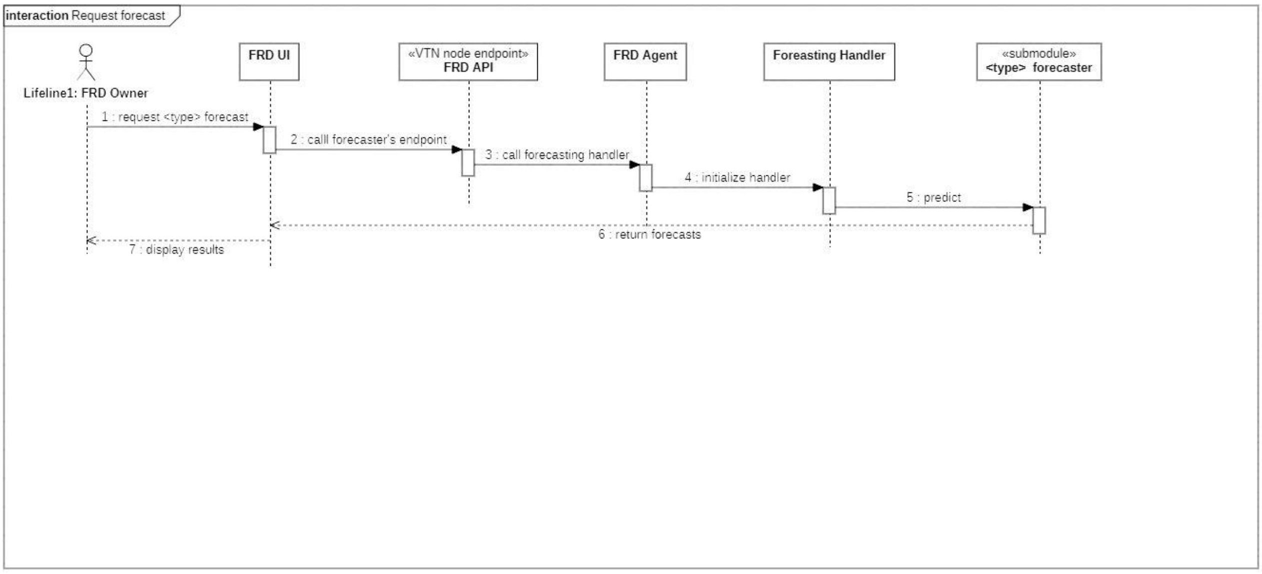

Figure 15 – Request forecast Sequence diagram

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3.1.1.5. Handle devices/assets/smart meters/BMS

FRD owner can display, alter, insert or delete devices, assets, smart meters or BMS using the UI. To support this functionality, the respective endpoints were created.

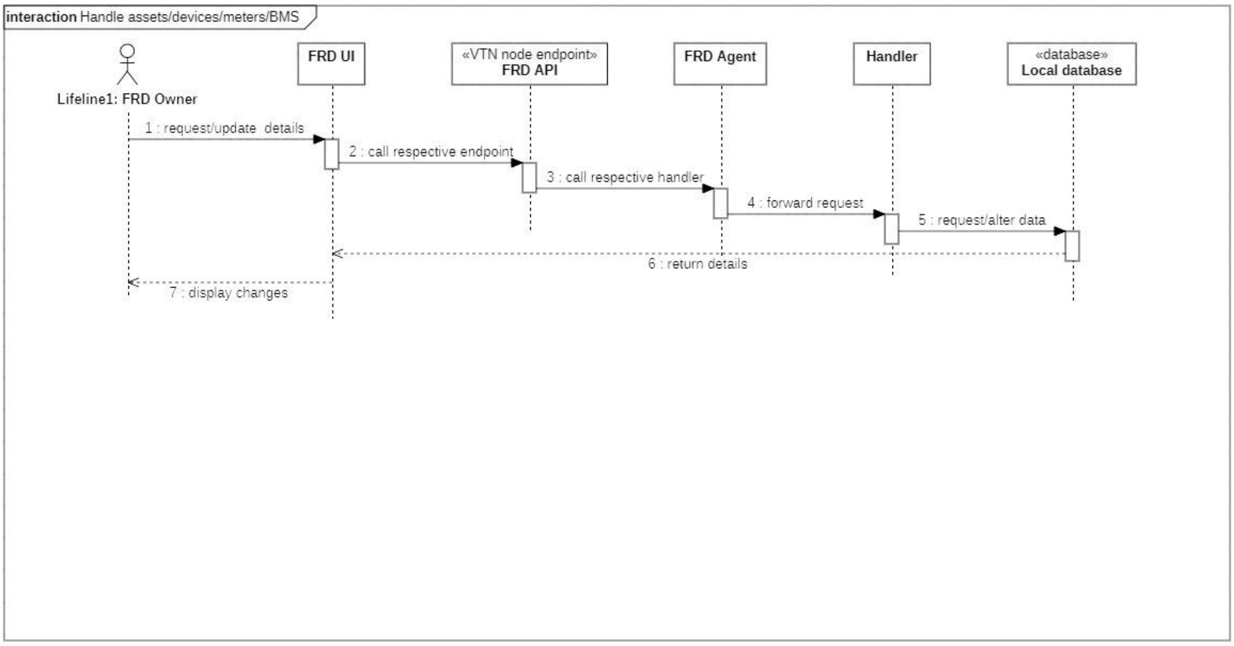

Figure 16 – Handle devices/assets/smart meters/ BMS Sequence diagram

3.1.1.6. DSM Handling

FRD serves as a Virtual End Node (VEN) in the procedure of DSM handling (further details provided in Chapter 5.2.2.3). The following sequence diagram depicts the process of receiving and replying to an OpenADR signal.

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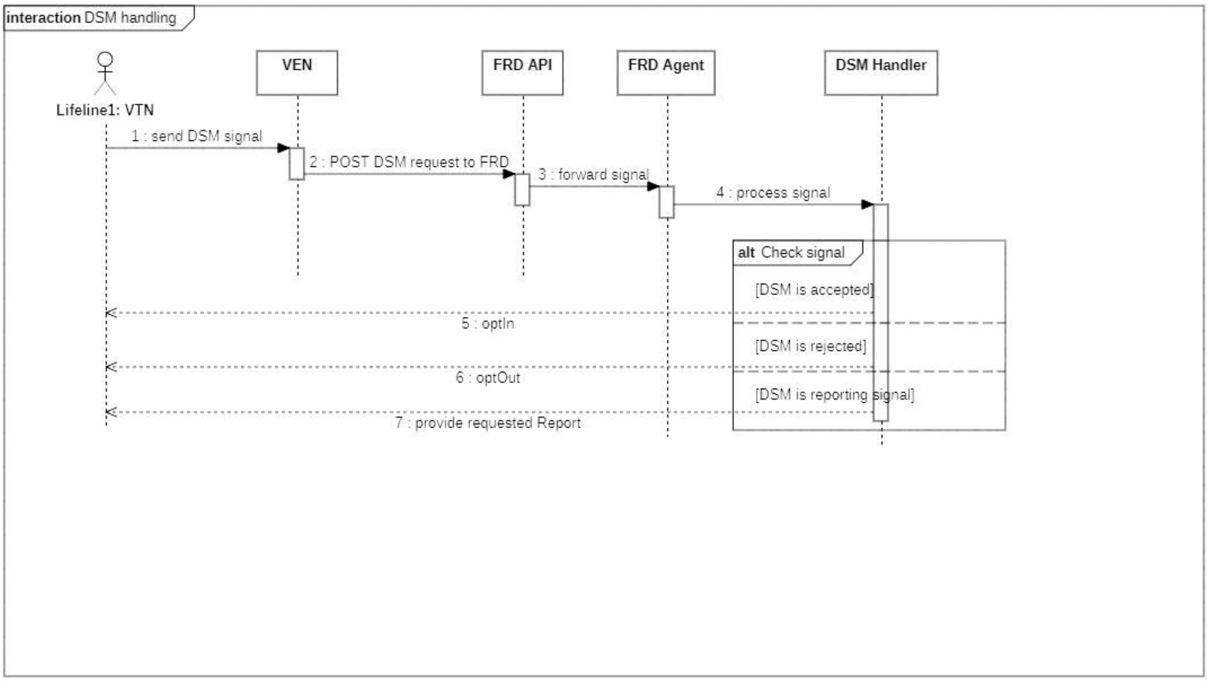

Figure 17 – DSM Handling Sequence diagram

3.1.2. Data storage

In order for the FRD to operate as a decentralized off-grid node, it is neccesary to keep a subset of the measurements that it collects from all of the interconnected devices. Therefore, it is vital to have a robust and quick-access database that stores data linked with a specific timestamp. For this reason, the InfluxDB database was selected to be utilized as FRD's main local database.

InfluxDB is an open-source time-series database written in the Go programming language for storage and retrieval of time series data. It is optimized for fast, high-availability storage and retrieval of time-series data in fields such as operations monitoring, application metrics, Internet of Things sensor data, and real-time analytics. It also has support for processing data from Graphite.

FRDs keeps track of a wide range of metrics taken in real time from the assets it uses. Because the FRD is a small intelligent device, keeping all data

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locally from when it was first installed to the end of its life cycle would be disastrous. As a result, FRDs' local database has a 3-month data retention policy. This time frame has been tested and found to be adequate not only for keeping clients up to date on recent operations, but also for updating forecasting tools on a regular basis through re-training sessions.

Because the data in InfluxDB is vital to the customer's infrastructure, the database has authentication enabled, which means that each user has distinct privileges. Furthermore, it is authenticated using RFC 2617's Section 2 Basic Authentication.

3.2.Grid monitoring and assets' control

In order to support Local Energy Communities' efficient energy management, FRD should be able to not only monitor and receive measurements from the assets, but also to control them in real-time.

3.2.1. Monitoring

FRD is constantly retrieving energy measurements from every interconnected asset. Voltage, current, power (active, reactive and apparent) as well as the status of the assets, are the variables that are observed by the FRD during its operation. Data are stored both locally, as described in Chapter 3.1.2, as well as in RENNAISSANCE Platform (RP).

The most significant metering device in an infrastructure is the energy meter. For that purpose, an internal module has developed, that allows the FRD to easily configure and adapt to the most commonly used commercial energy meters. Both remote and direct (serial) connection are supported. At this point, FRD supports Modbus protocol, both RTU and TCP. To configure Modbus-based devices, the registry mapping of the device should be known in advance. FRD supports both 1-ph and 3-ph energy meters. A flexible, modular and scalable approach was followed to allow FRD to support the integration of the majority of energy meters that can be used inside a Local

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Energy Community. As a starting point, a specific manufacturer (i.e. Carlo Gavazzi) has been integrated for testing at the CERTH/ITI Smart Home testbed. In the near future more manufacturers will be added to this compatibility list.

Apart from Modbus protocol, FRD can be upgraded (in terms of software) and support a wide variety of communication protocols, to enable connection with other energy meters, actuators and sensors. To configure any new device, all the necessary information (e.g. baud rate, port, byte size etc.) should be provided.

The software inside the EB can monitor a set of ZigBee sensors using the ZigBee automation home protocol that has been implemented following ZigBee standards. The Modbus protocol (serial and TCP) has also been implemented for the monitoring of a wide range of network analysers and some temperature sensors, as well as the control of different devices such as EV chargers or batteries that has been designed in the laboratories of CIRCE. For devices monitored by Modbus protocol, they must be previously known so that the memory map can be implemented.

3.2.2. Assets' control

Smart appliances, Renewable Energy Sources (RES), Energy Storage Systems (ESS), and Building Management Systems can all communicate directly with the FRD or through the BMS. FRD gets data from various devices and, if they have been labelled as controllable by the FRD's owner, it can change their operating status. The next paragraphs provide a more thorough explanation.

3.2.2.1. Building Management Systems

FRD is able to connect with a pre-developed BMS that is installed in the infrastructure. Following the flexible and modular approach, to ensure the interoperability of FRD across multiple Local Energy Communities, an abstract module that supports the BMS connection is developed, in order to

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utilize it, with small changes and configuration details provision. Currently, FRD supports three different BMS, Glowstick BMS, UCY EMS and Pragma IoT BMS, while each one having different architecture. BMS is employed to retrieve data from the grid, as well as control the operational status of the assets. All of the commercial BMS have a variety of security techniques for enforcing access control. The aforementioned systems use the basic authentication, meaning a simple username and password.

3.2.2.2. Renewable Energy Sources (PV)

FRD supports the connection with photovoltaic systems. At this time the measurements are collected either from the BMS system that is connected with it or directly through Modbus protocol (if the device supports it). These measurements are required for not only monitoring reasons but also as historical data during the re-training process. There is a wide range of models from different manufacturers, for both the PV modules and the inverters, that are supported.

3.2.2.3. Lighting

The devices related to lightning can be identified as 2-stage status (on/off) or dimmable devices. These devices can be connected with any of the supported protocols. In case that a device of this category is not smart, it can be directly connected to one of the two FRD's relays.

3.2.2.4. Heating, Ventilation and air Condition (HVAC)

HVAC is a technology that provides thermal comfort and appropriate air quality in an interior environment. As almost all devices contained in this category are high power consuming, they cannot be directly connected to FRD's relay. Therefore, their management and monitoring are performed through the interconnected BMS. All of this category's parameters can be controlled and altered by the FRD (status (on/off), temperature, fan speed and operation mode).

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3.2.2.5. Energy Storage Systems

Recent energy storage technologies such as Li-on batteries have become "smart", thus enabling remote communication and control. FRD can be connected with these assets either directly through Modbus protocol (if the asset supports it) or through the local BMS.

3.3. Forecasting modules

In the recent time various approaches have been developed that are aiming to provide an accurate forecasting model. Forecasting problems that we are dealing in RENAISSANCE are typical time-series supervised problems and the most common techniques for dealing with such problems are:

- Statistical models
- Machine learning models
- Deep learning models

Statistical methods are based on the assumption that the data have an internal structure, such as autocorrelation, trend or seasonal variation. The goal is to find a function that describes the model's behaviour as accurately as feasible using previous consumption values. The most common methods are autoregressive and autoregressive moving average models. Autoregressive models are based on the previous steps to predict the value of the next time step. Statistical measures are used to capture the correlation between the output variable and values at previous time steps at various different lags. In case of a strong correlation between a lag variable and the target variable, the autoregression model assigns a higher weight to this particular lag variable. While the autoregression model handles only time series that are stationary, autoregressive moving average model tackles this problem by differentiating the historical consumption values. The term "stationarity" refers to the fact that all of the statistical features that identify a time series remain constant over time. ARIMA is one of the most prominent and commonly utilized statistical methods when it comes

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to autoregressive moving average models [1]. Although the aforementioned models function admirably, their inability to capture non-linear patterns and the fact that external features are not utilized, have led to alternative solutions.

In the field of time-series forecasting, traditional machine learning is gaining traction after outperforming statistical methods in terms of accuracy and speed. Many attempts were made that employed machine learning techniques. Regression, decision trees and ensemble algorithms are widely used for time-series forecasting. Recently, the ensemble methods are becoming more and more popular outperforming almost all the other algorithms. Ensemble techniques are models composed of several weak learners who are trained independently, with the final prediction being the sum of the individual predictions of the weak learners. Especially, Gradient Boosted Regression Trees are usually chosen as weak learners. More particular, Lahouar and Slama [2] propose a load prediction model of one day ahead utilizing random forecast regressors performing a decent result. A similar approach was conducted in [1], but this time Support Vector Machines (SVM) were the regressors used for the modelling.

Deep learning (DL) techniques constitute a subfield of machine learning algorithms, including complex Artificial Neural Network (ANN) architectures that automatically identify and extract useful features from raw data. Furthermore, they are often employed for time-series forecasting due to their capability to learn complex correlations. Most common DL algorithms for time-series forecasting are Multilayer Perceptron (MLP) [3] and Long Short Term Memory (LSTM) [4]. MLP belongs to the category of Deep Neural Network (DNN) and LSTM to the category of Recurrent Neural Networks (RNN). LSTM is the most widely used among RNN, because of its underlying architecture, it is capable of learning long-term dependencies, making it excellent for energy consumption predictions. Another category of DL techniques is the Convolutional Neural Networks (CNN). CNN's ability of

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extracting feature patterns could be used in combination with LSTM in order to create a powerful forecasting model [4], [5].

3.3.1. Load forecasting

Considering the existing state of the art, a fully customizable load forecasting tool has been developed and deployed on the FRD to address all the challenges posed by FRD's computing power. Two different time horizons are utilized:

- day ahead load forecasting
- short term load forecasting

In most cases, short term forecasting is associated with the concept of predicting one time step ahead. Inside the premises of RENAISSANCE, short term load forecasting is used to forecast, by the end of the day, and update the results on each horizon step. Both versions of load forecasting, are based in the same model architecture, while only the required inputs are different. In order to estimate the loading of the following day, day ahead load forecasting utilizes the historical consumption of the previous day, while short term load forecasting, only requires the most recent past values of consumption. The input vector consists of energy based features and extracted contextual features. Regarding the forecasting model, different architectures were tested and deployed on FRD. Although, the best fitted candidate was gradient boosted tree (GBT) regressor, due to its efficiency and hardware requirements.

The overall process of load forecasting methodology is depicted in the following figure:

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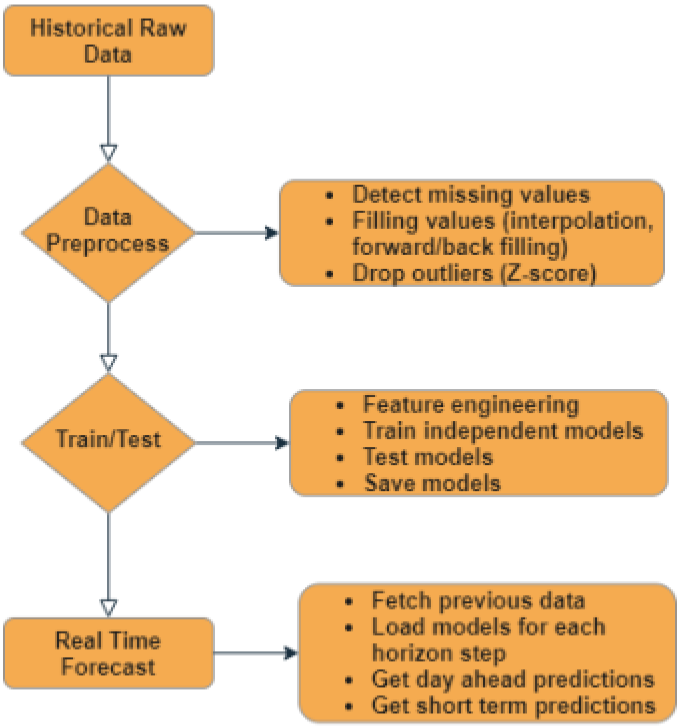

Figure 18 – Flowchart of load forecasting module

3.3.1.1. Data pre-processing/preparation

To enhance the quality of the dataset, a thorough preparation procedure is followed. Data provided from smart meters can sometimes contain corrupted, inaccurate or missing values. This submodule is responsible to initially identify and then handle these values and manage them accordingly (replacing, modifying, deleting). The primary purpose is to create a proper time-series input using data from the local database. To ensure the necessary completeness of the dataset, missing data is either omitted or supplemented in in case the number of the missing values is lower than a certain percent for every day respectively. Furthermore, outliers are also identified and removed using the z-score method. Zscore describes the

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position of a record in terms of the distance from the mean, when measured in standard deviation units. Finally, the pre-processing module converts the historical time series to power or energy consumption depending on the forecasting unit.

3.3.1.2. Training and predicting procedures

After preparing the dataset, the necessary models are constructed, through feature engineering. Day ahead load forecast is considered a multi-step time series forecasting problem, thus multiple models for each time horizon have to be developed. Direct multistep forecast strategy was adopted for this tool [5]. A separate model was created for each horizon step and stored locally in the DB of FRD. This approach, requires less computational power from the device, making it more suitable for the lightweight FRD, while making more flexible to increase the forecasting horizon (therefore the steps and models).

Illustration of the framework for multi-step ahead load forecasting applied on the FRD is shown below:

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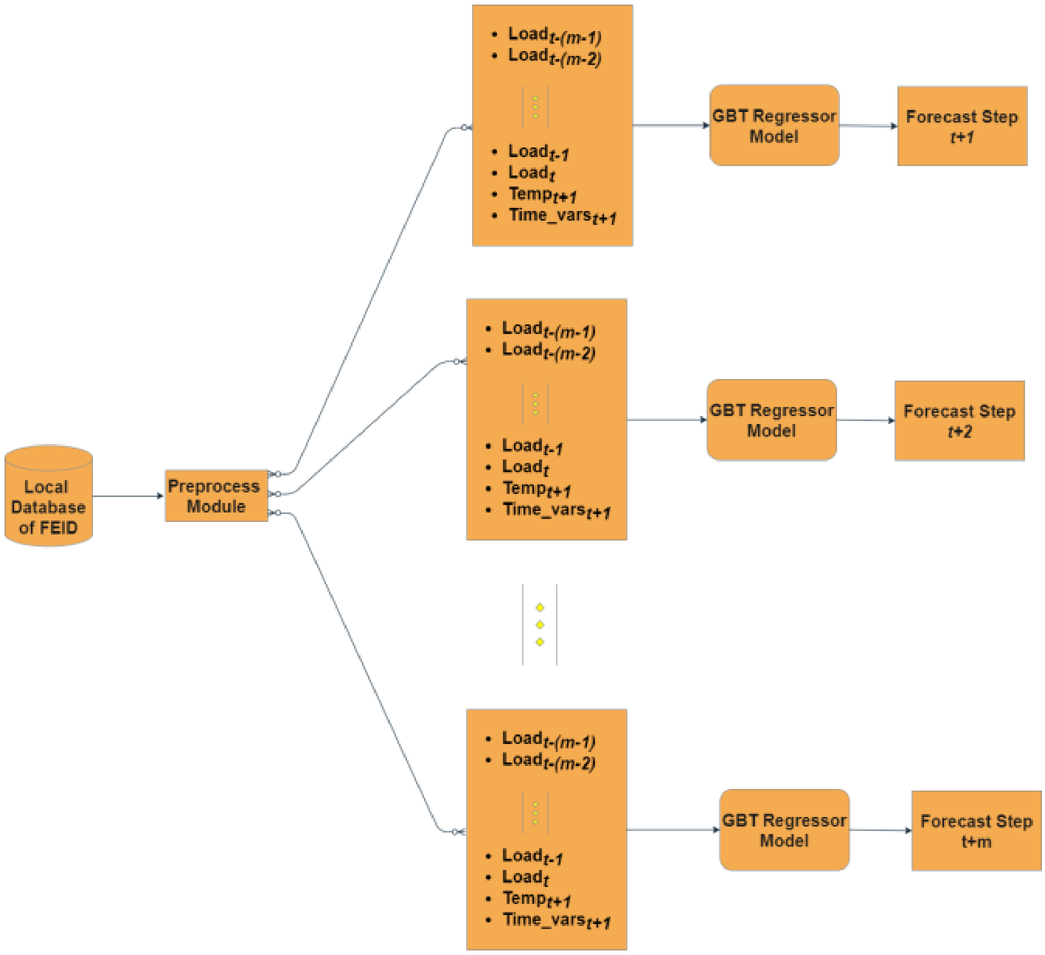

Figure 19 – Direct multi-step load forecasting

To enhance the accuracy of the models, weather data, such as temperature, and time features are also used in the input vector. The input feature of every model is formed as follows:

$$prediction_{t+1} = GBTregressor\left(load_{t-(m-1)}, load_{t-(m-2)}, \dots, load_{t-1)}, temperature_{t+1)}, timeFeatures_{t+1}\right)$$

In order to capture the time seasonality of load consumption time series, a decomposition is conducted and month, day of year , hour and minutes are extracted as individual features [6]. Time-related features are encoded

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following a cyclical approach. More specifically, to capture the seasonality of the time features, they are considered cyclical variables and transformed into sines and cosines, in order to preserve the relationships between them. Cyclical variable transformation is implemented through the following functions:

$$month_{sin} = sin\ sin\ \left(2\pi * \frac{t}{12}\right)\ month_{cos} = cos\ cos\ \left(2\pi * \frac{t}{12}\right)\ weekday_{sin} = sin\ sin\ \left(2\pi * \frac{t}{6}\right)\ weekday_{cos} = cos\ cos\ \left(2\pi * \frac{t}{6}\right)\ time_{sin} = sin\ sin\ \left(2\pi * \frac{t}{24}\right)\ time_{cos} = cos\ cos\ \left(2\pi * \frac{t}{24}\right)$$

Where, t = hour + minutes / 60.

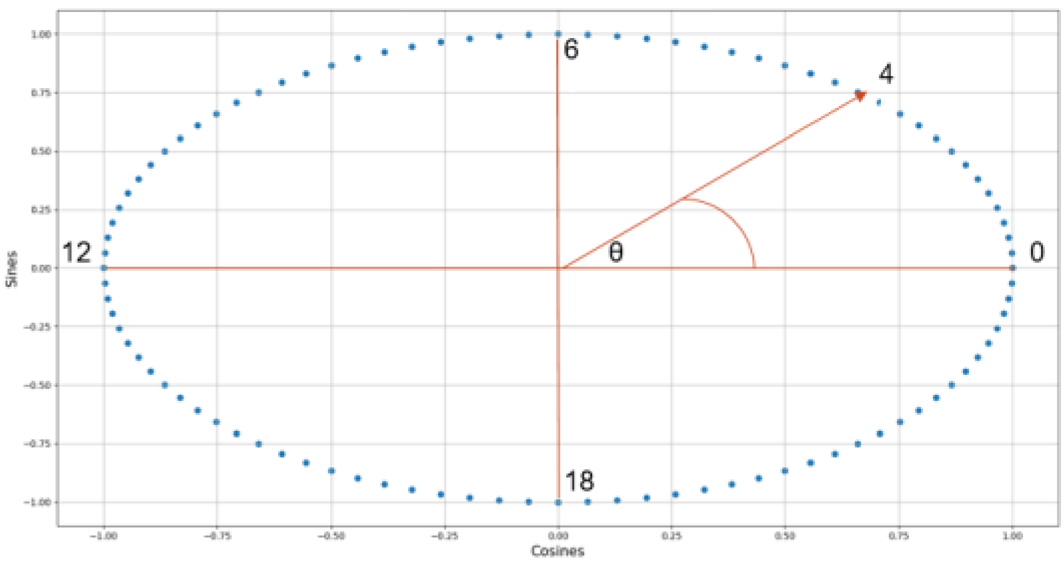

Figure 20 – Time mapped in sinus and cosinus components.

Generally, GBT is a model based on gradient boosting, a technique producing predictions as ensembles of multiple predictions generated by weak learners. The weak learners are trained sequentially, each one correcting the errors made by its predecessor. In the case of GBT, the weak learners are decision trees. GBT aims to minimize an objective function that

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combines a convex loss function and a penalty term for model complexity. The training process proceeds iteratively, adding new trees that predict the residuals of errors of prior trees that are then combined with previous trees resulting in the final prediction. Extreme GBT regressor (XGBoost) was chosen as the most suitable regressor model, as it is a fast, lightweight and flexible implementation of gradient boosted decision trees optimized in terms of execution speed and model performance by pushing the limits of computation resources through systems optimization and algorithm enhancements.

For all of the reasons stated above, XGBoost is an excellent choice for training models that solve all of the issues raised by FRD processing power. After a grid search, the optimal hyperparameters parameters of the XGBoost model were determined. Finally, three regression error metrics were employed to assess the accuracy of forecasting models: the mean absolute percentage error (MAPE), the symmetrical mean absolute percentage error (SMAPE), and the root mean squared error (RMSE) [7]. SMAPE and MAPE are percentages, while RMSE is represented in the predicted variable's unit.

To train the forecasting models, the values of the last three months, stored in the local database, are used. The hardware limitations of FRD do not allow a more extensive dataset to be stored locally. The evaluation of forecasted model was carried out for the period of one week taking into account two different time granularities, 60 and 15 minutes respectively. The results are illustrated in the following figures:

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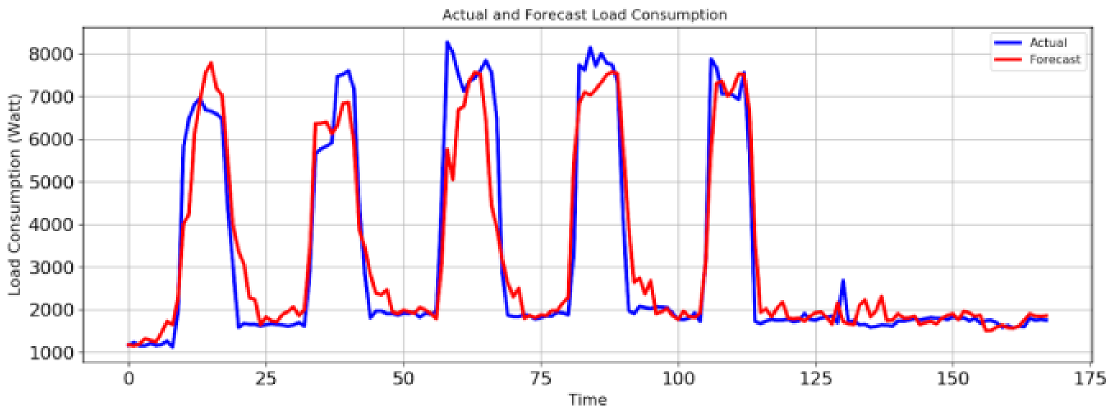

Figure 21 – Time resolution of hourly time intervals

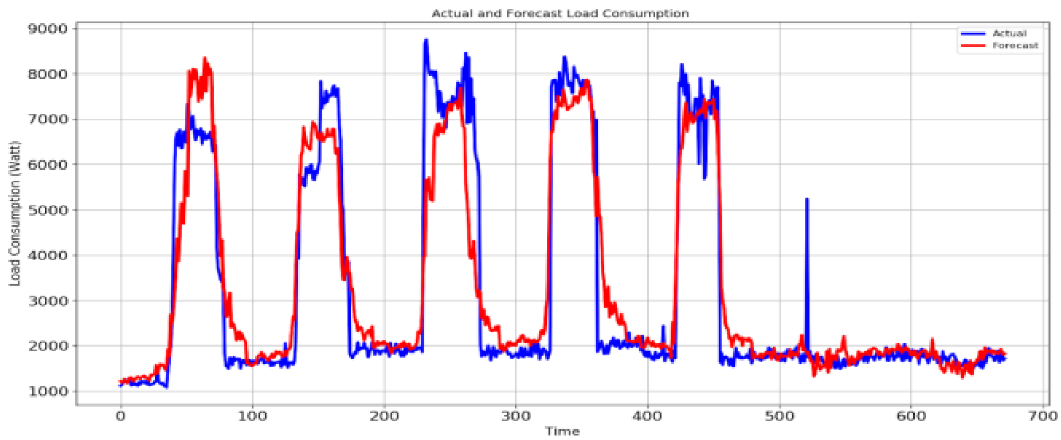

Figure 22 – Time resolution of fifteen minute time intervals

The results appear to be more accurate, as expected, in the first scenario, since the data are more detailed compared to the aggregated in hourly intervals. A detailed summary of the results of the forecasting module is presented in the following table:

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Prediction Type	SMAPE (%)	MAPE (%)	RMSE
Hourly Interval	6.57	13.14	752.31
Fifteen minutes interval	7.72	18.01	862.2

Table 4 – Error Metric Results for the Load Forecasting Module

The tool was tested and validate in CERTH's Smart Home environment. In the phase of integration to the pilot sites, the models should be re-trained in order to ensure their accuracy.

3.3.2. Generation forecasting

The amount of research on PV generation forecasts has undergone a drastic increase. PV forecasting can be accomplished in one of two ways: analytical approaches based on physical principles or data-driven approaches utilizing artificial intelligence models. Analytical models do not require any prior knowledge of the generated power since they provide their results through well-defined analytical equations, based on the technical specifications of the equipment and weather forecasts [8]. Data-driven solutions solely depend on the historical power generation data, without taking into consideration the system itself. The discovery of patterns and relationships within the available data is the foundation of these models. Due to the rapid rise of AI technologies several approaches were conducted in order to address the problems posed by the short term forecasting using machine learning (ML) and deep learning (DL) models. Most commonly models used for PV forecasting are MLPs [9], [10], or radial basis function networks [11]. Apart from ANNs, other ML techniques encountered in literature are autoregressive models (ARIMA), SVM and more specifically support vector regression, as PV forecasting is mainly a regression problem. [12] built a decision system that relies on cloud coverage to choose between

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a physical and an ANN-based model. Despite having outstanding outcomes on days with clear sky, cloudy days show a low performance.

The model developed in the premises of RENAISSANCE attempts to combine the best characteristics of both categories and achieve higher accuracy. This solution provides forecasts for 96 steps ahead (day ahead forecasting), with resolution of 15 minutes. The hybrid approach consists of three steps: analytical calculation (physical model), clear sky correction, and cloud correction, if total cloud coverage exceeds a threshold determined by trial and error.

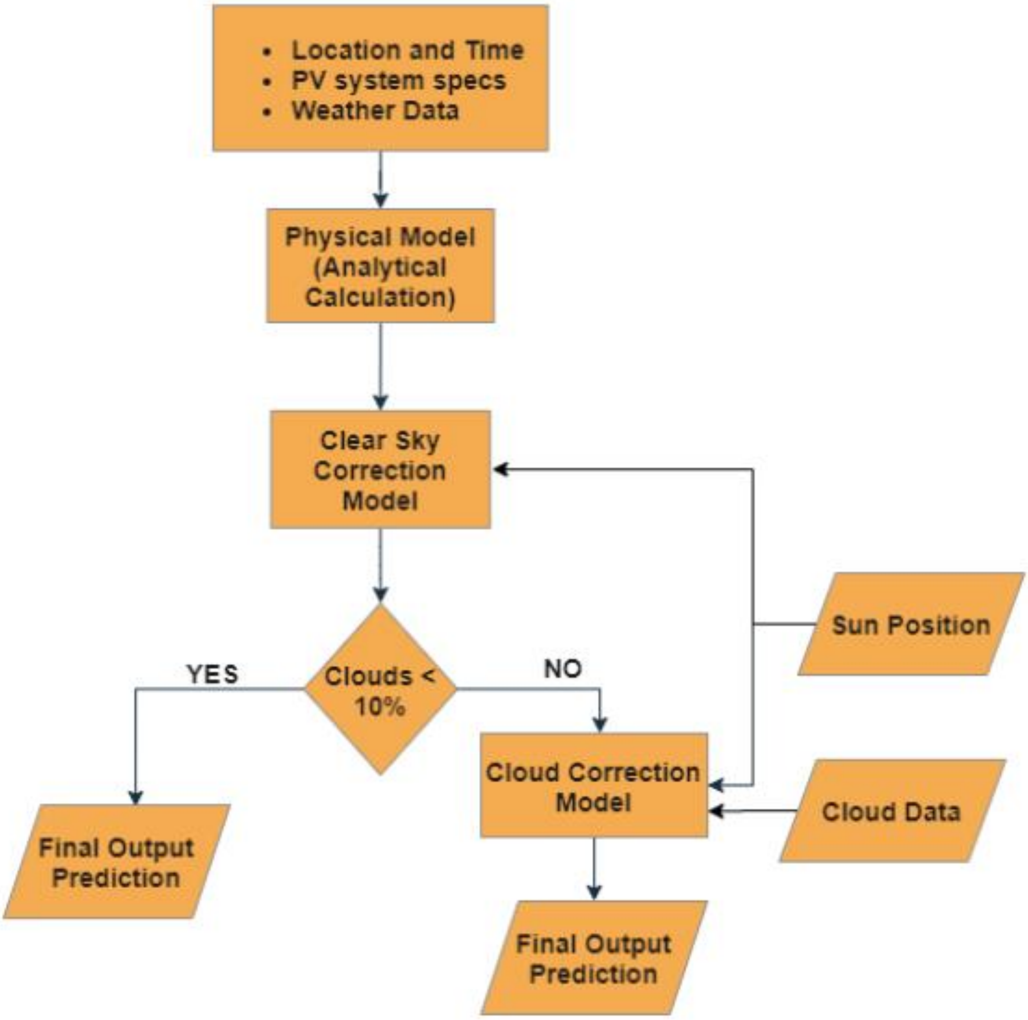

Figure 23 – Flowchart of PV forecasting module

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The hybrid model is described in the following subsections.

3.3.2.1. Physical model

As mentioned above, this step is responsible to assess the actual performance of the installed equipment based on analytical functions. To do that, Python open source library Pvlib [13] was utilized. Pvlib allows in depth analysis of the PV system by providing the following parameters:

- Geolocation and time: The exact position of the sun is determined using those values as input features to Pvlib, resulting in the extraction of solar irradiance components in every time instance, assuming clear sky conditions.
- PV system configuration: PV system specifications such as number and type of the PV panels, inverter type and surface tilt and surface azimuth angles.
- Weather prediction data: Cloud coverage plays a vital role in the accuracy of PV generation forecast, as it is used as input for the estimation of solar irradiance components. Temperature and wind speed are also taken into consideration for a more precise calculation of the PV system's performance.

3.3.2.2. Numerical Weather Predictions – Error Correction Models

Error correction models were employed to improve the analytical method's PV output, due to certain observations of error patterns. The two types of errors identified and validated through experiments are:

- Clear sky errors
- Cloud sky errors

To handle them, two ML models were developed on top of the Physical model using XGBoost regressors.

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Clear sky model handles the error that derives from the assumption that in clear sky conditions, the analytical equations have 100% accuracy on their results. This assumption was rejected through experimentation by comparing the calculated and the actual generation of the PVs. The deviations occur from certain mathematical calculations such as solar angles as well as the fact that modelling a PV installation cannot be totally accurate (i.e. deviations from PV specifications). The purpose of this corrective model is to isolate these errors and adjust accordingly the PV output. Since there is no globally accepted definition for “clear-sky” (in terms of solar irradiance or sunshine), an index that indicates cloudiness is employed. A threshold of 10% for the aforementioned index is set to separate clear sky days (<10%). An example of the extraction of clear sky days is illustrated in the following figure:

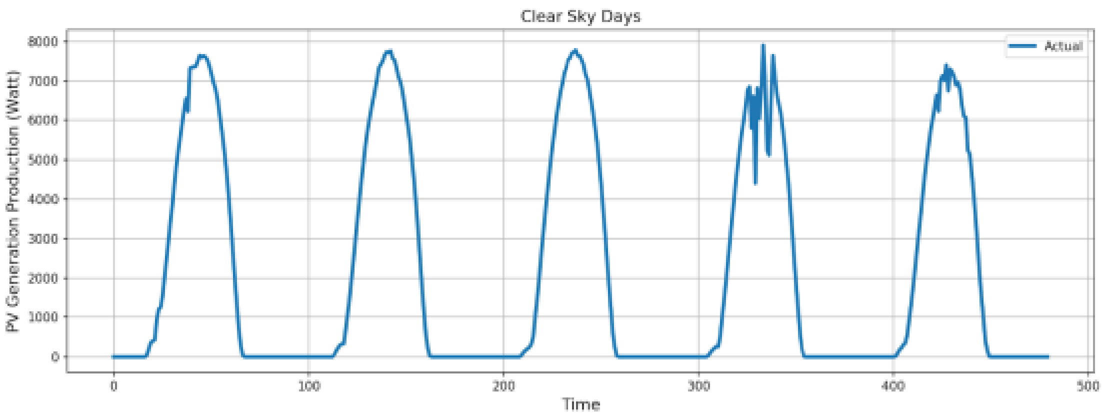

Figure 24 – PV Generation measurement under Clear Sky weather conditions

3.3.2.3. Prediction procedure

Cloud correction model is employed when a day is labelled as “cloudy”. During such days, the estimation of the solar irradiance is more challenging,

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since a total cloud coverage is required in order to extract the solar radiation components. The forecasted total cloud coverage usually has limited accuracy due to different factors, such as: the nature of weather (stochastic problem), geolocation distance between weather station and PV installation etc. A representation of cloudy days is depicted below:

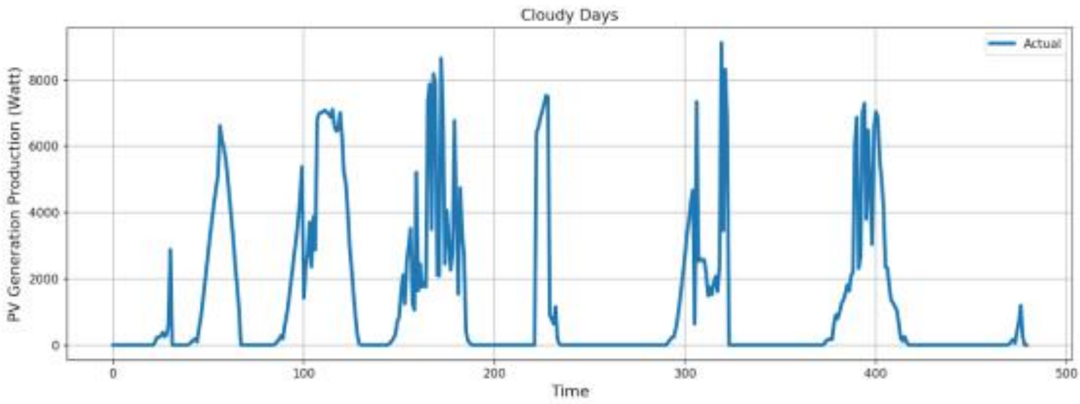

Figure 25 – PV Generation measurement under cloudy weather conditions

The provided prediction of the PV forecasting module is the combination of physical and correction models outputs. To evaluate the results, three error metrics were used, namely root mean squared error (RMSE), mean absolute error (MAE) and a new defined percentage error metric named weighted relative squared error (WRSE). WRSE is created in order to demonstrate the relative error in terms of magnitude of the evaluated generation and it is described by the following equation:

$$WRSE = \frac{[\sum_{i=1}^{M}[\sqrt{\frac{(y\_pred_i - y_i)^2}{y_i}}]]^2}{M * \sum_{i=1}^{M} y_i} * 100\%$$

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Where, y_i is the actual PV power generation value, y_pred$_i$ is the predicted value and M is the forecasting horizon. Results of one week evaluation procedure are illustrated in the following figure:

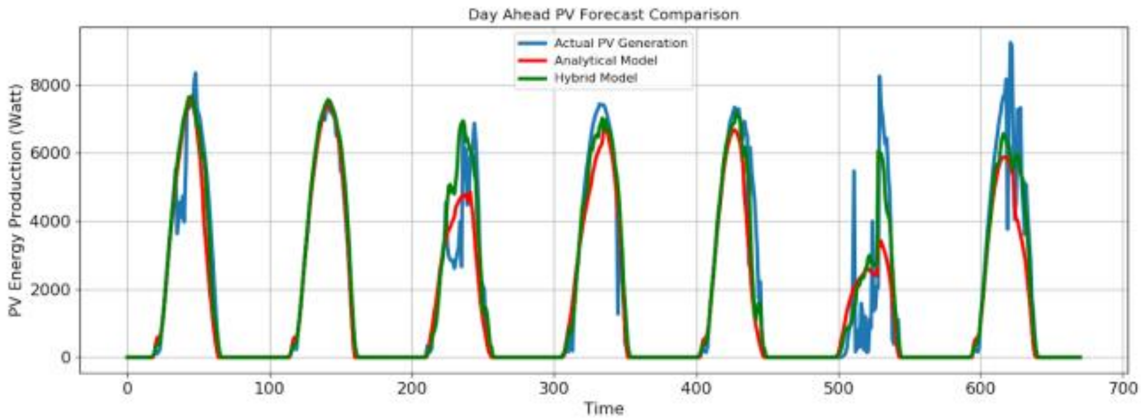

Figure 26 – PV Forecasting results of analytical and hybrid methods

A detailed summary of the results is provided by the table below:

Prediction Type	WRMSE (%)	MAE (Watt)	RMSE (Watt)
Physical model	11.01	410	890
Hybrid model	6.69	320	748

Table 5 – Results evaluation of PV forecasting tools

3.3.3. Flexibility forecasting

Before proceeding with the description of the tool itself, it is vital to establish a precise definition of demand flexibility in order to fully comprehend the untapped potential of energy flexibility. There are many definitions for the term flexibility. For instance, it can be defined as **the capacity to adapt across time, circumstances, intention and focus** [14]. However, the best way to describe demand flexibility in the case of

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residential demand is as an indicator of *how much load can be shifted or reduced within user-specified limits* [15].
There are many attempts to study and predict demand flexibility within the literature. All methods and technologies proposed can be divided mainly into two major categories depending on how they obtain the needed information about the consumption:

- Intrusive: the ones that require measurements to be taken directly from the devices
- Non-intrusive: the ones that collect and leverage measurements only from one central point for the entire household.

3.3.3.1. FRD's implementation

The main idea of this approach is to identify flexibility based on consumption routines of residents and possible patterns of flexible events. The calculation of flexibility is performed in 3 main steps. The first is to categorize the days of the year into clusters in order to establish some baselines of consumption since it is reasonable to expect different consumption on a working day and on the weekend, as well as normal consumption will be different in summer and winter. The second step is to analyse all days of the past year to find similar motifs and patterns of flexible events. After that, it is observed if in the course of a day the consumption deviates from the normal levels of the category in which this day belongs if so, an analysis is made to find a known pattern of flexibility and if it is identified then this consumption is considered flexible. In this way, flexibility can be achieved without compromising customer comfort and habits.
The figure below depicts the aforementioned process:

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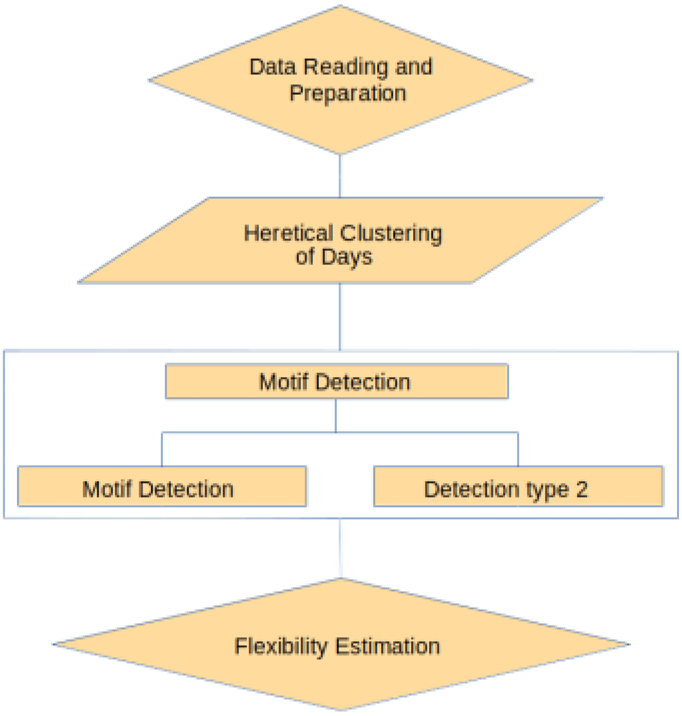

Figure 27 – Flexibility forecasting flowchart

3.3.3.2. Hierarchical clustering

After reading and preparing the data to be utilized by the models, on the second step of Flexibility module, the days' clusters are created. In order to optimize the results of clustering, the original time series of each day's power consumption is simplified, by using Fast Fourier Transformation. After this transformation, it is easier to group time series into more generalized clusters.

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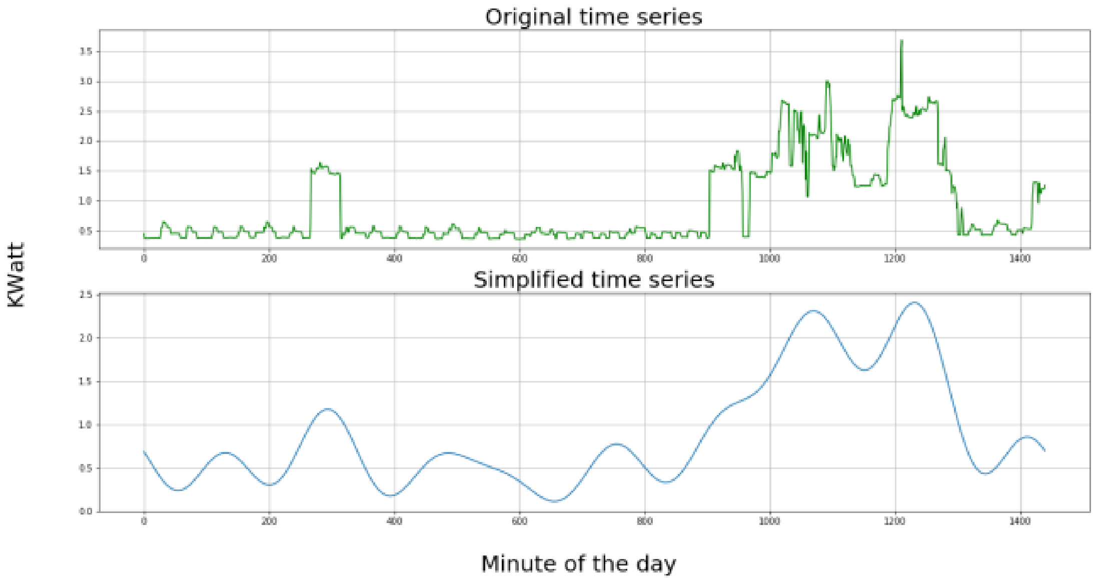

Figure 28 – Fast Fourier Transformation example

The next step is to perform clustering on this simplified time series using Heretical Clustering with Ward variance minimization algorithm for distance calculation. The final step after the establishment of the clusters is to determine which deviation level is considered normal. Currently, the upper and lower bounds are defined as the mean of cluster plus minus standard deviation.

3.3.3.3. Flexibility detection

On step 3 of module's execution, we strive to extract hidden patterns in consumption. These patterns are crucial for the tool's performance, because after locating them, they can then be correlated with some known events and decide if it is flexible or not. Two pattern discovery methods were utilised, one supervised and the other unsupervised. Each of them has advantages and disadvantages, for example, supervised has better accuracy on known data, but low generalization in unknown data, while unsupervised, has lower accuracy, but works better with unknown data. We

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call the supervised one flexibility prediction and the unsupervised one we call motif detection.

Motif detection takes as input the entire consumption history divided into one-day time series in minutes i.e. 1440 points per time series. The first step is to separate each time series into subsequences. Many existing motif detection algorithms have a predefined and fixed length of subsequences and use algorithms such as sliding-window for the segmentation. Since fixed window length restricts the right motif detection process (restricts the right motif detection process [16]), a segmentation algorithm is applied.

We use moving average to create a baseline and accepted levels of noise for each time series, whenever the consumption is higher than that, for some time, this part is stored as a subsequence. The next steps to be taken are, first, to normalize these subsequences so that they can be represented at the same scale regardless of their length and intensity, and second, to perform dimension reduction to store more generalized patterns and to speed up the process of detection. For these steps both Piecewise Aggregate Approximation (PAA) representation and Symbolic Aggregate approXimation (SAX) [17]. The PAA helps to represent subsequences in a scaled and reduced way and SAX mapping these representations to alphabetical symbols, so at the end, each subsequent has its signature with which it can be compared to others.

The next step is to create buckets of random projected signatures. First of all, we perform random projection on SAX representations in order to group signatures with small differentiation, which might occur due to accidental ups and downs. A bucket of each random projection contains all the signatures that produce this projection, which in essence represents a potential pattern. The buckets that contain small amounts of signatures are discarded as they are not repeatable enough to be considered as motifs. For the remaining buckets, a P-profile matrix is calculated. P-profile is a matrix of the probability for each symbol to appear in each position of the

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signature. Based on this matrix it is possible to calculate the probability that any signature belongs to this set. So when we want to determine if a new subsequence is a pattern, all we have to do is create a SAX signature and then compute the probability for each bucket to belong to it. If all probabilities are small (smaller than a certain threshold), then the subsequence is not a pattern, otherwise, it is considered as a pattern of the bucket with the highest probability.

Flexibility prediction uses a Recurrent Neural Network (RNN). The goal in our approach is to give to the model a subsequence of total consumption as input, and take a subsequence of potential flexible consumption as a result for the same period of time. This approach can have remarkably accurate results but a low level of generalization, which means that in different house it will need to be retrained.

Once the neural network returns a time series of potential flexibility, the next step is to check, at a certain point in time, if there is indeed flexibility, which affects the overall consumption. To do so, we convert both total and potential flexible consumption into PAA/SAX representation and compare their signatures. If they have a sufficient degree of similarity then this point in time is considered flexible. Finally, if we want to analyse a whole day for flexibility, we apply the sliding window algorithm and do this check for each subsequence.

3.3.3.4. Evaluation

In the CERTH/ITI Smart House (pre-pilot) where extra tests were performed, there is no data about flexible consumption, which implies that it is not possible to compute measurements such as, MSE or MAE, as there are no actual values to compare with the outcomes. In our tests, various appliances were active at different times to perceive what flexibility would be found. The model distinguished all the abnormal consumption that were added to the total consumption.

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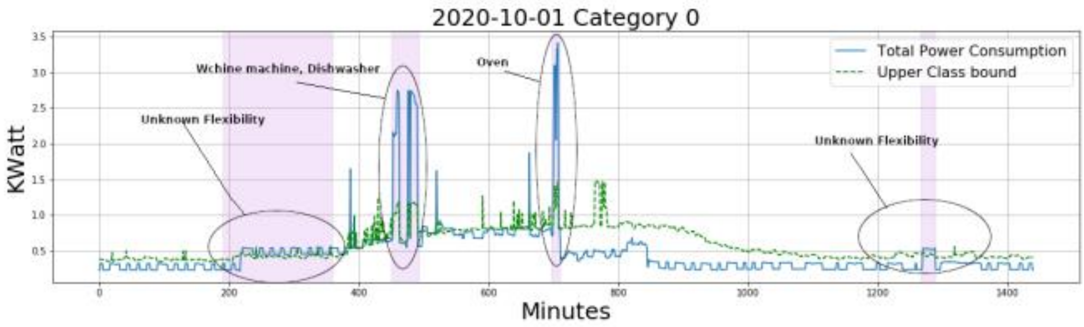

Figure 29 – Flexibility detected at CERTH/ITI Smart Home

3.3.4. Energy price forecasting

In recent years, Europe's power system has undergone significant modifications. The expanding importance of renewable energy sources, as well as the increasing popularity of electric vehicles and smart energy storage systems, all contribute to the push for a lower-carbon, more efficient system. LECs play a significant role in this transition by facilitating not only more efficient generation but also more active demand-side management. In this subchapter, the function and structure of the main electricity markets in Europe are discussed making sure that necessary theoretical background for optimal participation is provided, alongside the provided software solution.

3.3.4.1. Markets' description

The three main markets that are taken into consideration inside the premises of RENAISSANCE are:

- Day ahead market. Day ahead market takes place on day D-1 and it concerns the bidding process through which the power agents commit to sell or buy a certain amount of energy at every hour in the day D.

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- Intra-day market. The market operator runs many intra-day market sessions to better deal with the difficulty of a high degree of uncertainty. The agents can buy or sell energy in each session in order to adjust their acquired commitments in the day ahead market through a bidding process.
- Imbalance market. The imbalance market, also called balancing market, will determine the price of the deviation of the power agent with respect to what it was committed in the day ahead and intra-day market.

3.3.4.2. Methodology

The electricity price forecasting tool developed within the RENAISSANCE project, takes into consideration both day ahead and intraday markets. As a result, two forecasting tools, a day-ahead price forecasting tool and a supplementary tool for intraday price forecasting, were developed. Both tools were evaluated in the energy market of the United Kingdom, but it can be applied to other energy markets as well. Unlike the intraday tool, which is conducted continuously with a half-hour time intervals, day-ahead is executed every day and once a day, more specifically, every midnight. As previously said, the only difference between the tools is the time it takes to execute them.

The purpose of running the intraday forecasting program every half-hour is to discover and capture the price spikes that occur often in the electricity market. Below is a flow diagram illustrating the approach used to construct the electricity price forecasting tool.

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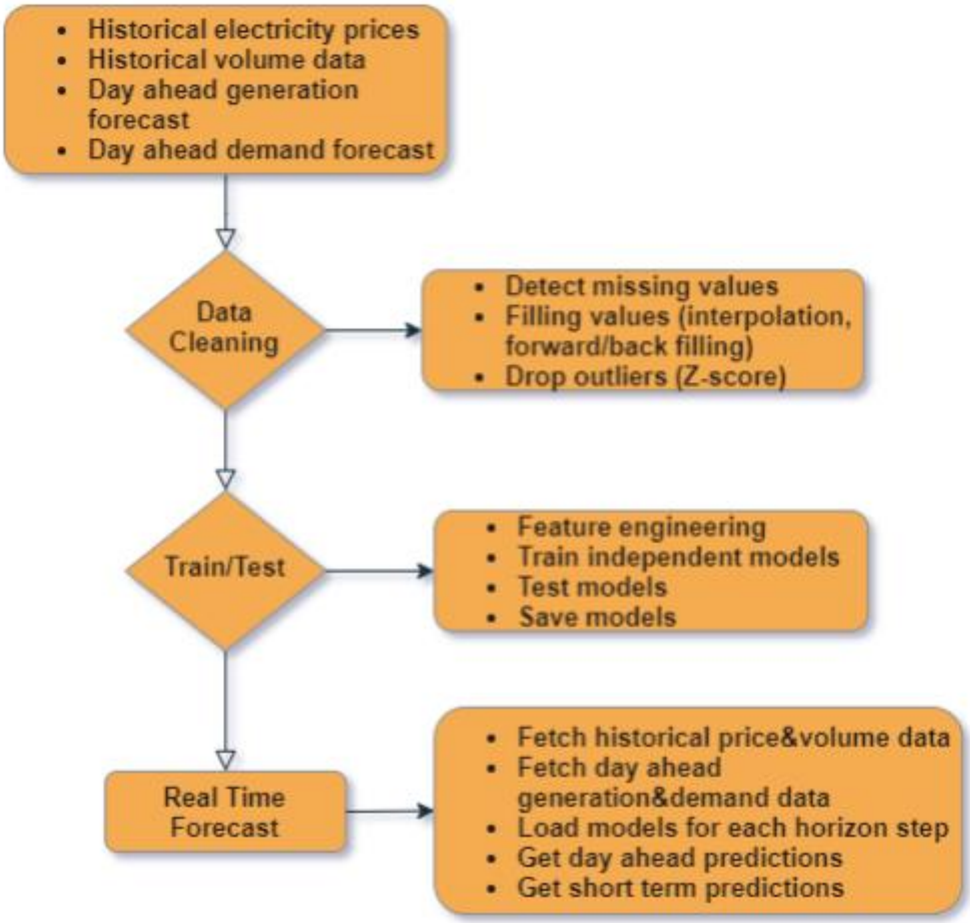

Figure 30 – Day-ahead and Intra-day forecasting methodology flow

3.3.4.3. Data pre-processing/preparation

One of the most critical and time-consuming components of time series forecasting is data cleaning. During the data gathering process, data is frequently either not collected or stored with the incorrect value. The data cleaning module is in charge of detecting such values and replacing, altering, or dropping them as necessary. The primary purpose is to create time series using data from the local database. Because the prediction models use records collected for a whole day, missing data is either omitted or supplemented in case the number of the missing values is lower than a certain percent for every day respectively. Finally, values that are considered outliers are removed using the z-score method. Z-score describes the

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position of a record in terms of the distance from the mean, when measured in standard deviation units.

The features that were considered important for the energy price forecasting modules are enlisted in the table below:

Prediction Type	Input features	Number of models	Output
Day-ahead	‣ 48 values of historical price data (30 min resolution) ‣ 48 values of historical volume data (30 min resolution) ‣ 48 values of forecasted day ahead generation data ‣ 48 values of forecasted day ahead demand data ‣ time features (Chapter 3.3.1.2)	48	48 price forecasting values
Intra day	‣ 48 values of historical price data (30 min resolution) ‣ 48 values of historical volume data (30 min resolution) ‣ 48 values of forecasted day ahead generation data ‣ 48 values of forecasted day ahead demand data	48	48 price forecasting values

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	▸ time features (Chapter 3.3.1.2)

Table 6 – Input parameters for the day-ahead/intra-day price forecasting engine

3.3.4.4. Training and predicting procedures

After preparing the dataset, the necessary models are constructed, through feature engineering. Following load forecasting module, direct multi-step strategy was adopted for the price forecasting tool. The only drawback for the direct strategy is that the development of many models adds a computational effort, especially when the number of the steps increase.

Intraday is utilizing the same model as the day ahead with the only difference being that the day ahead is executed only at midnight using only the previous days data, whereas the intraday is executed every thirty minutes based on the most recent historical values. The features listed in the table above were based on the literature and on experiments as well.

For the training, the GBT regressor was utilized for each model of each time horizon respectively. More specifically the variant of GBT that was utilized, was XGBoost. Different variants where also tested, like LightGBM, short for Light Gradient Boosting Machine. Although, they were not compatible with the hardware specifications of the lightweight FRD. Below a table with the comparison results between training models are provided. The evaluation of the models is conducted in terms of accuracy based on regression metrics and execution speed.

Forecasting approach	SMAPE (%)	MAPE (%)	RMSE	Execution time
LightGBM	6.41	1.582	7.21	125.12
XGBoost	6.79	1.75	7.4	192.46
MLP	7.31	1.78	7.46	348.94

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Table 7 – Summary results of the comparison of different ML models

LightGBM provided the best results, both in terms of accuracy and execution time. However, it could not operate in FRD or EB due to the fact that it requires a 64bit processor. The training of the algorithms was carried out with three months of historical data, including all the features described above.

A figure with the comparison between the actual and forecasted prices for the period of one week having as inputs the aforementioned features is illustrated below:

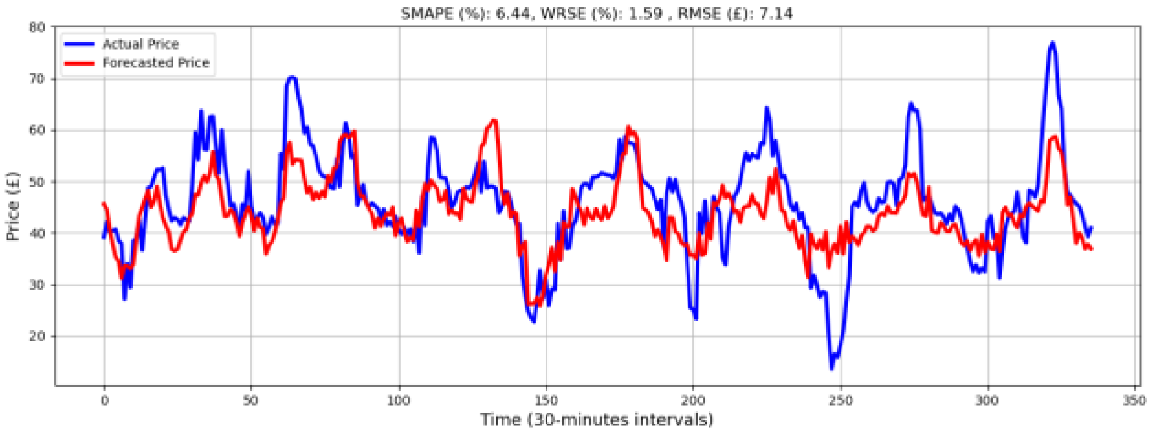

Figure 31 – Price forecasting results

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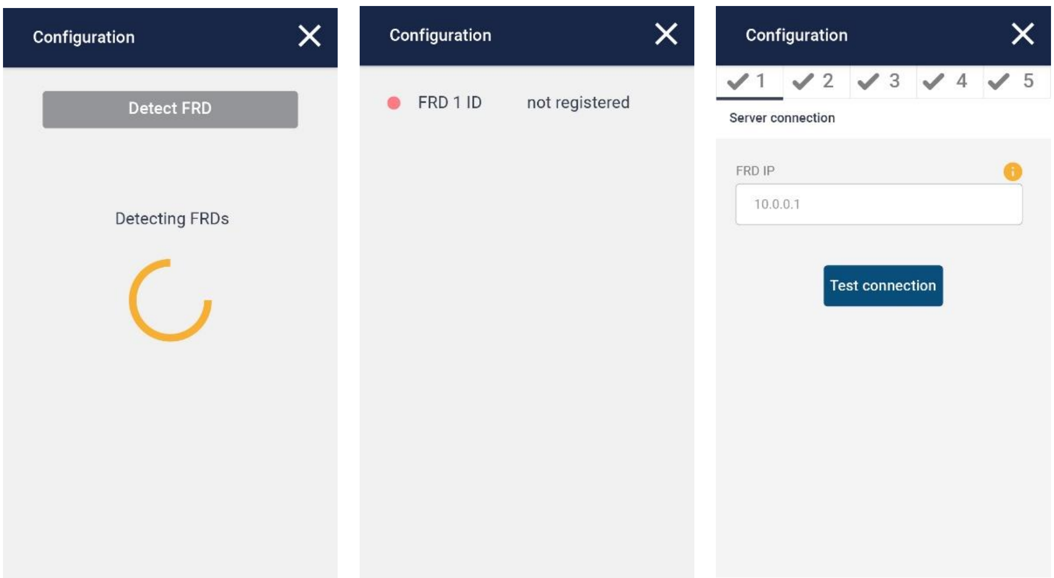
4. User Interface

The visualization of all the above, is possible via the main UI. It is a user-friendly, web-based interface, which has an intelligent restructure of FRDs' functionalities, among others, making it compatible with a wide range of screen sizes, from simple computer screens to cell phones.

4.1. Installation technician

An authorized technician is the responsible person for the FRD's installation in each facility. He/she will be logged in from a mobile or tablet device. This process will be done through the authorized technician account, while he/she will be given access to the respective end-user's details during the appointment and until the configuration of FRD and assets is complete.

The technician will complete the process through a simple wizard that will guide him through. This process is indicatively presented in the following figures.



This project has received funding from the European Union's H2020 research and innovation programme under the grant agreement No **824342**. This document reflects only the author's view and the Commission is not responsible for any use that may be made of the information it contains.

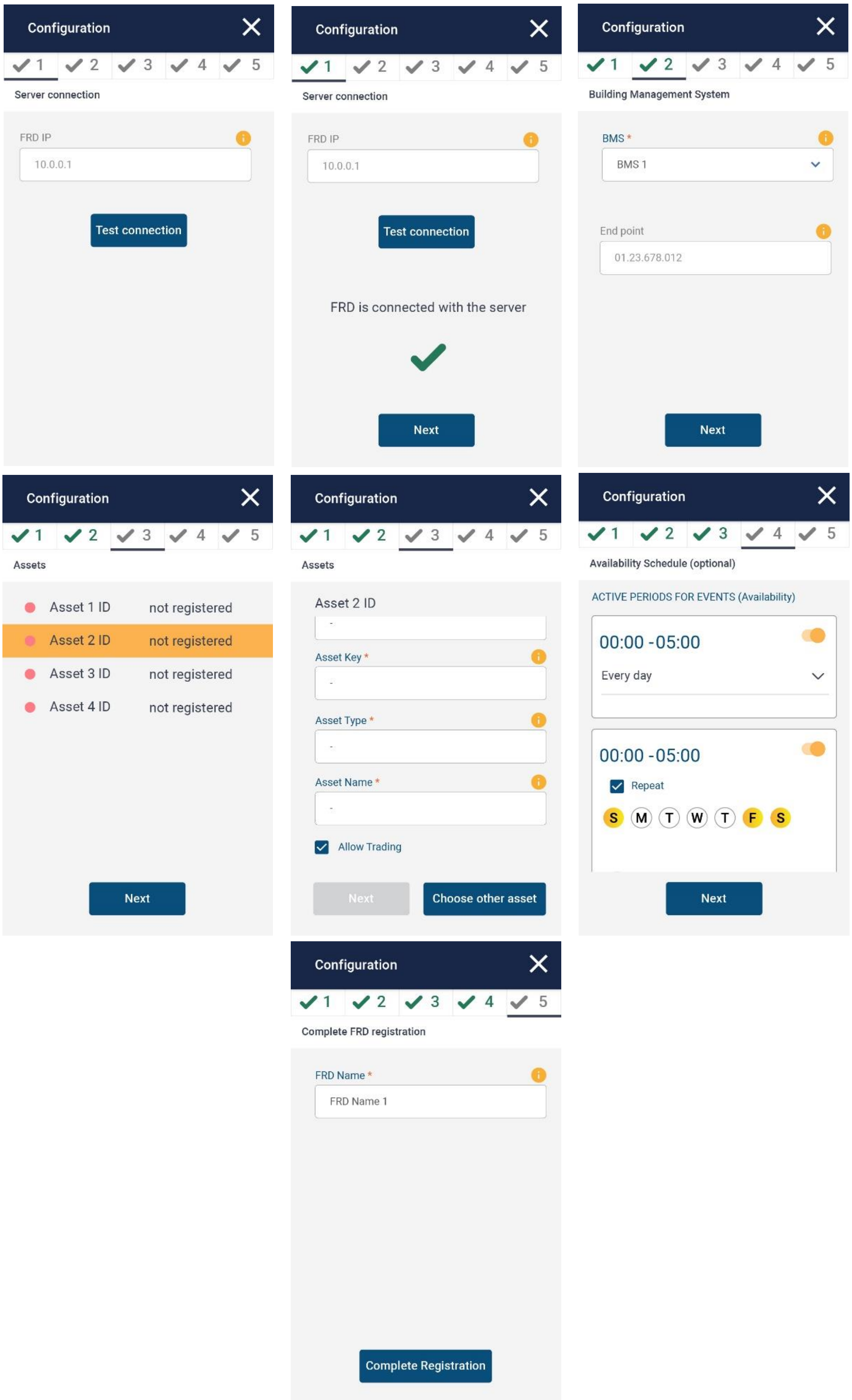


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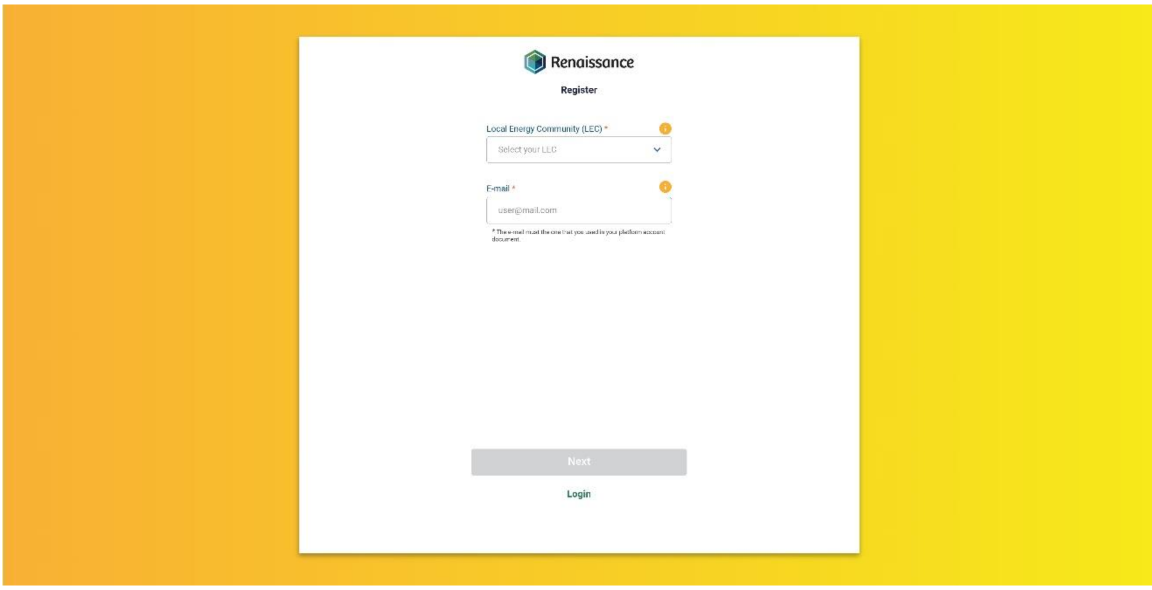
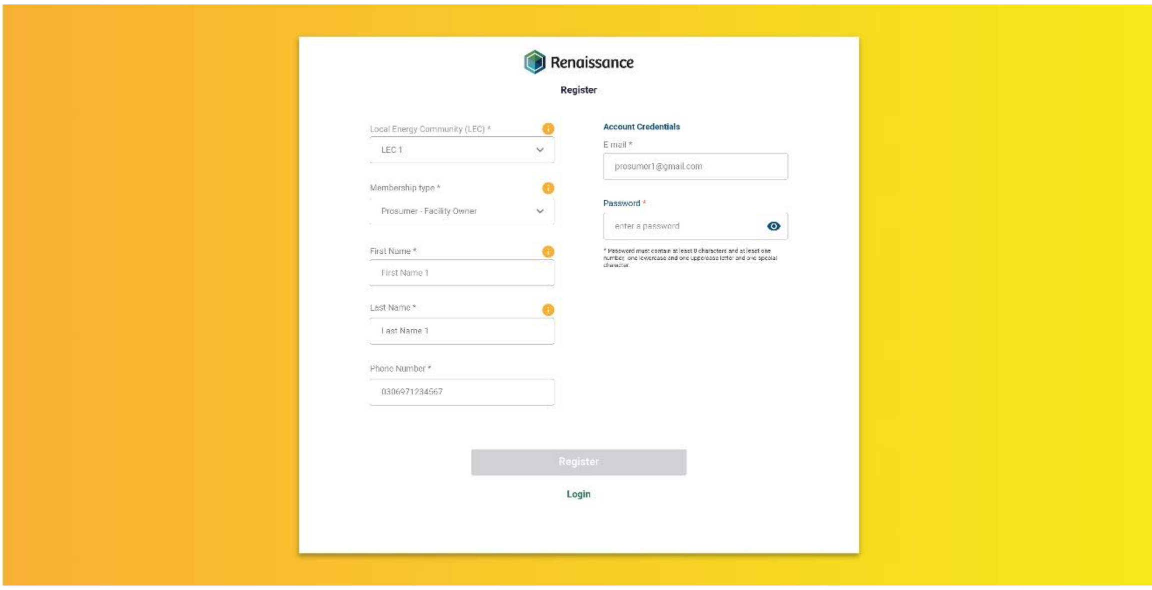
Figure 32 – Installation technician UI

4.2. LEC Members

All members of LEC can have access to the UI of the RENAISSANCE Platform. For a new user, that wants to register into the platform, the following registration form will be the first step. The user is prompt to answer whether the FRD installation is already completed by the authorized technician.





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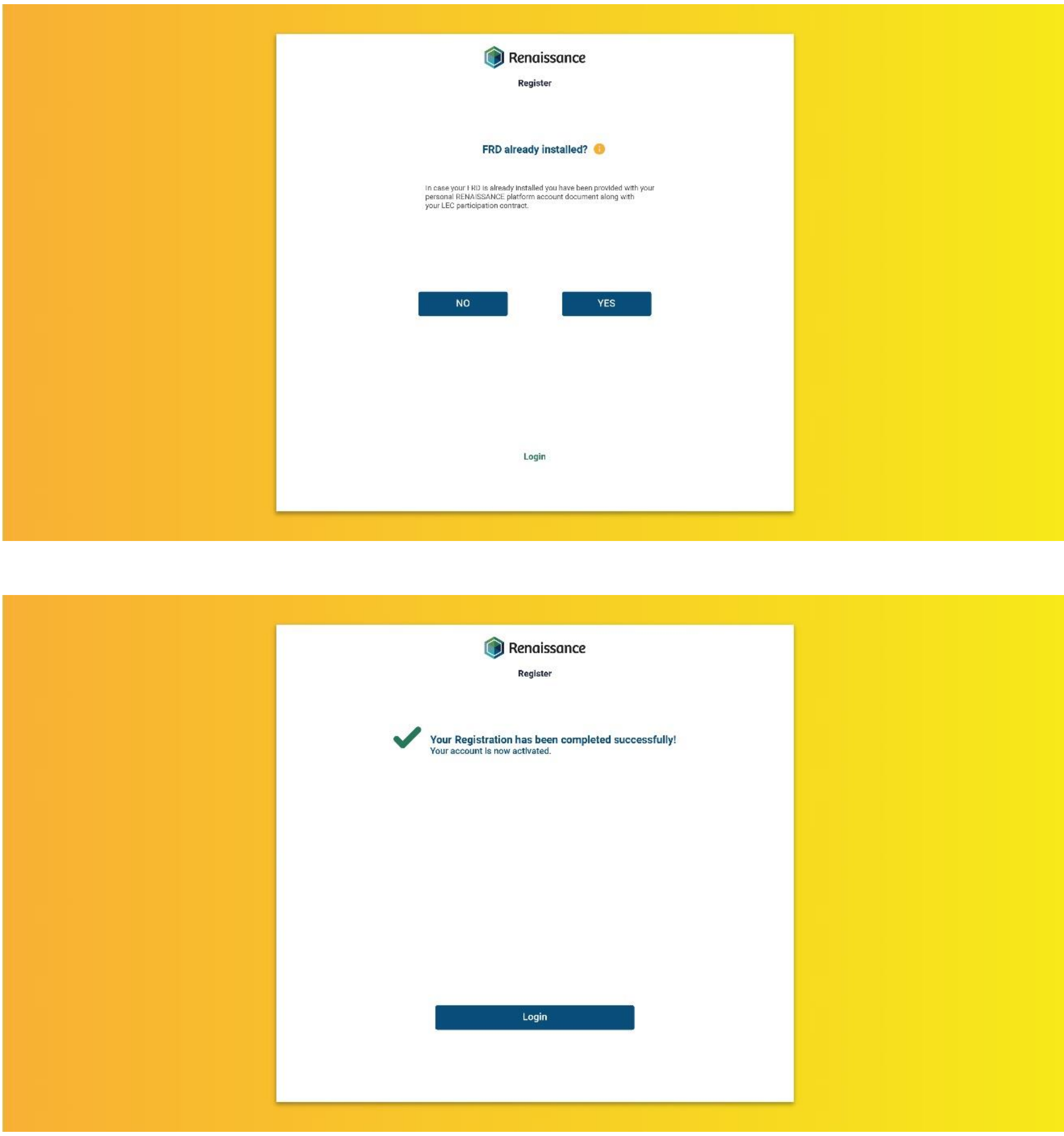

Figure 33 – New user's registration form and steps

After that, the user will be able to view the FRD's details and assets connected through the UI.

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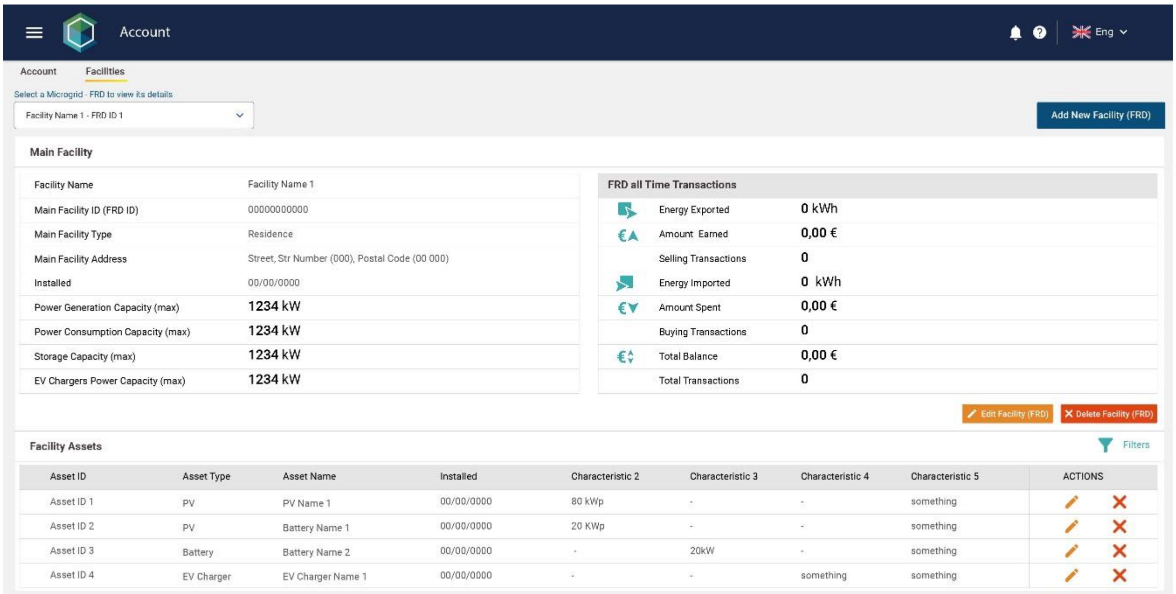

Figure 34 – User’s account

An overview of a prosumer’s facility status is presented in the following figure.

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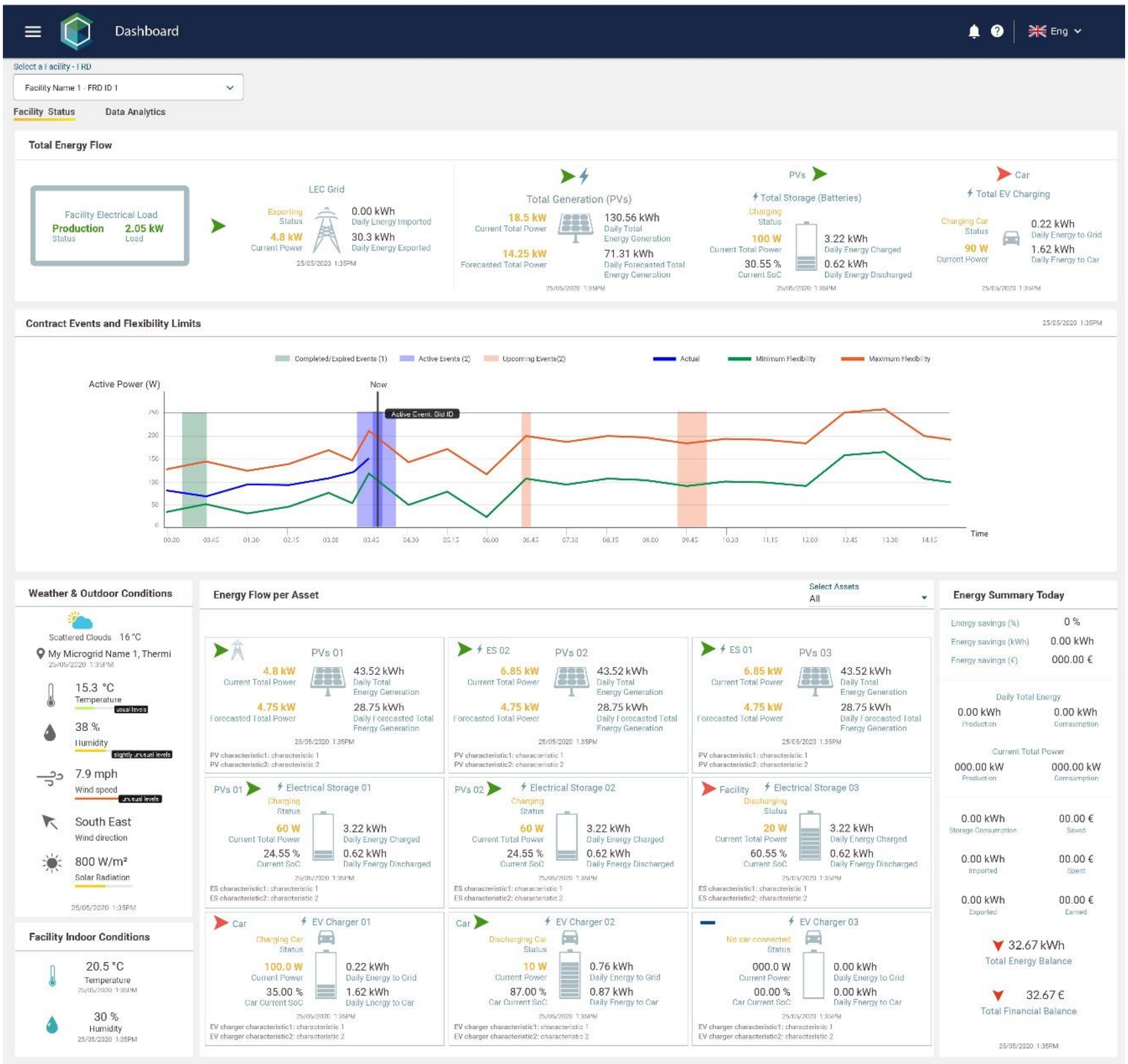

Figure 35 – Facility Status

The user can choose to view real-time data of the installed assets.

All forecasting modules developed, as detailed explained in section 3.3, are visually available for the user.

Moreover, the user can select to view the analytics of historical data (some sort cuts are given: last week, last month, last year), actual and predicted ones, for those periods of time. The user can also put a custom time range for which he/she wishes to inspect the respective historical data.

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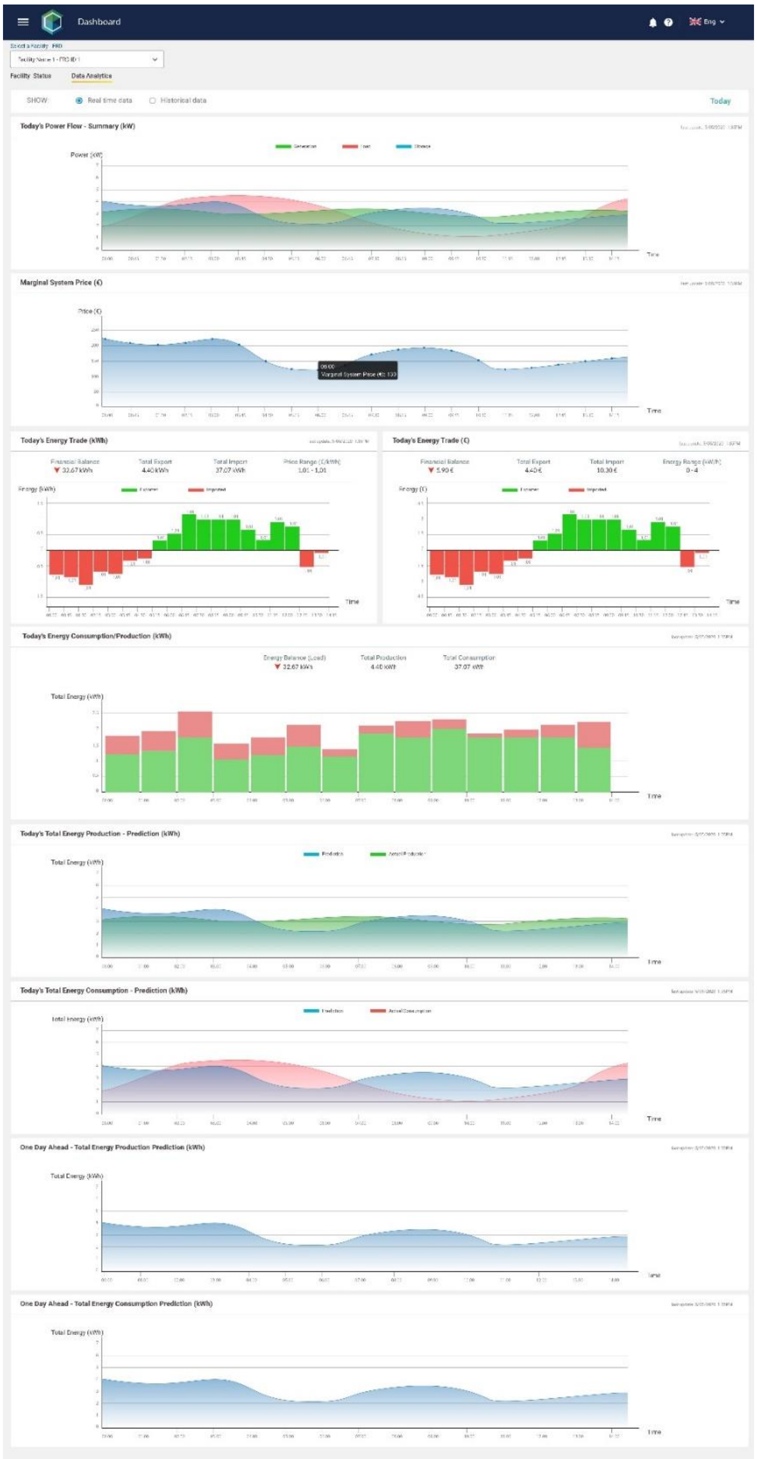

Figure 36 – Data Analytics

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5. Communication between FRD & external sources

5.1. Interactions between the FRDs and the RENAISSANCE Information Platform

Data ingestion and retrieval

The communication and retrieval of data between FRDs and external sources is performed using the Unified API component. This component basically provides a set of API endpoints that represent the context information and it's enclosed in the Data Layer of the architecture described in deliverable D4.1 – RENAISSANCE Information Platform.

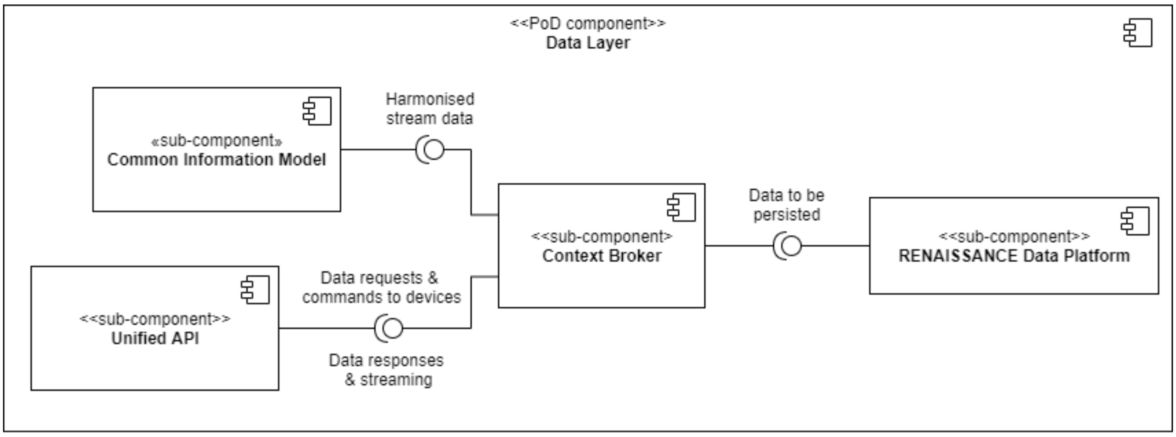

Figure 37 – Data Layer internal architecture

The data flow covers the next components of the Data Layer:

- Unified API
- CIM (Common Information Model)
- RENAISSANCE Data Platform
- Context Broker

This last subcomponent, the Context Broker, manages the context information that is streamed from the different data sources using the NGSI

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standard. This management of the information consists of its processing, and the logical values of each one of the streaming devices of the context information is updated in the RENAISSANCE Information Platform. The task of the CIM is the harmonization of the data so different data source types can be covered by this architectural approach.

The Unified API provides a bidirectional communication way to the Data Layer: on one direction, it provides responses from the different data requests; and in the other direction, it covers the signal forwarding related to the devices' transmission.

The logical diagram shown in the Figure 38 – Unified API diagram details the role of the Unified API as endpoint for components of the upper layers of the architecture (TSS, Modelling and Forecasting, DSS).

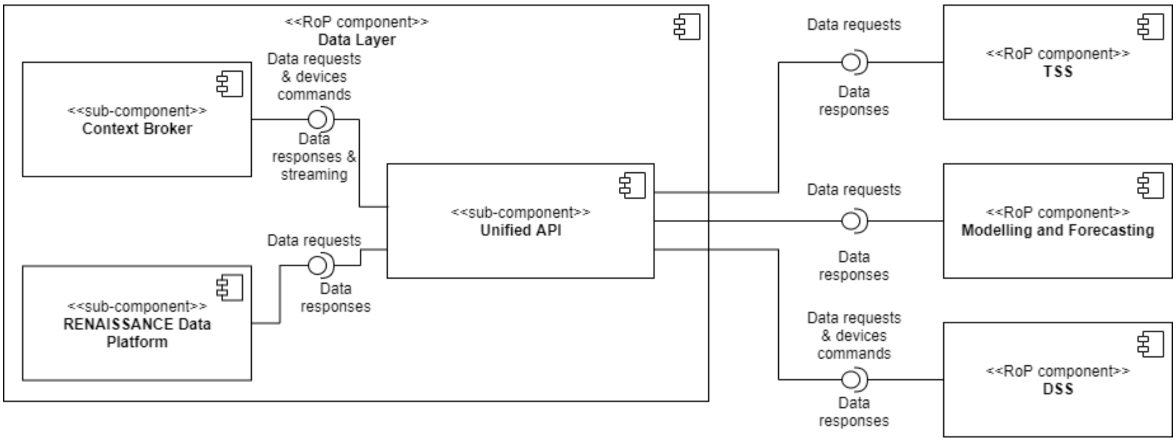

Figure 38 – Unified API diagram

Annex 1 – Unified API technical documentation, describes the technical information for the usage of the different endpoints available in the Unified API. The list of endpoints will be updated in upcoming deliverables of the project. Indeed, some of the listed endpoints are being currently developed.

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Authentication

When addressing the integration process, in this case between the Renaissance Information Platform and different devices which will be interchanging information with it, the management of user's credentials and identity tokens to third-party systems is a complex task and provides a significant difficulty level to the process. Furthermore, the integration approach has to be open enough to assure that, in the future, systems and components can have a smooth and easy integration process.

When managing the identity and granting access to the Renaissance Information Platform, we analysed different authentication methods, considering its advantages and cons, and tailoring them to the particularities of the Renaissance IT ecosystem.

Basic Auth

This basic authentication method is one of the most widely used, and it consists of a simple username/password authentication.
The main issue with this type of authentication is that it does not provide privacy protection for the transmitted credentials. For addressing this threat, is usually combined with HTTPS to provide an extra level of privacy and security.

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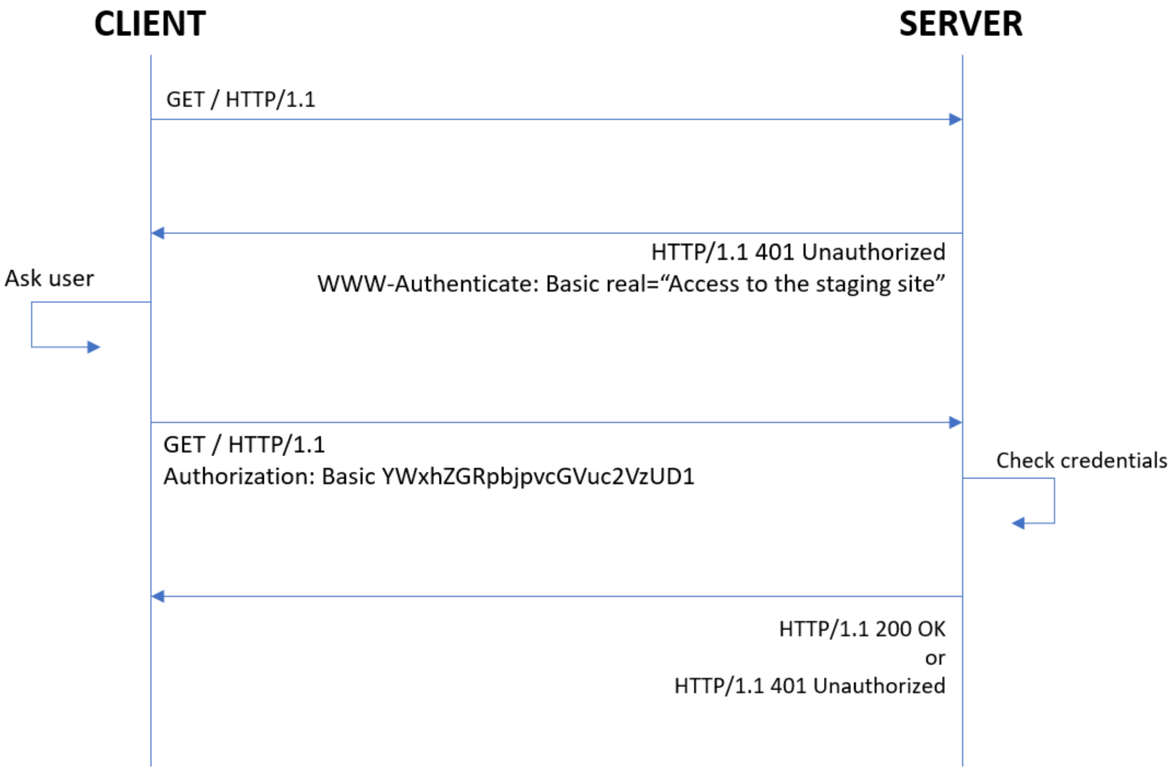

Figure 39 – Basic authentication process

The integration of the Renaissance Information Platform with the rest of the components in and out of the scope of the project (thinking about further use of the services provided for energy communities), is addressed by API endpoints with the different data and measurements of the demo sites. The way of granting access is basic authentication for providing a username and password access, but having in mind that in production environments, a stronger authorization system will have to be implemented.

OAuth1

The OAuth authorization protocolprovides access to different resources and components over the HTTP protocol. The way of working is quite simple, it provides an application with an access token (that is the representation of a user's permission: is allowed to access its data/resource).

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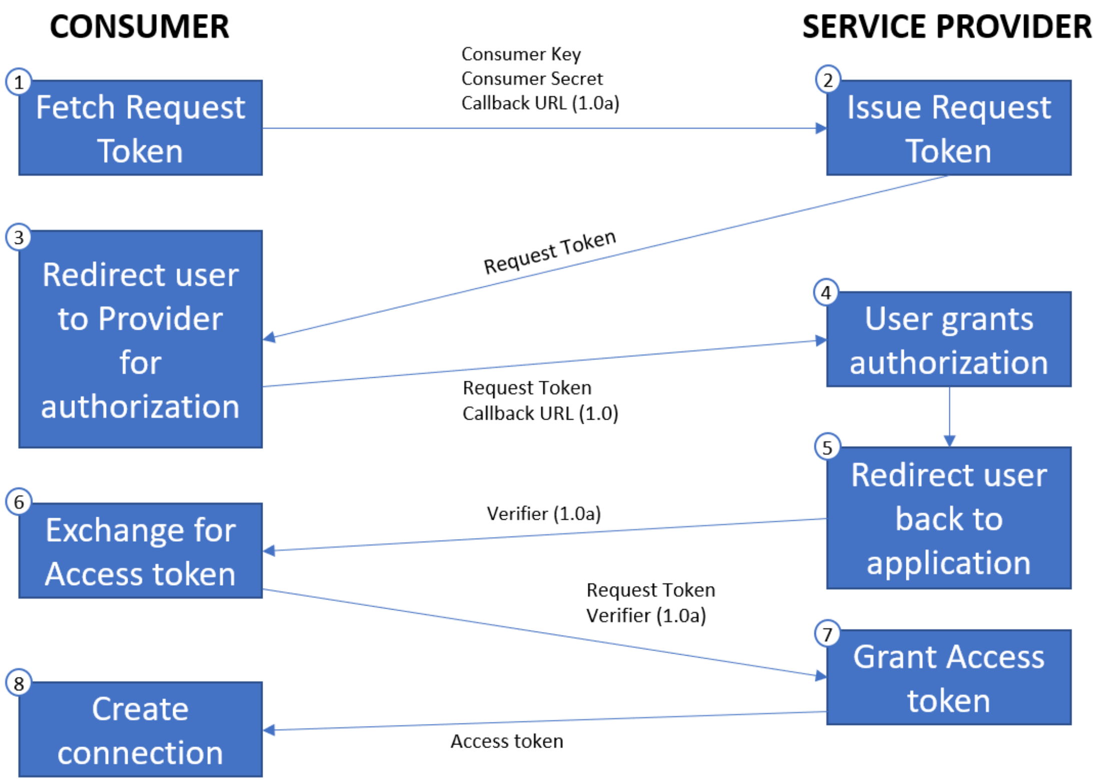

Figure 40 – OAuth1 authentication process

OAuth2

OAuth2 standard replaces OAuth1, and it can be considered as the de facto industry standard for web and digital processes authorization. Its main feature is that is able to provides access and actions restrictions of what the client component/user/application can do over the secured resources, without sharing the user's credentials.

OAuth2 uses Access Tokens, a data package that contains the authorization for accessing resources on behalf of the end user. The format usually comes from the JSON Web Token standard, but it's not defined in a sharp way. Furthermore, access tokens have expiration date for security reasons.

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When accessing a secured resource, before OAuth 2.0 is used, the client side has to get its own credentials (client identification and client secret) from the Authorization Server to its identification and authentication when requesting an Access Token.

The access requests are started by the Client, (web application, component, IoT device…). The token management flow is described below:

- Client requests authorization (authorization request) to the Authorization server, identifying it with its client id and client secret; it also provides an endpoint URI (redirect URI) to send the Access Token to.
- The Client get authenticated by the Authorization server and checks that the requested scopes are valid.
- The Resource owner gets the request of the Authorization server to grant access.
- The Authorization server returns an Authorization code or Access Token to the Client.
- The Client requests access to the resource from the Resource server providing the Access token.

5.2.DSM Signals handling

FRD supports DSM signals exchanging through OpenADR protocol, allowing it to be easily installed and utilized in different use cases. To achieve this, specific entities were developed to facilitate the communication in both ends, Virtual Top Node (VTN) and Virtual End Node (VEN). All network traffic is routed between those two entities. Depending in the use case scenario and the requirements of each pilot site, the FRD can have either the role of

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VEN or both VTN and VEN. Marketplace owner is usually considered to be the VTN, therefore this entity will be deployed in ATOS' FUSE platform. The relationship between VTN and VEN is depicted in the figure below:

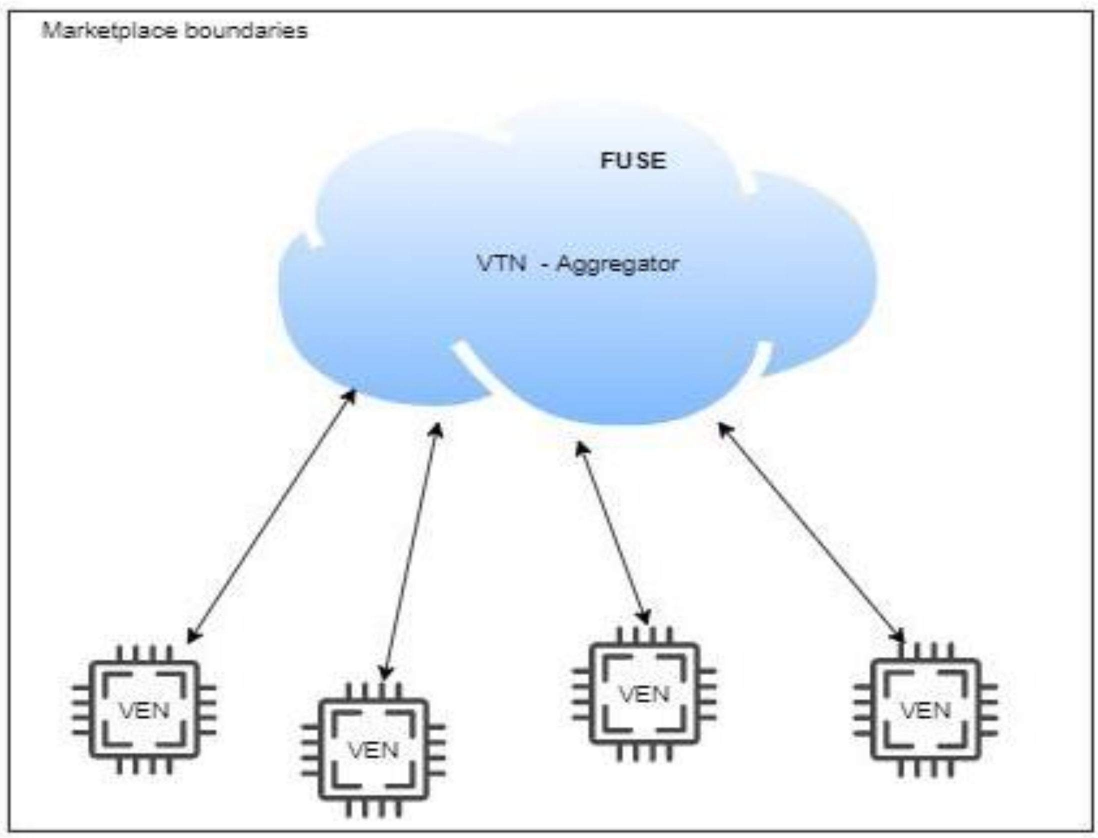

Figure 41 – VTN – VEN communication

5.2.1. OpenADR communication protocol

OpenADR[2] is an open, highly secure, and two-way information exchange model and global Smart Grid standard. OpenADR standardizes the message format used for Auto-DR and DER management so that dynamic price and reliability signals can be exchanged in a uniform and interoperable fashion among utilities, ISOs, and energy management and control systems. While

[2] www.openadr.org

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previously deployed Auto-DR systems are automated, they are not standardized or interoperable. OpenADR was created to automate and simplify DR and DER for the power industry with dynamic price and reliability signals that allow end users to modify their usage patterns to save money and optimize energy efficiency, while enhancing the effectiveness of power delivery across the Smart Grid.

5.2.2. Implementation

The following chapters demonstrate how this protocol is utilized inside the premises of RENAISSANCE.

5.2.2.1. OpenLEADR

OpenLEADR[3] is a Python 3 module that provides a convenient interface to OpenADR systems. It contains an OpenADR Client that you can use to talk to other OpenADR systems, and it contains an OpenADR Server (VTN) with convenient integration possibilities.

5.2.2.2. Virtual Top Node (VTN)

The VTN object was developed in Python programming language and utilized OpenLEADR open-source library. This entity is responsible to check new VTNs' registration, request status reports from the connected end nodes, collect DSM signals and distribute them to the appropriate end-node. The exchanged signals are in XML file format and follow the respective format of OpenADR protocol. The table below enlists the payloads that the VTN is developed to receive or generate:

[3] www.openleadr.org/docs

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OpenADR payload	Description
oadrCreatedPartyRegistration	A request from the VEN to the VTN to register. Contains information about the VENs capabilities.
oadrPoll	A generic poling mechanism for the B profile that returns payload for any other service that are new or have been updated.
oadrRegisterReport	Used to publish their reporting capabilities in a metadata report.
oadrUpdateReport	Deliver a requested report containing interval data.
oadrResponse	Deliver a requested report containing interval data.
oadrCreatedEvent	Used by the VEN to communicate whether it intends to participate in an event by opting in or out.
oadrCreateReport	Used to request a report that has been previously offered by the VEN or VTN.

Table 8 – VTN OpenADR supported payloads

OpenLEADR represents OpenADR payloads in a more simple and comprehensible way. The OpenLEADR payloads that are necessary for VTN's functionality are enlisted below:

Created party registration:

```
{'profiles':
[{'profile_name': '2.0b',
                'transports': [{'transport_name': 'simpleHttp'}]}],
 'registration_id': str,
 'response': {'request_id': str,
               'response_code': 200,
               'response_description': 'OK'},
```


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```
 'ven_id': str,
 'vtn_id': str}
```

Poll:

```
{'ven_id': str}
```

Register report:

```
{'report_request_id': str,
 'reports': [{'created_date_time': datetime.datetime,
              'report_descriptions': [{'market_context': str,
                                       'r_id': str,
                                       'reading_type': 'Direct Read',
                                       'report_data_source': {'resource_id': str},
                                       'report_subject': {'resource_id': str},
                                       'report_type': 'reading',
                                       'sampling_rate': {'max_period':datetime.timedelta
                                                         'min_period':datetime.timedelta,
                                                          'on_change': True}}],
              'report_id': str,
              'report_name': str,
              'report_request_id': str,
              'report_specifier_id': str}],
 'request_id': str,
 'ven_id': str}
```

Update report

```
{'reports': [{'created_date_time': datetime.datetime,
              'report_descriptions': [{'market_context': str,
                                       'r_id': str,
                                       'reading_type': 'Allocated',
                                       'report_data_source': {'resource_id': str},
                                       'report_subject': {'resource_id': '123ABC'},
                                       'report_type': 'availableEnergyStorage',
                                       'sampling_rate': {
                                                         'max_period':datetime.timedelta,
                                                         'min_period':datetime.timedelta,
                                                         'on_change': False}}],
              'report_id': str,
              'report_name': ' str,
```

```
             'report_request_id': str,
             'report_specifier_id': str }],
 'request_id': str,
 'ven_id': str }
```

Response

```
{'response': {'request_id': str,
              'response_code': 200,
              'response_description': 'OK'},
 'ven_id': str}
```

Created Event

```
{'event_responses': [{'event_id': str,
                      'modification_number': int,
                      'opt_type': 'optIn/optOut',
                      'request_id': str,
                      'response_code': 200,
                      'response_description': 'OK'},
                     {'event_id': str,
                      'modification_number': 1,
                      'opt_type': 'optIn/optOut',
                      'request_id': str,
                      'response_code': 200,
                      'response_description': 'OK'},
                     {'event_id': str,
                      'modification_number': 1,
                      'opt_type': 'optIn/optOut',
                      'request_id': str,
                      'response_code': 200,
                      'response_description': 'OK'}],
 'response': {'request_id': str,
              'response_code': 200,
              'response_description': 'OK'},
 'ven_id': str}
```

Create Report

```
{'report_requests': [{'report_request_id': str,
                      'report_specifier': {
                              'granularity': datetime.timedelta
```


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```
                             'report_back_duration': datetime.timedelta,
                             'report_interval': {
                                        'dtstart': datetime.datetime,
                                        'duration': datetime.timedelta
                                               },
                             'report_specifier_id': str,
                             'specifier_payloads':[{
                                      'r_id': str,
                                      'reading_type': 'Direct Read'
                    }]}}],
 'request_id': str,
 'ven_id': str}
```

The class of VTN with every handler developed to support the aforementioned functionalities is shown below:

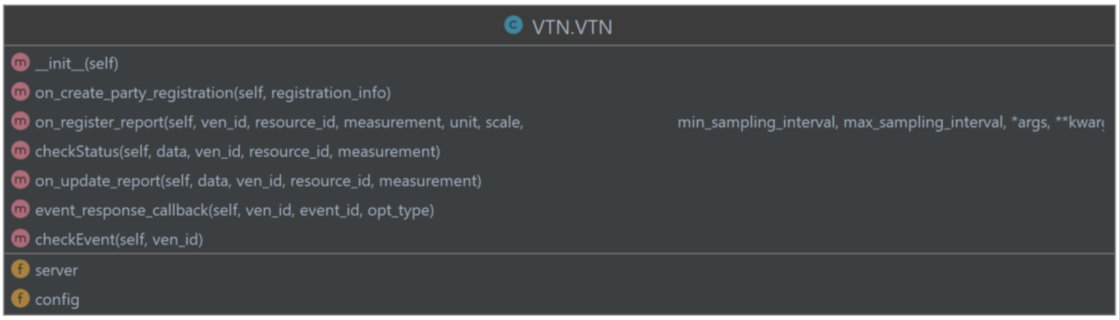

Figure 42 – VTN class diagram

5.2.2.3. Virtual End Node (VEN)

The VEN object was developed in Python programming language and utilized OpenLEADR open-source library. This entity is responsible to connect the FRDs (end nodes) to the market, acquire authentication from the Market Owner (VTN) and report to VTN or receive and handle DSM signals. The exchanged signals are in XML file format and follow the

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respective format of OpenADR protocol. The table below enlists the payloads that the VEN is developed to receive or generate:

OpenADR payload	Description
oadrCreatePartyRegistration	A request from the VEN to the VTN to register. Contains information about the VENs capabilities.
oadrPoll	A generic poling mechanism for the B profile that returns payload for any other service that are new or have been updated.
oadrRegisterReport	Used to publish their reporting capabilities in a metadata report.
oadrUpdateReport	Deliver a requested report containing interval data.
oadrResponse	Deliver a requested report containing interval data.
oadrCreateOp	Used for two distinctly different purposes o For the VEN to communicate a temporary availability schedule to the VTN with regards to its ability to participate in DR events o For the VEN to qualify the resources participating in an event
oadrCreatedReport	Used by the VEN to communicate whether it intends to participate in an event by opting in or out.

Table 9 – VEN OpenADR supported payloads

OpenLEADR represents OpenADR payloads in a more simple and comprehensible way. The OpenLEADR payloads that are necessary for VEN's

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functionality are enlisted below (those already described in VTN are omitted):

Create party registration:

```
{'http_pull_model': bool,
 'profile_name': '2.0b',
 'report_only': bool,
 'request_id': str,
 'transport_address': str,
 'transport_name': 'simpleHttp',
 'ven_id': str,
 'ven_name': str,
 'xml_signature': bool}
```

Create opt:

```
{'created_date_time': datetime.datetime,
 'event_id': str,
 'modification_number': int,
 'opt_id': str,
 'opt_reason': str,
 'opt_type': 'optIn/optOut,
 'request_id': str,
 'targets': [{'ven_id': str}],
 'targets_by_type': {'ven_id': [str]},
 'ven_id': str}
```

Created report:

```
{'pending_reports': [{'request_id': str},
                     {'request_id': str}],
 'response': {'request_id': str,
              'response_code': 200,
              'response_description': str},
 'ven_id': str}
```

At this point, since the FRDs are not physically installed in any RENAISSANCE pilot cite, the values for the reporting functionality of FRD are received through ATOS' Unified API for data exchanging. VEN can be expanded to

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support more reporting capabilities, if it considered necessary. Below, the initial class diagram of the VEN object is shown. This class will be extended, by implementing and integrating the needs of each Local Energy Community.

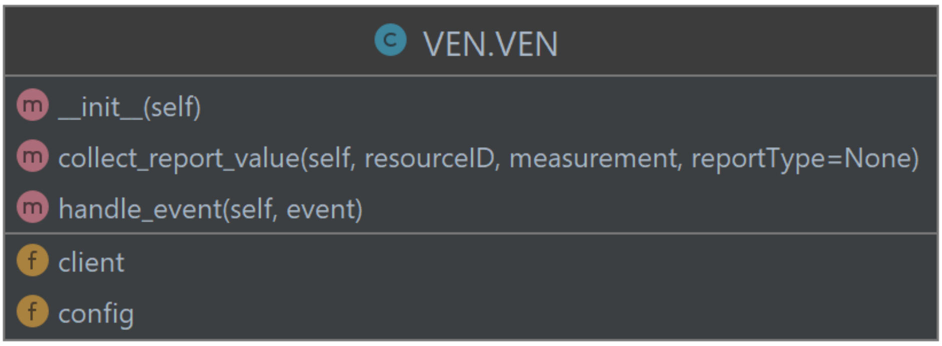

Figure 43 – VEN class diagram

5.2.2.4. Asset Optimization

Towards incorporating higher intelligence regarding the operation of the assets under the FRD, the Asset Handling tool, part of the Decision Support System, will be integrated. It constitutes an optimization engine that is deployed to solve a mixed-integer linear programming (MILP) problem; the minimization of the users' discomfort, as a result of any changes in the planned consumption pattern that are necessarily scheduled to respond to a received DR signal that was previously described. Moreover, both the dynamic constraints of the assets as well as the user's preferences regarding their flexible operation are considered. A similar approach, yet more generic and not focused on the DR-signals implementation is described in [18].

The problem formulation is presented below.

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$$Discomfort\ Cost = \sum_{t=0}^{H}\sum_{l=1}^{L}\frac{1}{fl_{t,l}}\cdot\left(E_{t,l}^{des} - E_{t,l}^{act}\right)$$

$$s.t.\ \sum_{t=start}^{t=finish}\sum_{l=1}^{L}\left(E_{t,l}^{act} - E_{t,l}^{des}\right) = DR\ signal\ target \quad (1)$$

$$(1 - b_{t,l})\cdot E_{t,l}^{des} + b_{t,l}\cdot E_{min,l}^{act} \leq E_{t,l}^{act} \leq \left(1 - b_{t,l}\right)\cdot E_{t,l}^{des} + b_{t,l}\cdot E_{max,l}^{act}, l \in [0, L] \quad (2)$$

$$\sum_{t=0}^{H} E_{t,l}^{act} = \sum_{t=0}^{H} E_{t,l}^{des}, l \in [0, L_1] \subseteq [0, L] \quad (3)$$

$$MinOperationalSlots \leq \sum_{t=0}^{H} b_{t,l} \leq MaxOperationalSlots, l \in [0, L] \quad (4)$$

Where,

- $t \in [0, H]$ are the time slots of the optimization horizon
- $l \in [0, L]$ are the different loads (i.e. assets) that can be rescheduled
- $fl_{t,l}$ is the degree of flexibility regarding the operation of load l during time slot t (user-defined)
- $E_{t,a}^{act}$, $E_{t,l}^{des}$ are the adjusted (optimized) and typically consumed (in-operation) energy for load l during time slot t, correspondingly
- $b_{t,l}$ are auxiliary binary variables

A number of both load-specific and DR target-restrictive constraints are also defined. Constraint (1) describes the essential energy displacement during the implementation of the DR signal. Constraint (2) bounds the energy allocated to each time slot between the allowed limits of each load. Finally, constraint (3) guarantees that the operation for a number of devices is shifted in the optimization horizon rather than adjusted, while constraint

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(4) indicates the amount of time slots where the load is allowed to be scheduled.

5.3. Edge nodes M2M security

RENAISSANCE Information Platform is a hybrid multi-cloud ICT solution that orchestrates the data exchange between edge devices, advanced services, the blockchain network and interfaces for users and administrators. Furthermore, it follows a microservice approach to foster modularity and covers as much energy vectors as necessary to fulfil the stakeholder's expectations.

The securization of the Unified API endpoints where edge devices will provide their streams of data is covered by sets of mechanisms implemented:

- Authentication: As a proof of concept, a Basic Authentication mechanism has been deployed in the public API, so only stakeholders of the project can access energy metering data from the different demo sites.
- User access: On top of the AA (authentication and authorization) technical schema, the user access policy complements it with a dynamic modulation according to flexibility in order to change those schemas in a different way (i.e. including new stakeholders or extending the number of demo sites)
- Security: According to the three previous points, there are in the market some solutions that provide this bundle package of Authentication + Authorization + User Access. A set of open-

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source solutions (e.g., ForgeRock[4], Gluu[5], OpenIAM[6]…) have been evaluated and proposed for extensions of more complex scenarios or tighter security requirements.

6. Conclusions

The design and development of the RENAISSANCE Fog-Ready Device (FRD) are documented in this deliverable. The hardware, software, and key features of each module thoroughly presented, as well as the reasons for their application in modern Local Energy Communities. As the need for efficient management of produced and consumed energy increases, utilization of tools that empower grid stability is becoming of high importance. This powerful, yet lightweight hardware solution and its software suite, is a strong asset towards a more sustainable future that will start from Local Energy Communities, and scale globally. The robust forecasting toolset that it has facilitates both the real time operation preventing undesired situations and the estimation of customer's flexibility that is used in the fairer distribution of DSM signals and therefore in the successful outcome of the whole market participation program.

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Renaissance

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Annex 1 – Unified API technical documentation

API architecture

- Base URL: http://information-platform.renaissance-h2020.eu
- Mandatory headers:
  - fiware-service=<pilot_site>
  - fiware-servicepath=<pilot_site_subsystem>
- Endpoints:
  - Real-time measurements and context: /v2
  - Historical data: /historical

The endpoints don't return any data without a proper sub-path. See the rest of the document for usage instructions.

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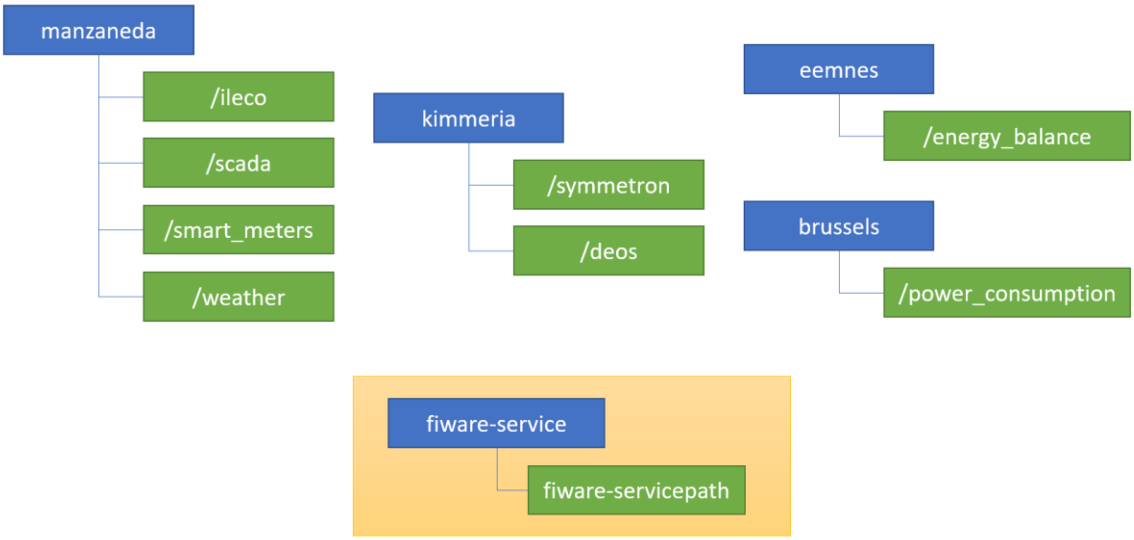
Header combinations



Manzaneda

Historical

- The URL to get the historical data of an entity is the following:
    - http://information-platform.renaissance-h2020.eu/**historical**/entities/<entity_id>?from=<iso_8601_date>&to=<iso_8601_date>
- Only the historical data of entities of type **FieldDevice** or **Weather** can be retrieved
- Remember to use the proper headers for each request (fiware-service & fiware-servicepath)
    - The same headers as in RT/context request are valid

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SCADA

Get substations

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities?type=Substation

Headers

fiware-service	manzaneda
fiware-servicepath	/scada

Params

type	Substation

Example request

```
curl --location --request GET 'http://information-platform.renaissance-
h2020.eu/v2/entities?type=Substation' \
--header 'fiware-service: manzaneda' \
--header 'fiware-servicepath: /scada'
```

Get a switchgear

Attribute "hasEquipment" in every switchgear JSON has a list with the IDs of field devices available in that switchgear. Put in "value" the switchgear id.

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities

Headers

fiware-service	manzaneda
fiware-servicepath	/scada

Params

	<switchgear_id>

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Example request

```
curl --location --request GET 'http://information-platform.renaissance-h2020.eu/v2/entities?=1'
\
--header 'fiware-service: manzaneda' \
--header 'fiware-servicepath: /scada'
```

Get a field device (meter)

Field devices can be consulted periodically to get the real-time or near real-time values of measurements. Attribute "refFieldDeviceStationary" in every field device JSON indicates the ID of its field device stationary entity. The field device stationary entity gives a list of the properties measured by the field device (attribute "measuresProperty") and their corresponding units of measurement ("isMeasuredIn", for every property). Put in "value" the field device id.

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities

Headers

fiware-service	manzaneda
fiware-servicepath	/scada

Params

	<field_device_id>

Example request

```
curl --location --request GET 'http://information-platform.renaissance-h2020.eu/v2/entities?=2'
\
--header 'fiware-service: manzaneda' \
--header 'fiware-servicepath: /scada'
```


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Smart meters

Get data concentrators

Attribute "concentratesDataForm" in every data contentrator JSON has a list with the IDs of the field devices (smart meters) concentrated by that data concentrator.

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities?type=DataConcentrator

Headers

fiware-service	manzaneda
fiware-servicepath	/smart_meters

Params

type	DataConcentrator

Example request

```
curl --location --request GET 'http://information-platform.renaissance-
h2020.eu/v2/entities?type=DataConcentrator' \
--header 'fiware-service: manzaneda' \
--header 'fiware-servicepath: /smart_meters'
```

Get a field device (meter)

Field devices can be retrieved periodically to get the real-time or near real-time values of measurements. Attribute "refFieldDeviceStationary" in every field device JSON indicates the ID of its field device stationary entity. The field device stationary entity gives a list of the properties measured by the field device (attribute "measuresProperty") and their corresponding units of measurement ("isMeasuredIn", for every property). Put in "value" the field device id.

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Base URL

http://information-platform.renaissance-h2020.eu/v2/entities

Headers

fiware-service	manzaneda
fiware-servicepath	/smart_meters

Params

	<field_device_id>

Example request

```
curl --location --request GET 'http://information-platform.renaissance-h2020.eu/v2/entities?=1' \
--header 'fiware-service: manzaneda' \
--header 'fiware-servicepath: /smart_meters'
```

Get a field device (stationary)

Field devices can be retreived periodically to get the real-time or near real-time values of measurements. Attribute "refFieldDeviceStationary" in every field device JSON indicates the ID of its field device stationary entity. The field device stationary entity gives a list of the properties measured by the field device (attribute "measuresProperty") and their corresponding units of measurement ("isMeasuredIn", for every property). Put in "value" the field device id.

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities

Headers

fiware-service	manzaneda
fiware-servicepath	/smart_meters

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Params

	<field_device_id>

Example request

```
curl --location --request GET 'http://information-platform.renaissance-h2020.eu/v2/entities?=2'
\
--header 'fiware-service: manzaneda' \
--header 'fiware-servicepath: /smart_meters
```

Weather

Get weather entity

The weather entity can be consulted periodically to get the real-time or near real-time values of measurements.

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities?type=Weather

Headers

fiware-service	manzaneda
fiware-servicepath	/weather

Params

type	Weather

Example request

```
curl --location --request GET 'http://information-platform.renaissance-
h2020.eu/v2/entities?type=Weather' --header 'fiware-service: manzaneda' \
--header 'fiware-servicepath: /weather'
```


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Get a field device (stationary)

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities?=2

Headers

fiware-service	manzaneda
fiware-servicepath	/weather

Params

	<field_device_id>

Example request

```
curl --location --request GET 'http://information-platform.renaissance-h2020.eu/v2/entities?=2'
\
--header 'fiware-service: manzaneda' \
--header 'fiware-servicepath: /weather'
```

Real time

Get entities

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities?type=FieldDevice

Headers

fiware-service	manzaneda
fiware-servicepath	/ ree-api'

Params

type	FieldDevice

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Example request

curl --location --request GET 'http://information-platform.renaissance-h2020.eu/v2/entities?type=FieldDevice' \
--header 'fiware-service: /manzaneda' \
--header 'fiware- servicepath: /ree-api'

Price

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities?=2

Headers

fiware-service	manzaneda
fiware-servicepath	/weather

Params

	2

Example request

curl --location --request GET 'http://information-platform.renaissance-h2020.eu/v2/entities?=2' \
--header 'fiware-service: manzaneda' \
--header 'fiware-servicepath: /weather'

Comparison non-renewable energy renewable

Get comparison non-renewable energy renewable metering

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_renewable_energy_comparison_non_renewable_energy_Renewable

Headers

fiware-service	manzaneda

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fiware-servicepath	/ree_api

Params

Example request

```
curl --location --request GET 'http://information-platform.renaissance-
h2020.eu/v2/entities/manzaneda_ree_api_renewable_energy_comparison_non_renewable_e
nergy_Renewable' \
--header 'fiware-service: manzaneda' \
--header 'fiware-servicepath: /ree_api'
```

Comparison non-renewable energy non-renewable

Get comparison non-renewable energy non-renewable metering

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_renewable_energy_comparison_non_renewable_energy_Nonrenewable

Headers

fiware-service	manzaneda
fiware-servicepath	/ree_api

Params

Example request

```
curl --location --request GET 'http://information-platform.renaissance-
h2020.eu/v2/entities/manzaneda_ree_api_renewable_energy_comparison_non_renewable_e
nergy_Nonrenewable' \
--header 'fiware-service: manzaneda' \
--header 'fiware-servicepath: /ree_api'
```


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Hydro

Get renewable hydro metering

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_renewable_energy_Hydro

Headers

fiware-service	manzaneda
fiware-servicepath	/ree_api

Params

Example request

```
curl --location --request GET 'http://information-platform.renaissance-
h2020.eu/v2/entities/manzaneda_ree_api_renewable_energy_Hydro' \
--header 'fiware-service: manzaneda' \
--header 'fiware-servicepath: /ree_api'
```

Hydroeolian

Get renewable hydroeolian metering

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_renewable_energy_Hydroeolian

Headers

fiware-service	manzaneda
fiware-servicepath	/ree_api

Params

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Example request

```
curl --location --request GET 'http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_renewable_energy_Hydroeolian' \
--header 'fiware-service: manzaneda' \
--header 'fiware-servicepath: /ree_api'
```

Wind

Get renewable wind metering

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_renewable_energy_Wind

Headers

fiware-service	manzaneda
fiware-servicepath	/ree_api

Params

Example request

```
curl --location --request GET 'http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_renewable_energy_Wind' \
--header 'fiware-service: manzaneda' \
--header 'fiware-servicepath: /ree_api'
```

Solarphotovoltaic

Get renewable solarphotovoltaic metering

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_renewable_energy_Solarphotovoltaic

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Headers

fiware-service	manzaneda
fiware-servicepath	/ree_api

Params

Example request

curl --location --request GET 'http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_renewable_energy_Solarphotovoltaic' \
--header 'fiware-service: manzaneda' \
--header 'fiware-servicepath: /ree_api'

Thermalsolar

Get renewable thermalsolar metering

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_renewable_energy_Thermalsola
r

Headers

fiware-service	manzaneda
fiware-servicepath	/ree_api

Params

Example request

curl --location --request GET 'http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_renewable_energy_Thermalsolar' \
--header 'fiware-service: manzaneda' \
--header 'fiware-servicepath: /ree_api'

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Other renewables

Get other renewables metering

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_renewable_energy_Otherrenewables

Headers

fiware-service	manzaneda
fiware-servicepath	/ree_api

Params

Example request

```
curl --location --request GET 'http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_renewable_energy_Otherrenewables' \
--header 'fiware-service: manzaneda' \
--header 'fiware-servicepath: /ree_api'
```

Renewable waste

Get renewable waste metering

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_renewable_energy_RenewableWaste

Headers

fiware-service	manzaneda
fiware-servicepath	/ree_api

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Params

Example request

curl --location --request GET 'http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_renewable_energy_RenewableWaste' \
--header 'fiware-service: manzaneda' \
--header 'fiware-servicepath: /ree_api'

Balance Hydro

Get hydro balance metering

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_Hydro

Headers

fiware-service	manzaneda
fiware-servicepath	/ree_api

Params

Example request

curl --location --request GET 'http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_Hydro' \
--header 'fiware-service: manzaneda' \
--header 'fiware-servicepath: /ree_api'

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Balance Wind

Get wind balance metering

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_Wind

Headers

fiware-service	manzaneda
fiware-servicepath	/ree_api

Params

Example request

```
curl --location --request GET 'http://information-platform.renaissance-
h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_Wind' \
--header 'fiware-service: manzaneda' \
--header 'fiware-servicepath: /ree_api'
```

Balance Thermalsolar

Get thermalsolar balance metering

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_Thermalsolar

Headers

fiware-service	manzaneda
fiware-servicepath	/ree_api

Params

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Example request

curl --location --request GET 'http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_Thermalsolar' \
--header 'fiware-service: manzaneda' \
--header 'fiware-servicepath: /ree_api'

Balance Hydroeolian

Get hydroeolian balance metering

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_Hydroeolian

Headers

fiware-service	manzaneda
fiware-servicepath	/ree_api

Params

Example request

curl --location --request GET 'http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_Hydroeolian' \
--header 'fiware-service: manzaneda' \
--header 'fiware-servicepath: /ree_api'

Balance Other renewables

Get other renewables balance metering

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_Otherrenewables

Horizon 2020
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Headers

fiware-service	manzaneda
fiware-servicepath	/ree_api

Params

Example request

```
curl --location --request GET 'http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_Otherrenewables' \
--header 'fiware-service: manzaneda' \
--header 'fiware-servicepath: /ree_api'
```

Balance Renewable waste

Get renewable waste balance metering

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_RenewableWaste

Headers

fiware-service	manzaneda
fiware-servicepath	/ree_api

Params

Example request

```
curl --location --request GET 'http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_RenewableWaste' \
--header 'fiware-service: manzaneda' \
--header 'fiware-servicepath: /ree_api'
```


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Balance Renewable generation

Get renewable generation balance metering

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_Renewablegeneration

Headers

fiware-service	manzaneda
fiware-servicepath	/ree_api

Params

Example request

```
curl --location --request GET 'http://information-platform.renaissance-
h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_Renewablegeneration' \
--header 'fiware-service: manzaneda' \
--header 'fiware-servicepath: /ree_api'
```

Balance Pumped Storage

Get pumped storage balance metering

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_Pumpedstorage

Headers

fiware-service	manzaneda
fiware-servicepath	/ree_api

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Params

Example request

```
curl --location --request GET 'http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_Pumpedstorage \
--header 'fiware-service: manzaneda' \
--header 'fiware-servicepath: /ree_api'
```

Balance Nuclear

Get nuclear balance waste metering

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_Nuclear

Headers

fiware-service	manzaneda
fiware-servicepath	/ree_api

Params

Example request

```
curl --location --request GET 'http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_Nuclear' \
--header 'fiware-service: manzaneda' \
--header 'fiware-servicepath: /ree_api'
```


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Balance Combined Cycle

Get combined cycle balance metering

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_ electric_balance_Combinedcycle'

Headers

fiware-service	manzaneda
fiware-servicepath	/ree_api

Params

Example request

```
curl --location --request GET 'http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_Combinedcycle' \
--header 'fiware-service: manzaneda' \
--header 'fiware-servicepath: /ree_api'
```

Balance Coal

Get coal balance metering

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_Coal

Headers

fiware-service	manzaneda
fiware-servicepath	/ree_api

Params

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Example request

curl --location --request GET 'http://information-platform.renaissance-
h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_Coal' \
--header 'fiware-service: manzaneda' \
--header 'fiware-servicepath: /ree_api'

Balance Diesel Engines

Get diesel engines balance metering

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_Dieselengines

Headers

fiware-service	manzaneda
fiware-servicepath	/ree_api

Params

Example request

curl --location --request GET 'http://information-platform.renaissance-
h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_Dieselengines \
--header 'fiware-service: manzaneda' \
--header 'fiware-servicepath: /ree_api'

Balance Gas Turbine

Get gas turbine balance metering

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_Gasturbine

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Headers

fiware-service	manzaneda
fiware-servicepath	/ree_api

Params

Example request

```
curl --location --request GET 'http://information-platform.renaissance-
h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_Gasturbine' \
--header 'fiware-service: manzaneda' \
--header 'fiware-servicepath: /ree_api'
```

Balance Steam Turbine

Get steam turbine balance metering

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_Steamturbine

Headers

fiware-service	manzaneda
fiware-servicepath	/ree_api

Params

Example request

```
curl --location --request GET 'http://information-platform.renaissance-
h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_Steamturbine' \
--header 'fiware-service: manzaneda' \
--header 'fiware-servicepath: /ree_api'
```


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Balance Cogeneration

Get cogeneration balance metering

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_Cogeneration

Headers

fiware-service	manzaneda
fiware-servicepath	/ree_api

Params

Example request

```
curl --location --request GET 'http://information-platform.renaissance-
h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_Cogeneration' \
--header 'fiware-service: manzaneda' \
--header 'fiware-servicepath: /ree_api'
```

Balance Non-renewable waste

Get non-renewable waste balance metering

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_Non-renewablewaste

Headers

fiware-service	manzaneda
fiware-servicepath	/ree_api

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Params

Example request

```
curl --location --request GET 'http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_Non-renewablewaste' \
--header 'fiware-service: manzaneda' \
--header 'fiware-servicepath: /ree_api'
```

Balance Non-renewable generation

Get non-renewable generation balance metering

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_Non-renewablegeneration

Headers

fiware-service	manzaneda
fiware-servicepath	/ree_api

Params

Example request

```
curl --location --request GET 'http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_Non-renewablegeneration' \
--header 'fiware-service: manzaneda' \
--header 'fiware-servicepath: /ree_api'
```


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Balance Cross-border Exchange

Get cross-border exchange balance metering

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_Cross-borderexchangebalance

Headers

fiware-service	manzaneda
fiware-servicepath	/ree_api

Params

Example request

```
curl --location --request GET 'http://information-platform.renaissance-
h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_Cross-borderexchangebalance' \
--header 'fiware-service: manzaneda' \
--header 'fiware-servicepath: /ree_api'
```

Balance Non-renewable waste

Get non-renewable waste balance metering

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_Non-renewablewaste

Headers

fiware-service	manzaneda
fiware-servicepath	/ree_api

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Params

Example request

curl --location --request GET 'http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_Non-renewablewaste' \
--header 'fiware-service: manzaneda' \
--header 'fiware-servicepath: /ree_api'

Balance Demand at Bus Bars

Get demand at bus bars metering

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_Demandatbusbars

Headers

fiware-service	manzaneda
fiware-servicepath	/ree_api

Params

Example request

curl --location --request GET 'http://information-platform.renaissance-h2020.eu/v2/entities/manzaneda_ree_api_electric_balance_Demandatbusbars' \
--header 'fiware-service: manzaneda' \
--header 'fiware-servicepath: /ree_api'

Kimmeria

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Symmetron

Get Buildings

Get all buildings information

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities?type=Building

Headers

fiware-service	kimmeria
fiware-servicepath	/symmetron

Params

type	Building

Example request

```
curl --location --request GET 'http://information-platform.renaissance-
h2020.eu/v2/entities?type=Building' \
--header 'fiware-service: kimmeria' \
--header 'fiware-servicepath: /symmetron'
```

Get a data concentrator

Base URL

http://information-platform.renaissance-h2020.eu/v2/entities

Headers

fiware-service	kimmeria
fiware-servicepath	/symmetron

Params

	1

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Example request

curl --location --request GET 'http://information-platform.renaissance-h2020.eu/v2/entities?=1' \
--header 'fiware-service: kimmeria' \
--header 'fiware-servicepath: /symmetron'

Eemnes

Historical

https://information-platform.renaissance-h2020.eu/historical/entities/8ff528fe-b2f8-4f7a-b886-5ebab60a94a1?from=20201010T000000Z&to=20201015T000000Z

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