



# Development and implementation of the “F-Channel” platform D8.2

## Authors:

Emmanouil Zoulias - UoA

Nenad Sijakovic - EIG

Aleksandar Terzic – EIG

Vladan Ristic - EIG

Dimitra Makrygiorgou - IPTO

Christos Christodoulou - HEDNO

<b>Responsible Partner</b>	University of Athens
<b>Checked by WP leader</b>	Emmanouil Zoulias, (UoA), 19/09/2023
<b>Verified by the appointed Reviewers</b>	Anastasis Tzoumpas, (Ubitech), 13/09/2023 Arslan Bashir (Volue), 27/09/2023
<b>Approved by Project Coordinator</b>	Padraic McKeever (Fraunhofer), 04/10/2023

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## About OneNet

The project OneNet (One Network for Europe) will provide a seamless integration of all the actors in the electricity network across Europe to create the conditions for a synergistic operation that optimizes the overall energy system while creating an open and fair market structure.

OneNet is funded through the EU's eighth Framework Programme Horizon 2020, "TSO – DSO Consumer: Large-scale demonstrations of innovative grid services through demand response, storage and small-scale (RES) generation" and responds to the call "Building a low-carbon, climate resilient future (LC)".

As the electrical grid moves from being a fully centralized to a highly decentralized system, grid operators have to adapt to this changing environment and adjust their current business model to accommodate faster reactions and adaptive flexibility. This is an unprecedented challenge requiring an unprecedented solution. The project brings together a consortium of over 70 partners, including key IT players, leading research institutions and the two most relevant associations for grid operators.

The key elements of the project are:

1. Definition of a common market design for Europe: this means standardized products and key parameters for grid services which aim at the coordination of all actors, from grid operators to customers;
2. Definition of a Common IT Architecture and Common IT Interfaces: this means not trying to create a single IT platform for all the products but enabling an open architecture of interactions among several platforms so that anybody can join any market across Europe; and
3. Large-scale demonstrators to implement and showcase the scalable solutions developed throughout the project. These demonstrators are organized in four clusters coming to include countries in every region of Europe and testing innovative use cases never validated before.



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## List of Abbreviations and Acronyms

Acronym	Meaning
aFRR	Automatic Frequency Restoration Reserve
AI	Artificial Intelligence
ANN	Artificial Neural Network
BM	Business Model
BUC	Business Use Case
DAG	Directed Acyclic Graph
DAM	Day-Ahead Market
DSO	Distribution System Operator
EnC	Energy Community
FSP	Flexibility Service Provider
FTP	File Transfer Protocol
GUI	Graphical User Interface
HEDN	Hellenic Electricity Distribution Network
IDM	Intra-Day Market
IP	Information Protocol
ISP	Imbalance Settlement Period
IT	Information Technology
KER	Key Exploitable Result
LFC	Load Frequency Control
MAPE	Mean Absolute Percentage Error
mFRR	Manual Frequency Restoration Reserve
MO	Market Operator
NWP	Numerical Weather Predictions
Pol	Point of Interest
PV	Photovoltaic
RDBM	Relational Database Management
RR	Replacement Reserve
RSC	Regional Security Center
SMEs	Small- and Medium-size Enterprises
SO	System Operator
SQL	Structured Query Language
SSH	Secure Shell
SUC	System Use Case
TSO	Transmission System Operator
UI	User Interface
WFP	Weather Forecast Provider
WFS	Web Feature Services
WMS	Web Map Services

## Executive Summary

The report is an overview of the most prominent activities that were performed in Task 8.2 of the OneNet project – Development and implementation of the platform in Greece. It is the continuation of the Deliverable 8.1, drafted and approved in 2021. It describes the main activities conducted by the partners that were directly involved in this task, under the Greek Demo of the Southern Cluster of the OneNet project. In line with that, the report contains the descriptions of the most important features of the F-channel platform, representing the main outcome of the conducted work. The platform itself has been created in such a way to combine the necessary options for the web-based client server application that will contribute to the desired effects and the user-friendly interface that would make the introduction of the new clients to the platform intuitive and fast.

The platform contains two modules –Forecasting module and Coordination module. The Forecasting module focuses on the energy production forecast for wind and solar units, load flow, voltage profile simulations and weather parameters forecasting. It is also equipped with the georeferenced map of the part of the system that was of interest for this task – the Greek transmission and distribution systems in Crete and Peloponnese, down to the lowest voltage levels. This achievement was one of the main outcomes of the OneNet Open Call solution named GEOGRID, which, along with georeferencing the map of the discussed system, also contributed to making of the typical load profiles for different demand types and the drafting of the codes necessary for the analyses. The Coordination module focuses on providing grid services for balancing and congestion management issues.

The report also includes the showcase of the results obtained by applying the advanced numerical weather forecast methods and using those as the inputs for the specially created ANNs, by which the production of the wind and solar units can be forecasted in a reliable and accurate manner. For that to be proven, the tests have been conducted on two solar units and two wind units in the observed area. The results, based on the work of ANN trained by using the historical measurements of the weather parameters and production powers, indicate the significant reduction of the prediction error up to seven days in advance. The errors that were calculated by applying this method are several times lower than the ones typically expected from commonly used techniques.

Finally, the simulations of the users' experiences when working with platform have been conducted. Effort has mostly been invested in trying to imitate the behaviour of the different users (such as the system operators, flexibility service providers, market operators or guests) and seeing the platform in the way they would see it. This allowed the creation of the step-by-step principle in which more of the hick-ups and potential uncertainties that the users could face were removed from the platform. After that was done, the F-channel platform reached its final form, being a powerful, yet easy-to-apply tool that will hopefully prove to be applicable for more than the scope of this project and set the basis for the development of the future projects that could build upon its achievements. For now, it is safe to say that the goals that have been set in front of the F-channel platform once the OneNet project was initiated have been successfully achieved through the hard work of involved partners.

# 1 Introduction

The document elaborates on the activities of the Greek Demo of the Southern Cluster of the OneNet project. In order to give the readers introduction to covered topics, this chapter will be divided into the four subchapters. The first subchapter will briefly explain the task upon which the report has been based. The second and the third subchapters will, respectively, be dedicated to the main objectives of this task and the ways in which the report has been organized. Finally, the fourth subchapter will provide an insight into the documents and literature that could help the interested readers find more details both on the Greek Demo and on the subjects related to it.

## 1.1 Task 8.2

The task related to this deliverable is the Task 8.2 of the OneNet project – Development and implementation of the platform in Greece. It was based on the idea of creating the user-friendly F-channel platform that could have the functionalities necessary for different participants in the energy market already implemented. In order to fulfil all of the desired goals, the partners included in the demo had to use different methodologies, starting from utilizing the high-resolution numerical weather forecasts, all the way to using cutting-edge techniques such as ANNs in order to improve the accuracy of the energy parameters forecasts. Since the area of interest for the performed demonstrations was located in Crete and Peloponnese, necessary inputs for that area were provided by the Greek system operators (both the TSO and the DSO). The operators also helped the rest of the partners understand what were the priorities that had to be considered when creating the platform’s work environment.

## 1.2 Objectives of the Work Reported in this Deliverable

The works that have been done in the scope of task around which this deliverable was constructed primarily revolve around the development and fine-tuning of different aspects of F-channel platform, envisaged as main outcome of the Greek Demo. The individual activities can be divided into those related to the creation of user-friendly work environment and those related to the creation of the background codes and functionalities that had to be incorporated into the F-channel platform. The former category was challenging since the appearance of the platform had to be intuitive enough not to scare the potential new clients away, but to also include enough options to fit the vision of that kind of tool that the users with several years of experience would have. For that to happen, tight collaboration with the partners from the Greek TSO (IPTO) and DSO (HEDNO) was established and kept throughout the project’s lifecycle. The latter category of activities meant that all of the partners active in the Greek Demo had to understand the basic principles of the flexibility service market functioning in order to translate those principles into the functionalities of the F-channel platform. The results of the work presented in this report confirm that both of those types of actions have been completed with success. The completion of foreseen activities also allowed the Greek Demo and its outcomes to properly fit into the defined OneNet vision.

In order to clarify the way in which this fitting happened, the definition of three goals of the OneNet project needs to be repeated, along with the analyses of the way in which the Greek Demo and the F-channel platform aid in reaching those goals. The first target that has been put before the developers of any solution included in the OneNet project was the one related to the definition of the common market design for the entire Europe. In particular, this was relevant for the standardization of products and key parameters for the grid services that aim at better coordination of the actors in energy market. The F-channel platform, by its definition, represents the universal platform that will be available to all market participants, making the communication between them seamless and the flow of the regular processes within the market smoother. If one would consider the situation in which the energy market is today, with the different channels used for the communication between different actors, they could spot a number of issues. These issues would vary from the large potential for human errors during the exchange of data to the lack of unified format used for these exchanges. Finally, one of the burning topics recognized throughout Europe is the chronic problem of the coordination procedures between the TSO and the DSO not being developed enough, with some of the initiatives set afoot in the last decade aiming at this problem and the way in which it could be resolved. Following that, the F-channel platform with its features aims at the highlighted room for improvement, ensuring a common space for the communication and coordination between the participants in the energy market processes with its all-encompassing and user-friendly approach.

Goal number two is referring to the definition of the common IT architecture and the common IT interfaces for the market processes. Although the F-channel platform focuses on the establishment of a unique space that can be used by any participant and/or stakeholder in energy market, this is, in the opinion of the developers of the platform, not an indicator of this platform missing the target, but an advantage. Namely, if this or a similar kind of platform would exist on the European scale, it would make joining to any energy market easier for the potential candidates. For this to happen, there were some pre-requirements that needed to be considered when creating such a platform to maximise the potential for usage that it offered. The most prominent one was the application of cyber-security measures in order to determine amount and type of data that would be available to each user. The clearance level of user would depend on the category to which that user belonged. This was considered while developing the F-channel platform. Along with that, it was also necessary to prevent leaks in which some of the confidential data would be released to the public, so some of the up-to-date cyber-security standards had to be integrated into the platform. Since this was done, it is safe to say that the F-channel platform is aligned with this goal as well. Moreover, installing the OneNet connector on the Greek demo server is done – the docker container is installed on server and the connection is established with the OneNet server. Testing of the data exchange system was successfully completed. Main issue was that, for the Greek Demo, available data that could be shared was scarce, so it had to be produced first. At the moment of writing report, the final process of setting up docker container on server is ongoing. Critical weather data, wind and solar production and cyber-security attacks reports are prepared daily. Establishing backend calculations and generating files for exchange features were completed. Data exchange can be conducted on the user's request and previewed in web-app.



The third and final goal of OneNet project was the one referring to the large-scale demonstrations needed for implementation and showcasing of the scalable solutions that have been developed throughout the OneNet cycle. Even though the following part of the goal explanation mentions that this is done by creating four different clusters in Europe, with the assignment of a country to a cluster depending on the geographic locations of that country, this is not something that is supposedly clear to the reader by now. Hence, the focus here will not be on clusters themselves, but on the term used in the declaration of this target, which is *scalability*. To simplify, scalability means that the solutions developed within the OneNet project had to be able to accommodate almost any environment or user that would be interested in trying it out, which is more of a complex issue than it may seem in the first place. In order to adapt to this principle, the F-channel platform was created in such a way that the users would find its usage simple and rather intuitive, with the ability of the user to take part in the processes covered by the platform solely depending on their ability to obtain the data that needs to be fed into the base of the platform. If it is taken that the users do have the relevant data related to their objects at disposal, then the F-channel platform can be scaled up as much as necessary, aligning with the third OneNet goal in the process.

Hence, not only the F-channel platform, described in this report, fulfilled the set requests of the OneNet, it also managed to go beyond them at some points. This proves the ambition and the vision that the developers had before starting the project. In the opinion of the partners in Demo, this simply verifies that the goals need to become more and more advanced through time, as some space for further improvement can always be found.

### 1.3 Outline of the Report

In order to ensure the readability of the document and the smooth transitions between the logical sections, this report is divided into a total of five chapters, with the first one being the introductory chapter, i.e., the one of which this subchapter is a part. The remaining four chapters of the report will be the following:

- Chapter 2 – the chapter that will be fully focused on the development of the F-channel platform, starting from the idea behind this application, over the steps that were taken in the process, all the way to the outcomes of the performed activities; the particular section of this chapter will also be dedicated to the OneNet Open Call and the results of the work of the selected solution developers.
- Chapter 3 – the chapter in which the scenarios used for the testing will be thoroughly described, along with the process of provisional testing of the use cases; the results that are available at the time of drafting of this chapter will also be enclosed near the end of it (based on the ANN forecasts of the RES production and the simulated experiences of the potential clients when using the platform).
- Chapter 4 – the conclusion drawn from the results of the completed work and an outlook to the future, attempting to offer the readers with the brief summary of the main points that would be good to bring into some of the further projects that would cover the same topic or the topics similar to this one.

## 1.4 How to read the Report

In order to provide the reader with the comprehensive overview of relevant documents, those are divided into three groups: the ones explaining the current framework in Greece that served as a basis for a number of procedures included in the F-channel platform, the ones representing the scientific papers that came during the development of this solution and the ones establishing the connection of this Report with other deliverables that have been written in the scope of OneNet project. The first category, for example, includes HETS Grid Code [1], Balancing Market Rulebook [2] or the Baseline Calculation Methodology [3]. In addition to that, some of the readers could be interested in Terms and Conditions valid in Greece for the Balancing Service Providers [4] and for the Balance Responsible Parties [5], as well as in Procedures of registration with the HETS Operator Registry [6]. With those out of the way, the reader can be considered informed about the current situation in Greece and can, therefore, move on to the documents belonging to the remaining two categories mentioned here.

In continuation of this, reader could also pay attention to papers related to the Greek Demo that have been published (or that are going through the review process at the moment of drafting of this deliverable). These papers cover some of the cutting-edge aspects investigated within the Greek Demo of the OneNet project and, in the process, proving the relevance of the reached conclusions and targets not only for the partners involved in the Demo, but for the wider scientific community as well. The first two of the papers [7]-[8] have already been published in 2022, with the first of them [7] dealing with the forecasts of transmission and distribution system flexibility needs and the second one [8] focusing more on the active system management approach for flexibility services. In addition to those, there are other papers [9]-[10] that have been drafted in cooperation with partners included in the Greek Demo and are currently being revised, so their publication is hopefully expected soon after the completion of this Report. As those could provide the readers with even more of an insight, they are strongly encouraged to seek the mentioned papers once they get published and become publicly available.

Finally, it needs to be noted that this deliverable is not isolated from the rest of the reports and deliverables created during the OneNet project and that some of those can be quite an interesting read serving as extension of the information given in this Report. Aside from the obvious choice given in Deliverable 8.1 [11], one should, for instance, consider going through the parts of Deliverable 3.2 [12] and Deliverable 11.5 [13] related to Greek Demo and to the topics covered in this Report. The authors have made an effort to draft the Report that can be seen as a stand-alone (in case the reader has a limited amount of time that can be dedicated to the Report), so some points mentioned in those deliverables can be found in appropriate places in this document. Nonetheless, the descriptions given in the individual deliverables are way more detailed, so the reader should consider going through those as well. The point that needed to be repeated in this report from [11] was the list of the BUCs and the SUCs considered in this Demo, since it can make it easier for the reader to have those, along with the related users' experiences, in the single file. Those descriptions have been attached to this report as the Appendix 1.

## 2 Flexibility Channel – Introduction

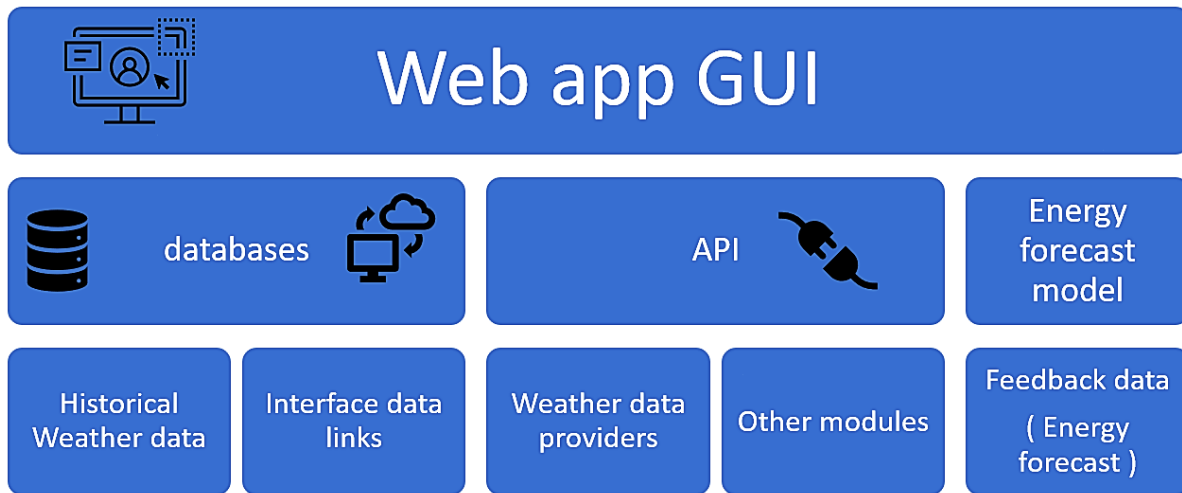
This chapter will be focused on describing both the ideas that represent the foundation behind the Flexibility platform, i.e., the main expected outcome of the activities of this Demo, and the progress that was made on the development of this platform in the meantime from the completion of Deliverable 8.1 and the drafting of this report. For that to happen, this chapter will focus on the activities related to the development of the platform.

### 2.1 Background

The F-channel platform is envisaged as the web based, client server application which will contribute to enhancing the active power management for TSO-DSO coordination by using artificial intelligence methods and cloud calculation engines. In order to achieve this, however, certain preconditions needed to be met, with the first of them being the availability of the detailed climatic data models. The luxury of having these models at hand opened the possibility of predicting the various parameters relevant from the SO point of view. For instance, the predictions of the wind speeds and the insolation patterns with the rather high resolution gave the chance of adapting the AI algorithms in order to connect those predictions with the behaviour of the generation units in the system in a way that improved existing practices. Along with that, the forecasts of the line power flows and the occurrences of conductor icing, storms, as well as other severe weather conditions that could harm the reliability of the system operations are also noteworthy. All of these can be seen as the idea behind the enhancements and advancements that are to be introduced in the Flexibility channel.

The climatic model that is established is based on the historical weather measurements and the advanced NWP (Numerical Weather Predictions) that are delivered by the external weather forecast provider or collected from the available open weather data hubs. These predictions are seen as a necessary tool for the fine-tuning of the created model and improving the forecast outcomes. This level of forecast accuracy is guaranteed to become even more prominent under the circumstances dictated by the integration of the distributed renewable generation, energy storages and demand response technologies and options. Namely, if the system operators have the ability of obtaining the precise predictions of the behaviour of the renewable energy sources and potential flexibility providers, they will also be able to modify their simulation models in order to duplicate the foreseen system state. This will let them see possible issues that could occur if the predictions come true and provide them with the time needed to react and minimize (or remove) the consequences of those problems through the set of the remedial actions determined specifically for each of the issues.

In order to enable the flawless run of the foreseen processes and calculations, while maintaining the desired level of the user-friendliness, it was necessary to find the optimal engines for performing the analyses that can be paired with the appropriate UI. For that to happen, the cloud computing engines were selected for the role. The diagram provided in Fig. 2.1 gives an overview of the basic architecture of the proposed web application.



**Figure 2.1:** Architecture of the suggested web application.

As suggested by this structure, the F-channel platform was designed while paying much appreciation to finding the best possible combination of the technical proficiency of the functionalities and easy-to-adapt-to UI to give the users the best possible experience while still satisfying the standards set by the modern tools that are applied for the system analyses by the interested parties. Regarding the storage of the data needed for conducting the foreseen procedures, the databases and the storage accounts were required. The allocated computing resources have been split into two groups: continuously allocated ones and the ones allocated per computation/transaction.

Alongside that, it was also necessary to specify the way in which the needed databases would be structured, for which purpose it was decided to use the traditional RDBM rational model. This decision allowed the easier representation, aggregation and query of all datasets, among other benefits. The display of the geospatial data was provided by the middleware software architecture supporting WMS and WFS. Special care here was given to the security of the server infrastructure, the question whose relevance has continuously been growing in the previous several years with the increasing number of information leaks and hacker attacks even on some of the largest and best-protected organizations whose field of work covers the power systems and their management. Therefore, the server access codes to the development environment had to be encrypted with the appropriate SSH keys. Furthermore, access to the different parts of the platform was restricted in a way to only give permission to enter to the specified IP address ranges. In line with that, the access to the web application on the user side also had to be limited to verified accounts created by users, with each of the users, depending on the designated type assigned to them, only seeing the appropriate page of the F-channel platform. More on these functionalities and other characteristics of the platform can be found in the subsequent parts of this chapter.

## 2.2 Demo Site and Input Data

For the purposes of enabling the foreseen functionalities of the F-channel platform in the best possible way, it was also necessary to obtain the appropriate amount of input data from the Greek system operators. This was relevant both from the point of view of exact values related to the specifications of the system in the regions of interest for the Demo and from the aspect of practical experience regarding certain processes. The list of the necessary data has been given in the appropriate part of [11], so only the main points will be repeated, with some of the most relevant changes highlighted. In [11] the following data requests have been stated:

- Network models' data;
- Geospatial data;
- Technical data for wind turbines;
- Technical data for solar parks;
- Technical data for selected overhead lines;
- Historical weather data;
- Historical SPP and WPP production data;
- Energy policy information.

The data had to be delivered for the area of interest for the Greek Demo (also known as the Demo Site). The Demo Site here included the geographic regions of Crete Island and the Peloponnese Peninsula. The geographic map of this region (with Peloponnese in blue and Crete in red) can be seen in Fig. 2.2, given below.



**Figure 2.2:** Indication of the positions of Crete and Peloponnese.

The network that was considered for the selected region included the grid on all voltages from 400 kV down to the 20 kV, for the total of 50 substations in Peloponnese and one substation in Crete (due to interconnection between Crete and Peloponnese). Out of the 50 substations in Peloponnese, 28 were the substations with the connected load and 22 were the ones to which renewable sources were connected. Customers in demo have been the virtual ones. Regarding resources taken into account in the Demo, the following numbers are valid:

- 161 OHL;
- 13 SPPs (there was an initial plan to include more SPPs, but the needed data was available only for 13);
- 37 WPPs.

What is of particular relevance for the results shown in Subchapter 3.3 of this report is the fact that, for all of the mentioned WPPs and SPPs, the hourly production power values have been collected for five-year period and then used while training the ANN in procedure that will be described in that subchapter. Due to the issues regarding the data confidentiality, the showcase of those values cannot be provided in the report. In addition to these, the data was collected on the EU level for the cases of critical combinations of icing and wind, and wind and precipitation, helping in confirming the applicability of the platform for the forecasts of the critical weather conditions that could cause severe system states. The routes of the lines in the system have mostly been given by the system operators, but, even if that was not the case, they could be found on the map services on internet.

In general, it needs to be stated that the cooperation between the participants in this Demo has been kept on the highest level throughout the process of completing the activities described in this document, so, in line with that, there were no major issues in the communication necessary for obtaining the necessary information from IPTO and HEDNO. In particular, the employees of IPTO that are active on the OneNet project volunteered to undertake the effort required to deliver the high-quality data. However, it needs to be stated that some of the data had to be delivered twice, since the initial collection referred to the period during which the power system of Crete was isolated from the system of mainland Greece. However, since the connection has been established in 2021, it was deemed better to use the updated information related to the state valid at the moment of the foreseen completion of the envisaged activities. The necessary steps were taken accordingly.

## 2.3 Database Design

The design of the pages that the different users of the F-channel platform will be able to access was decided on the basis of discussions among the partners in the Greek Demo. Since the screenshots that would illustrate the appearance of this database would need to be condensed in order to fit into the page, making the words in them unintelligible, this subchapter lists the tables in each database, followed by the respective data contained within them. The database used for these purposes is PostgreSQL database with spatial capability (PostGIS). The choice of this technology was made since this is the type of database that is the proper way to go when using a lot of geographic data (which is the case here). Data is processed and can be offered to OneNet for exchange.

**Table: db\_users**

- id
- user\_role\_id
- name
- surname
- company
- address
- phone number
- email
- username
- password

**Table: db\_user\_roles (contains the identifiers that are referred to in the second column of the first tab)**

- id
- user\_role\_id
- user\_role\_name

**Table: db\_tsos**

- id
- tso\_id
- area\_id
- tso\_name
- country
- address
- contact\_email
- contact\_phone
- grid\_microgrid\_id

**Table: db\_dsos**

- id
- dso\_id
- dso\_name
- country
- address
- contact\_email
- contact\_phone
- grid\_microgrid\_id
- tso\_id

**Table: db\_aggregators**

- id
- aggregator\_id
- aggregator\_name
- country
- address
- contact\_email
- contact\_phone
- dso\_id
- tso\_id

**Table: db\_energy\_communities**

- id
- energy\_community\_id
- energy\_community\_name
- country
- address
- contact\_email
- contact\_phone
- grid\_microgrid\_id
- dso\_id
- tso\_id
- aggregator\_id

**Table: db\_fsp\_register**

- id
- eic\_code
- area\_id
- fsp\_id
- fsp\_type
- production\_unit\_id\_list
- storage\_unit\_id\_list
- load\_id\_list
- grid\_microgrid\_id
- energy\_community\_id
- aggregator\_id
- dso\_id
- tso\_id
- district
- location
- substation\_id
- installed\_power
- maintainance\_schedule (flag regarding the unit availability)



**Table: db\_grid\_microgrid**

- id
- grid\_microgrid\_id
- grid\_microgrid\_name
- grid\_microgrid\_description
- lines
- transformers
- substations

**Table: db\_storage\_units**

- id
- storage\_id
- storage\_type
- nominal\_voltage
- nominal\_capacity
- state\_of\_charge
- depth\_of\_discharge
- ambient\_temperature
- ambient\_humidity
- nominal\_voltage
- nominal\_power
- grid\_microgrid\_id
- historic\_data\_id
- district
- location

**Table: db\_load**

- id
- load\_id
- load\_type
- grid\_microgrid\_id
- historic\_data\_id
- forecasted\_data\_id
- district
- location
- net\_load (from the DSO side)

**Table: db\_production\_units**

- id
- production\_unit\_id
- production\_unit\_type
- nominal\_voltage
- nominal\_power
- grid\_microgrid\_id
- historic\_data\_id
- forecasted\_data\_id
- for wind power plants:
  - number\_of\_towers
  - wind\_turbine\_type (for each individual tower)
  - rated\_power
  - rotor\_diameter
  - swept\_area
  - max\_rotor\_speed
  - rated\_wind\_speed
  - cut\_in\_wind\_speed
  - cut\_out\_wind\_speed
  - survival\_wind\_speed
  - power\_curve (debatable manner of implementation)

**Table: db\_lines**

- id
- line\_id
- line\_type
- grid\_microgrid\_id
- status (on/off)
- historic\_data\_id
- forecasted\_data\_id

**Table: db\_transformers**

- id
- transformer\_id
- transformer\_type
- grid\_microgrid\_id
- status
- historic\_data\_id
- forecasted\_data\_id

**Table: db\_substations**

- id
- substation\_id
- substation\_type
- grid\_microgrid\_id
- historic\_data\_id
- forecasted\_data\_id

**Table: db\_historic\_data**

- id
- historic\_data\_id
- historic\_data\_type
- date
- time
- district
- location
- weather\_data (station\_id, clouds, rain, temperature, wind\_direction, wind\_speed, solar\_radiation)
- value

**Table: db\_forecasted\_data**

- id
- forecasted\_data\_id
- forecasted\_data\_type
- date
- time
- value
- district
- location
- weather\_data (station\_id, clouds, rain, temperature, wind\_direction, wind\_speed, solar\_radiation)

**Tab: db\_weather\_station:**

- station\_id
- station\_name
- district
- location

**Table: db\_flex\_bids**

- id
- area\_id
- fsp\_id
- product\_type
- sale\_purchase
- valid\_from
- valid\_to
- timestamp
- active\_flex
- upward\_downward
- price
- settled\_price
- quantity
- accepted\_quantity
- status
- auction\_id
- location
- active\_power
- reactive\_power (can be replaced by the power\_factor)
- non\_activating\_bids (in the form of the flag)

**Table: db\_auctions**

- id
- auction\_name
- auction\_status (ongoing, completed)
- to\_repeat
- timestamp
- product\_interval
- number\_of\_intervals
- max\_user\_bids

**Table: db\_products\_ongoing\_auction**

- auction\_id
- product\_name

**Tab: db\_schedules:**

- ISP\_results
- DAM\_results
- IDM\_results

It was indicated that, in the platform, the bid, load and production quantities cannot be publicly available so the bids history might have to be excluded. In continuation of that, two additional tabs have been added to the database, covering the DSO and TSO respective flexibility needs. Since some of the market data turned out to be confidential, two separate pages have been prepared in the platform (one for the TSO users, one for the DSO users), but those will not be publicly available once the platform is operating.

## 2.4 The GEOGRID Solution

In order to enhance the development of the proposed solutions, the OneNet project organized an Open Call near the end of 2021. The Demos had the possibility of creating the scenarios for which the developers could apply with their suggested solutions. The solution selected for the scenario related to the Greek Demo was the GEOGRID solution. The main targets of that solution were: development of the power system simulation model that would include the voltage levels down to the lowest ones, and the creation of the GIS server that would then be used for the visualization of the obtained results. In line with that, those two improvements were treated as the first two KPIs by which the success of the work that was done in the scope of the GEOGRID project was measured. In addition to them, the third goal that was defined was the development of the appropriate GUI that would both hold the options of introducing all of the achievements of this solution to the users and fit into the overall environment of the F-channel platform. After agreeing the basic details, the developers of GEOGRID solution proposed the structure of the database containing the information regarding the network models. The base was made in Microsoft Excel, with each of the elements of the system necessary for the proper model development getting its own tab. The tabs included in this database once it was fully functional were:

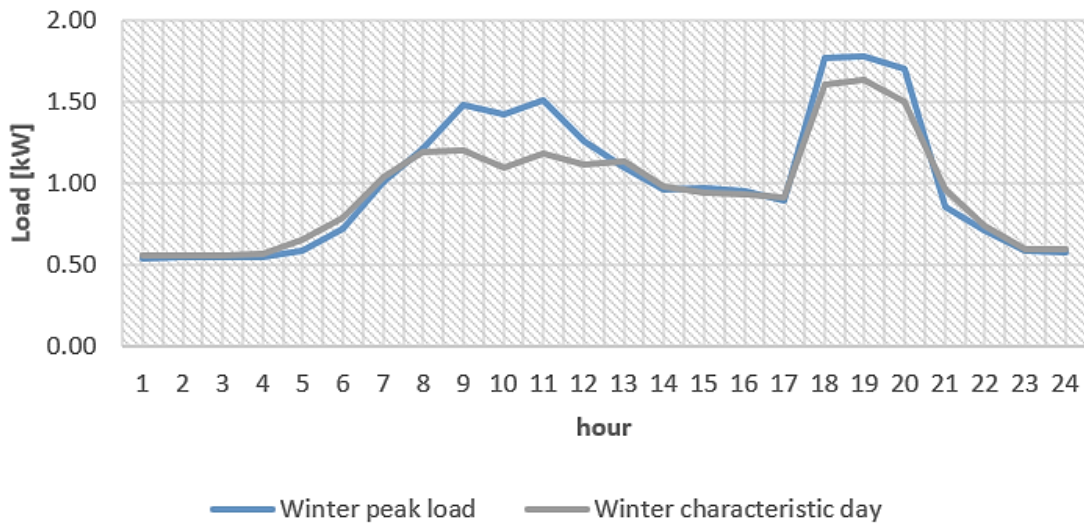
- Tab dedicated to the substations, containing the identifier of each substation in the selected part of the system, the type to which that substation belonged, the identifier of the microgrid in which that facility was located, as well as the historic and the forecasted data relevant for that respective substation.
- Tab dedicated to the lines in the system, containing technical data such as the identifier of each of the lines, the status of the line (if the line is switched on or off in the model), as well as the historic data and the forecasted data that needs to be considered for that line when performing the analyses.
- Tab dedicated to the transformers in the system, containing data similar to the information mentioned in the description of the tab dedicated to the power lines, such as the identifiers, the status and the identifiers related to the historic data and the forecasted data for every transformer in the model.

- Tab dedicated to the production units in the system, containing data such as the identifier of every generation unit in the observed part of the grid, the type to which each of the production units belongs, the nominal values of the voltage and the output power of those units, as well as the microgrid in which the units were located and the historic and forecasted data for each of those units.
- Tab dedicated to the storage units in the system, containing, among other general information that can also be found in the descriptions of the other system elements (such as the identifiers of the units or the rated voltages and powers of those units), information that can only be seen as relevant for energy storages, with the examples of this being, for instance, the state of charge and the discharge depth.
- Tab dedicated to the loads in the system, containing data rather similar to the general information mentioned in the bullet points referring to some of the other elements of the system, such as the unit identifiers, their types and powers, as well as the historic and forecasted data relevant for each load.

For the next task in the scope of the GEOGRID solution, it was needed to determine the load profiles that can be assigned to the specific types of the demand in the system. For this, it was necessary to make a decision related to the number of consumption categories that would be taken into account, so that the number is high enough to successfully cover all of the major types of load that exist in the system, but low enough to justify the introduction of the load categories at all. The decision was reached to use four types of demand:

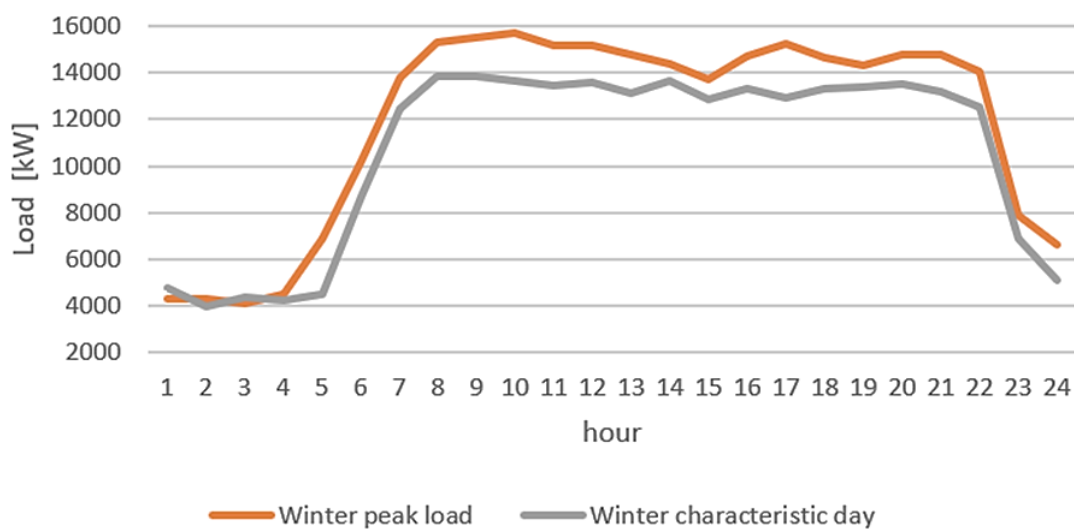
- household demand;
- industrial demand;
- commercial services demand;
- electric vehicles demand.

For each of these demand types, it was then necessary to figure out the daily profile by which the power of that type of load would vary throughout the day. To do so, the data obtained by the measurements was combined with the statements and estimations given in the literature dealing with similar topics. The first kind of consumption that was analysed in detail by the GEOGRID solution developers was the household demand, typical for the rural areas in which the industry is not developed yet, as well as for the urban areas that are not foreseen as the ones in which the large factories will be located, i.e., areas that will not be a part of the city's industrial zone in the future. The typical daily diagram of this type of demand can be seen in Fig. 2.3, reflecting the behaviour of the household consumption in the winter characteristic day, but also on the day of the measured winter peak of the demand power. These are marked with different colours in the figure, with the blue colour corresponding to the demand's behaviour on the day of the winter peak regime and with the grey line marking the change of the demand's power during the approximate winter characteristic day.



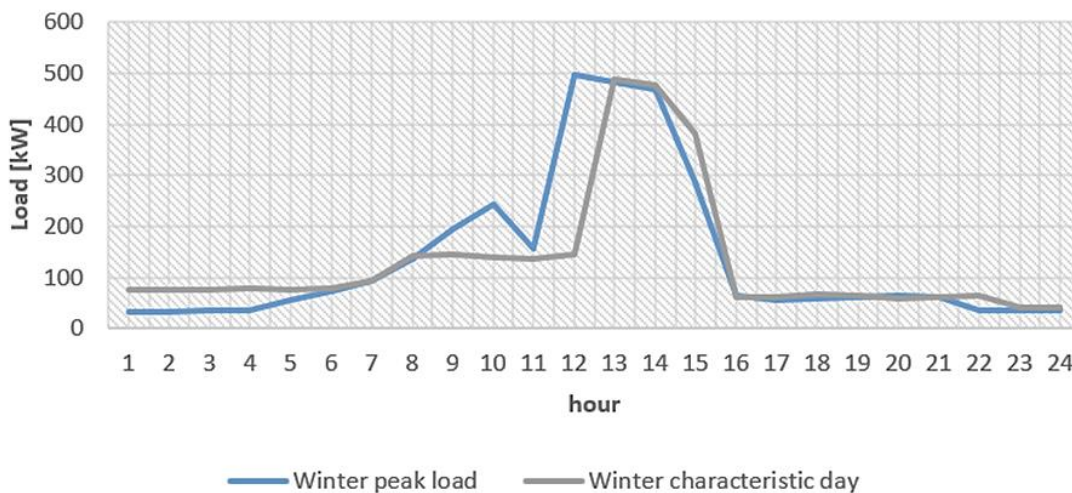
**Figure 2.3:** Daily diagram of the household demand.

The next type of the demand that was thought about in the scope of the third task of the GEOGRID solution was the industrial consumption, typical for the major industrial zone in which the large number of factories is located. This can either be the zones placed in the rural areas, located there in order to preserve the ecological standards of the air and water quality in the nearby towns, or they can be placed near the outskirts of the cities, depending on the type of processes that takes place in the facilities in the industrial zone and the decisions and priorities of the local governments. For this demand’s behaviour to be properly illustrated, Fig. 2.4 was included, with the different colours of the lines corresponding to the chosen days of the winter period. The orange and grey line, respectively, show the data valid for the winter peak load day and the winter characteristic day.



**Figure 2.4:** Daily diagram of the industry demand.

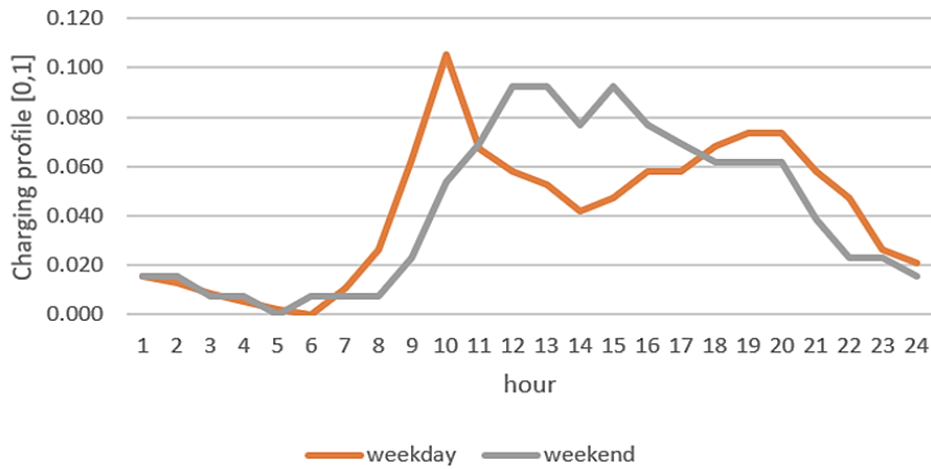
The third type of demand that will be briefly explained here is the commercial load, for which the daily diagram of power variation can be seen in Fig. 2.5, made with the same colour scheme used for Fig. 2.3. This category of demand corresponds, among other consumers that cannot be placed in the last two types, to the administration offices, which is the very example upon which the figure provided below was based.



**Figure 2.5:** Daily diagram of the commercial demand.

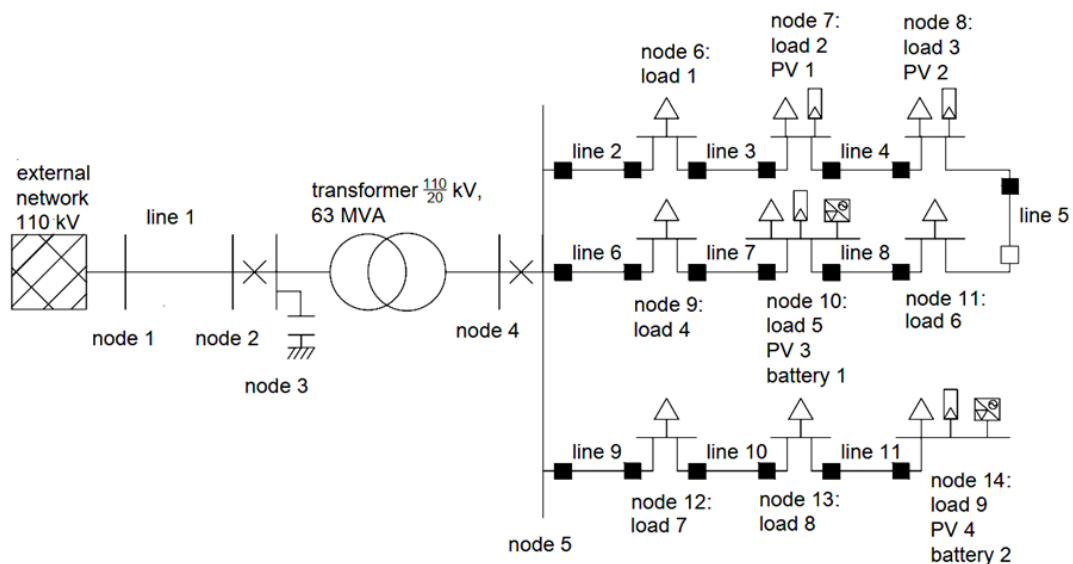
The fourth and final type of the consumers that was considered separately in the scope of this proposal was the demand related to the charging process of the electric vehicles. For this demand type, it needs to be stated that it was not present in the literature until recently, but, with the number of this type of vehicles on the streets increasing on a daily basis, it became a necessity to separate it from the other three categories. Along with the different type of variation throughout the day, what also makes this category of demand so different from the already described three is the fact that the power does not depend so much on the weather conditions or the season of the year, for instance (both of these are rather prominent factors for the household demand), but from the fact of whether the observed day belongs to the weekend or not. This is understandable, as the load related to this demand type and its distribution during the day changes with the number of people going to work or on fieldtrips. In line with this conclusion, the diagram given in Fig. 2.6 contains two lines, but, this time, the orange colour marks the weekday's load behaviour and the grey colour symbolizes the behaviour of the load during the days belonging to the weekends, which is different from the concept used for previous three figures.





**Figure 2.6:** Daily diagram of the electric vehicle demand.

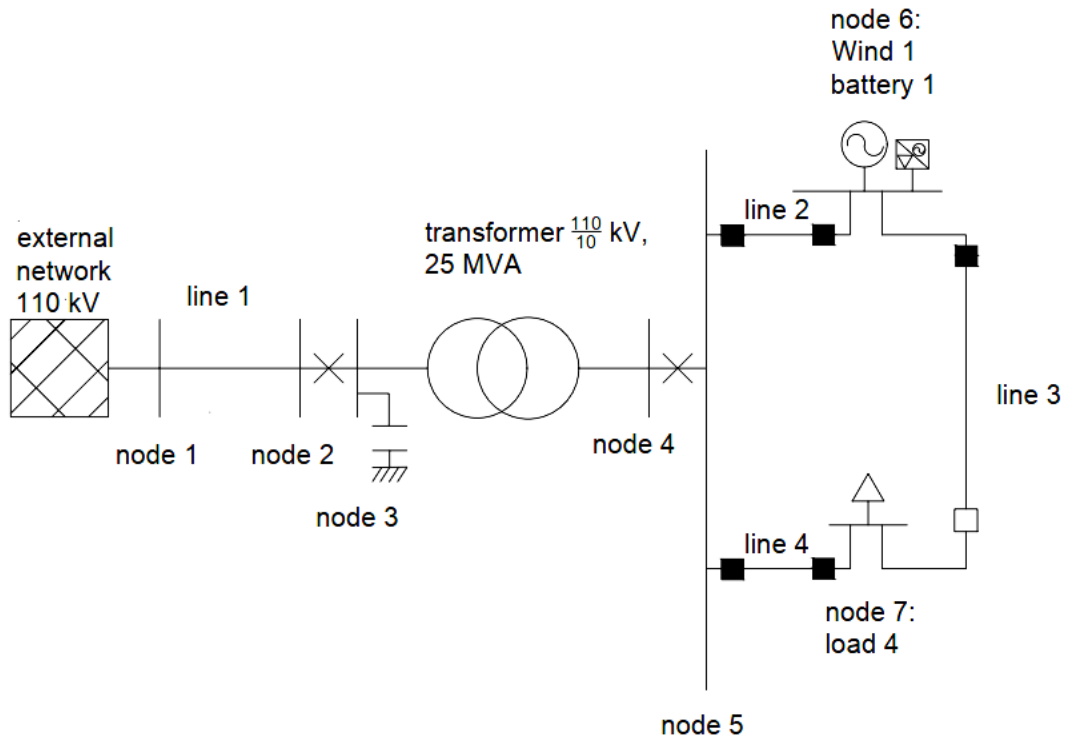
With the demand profiles out of the way, the developers of the GEOGRID solution moved to development of simulation models of various microgrids that were later combined with the model of the Crete transmission system, based on the data delivered by IPTO, so the model of the entire area of interest could be established. The approach that was adopted in this step was that each of the microgrids that were modelled needed to correspond to one of the load profiles developed in the previous part of this task. Therefore, four different microgrid models have been created, with Fig. 2.7, given below, giving an insight into the grid corresponding to the household demand, the first out of the mentioned four types.



**Figure 2.7:** Created microgrid model – household demand.

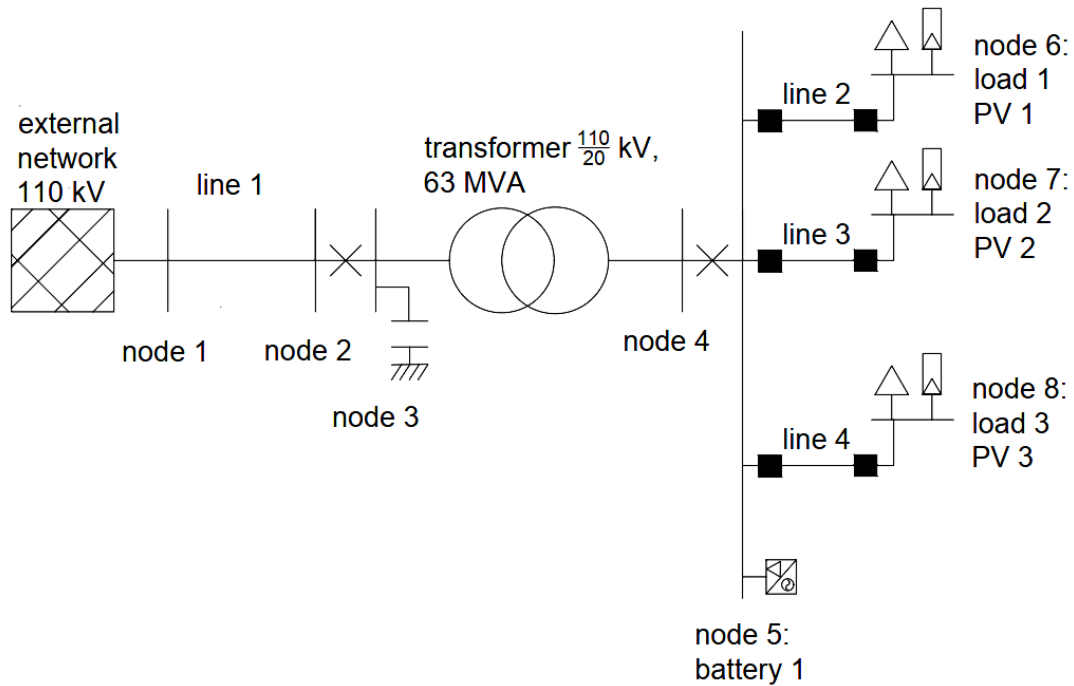
This example of the microgrid includes all of the entities that can be encountered in the common segment of the distribution system that contains the household load, with the 110 kV transmission system here seen in the form of the appropriate equivalent network. The provided diagram shows that, along with this equivalent, the microgrid contains the transformer connecting the transmission and distribution grids, the bus in the 20 kV part of the 110/20 kV substation and the branches that go from that busbar towards the loads in the observed section of the system. For this instance, it was decided that the load in the selected microgrid can be supplied by three feeders, with each of them containing three nodes with the demand attached. Two of the feeders are connected by an additional line (line 5 in Fig. 2.7), but the switch on that line is treated as turned off in the normal operation, matching the typical approach used when planning the distribution grid. Along with the nine loads, the created microgrid also contains four PV units (attached to nodes 7, 8, 10 and 14), as well as the two batteries (attached to nodes 10 and 14). Of course, the microgrids that were developed to correspond to the remaining three types of demand kept some of the elements given here, such as the external grid, same, while bringing enough variation to show different schematics of the distribution system operation.

Fig. 2.8 encloses the schematic of the microgrid that has been created for the industry consumption. As can be seen, the concept of energy provision for the needs of the households is rather different from the one used for the supply of energy for the large industrial consumers. The most obvious difference is the fact that, in the case of household consumption, there is more than one consumer that is supplied via one HV/MV transformer. However, the demand that belongs to some of the larger industrial facilities is often supplied via its own transformer, as illustrated in Fig. 2.8. Alongside difference regarding the transformer, the microgrid that was created for showcasing the situation related to the industry also contains the single node with load (given in the bottom part of the schematic) and another node to which the system composed of the wind generation unit and the battery is connected (shown in the upper part of the schematic). This concept of the microgrid reflects the modern-day tendency of large industrial facilities to have at least some sort of energy production in the close vicinity of the load, with the storage system added for at least partial damping of the production power variations of the wind generation unit. What should also be underlined is the fact that each of the two mentioned nodes is radially connected to the 10 kV node in the 110/10 kV substation, but that there is also an additional link that connects those two nodes directly, numbered as 3 in Fig. 2.8. The link is switched off in the normal operation, following the same logic as the one described for the household load, serving as a voucher of the uninterrupted supply in case of an outage of one of the other 10 kV lines. For the industrial load, this can be even more important than for the households due to the chemicals typically used in industry today.



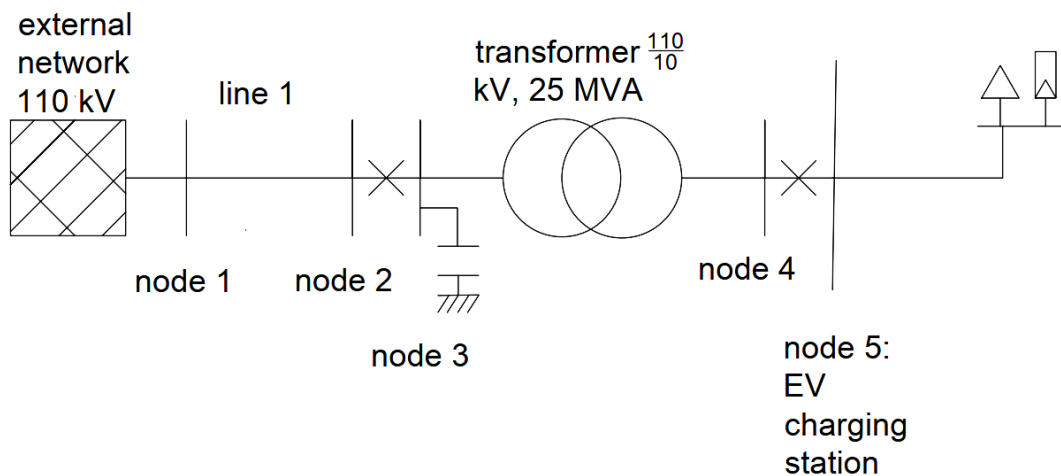
**Figure 2.8:** Created microgrid model – industry demand.

Next, Fig. 2.9 provides the schematic of the microgrid exclusively containing the commercial consumption. Once again, a comparison can be made between the microgrid created for the sake of including the load of the commercial service providers and the grids made for illustrating the behaviour of the loads for the previous two cases and, once again, some differences can be spotted. The first of these is the fact that, in this case, each of the different loads of the commercial service providers has its own feeder connecting it to the 20 kV bus in the 110/20 kV substation. However, this time, there is no additional line that could serve as a backup in case of one of the lines getting tripped, so the uninterrupted supply of energy is not guaranteed. This can be tolerated here since the load itself is less sensitive than, for example, the industrial facilities in which even the shortest pause in the supply could cause a disaster and put not only the facility, but also the surrounding area at risk of a natural catastrophe. It is presumed that each of the three commercial loads is equipped with its own solar unit and that the energy storage (assumed to be the battery) is common for all of them and located at the 20 kV bus in the 110/20 kV substation. The external 110 kV grid is, in line with what was already said, present here as well.



**Figure 2.9:** Created microgrid model – commercial demand.

Finally, Fig. 2.10 gives the schematic of the microgrid for the EV charging demand. Even though this schematic appears to be the simplest out of the four, it becomes a bit more complicated than that if the fact that the load that is attached to node 5 of this diagram does not represent a single charging socket, but all of the sockets that are located in the same facility is taken into consideration. In addition to this, it was assumed that this charging station is equipped with a solar production unit, ensuring the maximal potential for the provision of flexibility to the system by applying the combination of the generation in the solar unit and the load of the EV chargers.



**Figure 2.10:** Created microgrid model – EV charging stations.

A couple of points regarding the usage of these microgrids in the models and calculations have to be made. First of all, the apparent discrepancy between the voltage levels used in the models of microgrids shown here and the real-life situation in Crete needs to be addressed. Namely, the models from the solution use the 110 kV level as the HV side of the transformers, whereas the voltage of the transmission grid in Crete is 150 kV. In order to clarify this, one has to start from the fact that each of the microgrid models has only two elements for which the HV level is even relevant – the external grid element and the HV/MV transformer. By simply changing the parameters of this transformer, it could easily be modified to be fitting for connecting the HV side to the 150 kV level. On the other hand, the external grid is nothing more than a fictitious element that would, in case the model of the microgrid developed in this Open Call gets merged with some other model, end up deleted.

That was the exact case with the situation in which the unified model of the Crete grid needed to be created. For that to happen, the authors of the GEOGRID solution took the accurate model of the 150 kV transmission grid in the region of interest and then, instead of combining it with the accurate model of the distribution grid, used the developed microgrids (modified to be able to be connected to the 150 kV level) as the proxies of the distribution system. This step had to be completed that way due to the unavailability of high-quality input data related to the distribution system at the time of creation of the unified model. Of course, if the input data regarding the distribution grid would be available, it would definitely be better to use that instead of simulating it with the microgrids shown here. However, the mentioned situation in the moment of the unified model's making left the authors with no other option, but using the microgrids. This was achieved by taking each of the 150 kV nodes to which part of the distribution system should be connected and attaching one of the microgrids to it instead. The unified model will be shown in a later part of this subchapter. Before that, the codes that have been written in order to add the needed features to the solution have to be briefly explained.

Regarding the scripts (codes), it needs to be emphasized that the code lines needed for implementing each part of each microgrid model have also been drafted. Screenshots of the parts of the code are shown in the following figures with appropriate descriptions. Open source python libraries allowed this to be done in a very simple manner. For the purpose of reaching the unified model for demonstrations, the work was divided into four separate sub-tasks, each having their clear goal and leading into the sub-task succeeding them:

- Creation of the unified model of the selected part of the system on Crete island;
- Modification of the codes for the load flow calculation in order to run the analysis on the unified model;
- Projection of the created unified model on the appropriate map;
- Enabling the presentation of the obtained results on the map in a comprehensive manner.

The first of these sub-tasks was, as stated above, the combination of the distribution grid (medium and low voltage levels) models, partially shown in the Mid-term report of the Geogrid proposal, with the newly formed model of the 150 kV grid of the Crete island transmission network.

For that to happen, each of the individual elements of the mentioned high voltage grid needed to be described in the appropriate parts of the drafted code. First of all, it was necessary to define the buses in this 150 kV grid, with the received input data indicating that there were 16 buses that needed to be modelled in this part of the process. Their basic characteristics can be seen below, in Fig. 2.11a.

```
#create 150 kV busses
bus1 = pp.create_bus(net, name="HV Bus1", vn_kv=150, type="b")
bus2 = pp.create_bus(net, name="HV Bus2", vn_kv=150, type="b")
bus3 = pp.create_bus(net, name="HV Bus3", vn_kv=150, type="b")
bus4 = pp.create_bus(net, name="HV Bus4", vn_kv=150, type="b")
bus5 = pp.create_bus(net, name="HV Bus5", vn_kv=150, type="b")
bus6 = pp.create_bus(net, name="HV Bus6", vn_kv=150, type="b")
bus7 = pp.create_bus(net, name="HV Bus7", vn_kv=150, type="b")
bus8 = pp.create_bus(net, name="HV Bus8", vn_kv=150, type="b")
bus9 = pp.create_bus(net, name="HV Bus9", vn_kv=150, type="b")
bus10 = pp.create_bus(net, name="HV Bus10", vn_kv=150, type="b")
bus11 = pp.create_bus(net, name="HV Bus11", vn_kv=150, type="b")
bus12 = pp.create_bus(net, name="HV Bus12", vn_kv=150, type="b")
bus13 = pp.create_bus(net, name="HV Bus13", vn_kv=150, type="b")
bus14 = pp.create_bus(net, name="HV Bus14", vn_kv=150, type="b")
bus15 = pp.create_bus(net, name="HV Bus15", vn_kv=150, type="b")
bus16 = pp.create_bus(net, name="HV Bus16", vn_kv=150, type="b")
```

**Figure 2.11a:** Definition of the 150 kV nodes in the developed model.

Of course, the definition of the nodes themselves would not mean anything without the lines that would be used to connect those nodes. In the chosen part of the 150 kV grid, there were 19 lines that had to be considered. Their descriptions in the following section of the code can be seen in Fig. 2.11b, provided below, with some of the relevant parameters including the length of the lines and the nodes that are connected by them.

```
#create lines
line1 = pp.create_line(net, bus1, bus2, length_km=24, std_type="150 kV conductor", name="Line 1")
line2 = pp.create_line(net, bus2, bus4, length_km=53, std_type="150 kV conductor", name="Line 2")
line3 = pp.create_line(net, bus2, bus15, length_km=19, std_type="150 kV conductor", name="Line 3")
line4 = pp.create_line(net, bus3, bus15, length_km=81, std_type="150 kV conductor", name="Line 4")
line5 = pp.create_line(net, bus4, bus5, length_km=17, std_type="150 kV conductor", name="Line 5")
line6 = pp.create_line(net, bus3, bus4, length_km=47, std_type="150 kV conductor", name="Line 6")
line7 = pp.create_line(net, bus3, bus11, length_km=40, std_type="150 kV conductor", name="Line 7")
line8 = pp.create_line(net, bus3, bus7, length_km=19, std_type="150 kV conductor", name="Line 8")
line9 = pp.create_line(net, bus6, bus7, length_km=17, std_type="150 kV conductor", name="Line 9")
line10 = pp.create_line(net, bus7, bus16, length_km=14, std_type="150 kV conductor", name="Line 10")
line11 = pp.create_line(net, bus7, bus14, length_km=74, std_type="150 kV conductor", name="Line 11")
line12 = pp.create_line(net, bus11, bus12, length_km=29, std_type="150 kV conductor", name="Line 12")
line13 = pp.create_line(net, bus10, bus12, length_km=21, std_type="150 kV conductor", name="Line 13")
line14 = pp.create_line(net, bus9, bus10, length_km=58, std_type="150 kV conductor", name="Line 14")
line15 = pp.create_line(net, bus8, bus9, length_km=24, std_type="150 kV conductor", name="Line 15")
line16 = pp.create_line(net, bus3, bus8, length_km=39, std_type="150 kV conductor", name="Line 16")
line17 = pp.create_line(net, bus10, bus14, length_km=38, std_type="150 kV conductor", name="Line 17")
line18 = pp.create_line(net, bus13, bus14, length_km=24, std_type="150 kV conductor", name="Line 18")
line19 = pp.create_line(net, bus10, bus13, length_km=43, std_type="150 kV conductor", name="Line 19")
```

**Figure 2.11b:** Definition of the 150 kV lines in the developed model.

As can be seen, all of the lines in the part of the code given in Fig. 2.11b have the majority of their parameters filled in automatically, by assigning the standard type of the 150 kV conductor to them. For this to be successful, however, it was also necessary to define this standard type of conductors, which was done in order to avoid the unnecessary repetitions of the very same lines of code containing these characteristics for each of the 19 lines in this part of the system. Definition of this standard conductor type can be found in Fig. 2.11c.

```
#define standard types for 150 kV
line_data = {"c_nf_per_km": 0, "r_ohm_per_km": 0.12, "x_ohm_per_km": 0.4, "max_i_ka": 0.79}
pp.create_std_type(net, line_data, "150 kV conductor", element='line')
```

**Figure 2.11c:** Definition of the standard 150 kV conductor type in the developed model.

In line with what was stated above, the usage of standard types for the elements that are repeated multiple times in the different places in the grid increases the efficiency of the code and reduces the possibility of errors that could happen if there was a need to type the same lines of code over and over again. Therefore, it is logical that the principle of using the standard types was utilized on every occasion in which it was deemed plausible or not too time-consuming. The illustration of that can be found in the fact that the connection between the 150 kV grid and the medium voltage grid was also established by using one of the two standard types of transformers created for this purpose. The most prominent difference between them was the rated voltage of the nodes that were connected opposite to the 150 kV node. The definitions of the standard types of transformers are given in Fig. 2.11d.

```
pp.create_std_type(net, {"sn_mva": 63,
    "vn_hv_kv": 150,
    "vn_lv_kv": 20,
    "vk_percent": 16,
    "vkr_percent": 0.2,
    "pfe_kw": 25,
    "i0_percent": 0.2,
    "shift_degree": 0}, name='150/20 transformer', element="trafo")

pp.create_std_type(net, {"sn_mva": 25,
    "vn_hv_kv": 150,
    "vn_lv_kv": 10,
    "vk_percent": 16,
    "vkr_percent": 0.2,
    "pfe_kw": 25,
    "i0_percent": 0.2,
    "shift_degree": 0}, name='150/10 transformer', element="trafo")
```

**Figure 2.11d:** Definition of the standard 150/X kV transformer types in the developed model.

From this screenshot of the code, it can be seen that the first type of transformers was used when there was a need to connect the 150 kV node on one side to the 20 kV node on the other side, whereas the second type of transformers was created for utilization in the situation in which the link was created between the 150 kV node and the 10 kV node. The rated capacities of the transformer types were 63 MVA and 25 MVA, respectively.



The manner in which each of the individual transformers that was used for connecting the 150 kV grid with the medium voltage nodes is the same as the one used for defining the 150 kV lines – new element in the model gets introduced and, immediately after, it obtains the characteristics of the standard respective type to which it belongs. An example of this definition can be found in Fig. 2.11e, for which the first 150 kV node was considered.

```
#create transformer
trafo1111 = pp.create_transformer(net, bus1, bus111, name="110kV/20kV transformer", std_type='150/20 transformer')
```

**Figure 2.11e:** Definition of the individual 150/20 kV transformer in the developed model.

The focus can shift down to the medium and low voltage levels and the descriptions of the ways in which the various elements of the grid of those voltage levels were modelled and implemented into the code. Of course, the first thing that had to be done was to define the nodes of those voltage levels. However, what could be granted attention here is the way in which each of the single energy entities, such as the individual load, battery or the generation unit, was included in the model. This can, be seen in Fig. 2.11f. This figure can also be seen as an illustration of the principle that was used when creating the models of the grids of the voltage levels lower than 150 kV. Namely, since the simultaneous description of all parts of this grid would be extremely difficult to understand, the code was divided into sections, with each section dealing with the entities that are connected to the same 150 kV node. For example, the part of the code in Fig. 2.11f involves all of the loads, generation units and batteries connected to the first listed 150 kV node.

```
#create load
pp.create_load(net, bus1111, p_mw=1.5, q_mvar=0.75, scaling=scale_factor, name="load1")
pp.create_load(net, bus1112, p_mw=1.5, q_mvar=0.75, scaling=scale_factor, name="load2")
pp.create_load(net, bus1113, p_mw=1.5, q_mvar=0.75, scaling=scale_factor, name="load3")
pp.create_load(net, bus1114, p_mw=1.5, q_mvar=0.75, scaling=scale_factor, name="load4")
pp.create_load(net, bus1115, p_mw=1.5, q_mvar=0.75, scaling=scale_factor, name="load5")
pp.create_load(net, bus1116, p_mw=1.5, q_mvar=0.75, scaling=scale_factor, name="load6")
pp.create_load(net, bus1117, p_mw=3, q_mvar=1.5, scaling=scale_factor, name="load7")
pp.create_load(net, bus1118, p_mw=3, q_mvar=1.5, scaling=scale_factor, name="load8")
pp.create_load(net, bus1119, p_mw=3, q_mvar=1.5, scaling=scale_factor, name="load9")

#create pv power plants
pp.create_sgen(net, bus1112, p_mw=0.3*cf_pv, q_mvar=-0.1*cf_pv, name="pv1")
pp.create_sgen(net, bus1113, p_mw=0.3*cf_pv, q_mvar=-0.1*cf_pv, name="pv2")
pp.create_sgen(net, bus1115, p_mw=0.3*cf_pv, q_mvar=-0.1*cf_pv, name="pv3")
pp.create_sgen(net, bus1119, p_mw=0.6*cf_pv, q_mvar=-0.2*cf_pv, name="pv4")

#create battery
pp.create_storage(net, bus1115, p_mw = 0.3, max_e_mwh = 0.6, soc_percent = 0.5, min_e_mwh = 0.06)
pp.create_storage(net, bus1119, p_mw = 0.6, max_e_mwh = 1.2, soc_percent = 0.5, min_e_mwh = 0.12)
```

**Figure 2.11f:** Definition of the single entities in the developed model.

Once the definition of the various parts of the model had been completed and their connections established, the remaining part of the code needed to take care of the possibility of conducting the foreseen analyses, which, for this case, were the load flow calculations. In order to fulfil that part of the task (already mentioned as the second sub-task in this process), the sections of the code given in Fig. 2.11g were added, with the first line (aside from the comment) running the calculations, the following few exporting the results for the desired elements of the observed part of the grid and the last four lines writing those results in the *Microsoft Excel* spreadsheet, selected since most of the potential users are expected to be at least familiar with its environment.



```
#run load flow
pp.runpp(net)

#see bus results
bus_results=net.res_bus
ext_grid_results=net.res_ext_grid

#see line results
lines_results=net.res_line
trans_results=net.res_trafo

#save to excel (writer needs to be defined when multiple sheets written)
with pd.ExcelWriter(output) as writer:
    bus_results.to_excel(writer, sheet_name='buses')
    ext_grid_results.to_excel(writer, sheet_name='external grid')
    lines_results.to_excel(writer, sheet_name='lines')
    trans_results.to_excel(writer, sheet_name='transformers')
```

**Figure 2.11g:** Section of the code for running the load flow analysis.

For instance, the results regarding the relevant parameters of the buses in the observed part of the grid are saved in a particular sheet of the .xlsx file, with the name of the sheet simply defined as “buses”. In this sheet, the user can find the information regarding the voltage values and angles in each of the nodes in the system, as well as the active and reactive power balances of the nodes. The part of this sheet is provided in Fig. 2.11h.

	vm_pu	va_degree	p_mw	q_mvar
0	1	0,279401	-40	-20,4935
1	1	-0,51934	-10	-14,327
2	1	0	-87,1234	-52,1561
3	0,998111	-0,30939	0	0
4	0,997702	-0,34073	0	0
5	0,98066	-0,94414	0	0
6	0,98768	-0,59473	0	0
7	0,995939	-0,11623	0	0
8	0,994582	-0,16752	0	0
9	0,992702	-0,18401	0	0
		. . .		

**Figure 2.11h:** Part of the “buses” sheet of the report.

One clarification that needs to be given here is that the numbers on the left-hand side of this sheet are the ones that the code uses for recognizing the node in the model, meaning that they correspond to the order that was followed when the nodes were fed into the model. In quite a similar fashion, the sheet that is dedicated to the results obtained for the lines contains, among other values, the active and reactive power flows at starting and ending points of each line, the losses on those lines, calculated on the basis of the available flows, as well as the loading percentage of every line in the grid. This can be seen in Fig. 2.11i, provided below.

	p_from_mw	q_from_mvar	p_to_mw	q_to_mvar	pl_mw	ql_mvar	loading_percent
0	16,28184984	7,656335253	-16,24041392	-7,518215528	0,041435917	0,138119724	8,76606156
1	-3,007416169	2,914124458	3,012373202	-2,897601014	0,004957033	0,016523443	2,040302815
2	-4,671172648	1,424458764	4,67358934	-1,416403123	0,002416692	0,008055641	2,379334668
3	4,683892081	-1,382060654	-4,67358934	1,416403123	0,010302741	0,034342469	2,379334668
4	2,025554779	0,743695397	-2,02513104	-0,742282933	0,000423739	0,001412464	1,053286574
5	6,54473987	0,314711588	-6,533978083	-0,278838963	0,010761788	0,035872625	3,192382621
6	9,499709374	8,022191715	-9,466728033	-7,91225391	0,032981341	0,109937805	6,057951898
7	37,92700433	25,25313207	-37,71661826	-24,55184517	0,210386071	0,701286905	22,20001919
8	-24,18341641	-15,4634817	24,26109745	15,72241852	0,077681045	0,258936817	14,26115589
9	0	0	0	0	0	0	0
10	-4,229722528	-1,215913995	4,237558721	1,242034639	0,007836193	0,026120643	2,170992687
11	-8,215992458	-2,111659208	8,227296348	2,149338842	0,01130389	0,037679634	4,165207331
12	-6,505425192	-3,267160336	6,511448208	3,287237056	0,006023016	0,02007672	3,572884825
13	0,751903956	1,587651809	-0,750938925	-1,584435041	0,000965031	0,003216769	0,860554166
14	2,77858211	2,335516083	-2,776881911	-2,329848751	0,0017002	0,005667332	1,77568528

Figure 2.11i: Part of the “lines” sheet of the report.

Once again, the numbers on the left-hand sides of the report (i.e., in the first column of the created sheet) are the indicators of the order in which the lines have been defined when the code was initially written. Values similar to the ones given in the part of the report shown in the Fig. 2.11i can also be found in the sheet focused on the transformers in the grid, with the power flows calculated on the higher and the lower voltage sides of the transformer. The appearance of the sheet dedicated to the transformers is enclosed in Fig. 2.11j.

	p_hv_mw	q_hv_mvar	p_lv_mw	q_lv_mvar	pl_mw	ql_mvar	loading_percent
0	23,71815016	12,83717742	-23,67092966	-10,87580042	0,047221	1,961377	42,8084312
1	17,67858882	9,988375353	-17,64118235	-8,825041043	0,037406	1,163334	32,23043701
2	24,18185704	15,37423892	-24,13182672	-13,1762613	0,05003	2,197978	45,4846922
3	1,496050102	2,43274458	-1,47089081	-2,338786033	0,025159	0,093959	11,44539302
4	2,02513104	0,742282933	-2	-0,67	0,025131	0,072283	8,647399384
5	24,18341641	15,4634817	-24,1332165	-13,17974568	0,0502	2,283736	46,46149237
6	17,68524333	10,04534064	-17,64807903	-8,855193103	0,037164	1,190148	32,68689931
7	1,499474811	2,211085992	-1,474467165	-2,123540204	0,025008	0,087546	10,72988039
8	2,024977955	0,742196942	-2	-0,67	0,024978	0,072197	8,673828758

Figure 2.13j: Part of the “transformers” sheet of the report.

A little bit more effort went into drafting the sections of the code necessary for exporting the results obtained once the calculations were finished, with the manner of results’ presentation of choice being the one with which most of the partners and users, in general, are familiar – the Microsoft Excel spreadsheet. This made the further activities related to the integration of these functionalities in the F-channel environment even easier than it may have been if some other way of presentation was used. The code for exporting the results is given in Fig. 2.12.

```
#save to excel (writer needs to be defined when multiple sheets written)
with pd.ExcelWriter(output) as writer:
    bus_results.to_excel(writer, sheet_name='buses')
    ext_grid_results.to_excel(writer, sheet_name='external grid')
    lines_results.to_excel(writer, sheet_name='lines')
    trans_results.to_excel(writer, sheet_name='transformers')
```

**Figure 2.12:** Part of code – exporting the results.

As can be concluded if this part of the code was analysed in depth, the goal here was to create four different sheets in the output file, with each of them dedicated to one of the elements present in the microgrid:

- buses;
- external grid;
- lines;
- transformers.

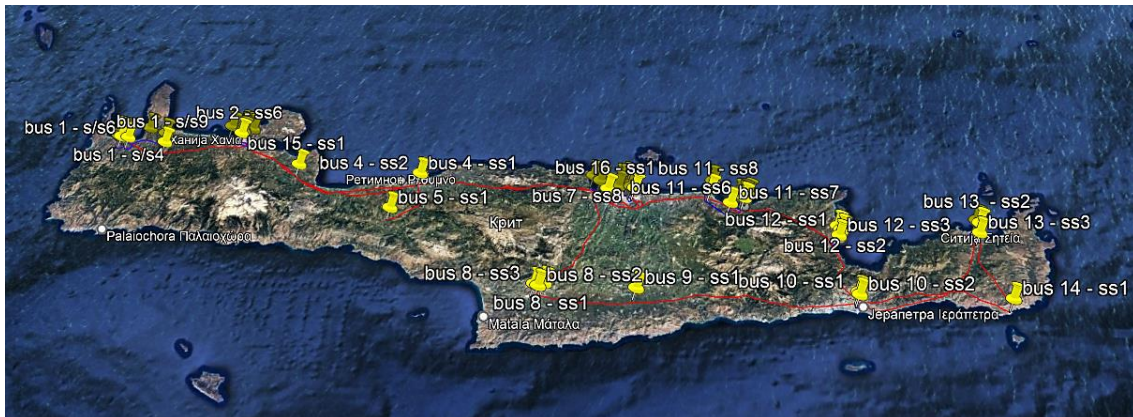
The information provided in the sheets varied depending on the type of the element to which that sheet was dedicated, so, for example, the sheet related to the external grid contained solely the active and reactive power flow from the external grid to the microgrid. The sheets related to the lines and the transformers, on the other hand, contained the flows over those elements, measured on both the starting and the ending bus of them. The sheet dedicated to the buses, finally, contained the columns for the active and reactive power demand in every bus, but also the value of the voltage in those nodes and the phase angles of those voltages. The ‘buses’ sheet for the grid shown in diagram in Fig. 2.7 is provided as an example of this and, thus, can be seen in Fig. 2.13.

	vm_pu	va_degree	p_mw	q_mvar
<b>1</b>	1	0	-17.70263086	-1.613118926
<b>2</b>	0.998606279	-0.108500652	0	0
<b>3</b>	0.998606279	-0.108500652	0	-2.991643503
<b>4</b>	0.970320257	-3.065417097	0	0
<b>5</b>	0.970320257	-3.065417097	0	0
<b>6</b>	0.963875716	-3.148921537	1.5	0.75
<b>7</b>	0.962404128	-3.16261563	1.2	0.85
<b>8</b>	0.960985693	-3.175314685	1.2	0.85
<b>9</b>	0.96003047	-3.252308041	1.5	0.75
<b>10</b>	0.958638112	-3.276229493	1.5	0.85
<b>11</b>	0.956926485	-3.308200821	1.5	0.75
<b>12</b>	0.958568178	-3.268087902	3	1.5
<b>13</b>	0.947224785	-3.458942047	3	1.5
<b>14</b>	0.942843588	-3.523809709	3	1.7

**Figure 2.15:** Obtained results for the household microgrid – buses.

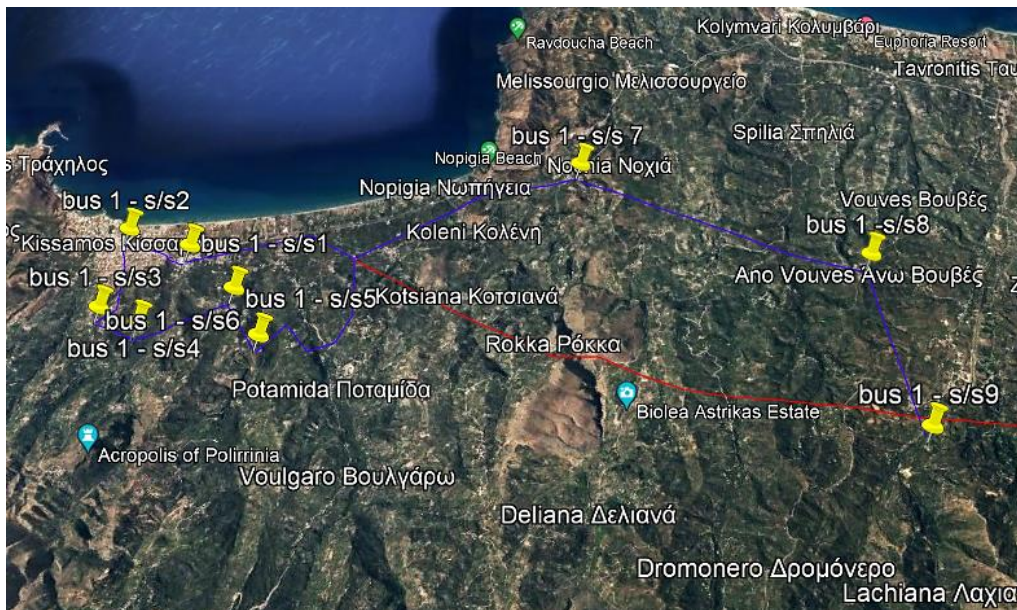
The developed georeferenced map of the entire grid of Crete island (all voltage levels) is shown in Fig. 2.14.





**Figure 2.14:** Georeferenced map of the Crete grid.

Even though the figure above gives an insight into the entirety of the grid of the Crete island (with the yellow pins, for example, showing the locations of the 150 kV facilities and the red lines marking the 150 kV power lines in this part of the system), it can be rather difficult to observe some of the phenomena occurring on some of the lower voltage levels in the form given in this figure. That is why the zoom-in option was also included when this map was developed. The zoomed-in part of terrain around the 150 kV node number 1 is enclosed in Fig. 2.15.

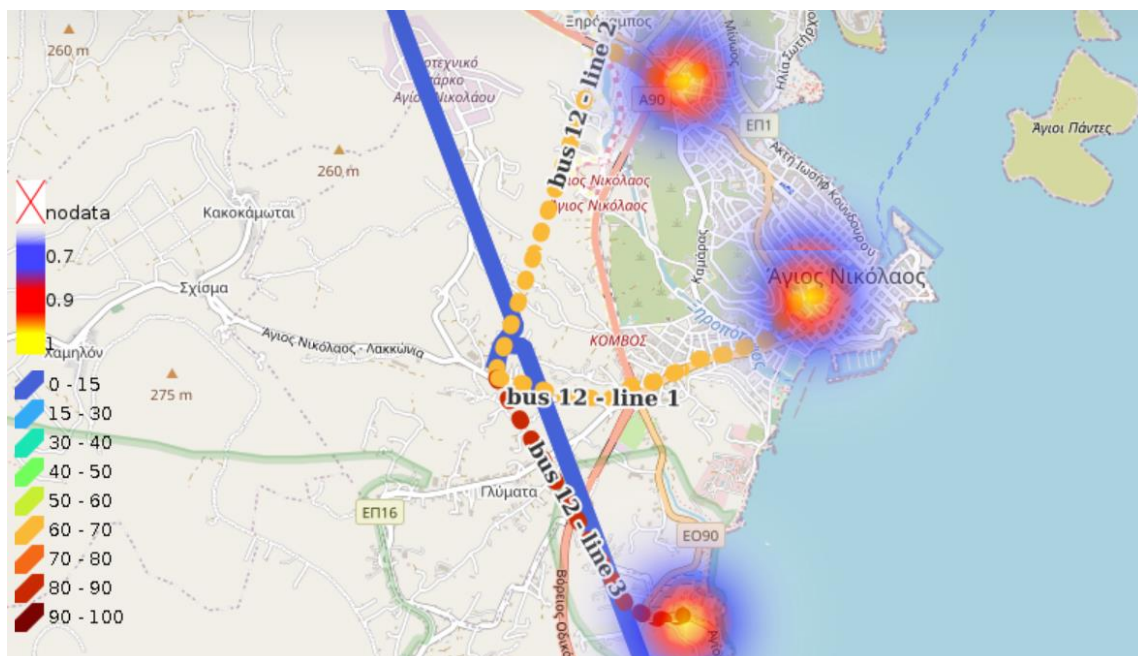


**Figure 2.15:** Zoomed-in part of the map of the Crete grid.

Here, it can also be seen that, once the map is zoomed-in to a scale high enough, the yellow pins show the locations of the distribution level facilities as well and that the blue lines, marking the routes of the distribution power lines, also become visible. However, in order to make the application of this functionality even more user-friendly, an additional option has been added, allowing the potential users to select the layers that the map will include, with one of the layers, containing, for example, the 150 kV grid in the area of interest.

By switching that layer off, the user can put more of an emphasis on the state of the distribution grid in case the report on which they are currently working on requests so. Next point was the development of the manner in which the results of load flow calculations could be included in the map of the grid. This was one of the main advancements of the GEOGRID proposal. Namely, the proper resolution of this issue also meant that the results of the performed analyses could be shown in a manner understandable both to the engineers that work in the software tools for these calculations on a daily basis and the general public to which the presentations of the most prominent conclusions of these analyses could be held. This improvement was seen as one of the main assets that could enhance the communication between the power industry and the authorities, explaining why this sub-task was set as one of the highest priorities by the mentors assigned to the proposal developers. For this to be accomplished, way in which the power flows and the voltages in the selected part of the georeferenced map would be presented needed to be chosen, with the option of having the colour schemes for both of those parameters surfacing as the best one. For the lines, the different colours of their referred to their loadings.

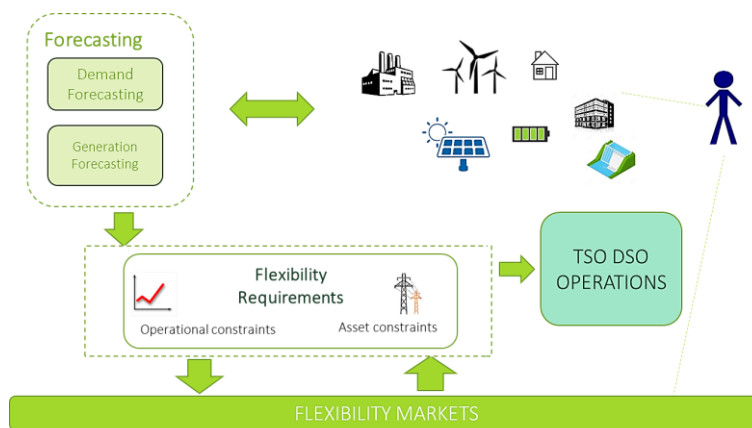
The blue shades show the relatively low loading of the lines and the red shades indicating the high loading of the lines. For the nodes and their voltages, a similar logic was used – if the colour surrounding the node was in the blue part of the spectre, the voltage of that node was on the low side and if the colour was closer to the yellow shades, the voltage of the node was closer to the rated value. This approach may seem confusing when described like this, but it is actually rather intuitive and simple to understand, which can be confirmed if Fig. 2.16, showing the loadings of the lines and voltages in the distribution grid around Agios Nikolaos, is observed.



**Figure 2.16:** Power flows and voltage levels in the distribution grid of Agios Nikolaos.

## 2.5 F-channel Platform

F-channel platform is the web based, client server application for the TSO-DSO coordination. It uses high-resolution weather forecasting, Artificial Intelligence methods, GUI based, georeferenced projection of the grid on the map , integrated within cloud calculation engines. The F-channel platform envelopes and implement set of common functionalities for SOs regarding the improvement of the forecasting ability and efficiency in various given time frames, limiting volume of flexibility needs in the process, as well as identification and prequalification of flexibility resources willing to procure grid services through “market-to-network” coupling of the alternative solutions. This kind of connection among the participants in the process is shown in a simplified manner in Fig. 2.17. It’s upper-left corner shows the forecasting functionalities, using the data from production units and high-resolution weather parameter measurements to feed the SOs the forecast of the grid state with the cutting-edge level of accuracy. The coordination functionalities (shown in the central part of the figure) of the F-channel platform serve for data exchange between the FSPs, aggregators, MOs and the SOs (on the right-hand side).



**Figure 2.17:** F-channel platform’s expected role in the flexibility market.

More of the technical details regarding the way in which the platform has been created, the functionalities that it offers to the potential users and the processes and procedures that should be followed in its operation can be found in the sections of the text within this subchapter, divided to ensure maximal understandability.

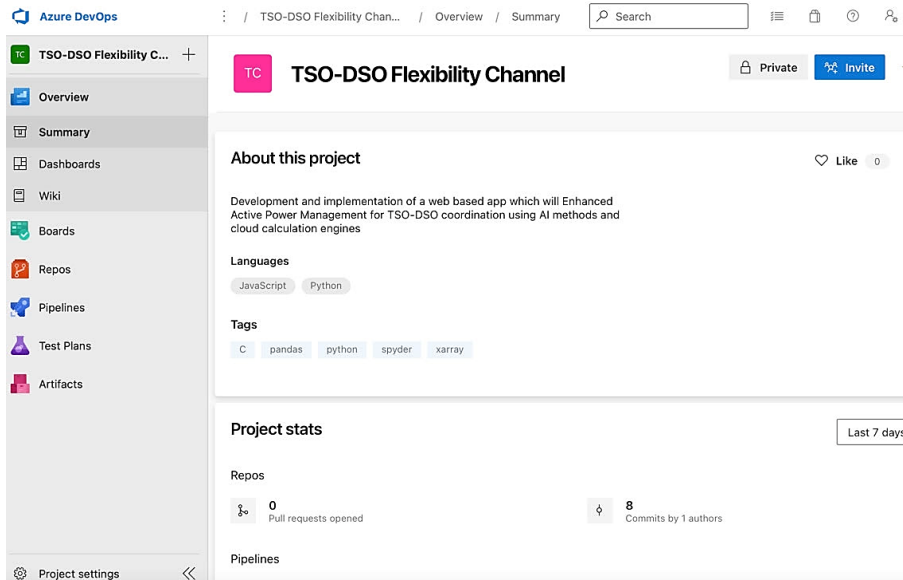
### 2.5.1 Development Environment

Before moving forward with the capabilities and features of the described platform, it would be appropriate to give at least some attention to the environment that was used throughout the process of designing it and, in continuation of the work within demo, modifying it and testing it. There, the following need to be mentioned:

- Microsoft Azure DevOps;
- Visual Studio Code (Azure repos);
- VMs on Linux servers (GIS server, MySQL, SQLite).

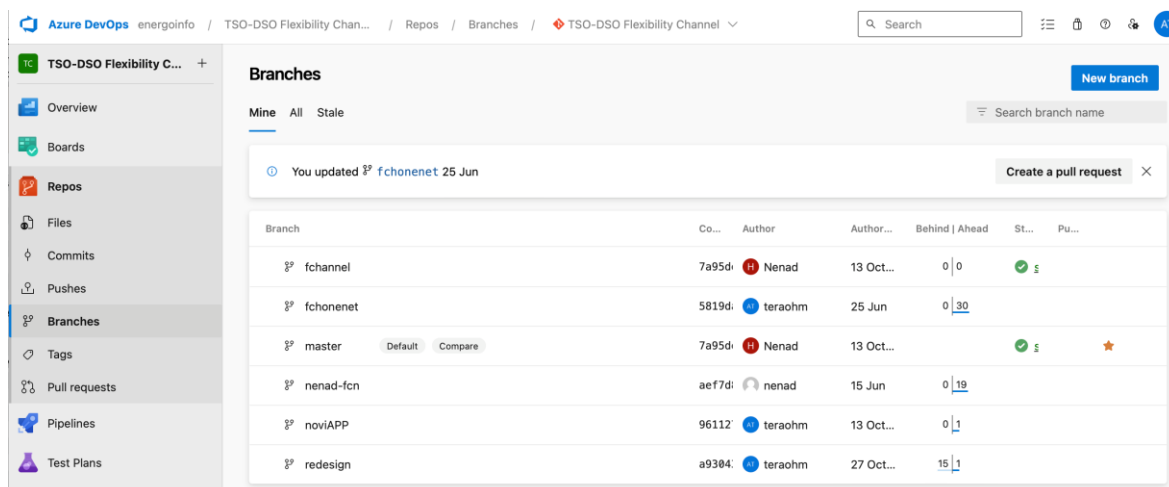


The application itself was coded in Python flask environment with Nginx webserver. Along with the Linux server, in which the code is run, the code is stored on Azure DevOps service, where the Git system is applied for tracking the revisions and pushing the commits. In Fig. 2.18, the basic layout of the home screen is shown.



**Figure 2.18:** Basic layout of the home screen in Azure DevOps.

In order to create the complex platform, such as the one proposed as the final result of the work conducted within the Greek Demo, different sections of the code needed to be written, each of them covering either one of the features and functionalities foreseen for implementation in the platform, or, in cases of some of the more complicated features, parts of them. Each of these parts of the code needed to be tested for the sake of reliability of the final outcome, after which their compatibility to work with one another needed to be confirmed. Branches of the code created during the development of the F-channel platform can be seen in Fig. 2.19, provided below.



**Figure 2.19:** Branches of the code in Azure DevOps.

The DevOps environment also allowed the usage of the folder structure in order to keep the code organized and simple to navigate and adapt to the need. The snapshot of the code folder structure is shown in Fig. 2.20.

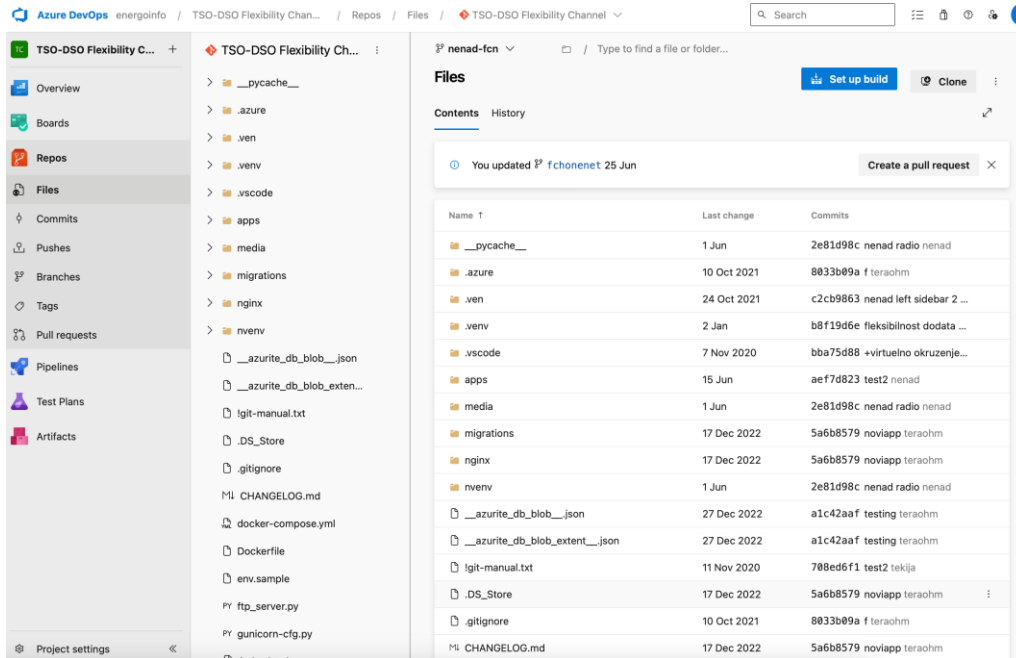


Figure 2.20: Code folder structure in Azure DevOps.

Preview of the georeferenced layers (more on this was mentioned in the previous subchapters) was achieved with GIS Geoserver environment. The welcome screen of the GEO server is enclosed below, giving some of the basic information (number of layers, workspaces and stores on the server, for instance) to its users. Alongside that, menu on the left-hand side allows the user to access more details regarding the data existing on the server.

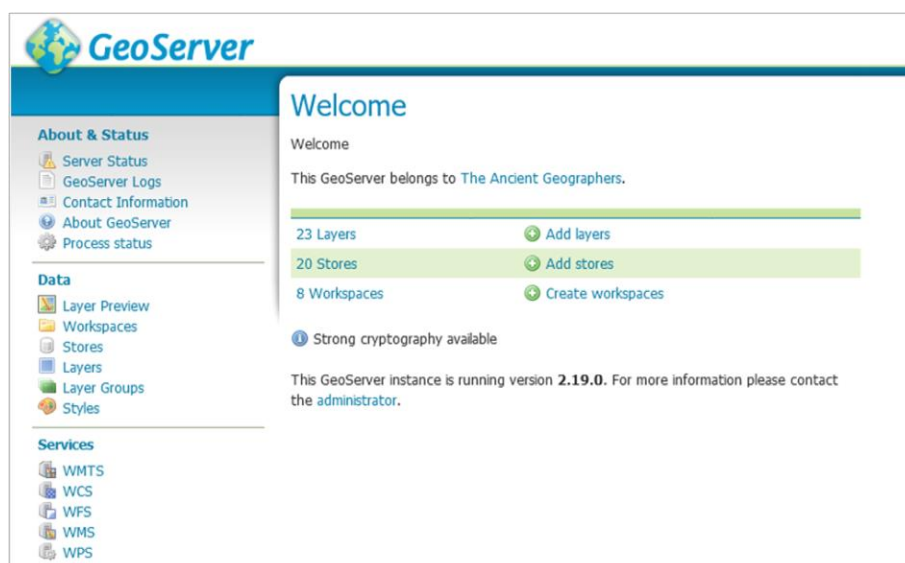
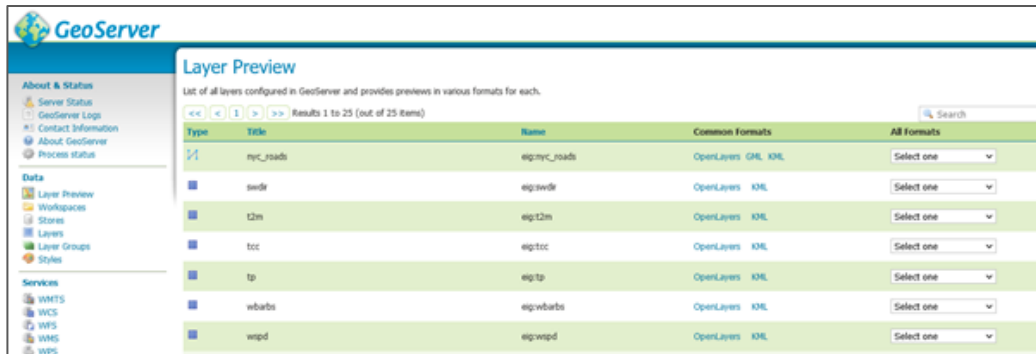


Figure 2.21: Welcome screen of the GEO Server.

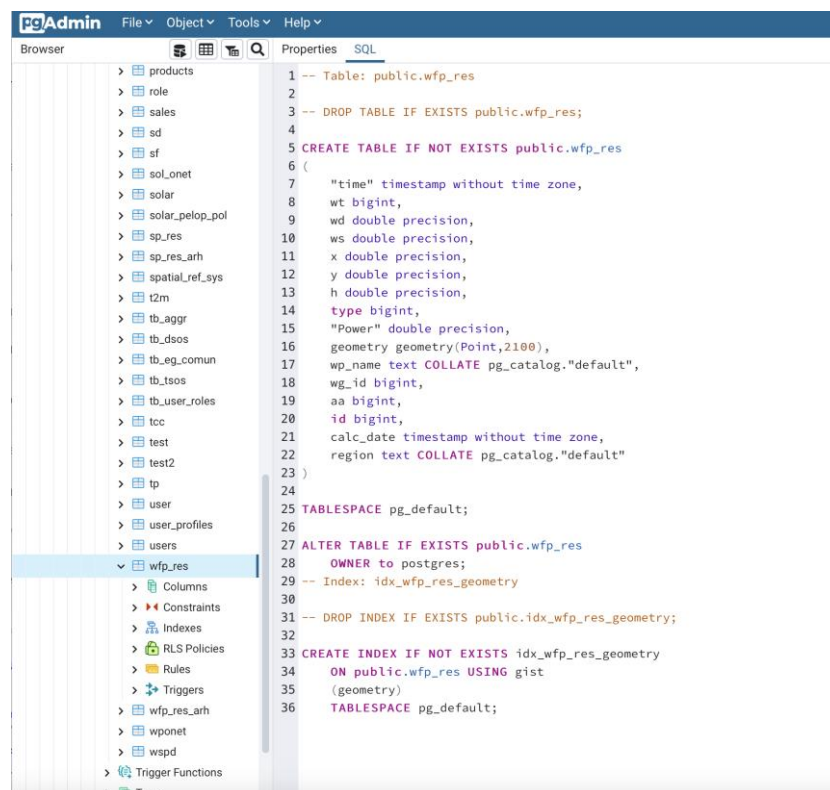


Geoserver acts as interface between backend database and frontend preview of layers inside the platform. Each layer can be called with simple JavaScript code inside leaflet environment or other service. The preview of the different layers included in the GEO server, providing the types and names of the layers, is given in Fig. 2.22.



**Figure 2.22:** Layer preview on the GEO Server.

The backend database consists of 48 tables in POSTGRES environment. Upon completing the calculations (i.e., wind and solar production forecasts or the indication of the critical climate conditions), all of the obtained results are automatically stored in the database. The calculations are performed twice a day. Since this database acts as the Geoserver backend, it has GIS capability – geometry data is stored for each record. As an example of this, the SQL query for creating the wind production data table is given in the screenshot enclosed in Fig. 2.23.



**Figure 2.23:** SQL query for the wind production data table.

It is possible to combine several queries together, as can be seen in the example provided in Fig. 2.24. In this example, the combination of the productions of the wind and solar capacities is obtained with UNION query.

```

1 SELECT
2 CAST (max(id) as int) as pv_no ,CAST ( company as VARCHAR(256)) as name_display, SUM(power_anem) AS pow_mw
3 FROM
4 "wponet"
5 GROUP BY company
6 UNION
7 SELECT CAST (pv_no AS int), CAST (name_display AS VARCHAR(256)), pow_mw FROM public.sol_onet
8
9 ;

```

pv_no	name_display	pow_mw
1	269 ΔΕΗ ΑΝΑΝΕΩΣΙΜΕΙ ΑΕ	30.3000000000000004
2	11 11. MESSHΝΙΑ - 4.9MW	4.9
3	1422 substation MOLAIQI district LAKONIA	18.9
4	1430 ARCADIA 1039	16.5
5	51 AEOLIOS A.E.	9.9
6	1360 substation MOLAIQI district LAKONIA	7.6499999999999999
7	6 6. LACONIA - 6MW	6
8	239 ΕΝΩΣΗ ΕΝΕΡΓΕΙΑΚΗ ΑΣΕ	2.7
9	1343 ARCADIA-ARGOLIDA 1030	39.5999999999999994
10	96 ANEMOI AAKYONHZ AEE	6.3000000000000001
11	58 ΑΙΟΙΚΗ ΜΟΥΣΟΥΠΟΝ ΑΕ	2.55
12	5 5. LACONIA - 5MW	5
13	1488 LACONIA 1044	17.1
14	8 8. MESSHΝΙΑ - 2.131MW	2.131
15	1284 substation ZARAKAS district LAKONIA	28.9000000000000016
16	1160 substation KARATZAS_TRIZINIAS district ARGOLIDA	39.0999999999999994
17	1444 LACONIA 1040	32.2

Figure 2.24: Union query for the productions of wind and solar units.

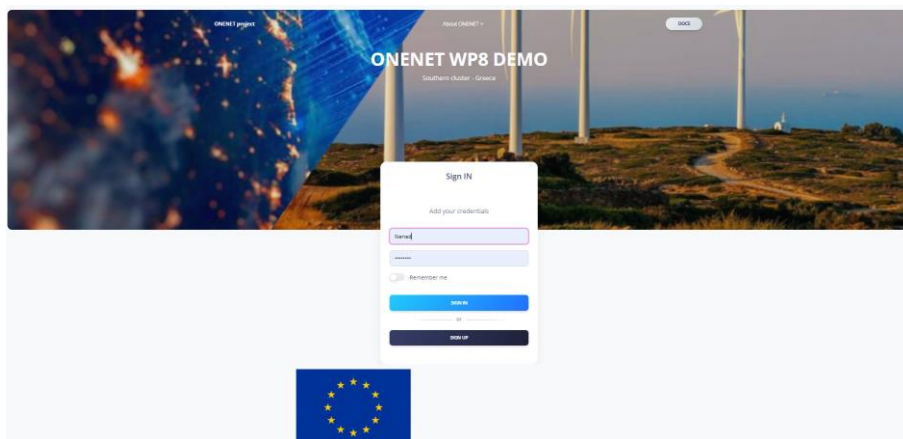
Running of the production forecast and weather monitor algorithms is scheduled by using the Apache Airflow service. This service enables joining several tasks together, scheduling them depending on individual task results (success, retry when fail, run task if result of previous task is within predefined range, etc.). Tasks are organized in DAGs, providing the common vocabulary of steps and transitions between them and making it easier to write the code and to understand it afterwards. The snapshot of the active DAGs in enclosed below, in Fig. 2.25.

DAG	Owner	Runs	Schedule	Last Run	Next Run	Recent Tasks
cp	airflow	1	3:00:00	2023-07-17, 16:53:43	2023-07-17, 19:53:43	cp
ohl_monitor	airflow	1	0 9/11***	2023-07-16, 22:00:00	2023-07-17, 11:00:00	ohl_monitor
ohl_monitor_na	airflow	1	0 0/12***	2023-07-17, 02:00:00	2023-07-17, 14:00:00	ohl_monitor_na
sol_wind_onet	airflow	1	0 9/11***	2023-07-16, 22:00:00	2023-07-17, 11:00:00	sol_wind_onet
ts	airflow	1	1:00:00	2023-07-17, 18:46:53	2023-07-17, 19:46:53	ts

Figure 2.25: The list of active DAGs in the task organization.

## 2.5.2 F-channel Platform GUI

The F-channel platform is accessed by the user by typing the web address of the dedicated server which is hosting the F-channel platform into the internet browser. Once that is done, the user is greeted by a “Log in” screen as the first screen with a pop-up window in which the username and password of the user have to be provided. It is based on the large number of log-in screens existing in the applications that the users encounter on a daily basis, making this rather intuitive and giving the users the sense of familiarity, thus improving the first impression that the platform leaves on them. The appearance of this log-in screen can be seen in Fig. 2.26.

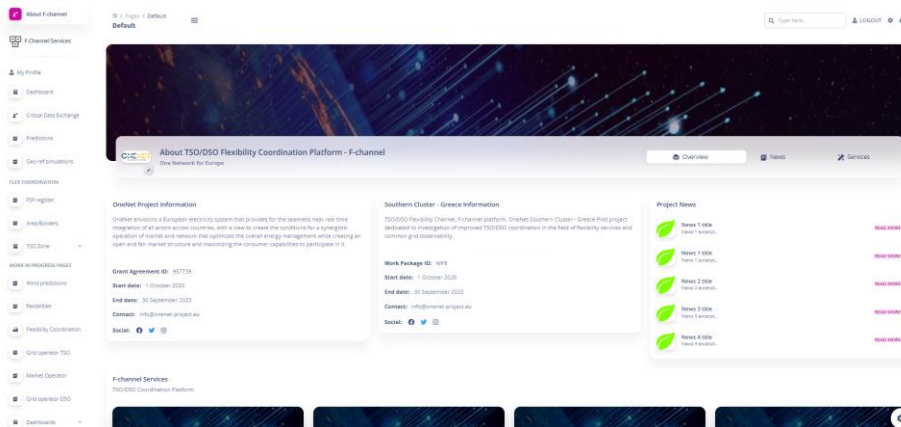


**Figure 2.26:** F-channel platform log-in screen.

In order to access the F-channel platform, the user needs to enter the “Username” and “Password” into the corresponding fields in the log-in screen. By clicking on the “Sign in” button below those fields, the user sends the request for accessing the platform. The credentials are then checked and, if the access is authorized, the main dashboard page is loaded into the web browser. In case the user is attempting to join the platform for the first time, they have the option to create a new account by clicking the “Sign up” button on the same log-in screen. Once the log-in is successfully performed, the dashboard’s appearance varies depending on the type of user that has logged in the platform. Each of the types is defined with different, type-specific roles and rights. Five types of users (accounts) of the platform are, together with respective rights and duties, listed here:

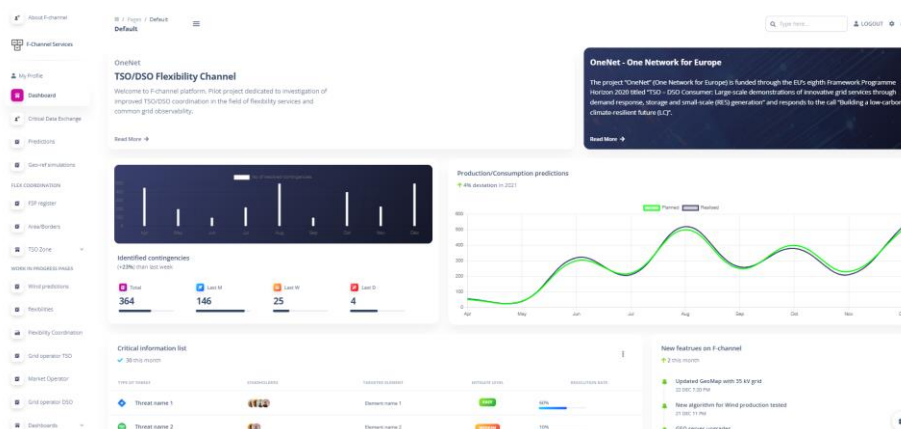
1. FSP/Aggregator – places bids to offer different flexibility products, can view the auction results;
2. TSO – uploads and changes the grid parameters and places bids for purchase of different products, can view the auction results, can edit and view FSP register;
3. DSO – uploads and changes the grid parameters and places bids for purchase of different products, can view the auction results, can edit and view FSP register (only for products relevant for the DSO);
4. Market Operator – sets and performs auctions, can view the auction results, can view FSP register;
5. Guest – can view the auction results.

Taking into consideration the previously mentioned possibility that the user may be logging in to the platform for the very first time, it was important to incorporate the introductory section into the platform, with this part giving the new users a short summary of the services and features that the platform offers, as well as a brief history of the platform’s development, including, among other information, descriptions of the OneNet project and the Southern Cluster of this project. The introductory screen is also enclosed in this report, as Fig. 2.27.



**Figure 2.27:** F-channel platform – about F-channel.

For the experienced users, however, the most important section of this platform and, probably, the section on which they will spend the majority of their time dedicated to the platform would be the dashboard. As stated already, the dashboard can be seen as the sort of a homepage that is first opened as soon as the log-in process is completed successfully. What is included in it, however, varies depending on the role that is taken by the user, with the “need-to-know” principle applied when designing the dashboards for each of the five specified types. The sole exception from this rule are the pages for the TSO and the DSO, which are quite similar, with the main difference between them being the set of products relevant for the respective system operator. This exact window is shown in Fig. 2.28, where the functionalities offered to the system operators can be seen.



**Figure 2.28:** F-channel platform – TSO/DSO dashboard.

### 2.5.3 Forecasting module

The F-channel platform contains two major modules – the Forecasting module and the Coordination module. The Forecasting module is equipped with an appropriate GUI based on a georeferenced map presentation that was developed in cooperation with the OneNet Open Call and includes the GEOGRID solution that came out of it. The F-channel’s Forecasting module is capable of energy production forecast for wind and solar units, load flow, voltage profile simulations and the weather parameters forecasts, including the severe weather conditions identification. Results are shown on a GIS based map (Map View) and in a tabular view, such as one in Fig. 2.29.

NAME	POWER (MW)	FROM	TO	PRODUCTION RUN TIME	STATUS	VIEW
AIDUSSA A.E.	456.2	2023-07-27 10:00:00	2023-07-29 11:00:00	2023-07-27 09:00:05	MPHTM	32
TEPNA ENPEPESH ABETE	450.4	2023-07-27 10:00:00	2023-07-29 11:00:00	2023-07-27 09:00:05	MPHTM	10
AEI ANANEZMET AE	449.1	2023-07-27 10:00:00	2023-07-29 11:00:00	2023-07-27 09:00:05	MPHTM	67M
POKAL AIOVNA ABE	432.1	2023-07-27 10:00:00	2023-07-29 11:00:00	2023-07-27 09:00:05	MPHTM	26
AIDUSSA TAPPA EPYON AE	392.5	2023-07-27 10:00:00	2023-07-29 11:00:00	2023-07-27 09:00:05	MPHTM	46
AIDUSSA TAPPA ANAGION AE	384.8	2023-07-27 10:00:00	2023-07-29 11:00:00	2023-07-27 09:00:05	MPHTM	47
Substation PANACHWARD-BAVNA ACHVIA	365.1	2023-07-27 10:00:00	2023-07-29 11:00:00	2023-07-27 09:00:05	REAGFORME/CE	1002
AEI ANANEZMET AE	319.6	2023-07-27 10:00:00	2023-07-29 11:00:00	2023-07-27 09:00:05	MPHTM	534
THAKTICA MPHTM ABE	287.6	2023-07-27 10:00:00	2023-07-29 11:00:00	2023-07-27 09:00:05	MPHTM	204
AEI ANANEZMET AE	269.8	2023-07-27 10:00:00	2023-07-29 11:00:00	2023-07-27 09:00:05	MPHTM	523

Figure 2.29: Tabular view in the Forecasting module.

The idea on which the Forecasting module has been developed on, is that the users should be given the option to see whatever they find interesting out of the predefined set of parameters and to turn off everything else. Layers were created on the georeferenced map of the area of interest, with each of those corresponding to one of the weather parameters or the parts of the grid. The available layers of the selected area can be seen in Fig. 2.30, including WPPs on Crete, WPPs on Peloponnese, SPPs, Crete Unified Model, Crete-Mainland connection, Power flow results, Voltage profile results, Cloud cover, Wind speed, Precipitation and Temperature.

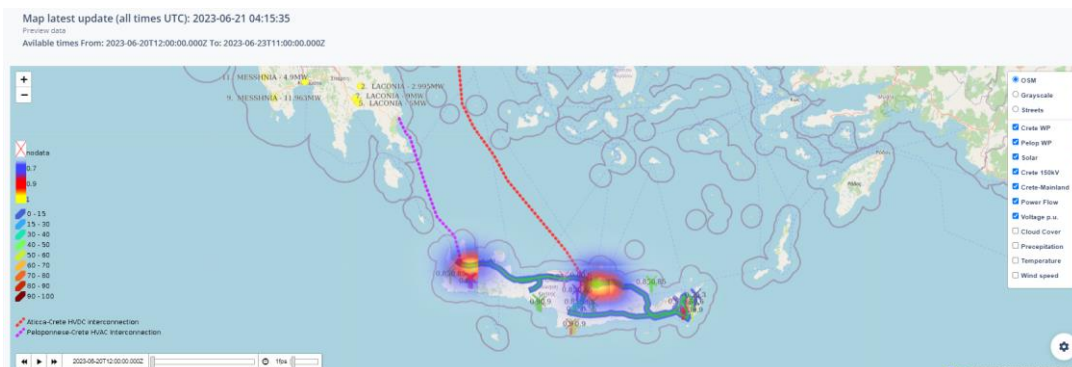
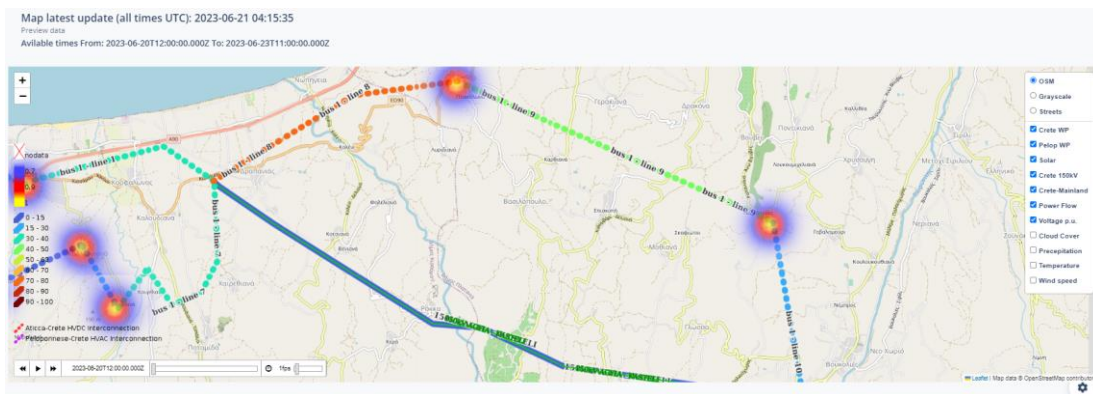


Figure 2.30: F-channel platform – Grid layers.

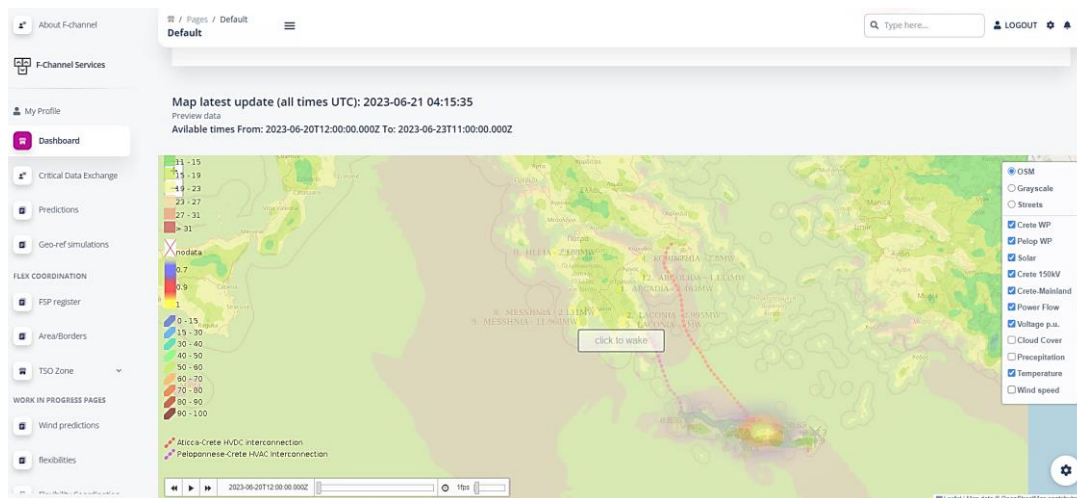


The way in which the results of the load flow and voltage conditions calculations are shown on the map has also been explained in the subchapter dealing with the GEOGRID solution, so here only a short reminder that it is done in line with the colour coding principle, in order to give quick indication to the user, is made. What should be underlined, however, is the fact that each calculated parameter (loadings of the lines, voltages of the nodes, etc.) has a dedicated layer for itself, so its projection on the map can be switched on or off, depending on the preferences of the user. The part of the map from Fig. 2.30, which, zoomed in, shows more details and results of the calculations, can be seen in Fig. 2.31.



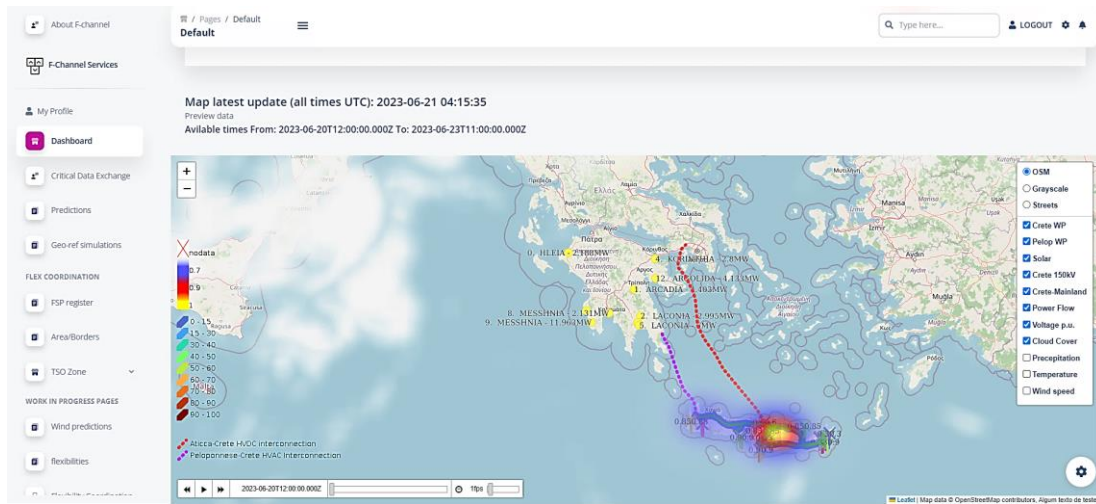
**Figure 2.31:** F-channel platform – Grid layers – zoomed in.

In addition to the grid layers, the Forecasting module also includes the weather layers, showing the forecasts of the climatic indicators relevant for the operation of the different parts of the power system. For example, the map shown in Fig. 2.32 shows the values of temperature in the entire region of interest, which is quite important, since the temperature variations can affect a number of the elements of the system, such as the lines (for which the rise of temperature reduces the transmission capacity) or the solar production units (for which the efficiency of the generation varies depending on the temperature). As illustrated here, this parameter is also colour coded.



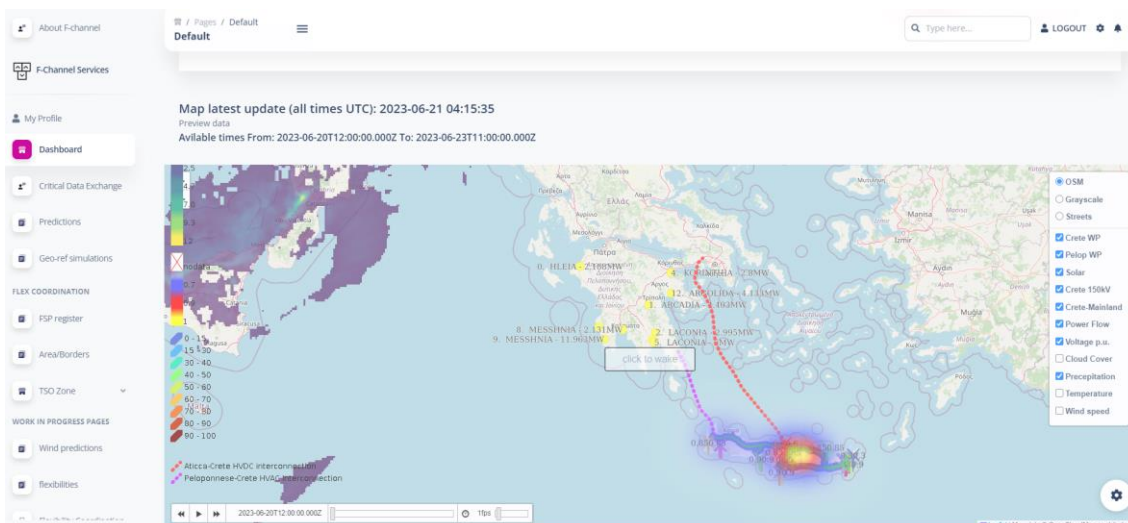
**Figure 2.32:** F-channel platform – Weather layers – Temperature.

What should also be highlighted is the fact that, although the temperature was selected for showing in the map in Fig. 2.32, power lines and the nodes of the grid also remained visible. This correctly indicates that the grid and weather layers of the Forecasting module can be available to the user simultaneously, allowing them to draw some conclusions or spot correlations that would, otherwise, be overlooked. A similar map, but with the cloud coverage selected as the climatic parameter of interest, is given in Fig. 2.33.



**Figure 2.33:** F-channel platform – Weather layers – Cloud coverage.

The cloud coverage is, as anyone with experience in solar plants knows quite well, particularly relevant for this type of production units, since the sudden appearance of the cloud can reduce the production power of a solar panel even down to zero in a matter of seconds. Therefore, it is good to constantly be able to follow if there are any clouds in the area of interest and if there will be any clouds in that area in the upcoming hours. As the final example of the weather layers, the map showing the precipitation, given in Fig. 2.34, was selected.



**Figure 2.34:** F-channel platform – Weather layers – Precipitation.

## 2.5.4 Coordination module

The F-channel Coordination module for providing grid services (frequency and non-frequency) for the balancing and congestion management challenges was finalized following the successful integration of the results of the OneNet Open Call in the F-channel environment. Within this module, TSOs and DSOs will have interfaces towards the Flexibility Register and the TSO-DSO Coordination Platform. These two systems will be given interfaces towards the FSPs, market operators, metering data administrators and consent administrators. Data will be exchanged at TSO level for interoperability towards the distribution system. It is not foreseen that any market data will be shared directly between SOs. Grid data will, on the other hand, be shared directly between the SOs in order to meet requirements related to the existing practices related to the network security and operational stability regular checks. The TSO and DSO will, along with that, be able to share information related to future flexibility needs, calls for flexibility tenders, flexibility purchase offers, grid data for qualification and finished auctions, flexibility requirements that are checked against operational and asset-based constraints and activation requests within their systems. Since there is no existing framework for communication between the SOs and the further market is not operational yet, several dry-run scenarios will be executed in Greek Demo.

### 2.5.4.1 Auction submodule – Supported Products

The Auction submodule of the F-channel platform will provide the market participants with week-ahead to day-ahead frequency responses, re-dispatching auction-based procurements of the capacity reserves and available flexibility products. F-channel will bring the flexibility products, including the ancillary services market operation, closer to real-time, recognising the time-dependent and location-dependent values of balancing products and enabling new participants to take part in the electricity market. The TSO is expected to enter the amount of secondary and tertiary reserve needed in its control area. Based on the information from the registry, the Market Operator sets up auctions. Each DSO/TSO enters forecasted: contingencies, bottlenecks and voltage problems to be resolved. The following products that can be auctioned are supported on the F-channel platform:

1. aFRR UP;
2. aFRR DOWN;
3. mFRR UP;
4. mFRR DOWN;
5. predictive short term local active product UP;
6. predictive short term local active product DOWN;
7. predictive short-term local reactive product UP;
8. predictive short-term local reactive product DOWN;
9. predictive long-term local active product UP;
10. predictive long-term local active product DOWN.



In order to introduce the products that are proposed by the Greek Demo to the user and, in turn, make the understanding of the remainder of this section simpler and faster for them, Tab. 2.1 gives a short description of them, followed by mentioning the harmonized product corresponding to the product proposed by Greek Demo.

**Table 2.1:** Description of the products proposed by the Greek Demo.

Products proposed by Greek Demo	Description	Harmonized Products
Predictive reactive support	<p>This product would be used to react by using reactive power to a forecasted system need within the operational planning timeframe. Therefore, activation can be planned which would reduce the pressure on the full activation period and, hence, increase liquidity. The product can be acquired as a capacity only (it can be combined with the reactive power product), a reactive power product or both capacity and reactive power products. The procurement of this product would happen at least once a month (i.e., the duration of the product is under one month) to increase the market liquidity. This product will include information about the location of the flexibility.</p> <p>The product includes provision or absorption of the MVarh in specific timeframes in the local distribution grid through the optimized coordinated tap change control on the TSO-DSO interface. It can be used both to regulate voltage and reduce losses in the distribution grid. It is connected to the voltage control. The reactive support product would be automatically activated and the flexibility resource would provide reactive compensation to the distribution grid when needed.</p>	Predictive short-term local reactive product
Predictive congestion management for TSO/DSO product	Product for cases in which forecasted or realized power flows violate thermal limits of the elements of the grid and voltage stability or angle stability limits of the system. For congestions that are forecastable (e.g., redispatch, countertrading, as well as the use of active power flexibility) grid-related or market-related measures can be procured via this product.	Predictive short-term local active product
Power regulation mFRR	Provision of identification of flexibility resources (secondary and available tertiary reserve) more accurately and efficiently and of identification of the flexibility needs in a more precise manner and for longer time horizon than what is done today.	mFRR
Power regulation aFRR	Provision of identification of flexibility resources (secondary and available tertiary reserve) more accurately and efficiently and of identification of the flexibility needs in a more precise manner and for longer time horizon than what is done today.	aFRR
Severe state prevention/restoration product	Provision of improved identification of severe system states and contingencies that may cause such states in more precise manner and for longer time horizon than what is done today, together with improved identification of flexibility resources and the enhanced identification of the flexibility needs.	Predictive long-term local active product

After the brief introduction that was given in Tab. 2.1, the next part of the description of the products of interest for the Greek Demo will be based on going through the products one-by-one and providing some of the more prominent characteristics of those products. Those characteristics will be given in the tabular forms.

### aFRR

Before moving on with the detailed explanation of this product, it was deemed good to give some sort of a definition of the aFRR, for the readers outside of this area of expertise. By the literature, aFRR can be defined as the active power reserves that are available in order to restore the system frequency to the nominal frequency and, for a synchronous area consisting of more than one LFC area, to restore the power balance to the scheduled value. The “a” in its name comes from the fact that activation of this product always takes place automatically. In Table 2.2, the attributes related to this product can be found. This is the same form that will later be used for all of the remaining products as well, As can be seen, the left column of the table is reserved for the attributes corresponding to the product, whereas the right column gives the values for each of the attributes. Sometimes those values are not numerical, but logical (yes/no questions) or even descriptive, but always help in describing the product better.

*Table 2.2: Attributes for the product in the Greek Demo - aFRR.*

Attributes	Values
Capacity/energy	Capacity and energy
Location required (Y/N)	No
Maximum full activation time	5 minutes
Minimum required duration of delivery period	Each bid can be activated and deactivated at any moment within the validity period
Maximum deactivation period	≤ full activation time
Maximum recovery period	
Maximum number of activations (per day, week...)	
Required mode of activation	Automatic
Minimum quantity	1 MW
Divisibility (Y accepted / Y required /N)	Each bid shall be divisible
Granularity	1 MW
Maximum and minimum price	
Availability price (Y/N)	If required, in €/MW
Activation price (Y/N)	Yes, in €/MWh
Symmetric/asymmetric product (Y/N)	No symmetry required
Aggregation allowed (Y/N)	Allowed

### mFRR

Judging by the literature that is dealing with this topic, mFRR can be defined as the active power reserves available for restoration of system frequency to the nominal frequency and, for the synchronous area consisting of more than one LFC area, restoration of the power balance to the scheduled value. The “m” in its name refers to the fact that the activation of this product always takes place manually (in contrast to the previous product). Some of the TSOs in Europe (e.g., Norwegian TSO Statnett) intend to activate bids submitted to mFRR standard product market to manage congestions inside bidding zones. To achieve this, Statnett will require the potential service providers to disclose the additional information (e.g., location of their resources) in the bids that can be used when needed to select and activate the bids suitable for handling intra-zonal system constraints. The result of such an approach is that this would transform this product into a variety of Predictive short term / long-term local active products discussed on one of the following pages. By using a similar template as the one applied for the aFRR in Tab. 2.2, Tab. 2.3 was created in order to provide more details on the discussed mFRR product.

**Table 2.3: Attributes for the product in the Greek Demo - mFRR.**

Attributes	Values
Capacity/energy	Capacity and energy
Location required (Y/N)	No
Maximum full activation time	12.5 minutes
Minimum required duration of delivery period	5 minutes
Maximum deactivation period	To be consistent with requirements set on the FAT and on the minimum duration of delivery period
Maximum recovery period	Defined in terms and conditions for FSPs
Maximum number of activations (per day, week...)	
Required mode of activation	Manual
Minimum quantity	1 MW
Divisibility (Y accepted / Y required /N)	Divisible and indivisible bids are allowed
Granularity	1 MW
Maximum and minimum price	
Availability price (Y/N)	If required, in €/MW
Activation price (Y/N)	Yes, in €/MWh
Symmetric/asymmetric product (Y/N)	No symmetry required
Aggregation allowed (Y/N)	Allowed

### **Predictive short-term local active product**

This product would be used to react to a forecasted system need within the operational planning timeframe by using the active power. Therefore, the activation of the product can be planned which would, in turn, reduce the pressure on the full activation period and, thus, increase liquidity. The product can be acquired as capacity only (in which case it would be combined with an energy product), as energy product or as both (capacity and energy product). The procurement of this product would happen at least once a month (i.e., the duration of the product would be shorter than one month) in order to increase the liquidity of the market. The product would need to include the additional information regarding the location of the flexibility resource that would provide the service later on, as this would allow the activation of the resources that would be closer to the place in which the need for the product has been spotted. Also, what differs this product from the previous two products is the fact that the activation can either happen manually or automatically. All of this can be learned from Tab. 2.4.

**Table 2.4:** Attributes for the product in the Greek Demo – Predictive short term local active product.

Attributes	Values
Capacity/energy	Capacity, Energy or both
Location required (Y/N)	Yes
Maximum full activation time	<60 min
Minimum required duration of delivery period	A multiple of 15 minutes up to 1 hour
Maximum deactivation period	Defined in terms and conditions for FSPs
Maximum recovery period	Defined in terms and conditions for FSPs
Maximum number of activations (per day, week...)	
Required mode of activation	Automatic/ Manual
Minimum quantity	1 MW for TSOs 0.01 MW for DSOs
Divisibility (Y accepted / Y required /N)	Divisible and indivisible bids are allowed
Granularity	1 MW for TSOs 0.01 MW for DSOs
Maximum and minimum price	
Availability price (Y/N)	Yes, in €/MWh
Activation price (Y/N)	Yes, in €/MWh
Symmetric/asymmetric product (Y/N)	No symmetry required
Aggregation allowed (Y/N)	Allowed

**Predictive long-term local active product**

This product would be used to mitigate and/or delay the need for additional grid reinforcements using active energy, thus enabling the better management of the available budget of system operators and the redirection of the resources that would otherwise be used for those reinforcements to some of the other urgent projects in the grid. This product could contract capacity (together with energy or alone, with the acquisition of the energy left to the following procurement processes). The duration of the product could extend over a long period (over a month, but it could, in some situation, cover up to multiple years). Activation can either be planned (scheduled delivery) or performed at the request of the SO (this could, however, require the separate procurement process if the initial product is a capacity-only product). This product would, in the same fashion as the previous product, include the information about the location of the flexibility resource that could provide the requested service. More information on it, including the mode of activation and the minimum quantity, can be found in Tab. 2.5.

**Table 2.5:** Attributes for the product in the Greek Demo – Predictive long term local active product.

Attributes	Values
Capacity/energy	Capacity, Energy or both
Location required (Y/N)	Yes
Maximum full activation time	24h
Minimum required duration of delivery period	A multiple of 15 minutes up to 1 hour
Maximum deactivation period	Defined in terms and conditions for FSPs
Maximum recovery period	Defined in terms and conditions for FSPs
Maximum number of activations (per day, week...)	
Required mode of activation	Automatic/ Manual
Minimum quantity	1 MW for TSOs 0.01 MW for DSOs
Divisibility (Y accepted / Y required /N)	Divisible and indivisible bids are allowed
Granularity	1 MW for TSOs 0.01 MW for DSOs
Maximum and minimum price	
Availability price (Y/N)	If required, in €/MWh
Activation price (Y/N)	Yes, in €/MWh
Symmetric/asymmetric product (Y/N)	No symmetry required
Aggregation allowed (Y/N)	Allowed

### **Predictive short-term local reactive product**

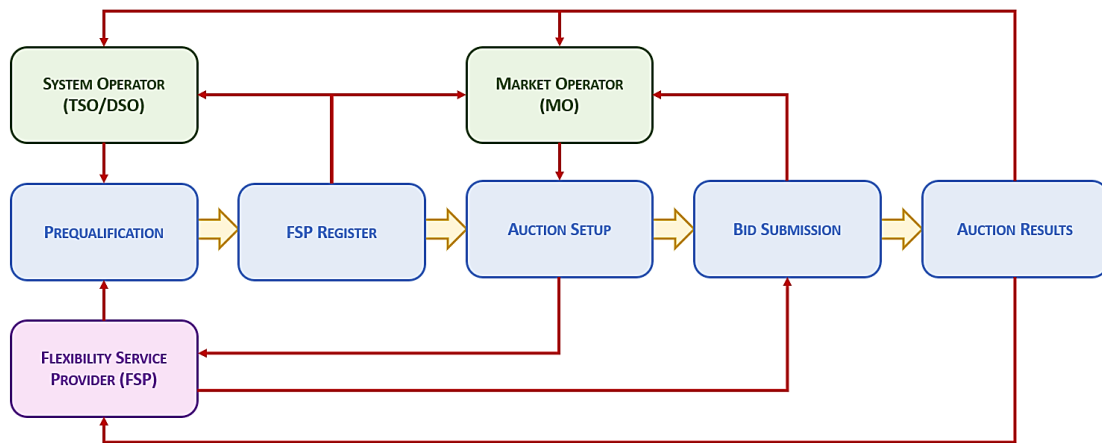
This product would be used to react to a forecasted system need within the operational planning timeframe by using the reactive power, heavily intertwined with the voltage values on the nodes in the system. In line with the specified timeframe assigned to this product, the activation can be planned, which would, therefore, reduce the pressure on the full activation period and, as a result, increase the liquidity. The product can be acquired as capacity only (in order to be combined with the reactive power product), reactive power product only or as both – capacity and reactive power product. The procurement of this product would occur at least once a month (i.e., the duration of the product is less than one month) in order to increase the liquidity of the market. This product would, similarly to both of the products dealing with the active power and its usage for the satisfaction of system needs, also include information about the location of the flexibility resource that would provide the system with its reactive capabilities. The activation of this product could be done either manually or automatically, so there was no need to define two separate products depending on the manner of the foreseen activation. The fifth and final table with the attributes of the products is dedicated to this product and is marked here as Tab. 2.6.

**Table 2.6:** Attributes for the product in the Greek Demo – Predictive short term local reactive product.

Attributes	Values
Capacity/energy	Capacity, Energy or both
Location required (Y/N)	Yes
Maximum full activation time	<60 min
Minimum required duration of delivery period	A multiple of 15 minutes up to 1 hour
Maximum deactivation period	Defined in terms and conditions for FSPs
Maximum recovery period	Defined in terms and conditions for FSPs
Maximum number of activations (per day, week...)	
Required mode of activation	Manual/ Automatic
Minimum quantity	0.01 MVar or 0.1 MVar
Divisibility (Y accepted / Y required /N)	Divisible and indivisible bids are allowed
Granularity	0.01 MVar
Maximum and minimum price	
Availability price (Y/N)	Yes, in €/MVar
Activation price (Y/N)	Yes, in €/MVarh
Symmetric/asymmetric product (Y/N)	No symmetry required
Aggregation allowed (Y/N)	Allowed

### 2.5.4.2 Auction submodule – Auction Flow

Once the products that are supported by the platform have been defined, the next step would be the design of the flow of the auctions based on which the potential service providers would submit the bids and be selected if the conditions for that are right. The basic flowchart of the process, as envisaged taking into account both the present situation in Greece and the expected changes in the upcoming period, can be seen below, in Fig. 2.35.



**Figure 2.35:** F-channel platform – Auction flow diagram.

As can be seen, the entire auctioning process can roughly be divided into five sequential steps, out of which the first two take place way before the need for the product is even established. The first step here would have to be the precondition for the entirety of the remainder of the procedure, since the provision of the services by the energy entities can only be expected if those entities are capable of providing those services at all. In order to ensure that, the entities need to go through the prequalification process, after which, if it goes successfully, the entities are added to the unified FSP register. Only the providers verified through the register can take part in the auctions regarding the particular products for which they went through the prequalification process. Once the register is formed, it can be accessed both by the SOs and the MO. Based on the information presented in the register, the MO sets up an auction, defining all of the necessary parameters, such as, for instance, the date and time of the auction and the products that will be auctioned. After the auction is all set, the bids can be submitted, with the SOs submitting the so-called “buy bids”, defining the service that the system requires, along with all of the remaining parameters such as the necessary amount and the price that they would be willing to pay for that service. On the other hand, the FSPs define the “sell bids”, specifying, in the process, the amount of the service that they would be able to provide in the specified time and the price that they would request for that service. Once all of the bids are collected, the auction is launched at the scheduled time, with the outcomes depending on the results of the predefined optimization process, run by the MO. After that is done and the auction is finished, the results get sent to all of the interested parties and are also published on the F-channel platform’s publicly available area.

### 2.5.4.3 Prequalification Process

As already mentioned, the prequalification process ensures that the potential flexibility service provider is capable of providing the system with the necessary services, based on the appropriate auction. This process is done for the first time when the provider initially appears in the energy market for the certain product and can be repeated either in regular timeframes or after a specific request of the SOs. The basic flowchart of this process can be seen on the next page, in Fig. 2.36, in which the blue rectangles mark the situations in which the entity (the SO or the potential FSP) send the data to the other entity and the red rectangles mark the moment at which the data is received by the entity (once again, the SO or the potential FSP). Since the dashed line down the middle of this diagram separates the parts of the process that are the responsibility of one entity from the parts that are the responsibility of the other entity, it makes sense that the green arrows crossing this line represent the information exchanges that take place between the two entities in the prequalification procedure.

From this diagram, it is visible that the prequalification process needs to be initiated by the potential service provider, which is expected to submit the formal Application for the prequalification process to the Operator by using the predefined form, with the necessary data regarding both the provider itself and the resources at their disposal accompanying the Application. The completeness of the Application is then evaluated by the Operator and the potential provider is informed of the outcome of the evaluation. If the Application is missing some data, the potential FSP has to provide that as well before proceeding with the prequalification. The next steps of the procedure include the back-and-forth exchange of information between the SO and the potential FSP, with the FSP, first of all, suggesting the plan and protocol of the tests that need to be conducted, to which the SO should respond with the nomination of the single point-of-contact in their company. That point-of-contact, from that moment on, becomes the primary channel of communication between the potential FSP and the SO, thus ensuring that the prequalification procedure goes on with as little confusion as possible. With that out of the way, the potential FSP proposes the date of the start of the testing procedure, with the SO either confirming the proposal or requesting some other date, if the initial proposal is not a viable option. Following the tests needed for the prequalification process, the potential FSP drafts the Report on the outcomes of the tests and sends it to the SO, which evaluates it and confirms its truthfulness with the nominated point-of-contact. If the testing was successful, the SO sends the Confirmation of the completed prequalification to the FSP and adds it to the unified FSP register. However, if the testing was not successful, the aspiring FSP needs to implement the appropriate measures on its side, so the tests can be run again. This usually means, if the corrections are not so simple and require some time to be properly performed, that the new date of the tests needs to be harmonized between both sides, after which the testing procedure is restarted. This can be repeated until all of the requests of the SO are fulfilled adequately. What needs to be mentioned here is that, although Fig. 2.36 lays out the basic steps that need to happen in the prequalification process, some of the finer details of these steps may vary depending on the entities participating in the procedure and the product for which the prequalification was started.



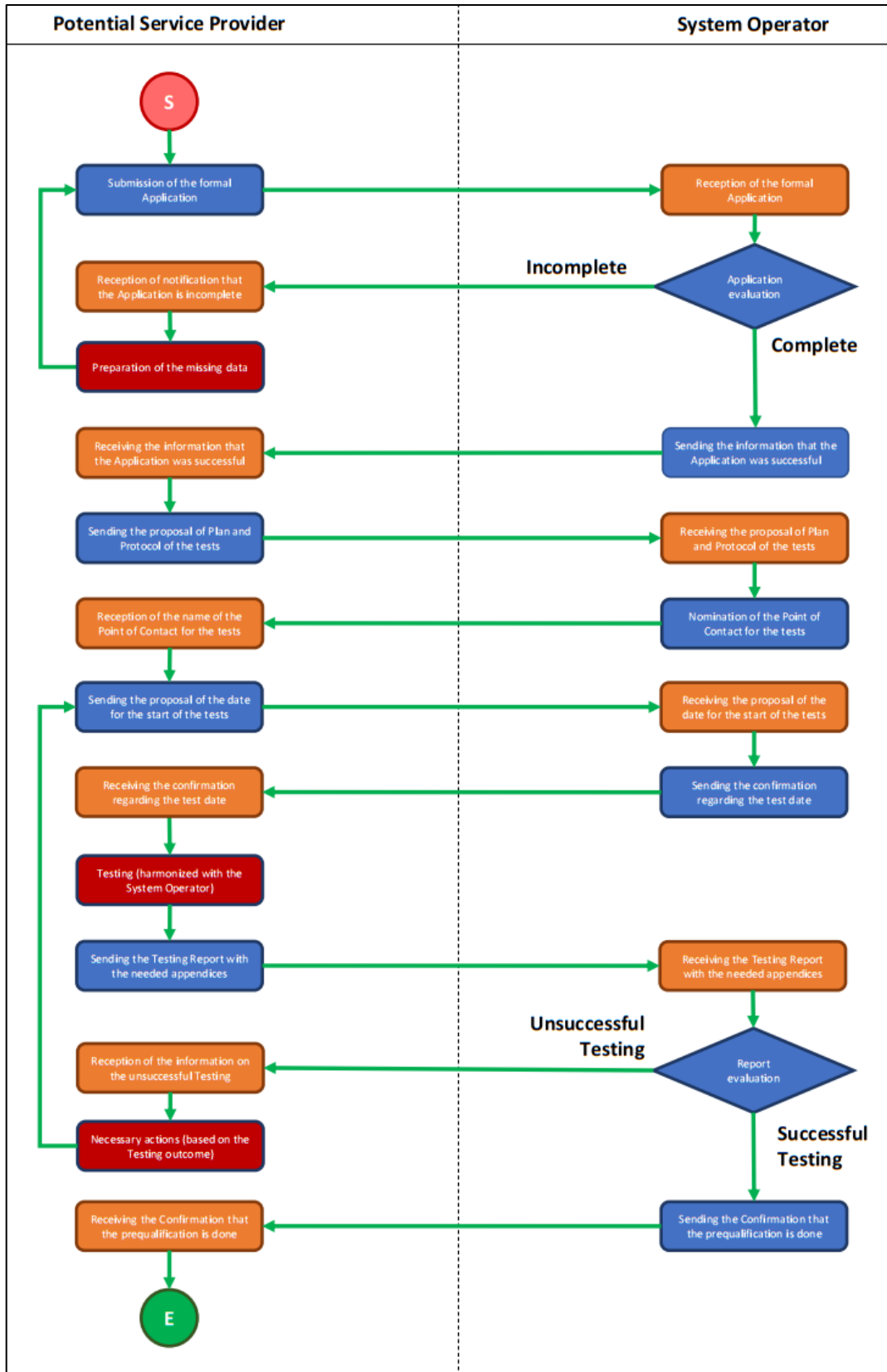
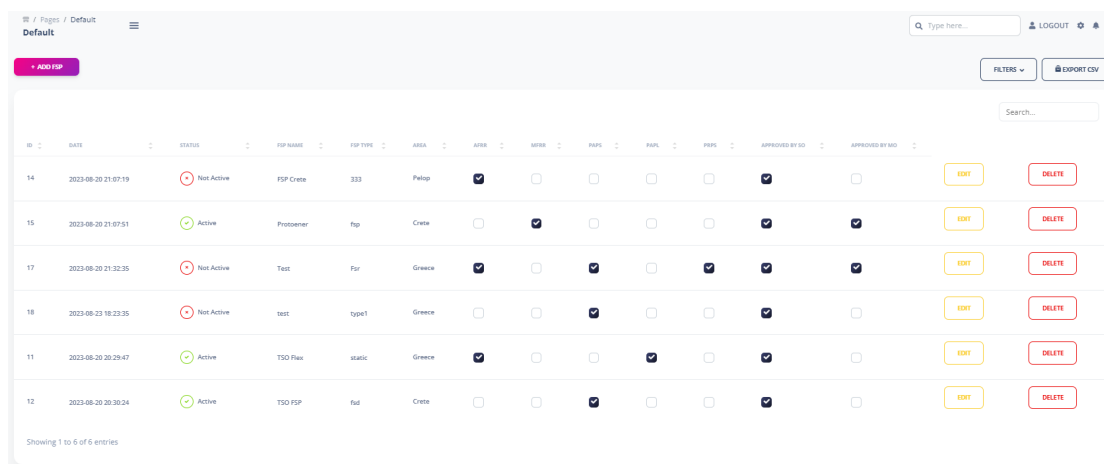


Figure 2.36: Prequalification process flowchart.

### 2.5.4.4 Coordination module – FSP register

Once the FSP passes through the prequalification process successfully, it is added to the unified FSP register of the F-channel platform. This register represents one of the main contributions of the activities conducted in the scope of the actions carried out by the partners involved in the Greek Demo, since it gives both the SOs and the MO the close-to-instant overview of all of the potential FSPs, making it much easier for them to know what the situation regarding the resources for some particular service is at which time. This is, as such, envisaged as the valuable tool that will not only increase the transparency of the amount of available resources, but also enhance the efficiency of the initial steps of the auction process. The screenshot of the part of the platform that is dedicated to the FSP register and, hence, visible to the SOs and the MO, is enclosed in this report as Fig. 2.37.



ID	DATE	STATUS	FSP NAME	FSP TYPE	AREA	AREA	AREA	AREA	AREA	AREA	APPROVED BY SO	APPROVED BY MO		
14	2023-08-20 21:07:19	Not Active	FSP Create	333	Philop	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	EDIT	DELETE
15	2023-08-20 21:07:51	Active	Prosemer	flp	Crete	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	EDIT	DELETE
17	2023-08-20 21:32:35	Not Active	Text	Far	Greece	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	EDIT	DELETE
18	2023-08-23 18:23:35	Not Active	test	type1	Greece	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	EDIT	DELETE
11	2023-08-20 20:29:47	Active	TSD Flex	static	Greece	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	EDIT	DELETE
12	2023-08-20 20:30:24	Active	TSD FSP	fad	Crete	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	EDIT	DELETE

**Figure 2.37:** F-channel platform – FSP register.

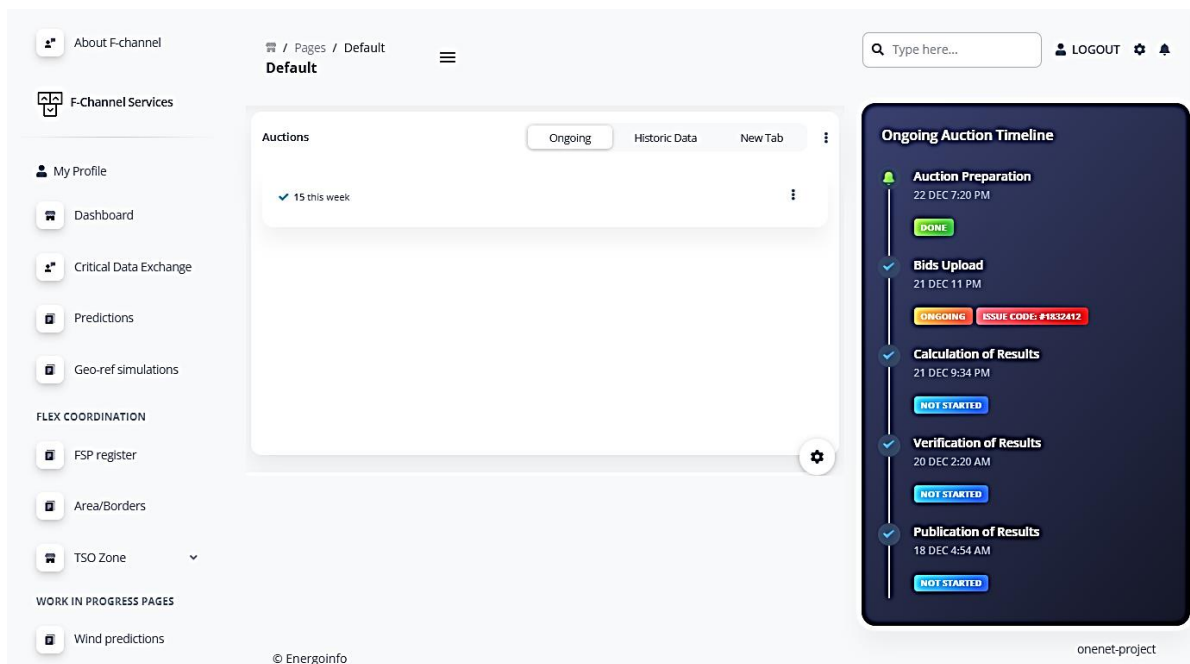
It is clear from this screenshot what kind of information will be available for each FSP that previously went through the prequalification procedure. Some of the more prominent information are the following:

- identifier of the FSP in the register;
- status of the FSP;
- name of the FSP;
- type of the FSP;
- area in which the resources of the FSP are located;
- capability of the FSP to offer different services and products;
- information on whether or not the FSP was approved by the SO;
- information on whether or not the FSP was approved by the MO.

Out of these, for instance, the capability of the FSP to offer different products to the system could be pointed out as one of the most relevant ones, especially in the situations in which the FSP submits the sell bids for more than one product in the auctions. By checking these columns, it can immediately be seen if the FSP even has the possibility of offering those products, which could, in turn, increase the reliability of the auctioning process and reduce the possibility of issues in the system that could otherwise arise in the system due to potential oversights.

### 2.5.4.5 Coordination module – Auction wizard

After the FSPs’ passing of the prequalification process and the tests done in the scope of it and their addition to the unified FSP register, they are allowed to participate in the auctions organized for responding to the needs spotted in the system. However, the following of those auctions can, even for the most experienced experts on the topic, turn out to be quite a tiresome and confusing task, especially if there is more than one auction taking place at the same time. Since each of those auctions would probably be either for the different timeframes or for the different products, it is understandable how this could overwhelm not only the FSPs, but the employees of the SO and the MO as well. To make this less tiresome, the F-channel platform’s Coordination module also includes the Auction wizard, with the basic view of this part of the platform shown in Fig. 2.38.



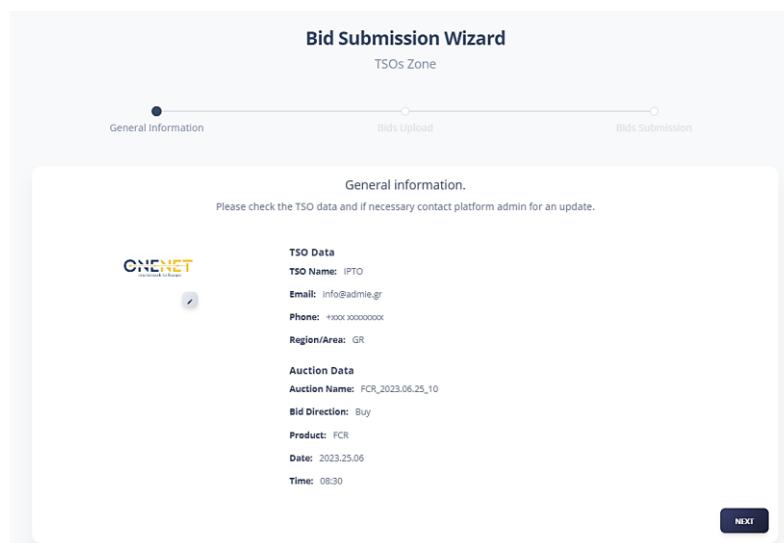
**Figure 2.38:** F-channel platform – Auction wizard.

The middle part of the screen is rather straightforward, allowing the user to select the auction of interest at the moment by simply clicking on it. However, the right-hand side of the screen should get some extra attention here, since it provides the users with the intuitive and comprehensive overview of the entire auction process for the selected auction.

It gives the information regarding the parts of the auctioning procedure that have already been completed (those are marked in green colour, which can be seen for the “Auction Preparation” task in the figure above), which of them are currently ongoing (those are marked in red colour, as illustrated for the “Bids Upload” task in Fig. 2.38) and which of them are yet to be started (those are marked in blue colour, similar to the “Calculation of Results”, “Verification of Results” and “Publication of Results” tasks in this figure). Along with the information on the status of each step in the auction, the platform also shows the details on the dates and times on which the activities were completed and/or dates and times by which those activities should be done.

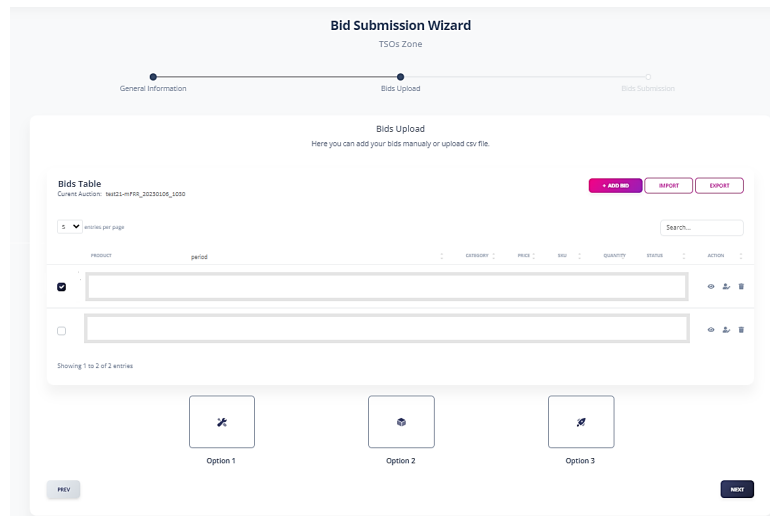
#### 2.5.4.6 Coordination module – Bid submission wizard

In addition to making the following of the auction process simpler for the users, the F-channel platform also makes the submission of the bids for those auctions rather easy via a section called “Bid Submission Wizard”. This part of the platform incorporates three consecutive steps, out of which the first is the confirmation of the general information on the user that exists on the platform. This step of the process is shown here, in Fig. 2.39.



**Figure 2.39:** F-channel platform – Bid submission wizard – 1<sup>st</sup> window.

Once the general information is verified (or modified in case there is a need for that), the user goes forward to the second step, in which the bids for the specified ongoing auctions can be uploaded to the platform. This is enclosed in Fig. 2.40. After the successful upload of the desired bids, the user can click on the “Next” button in the bottom-right part of the screen to move to the last step, in which the uploaded bids are officially submitted.

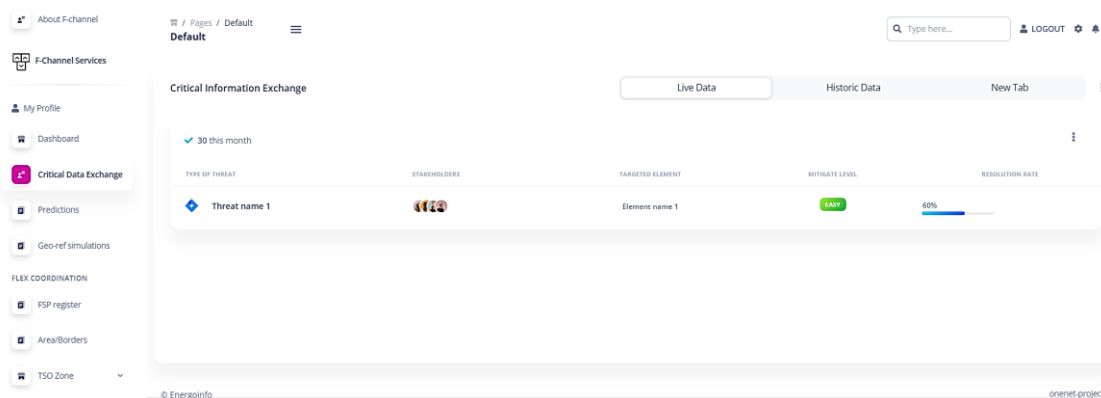


**Figure 2.40:** F-channel platform – Bid submission wizard – 2<sup>nd</sup> window.

After the bids are submitted, the optimization takes place, with the information regarding the results of the auction getting sent to all of the interested sides in the end of procedure. The results of auctions can be accessed in two ways, with the first of those being direct message that the sides that participated in the auction process will receive via the platform. The second way is by looking into the publicly available areas of F-channel platform, in which the final results of every auction will be published for the desired level of transparency of the market.

### 2.5.4.7 Coordination module – critical information exchange

Finally, before moving on with the ways in which the actions of the Greek Demo fitted into the overall vision of the OneNet project, one additional area of the F-channel platform’s Coordination module needs to be briefly mentioned. It is the one that allows the exchange of the critical information regarding the system, allowing the SOs to predict the potentially harmful states of the grid and react accordingly, without the delays caused by the lack of communications between the actors in the power sector. The appearance of this area is given in Fig. 2.41.



(a)

Pages / Default

Default

Cyber Attacks

Detected brute force logins

Report CSV

Search...

time	#access	country	region	city
2023-08-27 12:47:51	81.28.174.6	Russia	Samara Oblast	Tolyatti
2023-08-27 13:00:13	114.199.123.211	Indonesia	Jakarta	Jakarta
2023-08-27 13:03:54	39.170.36.149	China	Zhejiang	Jubao
2023-08-27 13:04:46	199.223.135.216	United States	New Jersey	North Bergen
2023-08-27 13:04:59	216.105.90.97	Canada	Ontario	Richmond Hill
2023-08-27 13:07:20	14.225.208.62	Vietnam	Hanoi	Hanoi
2023-08-27 13:07:34	43.153.56.90	United States	California	Santa Clara
2023-08-27 13:08:26	157.7.207.25	Japan	Tokyo	Chiyoda
2023-08-27 13:08:30	93.136.7.242	Germany	North Rhine-Westphalia	Düsseldorf
2023-08-27 13:09:11	185.126.3.8	Iran	Ardabil	Khalandil

Showing 71 to 80 of 755 entries

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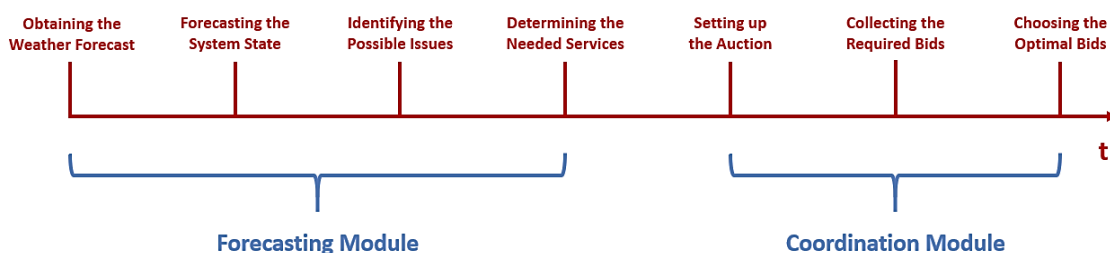
(b)

**Figure 2.43:** F-channel platform – Critical information exchange and cyber-attacks exchange hub.

This area includes fields for all of the parameters that could be relevant for any kind of critical information, such as, for example, the name of the established threat, the list of the stakeholders that could be affected by that threat, the element that could be put at risk due to the threat, the mitigation level of the threat and the rate of mitigation. Parameters are shown in a user-friendly environment, making sure that even the stakeholders that are not familiar with the F-channel platform can extract valuable information related to the noticed threats. In order to understand the magnitude of the last mentioned point, one should bear in mind that one of the main issues that are put before the operators is explaining the severity of some situations to their higher-ups. For this to be mitigated, any tool that helps in exchanging the information on the critical states of the system is welcome.

### 2.5.5 Relation between the Modules of the Platform

Even though the previous parts of this subchapter contain the descriptions of the functionalities of each of the two individual modules enveloped by the F-channel platform, the reader could notice that there was not a clear insight into the relation between these modules and the way in which they can operate together once the implementation of the platform is done. In order to illustrate this, the flowchart given in Fig. 2.44 was created.



**Figure 2.44:** F-channel platform – Activities by Modules.

As can be seen from this diagram, a total of seven main activities or, to put it that way, stages in spotting and resolving the issue in the grid was selected for this example. Out of those, the first four activities were marked as belonging to the Forecasting module of the F-channel platform, in focus of Section 2.9.3. Those are:

- obtaining the weather forecast;
- forecasting the system state;
- identifying the possible issues (by implementing the forecast into the unified grid model);
- determining the needed services.

If one would now compare these activities with the established scope of operation of this module, they could see that those, indeed, match each other quite well. Three activities assigned to the Coordination module were:

- setting up the auction;
- collecting the required bids;
- choosing the optimal bids (done by MO outside of the platform).

If those activities, logically following the ones related to the Forecasting module, were to be compared with the descriptions of the Coordination module from Section 2.9.4, there would also be a match. This can be seen as the proof of the entwinement of the activities belonging to the different modules of the F-channel platform.

## 3 Greek Demo Outcomes

This chapter can now cover the practical aspects of this platform's development and verification of reliability. In order to achieve that, it will focus, first of all, on the scenarios for the testing process, defined as early as the Business Use Cases related to this demo, only to move on to the actual testing actions once the scenarios are fully explained. It is organized in such a way that the first subchapter belongs to the defined scenarios, shown in the logical sequence depending primarily on the Business Use Case to which each of these scenarios is assigned, whereas the second subchapter covers the training procedure of the used ANN. The third subchapter here serves as the showcase of the forecasting improvements made by the ANN. Finally, the last two subchapters cover the ground of the users' experience when using the F-channel platform (by BUC and by SUC).

Before going into the description of the scenarios, however, another additional clarification has to be made. As stated in the paragraph above, the scenarios that were deemed fit for the testing process were established at the same time as the use cases to which they are related, meaning that they were available at the time of the drafting of Deliverable 8.1. In line with that, it needs to be stated that the descriptions in the following part of this chapter will only represent a summary of the explanations given there, detailed enough only to allow the proper understanding of the subchapters that will come near the end of this chapter. However, if the reader is interested in seeing more thorough explanations of each scenario, it should be underlined that, in Deliverable 8.1, every scenario is given its own table, containing and specifying the following characteristics:

- scenario name;
- scenario description;
- primary actor(s);
- triggering event(s);
- preconditions;
- post-condition.

What can also be of great help to the reader is the section of Deliverable 8.1 that precedes the detailed description of each of the considered scenarios, since it contains the details regarding the roles of the specified actors, regardless of whether these actors have been declared as primary actors in any of the analysed scenarios (for example, the system operators or the flexibility service providers) or not. Either way, Subchapter 3.1 should provide the reader with a foundation strong enough for the proper understanding of the subchapters after it.

### 3.1 Scenarios for Testing

There is a total of four scenarios that will need to be covered in the scope of this subchapter, shared among the two Business Use Cases in the Greek Demo. This distribution is, however, not equal, since the first BUC has three scenarios assigned to it and the second defined BUC has only one. The remainder of this subchapter will be organized in such a manner to provide some basic information on each of these scenarios.



### **BUC 1 – Scenario 1: Contingency identification and mitigation**

This scenario takes into account the potential situation in which the contingencies in the distribution and the transmission grids are spotted well in advance by the application of the enhanced system state prediction tools, with the precondition being the availability of the input data of high-enough quality. Mentioned contingencies are obtained as one of the results of the calculations done on the unified simulation model, based upon the production and grid capacity predictions that are determined by considering the specialized weather forecasts. When the contingency is observed and the measures for its mitigation are suggested, the goal is to achieve the recommended system state (i.e., to implement the listed measures). The needed flexibility resources are then coordinated by the system operators for the needed active power regulation services to be provided to the grid. The flexibility services that will be included in this process are nominated by the market beforehand (declaring the availability through the submitted bids) and their bids have been prequalified. Once the command has been given to the flexibility sources, their response is then observed, with the report on this check given to the market operator afterwards. The actors included in this scenario are the system operators, aggregators, prosumers, as well as the FSPs that can provide the necessary flexibility to the system in case it's needed.

### **BUC 1 – Scenario 2: Coordinated voltage control**

This scenario is based upon the possible situation in which the severe overvoltage or undervoltage states in the distribution and transmission grids are spotted in advance by the application of the enhanced system state prediction tools. The mentioned system state estimations are obtained as one of the results of the calculations performed on the unified simulation model, based upon the demand, production and capacity predictions that are determined by considering the specialized weather forecasts. The states like the ones that are highlighted here can endanger the power system voltage stability of the system, making their forecast and timely mitigation a task of utmost importance for the proper operation of the future power systems. In case a warning for the possible voltage instability is issued, the DSO coordinates the flexible resources to provide the requested amount of the reactive power flexibility. It should be said that the flexible resources that participate in this scenario have previously been awarded by the market (declaring their availability through the bids) and their bids have been prequalified in order for them to participate in the reactive power compensation. This service is not solely limited to the DSO level, as it is also possible to use the reactive power from the TSO level through the interconnection transformers (transformers between TSO and DSO), equipped with the tap change possibility.

### **BUC 1 – Scenario 3: Improved power regulation through mFRR and aFRR**

This scenario is based on the suggested way of improvement of a rather regular activity for the power system operators – obtaining the accurate information on the available flexibility resources (usually referred to as the primary reserve, the secondary reserve and the tertiary reserve) and the complementary identification of the flexibility needs of the system. The primary targets for improvement (concerning the commonly utilized procedures) are the reliability of the conducted calculations, the accuracy of the results obtained via those

analyses, the precision with which the identification of the system needs and resources is carried out and the extension of the time horizon that can successfully be enveloped by the performed estimations. For all of this to be achieved, however, a process similar to those already described for the former two scenarios has to be followed, especially when it comes to steps such as, for instance, updating the grid model in order to ensure its compliance with the most up-to-date calculations regarding the generation, load and transfer capacities. Once a need for the reserve activation is reported, the resources that are available are coordinated in such a way that the necessary amount of flexibility (in this case, that would be the reserve) is provided to the system, thus mitigating the problem that occurred before the initiation of this scenario in a fashion that does not harm any of the other indicators of the system's secure and reliable operation. Along with this, it needs to be emphasized that the flexibility resources (in this case, the resources providing the reserve) participating in the scenario have previously been selected by the market operator, after that had declared their capability to provide those services through the appropriate bids. Also, their bids, before getting chosen for the participation in this scenario and the mitigation of the problems in the system, needed to go through the prequalification procedure.

A careful reader could notice an interesting peculiarity regarding the previously mentioned scenarios – they can either be observed totally separately or they could be combined into one or multiple series of the sequential events. An example for this can be found, for instance, in the following situation: if there is an emergency in the part of the grid of interest for this observation, such as the unit trip or the deviation in the load forecast or the RES production forecast, the three scenarios could be present even simultaneously. In such an event, there could be a voltage variation above or below the specified limits around the nominal voltage value. This would, in turn, be the trigger for Scenario 2 of BUC 1. Depending on the scale of the problem, this could be followed by the need for the power units that could contribute either to the aFRR or to the mFRR. This would trigger Scenario 3 of BUC 1, described in the previous paragraph. To face both of those problems, the units that provide FRR must react and additional flexibility services must be provided to the system. This would, finally, be the trigger for Scenario 1. What needs to be clarified, however, is that the fact that all of these scenarios could happen simultaneously does not make them unfit for the purposes of the testing required here. Each of them could also happen without the need to trigger the rest of them, or two out of three could come to be without the last one. This peculiarity, from the point of view of the authors, thus not only does not discredit these scenarios for the testing purposes, but actually brings them closer to real-life situations in which the issues in the system sometimes do not occur one by one, but happen at the same time, troubling the system operators even more.

## **BUC 2 – Scenario 1: Early severe state warning system / prevention and restoration**

In order to avoid severe damages of the equipment and load losses it is of utmost importance to prepare the power system elements for the incoming severe weather conditions, as well as for the power system conditions that could occur as a consequence of those weather conditions. For that to happen, it is necessary to provide the operators with the improved identification of severe weather conditions, so that they can predict the potentially harmful system states and contingencies in order to avoid the potential consequences. The forecasts have to be given in a more precise manner and envelop a longer time horizon than what is being done today, with the improved identification of the system flexibility needs and available resources that could be utilized to saturate the spotted needs being just as important. The process itself starts similarly to those included in other scenarios, with the weather forecast provider informing the operators of the expected climatic conditions and the units in the operator companies making the unified grid model based on those forecasts. Then, the calculations are done on these models, with the employees working on those calculations monitoring the appearance of any possibly dangerous system regimes. If such a regime happens, the critical outages and the critical elements that could be at risk in case those outages are listed, followed by the mitigation measures determined by experts, based on the established set of the flexibility resources available to the operators.

Of course, all of this would make much more sense if some of the practical examples for these situations that could be forecasted can be found. Luckily, these examples can be found at almost any voltage level, taking into account almost any element of the power system. For instance, if an area rich in wind potential was observed and it was assumed that the major share of the energy production in this area came from the wind power plants, it would be absolutely priceless for the system operator to know well in advance that the wind speed will be too high or too low at some specified hour in the future. Since both of those events could lead to zero production from the wind units, the operator would need to make sure that the missing energy can either be produced by the other sources in the same area or imported from some other area. If this does not happen, there would be a risk of the security of energy supply to the load getting compromised. Similar situations could be provided for areas with high solar production and clouds that could substantially reduce the generation power of the solar units, leading to the same effects as the extreme wind speed variations from the previous example. Moreover, it should be considered that this kind of phenomena is not only focused on the generation capacities, as already mentioned. For instance, the early warning system could indicate the possibility of ice appearing on conductors of the power lines, alarming the operators of the potential outage of those lines. If something like that happens, the operator would, thanks to the warning system developed in the scope of the Greek Demo and presented in this report, have a sufficient amount of time to activate the flexibility resources at their disposal (changes in the generation pattern, demand-side response, switching the circuit breakers on or off, etc.) in order to minimize the effect that the expected icing of the lines would have on the remainder of the system and, especially, on the users supplied with energy by the system. Hopefully, these examples provided somewhat better insight into the idea behind the implementation of this feature into the platform and behind this scenario, dedicated to it.

## 3.2 Artificial Neural Network Training

The training and testing process of ANN is carried out through three phases by the MATLAB neural network toolbox to train and develop the neural network models. The training data is selected among the whole set of available data. Database was made from the data provided by the Greek SOs for the demo site, as specified in Subchapter 2.2. The training uses 70% of the database, testing 15% of the data base, and the remaining 15% goes to the validation. These events in the database were randomly chosen and formed. This is very important because picking a uniform part of the base can lead to wrong conclusions. The data is then normalized to avoid saturation. Training the ANN has been done using the backpropagation algorithm. Basically, the ANN is fed input data, after which the obtained output is compared to the already available measured output value. Based on the difference between the calculated and the measured values, the weighting factors can be modified in order to improve the precision of the ANN. This process is iterative and gets repeated until a sufficient accuracy is achieved. The Mean Average Percentage Error (MAPE) is commonly used as a performance index to evaluate the prediction capability of each model. Typically, the model that minimizes the criteria formally given by (3.1) gets chosen.

$$MAPE(x, y) = MPE(x, y) = \frac{\sum_{i=1}^N \frac{|y_i - x_i|}{x_i}}{N} * 100\% \quad (3.1)$$

Here,  $y$  marks the forecasted value of the relevant parameter (in this case, it would be the indicator of the forecasted production values) and  $x$  is used to specify the accurate value that should be calculated by the ANN (here, the  $x$ -set would be defined as the set of the measured productions of the units in the area of interest). The best way to achieve the minimal error in the prediction of power plant production is to have a good and well-organized database. Better input data gives better performance for ANN and better production prediction. Meteorological data are the most important for wind and solar power plants because they are fed into physical models of these renewable sources. To improve the prediction, the database is further processed by adding an entry for the seasons (summer, winter, autumn, and spring) and time of day (night or day). This way, the ANN is enabled to recognize even more complex patterns related to the production prediction. Next way to decrease the MAPE would be based on improving the forecast for some hour by taking production from the same hour of the previous day and production from the previous hour as inputs. The database used in this case consists of the measured production values from 1. January 2018. up to 1. March 2023, where 45242 hourly measurements exist for the predefined set of wind and solar units. For the wind units, the meteorological data was the following: wind direction, wind speed and temperature. The optimal ANN structure for WPPs had five layers with 30, 20, 10, 10 and 10 neurons, which has been determined through the series of tests. Results have been compared to the measured values until the best option was found. More layers led to overfitting and increasing the error. The meteorological data for solar units was the following: global horizontal irradiance, temperature and wind speed. The optimal structure for solar units had three layers with 60, 30 and 20 neurons per layer.

### 3.3 Forecast Improvement Results

The results given in this subchapter have been obtained by using the developed ANN method for the forecast of the renewable energy sources production, taking into account the time horizon of 168 hours into the future. This kind of generation power forecast has been done for the period from the 7<sup>th</sup> of January 2023 to the 14<sup>th</sup> of January 2023, allowing its further comparison with the actual measured values of the same parameter. During this analysis, four separate renewable energy sources have been taken into consideration, as listed below:

- SPP Arcadia (installed capacity of 4.403 MW);
- SPP Messhnia (installed capacity of 11.963 MW);
- WPP Elliniki (installed capacity of 5.95 MW);
- WPP Enel (installed capacity of 7.2 MW).

The obtained findings are crucial for the rest of the demonstration outcomes as they gave an unprecedentedly accurate base for further investigations of application in congestion management, mFRR and aFRR dimensioning and activations, as well as within the other weather-forecasting-related improved transmission and distribution system planning and operation processes. For the sake of easier understanding, the results will first be shown for the two considered wind power plants and then for the solar power plants that were taken into account.

#### 3.3.1 Results for the Wind Power Plants

Tab. 3.1 gives a comparison of the results obtained by the ANN forecast and the actual production values of the wind plants that were analysed in the scope of this step. Here the MAPE values are provided for every hour, so the average MAPE could be calculated for these 168 hours for each of the WPPs. By that, it was calculated that the average MAPE for WPP Elliniki was equal to 3% and the average MAPE for WPP Enel was equal to 1%. As a benchmark, the MAPE of the WPP forecast (market schedules) is typically around 9%, highlighting the improvement made by the usage of ANN methods. Also, if these 7 days are observed accumulatively from the point of view of the failures in the production planning, it can be seen that the cumulative error for the ANN amounted to 0.488 MW for WPP Elliniki and to -0.534 MW for WPP Enel. Thus, the cumulative errors were 0.37 % for WPP Elliniki and 0.74% for WPP Enel. Tab. 3.1 is clearly divided into two sections, with columns 2, 3 and 4 covering the results for WPP Elliniki and columns 5, 6 and 7 dealing with the results for WPP Enel.

**Table 3.1:** Obtained results for the wind power plants.

Date and time	WPP Elliniki – power [kW]	ANN for WPP Elliniki [kW]	MAPE for WPP Elliniki [%]	WPP Enel – power [kW]	ANN for WPP Enel [kW]	MAPE for WPP Enel [%]
1-7-23 10:00 AM	1965.165	2214	4	542	887	5
1-7-23 11:00 AM	1981.804	2096	2	560	607	0
1-7-23 12:00 PM	1227.927	2121	15	535	548	0

Date and time	WPP Elliniki – power [kW]	ANN for WPP Elliniki [kW]	MAPE for WPP Elliniki [%]	WPP Enel – power [kW]	ANN for WPP Enel [kW]	MAPE for WPP Enel [%]
1-7-23 1:00 PM	606.7404	1311	12	324	542	2
1-7-23 2:00 PM	387.91	678	5	141	310	1
1-7-23 3:00 PM	646.2329	458	3	35	149	1
1-7-23 4:00 PM	1526.257	732	13	255	57	2
1-7-23 5:00 PM	3367.025	1670	29	330	278	0
1-7-23 6:00 PM	3395.864	3355	1	654	315	3
1-7-23 7:00 PM	3368.026	3436	1	720	657	1
1-7-23 8:00 PM	3489.02	3455	1	749	782	0
1-7-23 9:00 PM	2294.649	3641	23	620	761	1
1-7-23 10:00 PM	1923.203	2256	6	484	554	1
1-7-23 11:00 PM	2035.462	1851	3	297	412	1
1-8-23 12:00 AM	1860.57	2012	3	135	267	1
1-8-23 1:00 AM	1549.899	1849	5	7	184	1
1-8-23 2:00 AM	1149.331	1524	6	0	59	0
1-8-23 3:00 AM	825.4658	1153	5	0	54	0
1-8-23 4:00 AM	445.3258	809	6	38	78	0
1-8-23 5:00 AM	320.1042	463	2	165	78	1
1-8-23 6:00 AM	177.1351	322	2	207	209	0
1-8-23 7:00 AM	89.15893	140	1	101	271	1
1-8-23 8:00 AM	84.77195	98	0	116	135	0
1-8-23 9:00 AM	179.5625	128	1	150	125	0
1-8-23 10:00 AM	133.5817	215	1	103	137	0
1-8-23 11:00 AM	75.44246	189	2	151	142	0
1-8-23 12:00 PM	155.7397	82	1	177	166	0
1-8-23 1:00 PM	137.9424	115	0	144	222	1
1-8-23 2:00 PM	107.8363	62	1	54	163	1
1-8-23 3:00 PM	53.54224	64	0	121	75	0
1-8-23 4:00 PM	30.34239	0	1	205	151	0
1-8-23 5:00 PM	27.17389	0	0	429	233	2
1-8-23 6:00 PM	5.316632	0	0	721	358	3
1-8-23 7:00 PM	49.29967	59	0	723	612	1
1-8-23 8:00 PM	25.26206	97	1	756	661	1
1-8-23 9:00 PM	294.681	67	4	716	773	0
1-8-23 10:00 PM	558.0364	337	4	654	770	1
1-8-23 11:00 PM	925.114	604	5	776	684	1
1-9-23 12:00 AM	1668.774	998	11	1074	800	2

Date and time	WPP Elliniki – power [kW]	ANN for WPP Elliniki [kW]	MAPE for WPP Elliniki [%]	WPP Enel – power [kW]	ANN for WPP Enel [kW]	MAPE for WPP Enel [%]
1-9-23 1:00 AM	2615.017	1733	15	1107	1125	0
1-9-23 2:00 AM	2320.283	2523	3	936	1174	2
1-9-23 3:00 AM	2697.805	2208	8	841	831	0
1-9-23 4:00 AM	2898.989	2478	7	933	775	1
1-9-23 5:00 AM	2522.203	2590	1	1032	962	1
1-9-23 6:00 AM	3093.589	2481	10	1133	1029	1
1-9-23 7:00 AM	2722.943	3042	5	1063	1193	1
1-9-23 8:00 AM	2253.973	2694	7	1059	1146	1
1-9-23 9:00 AM	2401.718	2270	2	1188	1053	1
1-9-23 10:00 AM	2248.23	2417	3	1453	1191	2
1-9-23 11:00 AM	2359.27	2254	2	1647	1460	2
1-9-23 12:00 PM	2313.835	2361	1	1518	1566	0
1-9-23 1:00 PM	2584.892	2301	5	1160	1449	2
1-9-23 2:00 PM	2268.536	2561	5	985	1180	2
1-9-23 3:00 PM	2026.558	2277	4	922	971	0
1-9-23 4:00 PM	1862.754	2071	4	774	883	1
1-9-23 5:00 PM	1549.138	1926	6	531	714	2
1-9-23 6:00 PM	1203.339	1514	5	575	432	1
1-9-23 7:00 PM	1009.535	1181	3	634	526	1
1-9-23 8:00 PM	686.3395	921	4	786	641	1
1-9-23 9:00 PM	410.3795	571	3	724	806	1
1-9-23 10:00 PM	718.0567	360	6	772	781	0
1-9-23 11:00 PM	1106.591	646	8	1004	840	1
1-10-23 12:00 AM	1277.941	1003	5	1188	1072	1
1-10-23 1:00 AM	1426.429	1155	5	1289	1195	1
1-10-23 2:00 AM	1222.987	1270	1	1305	1210	1
1-10-23 3:00 AM	1086.854	1133	1	1463	1216	2
1-10-23 4:00 AM	1330.645	1011	5	1403	1462	0
1-10-23 5:00 AM	1074.681	1150	1	1120	1271	1
1-10-23 6:00 AM	1146.803	1069	1	899	1142	2
1-10-23 7:00 AM	1363.657	1173	3	817	904	1
1-10-23 8:00 AM	1298.316	1380	1	922	846	1
1-10-23 9:00 AM	1530.878	1340	3	1101	864	2
1-10-23 10:00 AM	1485.815	1520	1	1097	1010	1
1-10-23 11:00 AM	1195.458	1444	4	1047	990	0
1-10-23 12:00 PM	1454.147	1162	5	1212	953	2



Date and time	WPP Elliniki – power [kW]	ANN for WPP Elliniki [kW]	MAPE for WPP Elliniki [%]	WPP Enel – power [kW]	ANN for WPP Enel [kW]	MAPE for WPP Enel [%]
1-10-23 1:00 PM	1414.632	1589	3	1196	1114	1
1-10-23 2:00 PM	991.6001	1541	9	943	1110	1
1-10-23 3:00 PM	738.8829	1060	5	632	883	2
1-10-23 4:00 PM	428.6064	751	5	426	634	2
1-10-23 5:00 PM	221.8808	392	3	204	398	2
1-10-23 6:00 PM	160.0575	190	1	189	187	0
1-10-23 7:00 PM	80.2328	174	2	95	175	1
1-10-23 8:00 PM	28.40907	143	2	73	103	0
1-10-23 9:00 PM	24.1128	57	1	92	69	0
1-10-23 10:00 PM	10.68697	56	1	162	84	1
1-10-23 11:00 PM	54.73445	0	1	271	164	1
1-11-23 12:00 AM	203.5517	96	2	347	313	0
1-11-23 1:00 AM	482.2765	228	4	403	392	0
1-11-23 2:00 AM	585.348	509	1	289	459	1
1-11-23 3:00 AM	555.6848	571	0	220	285	1
1-11-23 4:00 AM	81.72939	564	8	143	165	0
1-11-23 5:00 AM	36.35717	153	2	93	140	0
1-11-23 6:00 AM	54.99223	0	1	103	0	1
1-11-23 7:00 AM	26.04612	0	0	54	0	0
1-11-23 8:00 AM	24.65494	0	0	39	135	1
1-11-23 9:00 AM	47.20524	0	1	21	115	1
1-11-23 10:00 AM	12.8888	0	0	2	90	1
1-11-23 11:00 AM	1.224436	0	0	0	76	1
1-11-23 12:00 PM	0	0	0	1	67	1
1-11-23 1:00 PM	0	0	0	25	72	0
1-11-23 2:00 PM	17.67914	0	0	130	78	0
1-11-23 3:00 PM	4.639969	0	0	310	150	1
1-11-23 4:00 PM	1.772211	0	0	700	346	3
1-11-23 5:00 PM	0	0	0	723	807	1
1-11-23 6:00 PM	0	0	0	596	741	1
1-11-23 7:00 PM	0	0	0	732	603	1
1-11-23 8:00 PM	5.048115	0	0	643	750	1
1-11-23 9:00 PM	112.2185	0	2	487	652	1
1-11-23 10:00 PM	241.8943	115	2	233	487	2
1-11-23 11:00 PM	643.387	225	7	190	215	0
1-12-23 12:00 AM	1028.295	569	8	127	183	0

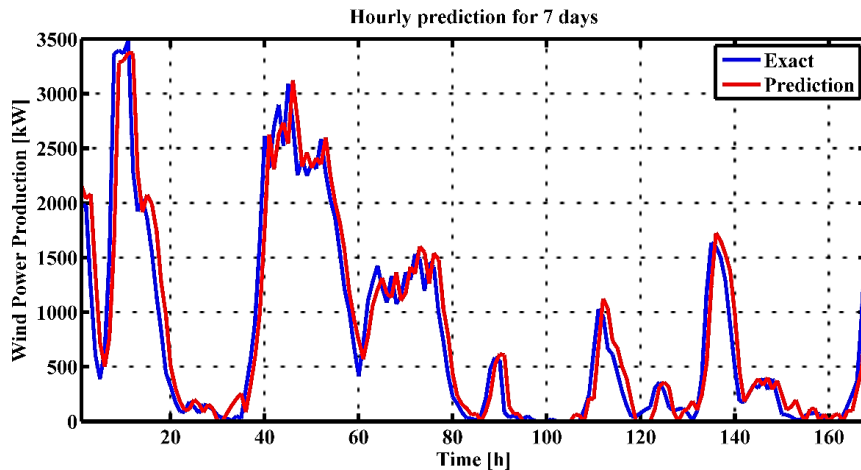




Date and time	WPP Elliniki – power [kW]	ANN for WPP Elliniki [kW]	MAPE for WPP Elliniki [%]	WPP Enel – power [kW]	ANN for WPP Enel [kW]	MAPE for WPP Enel [%]
1-12-23 1:00 AM	958.8741	982	0	45	140	1
1-12-23 2:00 AM	665.1068	913	4	180	61	1
1-12-23 3:00 AM	612.4585	624	0	309	208	1
1-12-23 4:00 AM	446.1248	540	2	424	359	1
1-12-23 5:00 AM	275.9159	384	2	767	450	3
1-12-23 6:00 AM	144.0905	338	3	657	724	1
1-12-23 7:00 AM	41.65727	159	2	591	626	0
1-12-23 8:00 AM	46.55006	0	1	558	526	0
1-12-23 9:00 AM	78.14911	0	1	496	596	1
1-12-23 10:00 AM	107.5463	0	2	231	522	2
1-12-23 11:00 AM	130.0803	73	1	119	225	1
1-12-23 12:00 PM	303.8143	153	3	66	124	0
1-12-23 1:00 PM	358.4439	301	1	98	84	0
1-12-23 2:00 PM	272.856	352	1	274	119	1
1-12-23 3:00 PM	127.6421	300	3	276	321	0
1-12-23 4:00 PM	98.04083	93	0	311	296	0
1-12-23 5:00 PM	111.5633	0	2	228	330	1
1-12-23 6:00 PM	118.2011	229	2	141	188	0
1-12-23 7:00 PM	73.05804	228	3	106	120	0
1-12-23 8:00 PM	6.584031	193	3	121	95	0
1-12-23 9:00 PM	98.33792	116	0	175	103	1
1-12-23 10:00 PM	408.4442	227	3	100	152	0
1-12-23 11:00 PM	1168.294	520	11	59	124	1
1-13-23 12:00 AM	1634.988	1234	7	88	73	0
1-13-23 1:00 AM	1597.865	1678	1	133	132	0
1-13-23 2:00 AM	1499.617	1589	2	220	174	0
1-13-23 3:00 AM	1283.93	1482	3	24	266	2
1-13-23 4:00 AM	890.4254	1347	8	216	106	1
1-13-23 5:00 AM	487.4392	968	8	229	183	0
1-13-23 6:00 AM	183.5988	444	4	353	228	1
1-13-23 7:00 AM	178.4249	188	0	437	358	1
1-13-23 8:00 AM	253.0072	187	1	531	462	1
1-13-23 9:00 AM	334.5396	255	1	721	589	1
1-13-23 10:00 AM	304.8954	322	0	881	766	1

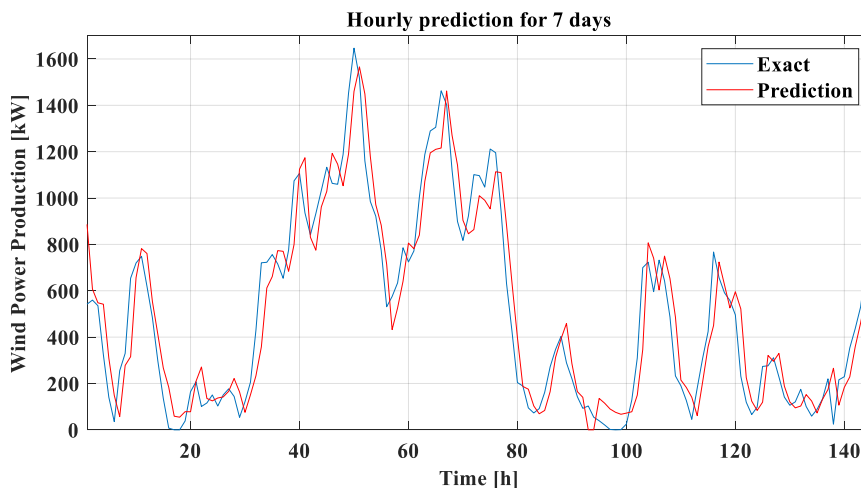


Even though the analysis of the values given for each hour can lead to some conclusions, it can be impractical to go through a table of this size. In order to make the examination of the results easier for the reader, those results have been used to create diagrams on which the exact measured production powers are given in blue, whereas the ANN forecast results are shown in red. This kind of diagram for WPP Elliniki can be seen in Fig. 3.2.



**Figure 3.2:** Comparative analysis for WPP Elliniki (7-days period).

By comparing the two plots in Fig. 3.2, one could conclude that forecasted values of the production power of WPP Elliniki and the exact production power values match each other almost perfectly. In order to check if this conclusion would also be valid for WPP Enel, a similar diagram has been created for that power plant as well. This diagram, with the same legend as the one given in Fig. 3.2, can be seen in Fig. 3.3.



**Figure 3.3:** Comparative analysis for WPP Enel (7-days period).

In quite a similar fashion to what was already said for WPP Elliniki, an observation of the two curves shown for WPP Enel also indicates that the results of the ANN forecast matched the measured production values well, thus confirming the assumption of ANN’s ability to significantly improve the quality of the WPPs’ power forecast.

### 3.3.2 Results for the Solar Power Plants

Tab. 3.2 gives a comparison of the results obtained by the ANN forecast and the actual production values of the solar plants that were analysed in the scope of this step. Here the MAPE values are provided for every hour, so the average MAPE could be calculated for these 168 hours for each of the SPPs. By that, it was calculated that the average MAPE for SPP Arcadia was equal to 1% and the average MAPE for SPP Messhnia was around 4%. As a benchmark, the MAPE of the SPP forecast is typically between 5% and 10%, highlighting the improvement made by the usage of the ANN methods. Also, if these 7 days are observed accumulatively from the point of view of the failures in the production planning, it can be seen that the cumulative error for the ANN amounted to -0.2025 MW for SPP Arcadia and to -4,107 MW for SPP Messhnia. From the aspect of energy balancing and long-term plans, the ANN provided very good results. The ANN can monitor the changes in the production more accurately and therefore generate a more realistic production plan for the solar power plants than any classic planning technique. Just as Tab. 3.1 was divided between two WPPs, Tab. 3.2 is divided between two SPPs.

**Table 3.2:** Obtained results for the solar power plants.

Date and time	SPP Arcadia – power [kW]	ANN for SPP Arcadia [kW]	MAPE for SPP Arcadia [%]	SPP Messhnia – power [kW]	ANN for SPP Messhnia [kW]	MAPE for SPP Messhnia [%]
1.7.23 10:00 AM	0	0	0	0	0	0
1.7.23 11:00 AM	0	0	0	0	0	0
1.7.23 12:00 PM	0	0	0	0	0	0
1.7.23 1:00 PM	0	0	0	0	0	0
1.7.23 2:00 PM	0	0	0	0	0	0
1.7.23 3:00 PM	0	0	0	0	0	0
1.7.23 4:00 PM	0	0	0	101	0	1
1.7.23 5:00 PM	0	0	0	922	1012	1
1.7.23 6:00 PM	0	0	0	2805	2068	6
1.7.23 7:00 PM	182	131	1	4976	4437	5
1.7.23 8:00 PM	907	800	2	6723	6899	1
1.7.23 9:00 PM	1692	1619	2	8155	6991	10
1.7.23 10:00 PM	2092	2156	1	8463	8065	3
1.7.23 11:00 PM	2219	2234	0	8207	8335	1
1.8.23 12:00 AM	2106	2134	1	7323	8168	7
1.8.23 1:00 AM	1799	1740	1	6267	7217	8
1.8.23 2:00 AM	1328	1087	5	4922	6331	12
1.8.23 3:00 AM	488	474	0	3595	4848	10
1.8.23 4:00 AM	9	0	0	1723	3381	14
1.8.23 5:00 AM	0	0	0	477	349	1
1.8.23 6:00 AM	0	0	0	17	0	0

Date and time	SPP Arcadia – power [kW]	ANN for SPP Arcadia [kW]	MAPE for SPP Arcadia [%]	SPP Messhnia – power [kW]	ANN for SPP Messhnia [kW]	MAPE for SPP Messhnia [%]
1.8.23 7:00 AM	0	0	0	0	0	0
1.8.23 8:00 AM	0	0	0	0	0	0
1.8.23 9:00 AM	0	0	0	0	0	0
1.8.23 10:00 AM	0	0	0	0	0	0
1.8.23 11:00 AM	0	0	0	0	0	0
1.8.23 12:00 PM	0	0	0	0	0	0
1.8.23 1:00 PM	0	0	0	0	0	0
1.8.23 2:00 PM	0	0	0	0	0	0
1.8.23 3:00 PM	0	0	0	0	0	0
1.8.23 4:00 PM	0	0	0	59	0	0
1.8.23 5:00 PM	0	0	0	867	955	1
1.8.23 6:00 PM	0	0	0	2834	1981	7
1.8.23 7:00 PM	181	133	1	5044	4371	6
1.8.23 8:00 PM	917	822	2	6874	6125	6
1.8.23 9:00 PM	1709	1622	2	8432	7309	9
1.8.23 10:00 PM	2101	2148	1	7960	8184	2
1.8.23 11:00 PM	2227	2239	0	9136	7958	10
1.9.23 12:00 AM	2107	2105	0	8808	8366	4
1.9.23 1:00 AM	1931	1827	2	7834	8315	4
1.9.23 2:00 AM	1319	1219	2	2442	6304	32
1.9.23 3:00 AM	494	481	0	2466	3653	10
1.9.23 4:00 AM	10	0	0	2415	2424	0
1.9.23 5:00 AM	0	0	0	1310	663	5
1.9.23 6:00 AM	0	0	0	229	200	0
1.9.23 7:00 AM	0	0	0	0	0	0
1.9.23 8:00 AM	0	0	0	0	0	0
1.9.23 9:00 AM	0	0	0	0	0	0
1.9.23 10:00 AM	0	0	0	0	0	0
1.9.23 11:00 AM	0	0	0	0	0	0
1.9.23 12:00 PM	0	0	0	0	0	0
1.9.23 1:00 PM	0	0	0	0	0	0
1.9.23 2:00 PM	0	0	0	0	0	0
1.9.23 3:00 PM	0	0	0	0	0	0
1.9.23 4:00 PM	0	0	0	40	0	0
1.9.23 5:00 PM	0	0	0	813	923	1
1.9.23 6:00 PM	0	0	0	2788	1948	7
1.9.23 7:00 PM	64	171	2	4962	4348	5



Date and time	SPP Arcadia – power [kW]	ANN for SPP Arcadia [kW]	MAPE for SPP Arcadia [%]	SPP Messhnia – power [kW]	ANN for SPP Messhnia [kW]	MAPE for SPP Messhnia [%]
1.9.23 8:00 PM	876	525	8	6820	6738	1
1.9.23 9:00 PM	1702	1571	3	6254	7296	9
1.9.23 10:00 PM	2098	2114	0	6233	6611	3
1.9.23 11:00 PM	2216	2220	0	9117	7073	17
1.10.23 12:00 AM	1916	2087	4	8929	8371	5
1.10.23 1:00 AM	1486	1700	5	3551	8340	40
1.10.23 2:00 AM	383	933	12	2684	3322	5
1.10.23 3:00 AM	302	123	4	1584	3118	13
1.10.23 4:00 AM	4	0	0	919	2354	12
1.10.23 5:00 AM	0	0	0	608	170	4
1.10.23 6:00 AM	0	0	0	164	0	1
1.10.23 7:00 AM	0	0	0	0	0	0
1.10.23 8:00 AM	0	0	0	0	0	0
1.10.23 9:00 AM	0	0	0	0	0	0
1.10.23 10:00 AM	0	0	0	0	0	0
1.10.23 11:00 AM	0	0	0	0	0	0
1.10.23 12:00 PM	0	0	0	0	0	0
1.10.23 1:00 PM	0	0	0	0	0	0
1.10.23 2:00 PM	0	0	0	0	0	0
1.10.23 3:00 PM	0	0	0	0	0	0
1.10.23 4:00 PM	0	0	0	40	0	0
1.10.23 5:00 PM	0	0	0	810	896	1
1.10.23 6:00 PM	0	0	0	2824	1935	7
1.10.23 7:00 PM	26	123	2	4685	4359	3
1.10.23 8:00 PM	281	461	4	5947	5280	6
1.10.23 9:00 PM	780	825	1	5616	6482	7
1.10.23 10:00 PM	2135	1502	14	2401	4290	16
1.10.23 11:00 PM	2248	2254	0	6011	4528	12
1.11.23 12:00 AM	2125	2146	0	6418	6829	3
1.11.23 1:00 AM	1784	1818	1	8221	6259	16
1.11.23 2:00 AM	1308	1113	4	6859	7548	6
1.11.23 3:00 AM	470	449	0	3138	5289	18
1.11.23 4:00 AM	8	0	0	1948	1868	1
1.11.23 5:00 AM	0	0	0	389	320	1
1.11.23 6:00 AM	0	0	0	55	0	0
1.11.23 7:00 AM	0	0	0	0	0	0
1.11.23 8:00 AM	0	0	0	0	0	0



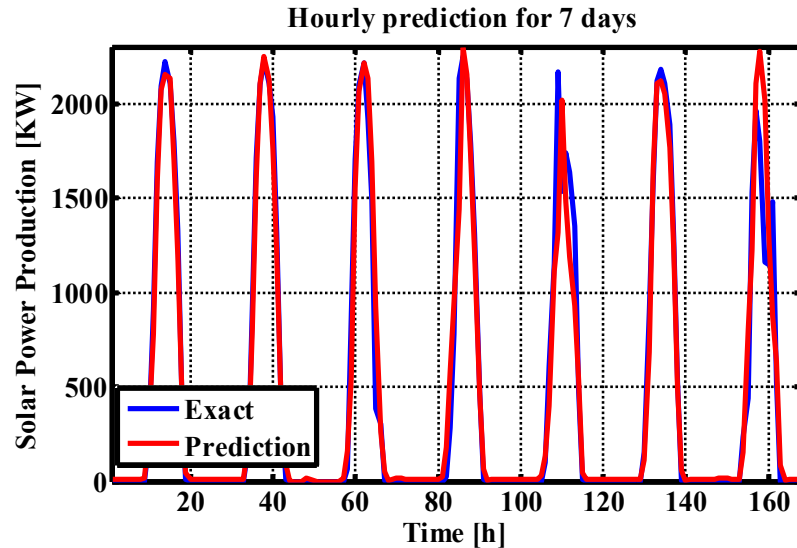
Date and time	SPP Arcadia – power [kW]	ANN for SPP Arcadia [kW]	MAPE for SPP Arcadia [%]	SPP Messhnia – power [kW]	ANN for SPP Messhnia [kW]	MAPE for SPP Messhnia [%]
1.11.23 9:00 AM	0	0	0	0	0	0
1.11.23 10:00 AM	0	0	0	0	0	0
1.11.23 11:00 AM	0	0	0	0	0	0
1.11.23 12:00 PM	0	0	0	0	0	0
1.11.23 1:00 PM	0	0	0	0	0	0
1.11.23 2:00 PM	0	0	0	0	0	0
1.11.23 3:00 PM	0	0	0	0	0	0
1.11.23 4:00 PM	0	0	0	41	0	0
1.11.23 5:00 PM	0	0	0	806	895	1
1.11.23 6:00 PM	0	0	0	2821	1941	7
1.11.23 7:00 PM	97	0	2	5196	4288	8
1.11.23 8:00 PM	611	334	6	3768	4994	10
1.11.23 9:00 PM	1152	1125	1	6460	4506	16
1.11.23 10:00 PM	2170	1348	19	7972	6238	14
1.11.23 11:00 PM	1536	1991	10	8854	6444	20
1.12.23 12:00 AM	1739	1484	6	8950	8337	5
1.12.23 1:00 AM	1637	1330	7	8037	8336	2
1.12.23 2:00 AM	1352	1020	8	6752	7010	2
1.12.23 3:00 AM	471	483	0	4912	5025	1
1.12.23 4:00 AM	7	0	0	2654	3010	3
1.12.23 5:00 AM	0	0	0	685	603	1
1.12.23 6:00 AM	0	0	0	181	125	0
1.12.23 7:00 AM	0	0	0	0	0	0
1.12.23 8:00 AM	0	0	0	0	0	0
1.12.23 9:00 AM	0	0	0	0	0	0
1.12.23 10:00 AM	0	0	0	0	0	0
1.12.23 11:00 AM	0	0	0	0	0	0
1.12.23 12:00 PM	0	0	0	0	0	0
1.12.23 1:00 PM	0	0	0	0	0	0
1.12.23 2:00 PM	0	0	0	0	0	0
1.12.23 3:00 PM	0	0	0	0	0	0
1.12.23 4:00 PM	0	0	0	47	0	0
1.12.23 5:00 PM	0	0	0	832	896	1
1.12.23 6:00 PM	0	0	0	2908	1959	8
1.12.23 7:00 PM	154	0	3	4966	4508	4
1.12.23 8:00 PM	896	703	4	6769	4341	20
1.12.23 9:00 PM	1573	1575	0	7676	6755	8



Date and time	SPP Arcadia – power [kW]	ANN for SPP Arcadia [kW]	MAPE for SPP Arcadia [%]	SPP Messhnia – power [kW]	ANN for SPP Messhnia [kW]	MAPE for SPP Messhnia [%]
1.12.23 10:00 PM	2123	2167	1	7686	7587	1
1.12.23 11:00 PM	2184	2246	1	8229	7941	2
1.13.23 12:00 AM	2105	2087	0	7319	8247	8
1.13.23 1:00 AM	1891	1829	1	8288	7263	9
1.13.23 2:00 AM	1298	1236	1	6959	6995	0
1.13.23 3:00 AM	525	455	2	4079	5624	13
1.13.23 4:00 AM	4	0	0	2168	3680	13
1.13.23 5:00 AM	0	0	0	645	413	2
1.13.23 6:00 AM	0	0	0	124	0	1
1.13.23 7:00 AM	0	0	0	0	0	0
1.13.23 8:00 AM	0	0	0	0	0	0
1.13.23 9:00 AM	0	0	0	0	0	0
1.13.23 10:00 AM	0	0	0	0	0	0
1.13.23 11:00 AM	0	0	0	0	0	0
1.13.23 12:00 PM	0	0	0	0	0	0
1.13.23 1:00 PM	0	0	0	0	0	0
1.13.23 2:00 PM	0	0	0	0	0	0
1.13.23 3:00 PM	0	0	0	0	0	0
1.13.23 4:00 PM	0	0	0	56	0	0
1.13.23 5:00 PM	0	0	0	895	914	0
1.13.23 6:00 PM	0	0	0	2932	2023	8
1.13.23 7:00 PM	235	135	2	4750	4446	3
1.13.23 8:00 PM	441	839	9	5266	5099	1
1.13.23 9:00 PM	1530	1160	8	6248	5945	3
1.13.23 10:00 PM	1960	2147	4	6986	6735	2
1.13.23 11:00 PM	1800	2247	10	8893	7412	12
1.14.23 12:00 AM	1157	2009	19	8282	8343	1
1.14.23 1:00 AM	1149	1325	4	7545	8097	5
1.14.23 2:00 AM	1478	851	14	4450	7313	24
1.14.23 3:00 AM	525	576	1	3012	4588	13
1.14.23 4:00 AM	0	0	0	714	2886	18
1.14.23 5:00 AM	0	0	0	24	0	0
1.14.23 6:00 AM	0	0	0	0	0	0
1.14.23 7:00 AM	0	0	0	0	0	0
1.14.23 8:00 AM	0	0	0	0	0	0
1.14.23 9:00 AM	0	0	0	0	0	0
1.14.23 10:00 AM	0	0	0	0	0	0

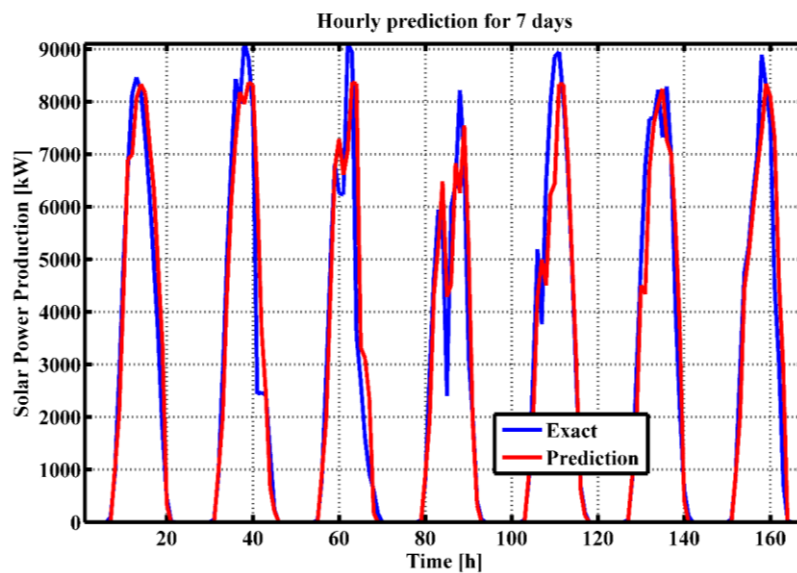


Just as Fig. 3.2 and 3.3 showed the comparative results for the WPPs included in the analyses, Fig. 3.4 gives the same level of insight, but covering the exact and the forecasted production power values for SPP Arcadia.



**Figure 3.4:** Comparative analysis for SPP Arcadia (7-days period).

As can be seen from Fig. 3.4, the forecasted values follow the exact measured production powers well even for the SPPs. In order to confirm this, a similar diagram was created for SPP Messhnia. It is given in Fig. 3.5.

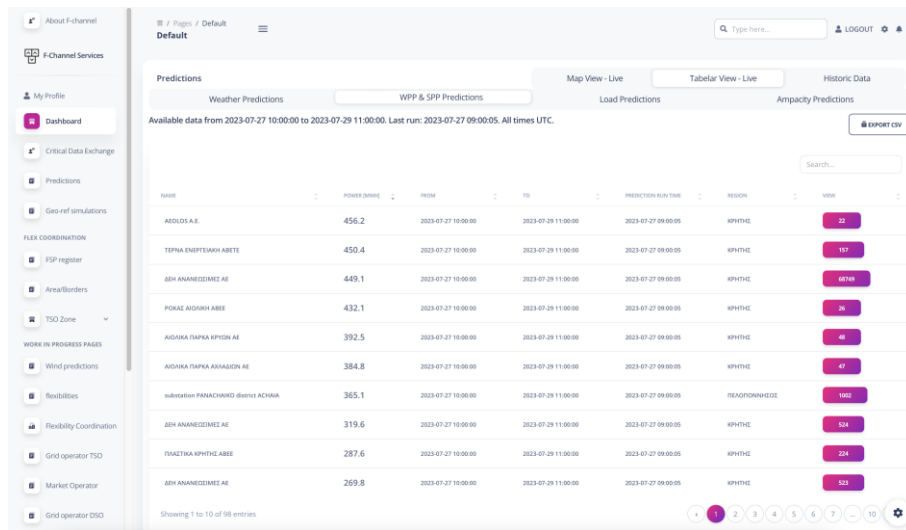


**Figure 3.5:** Comparative analysis for SPP Messhnia (7-days period).

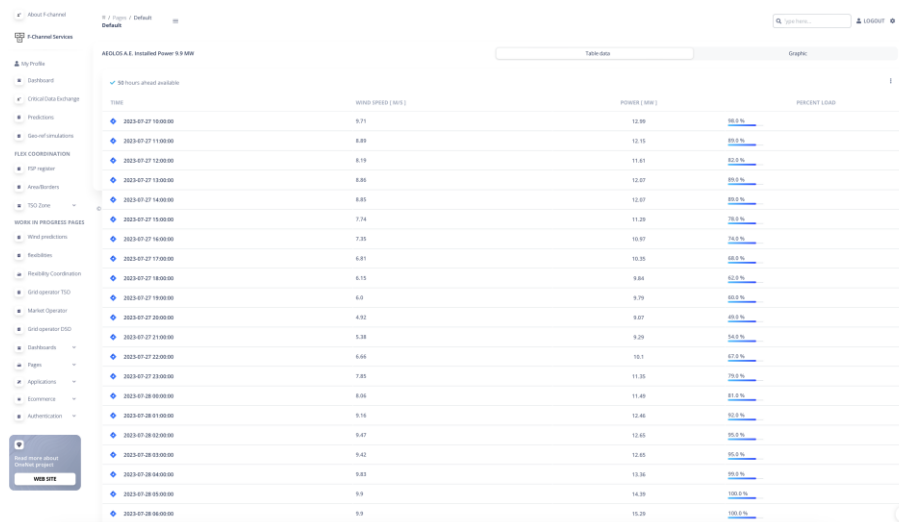
The conclusion that has been made after the observation of the diagram created for SPP Arcadia has been verified by the diagram created for the generation power of SPP Messhnia. Therefore, it was confirmed that the ANN forecasting method can be used efficiently and reliably for both of the main types of renewable sources.







(a)



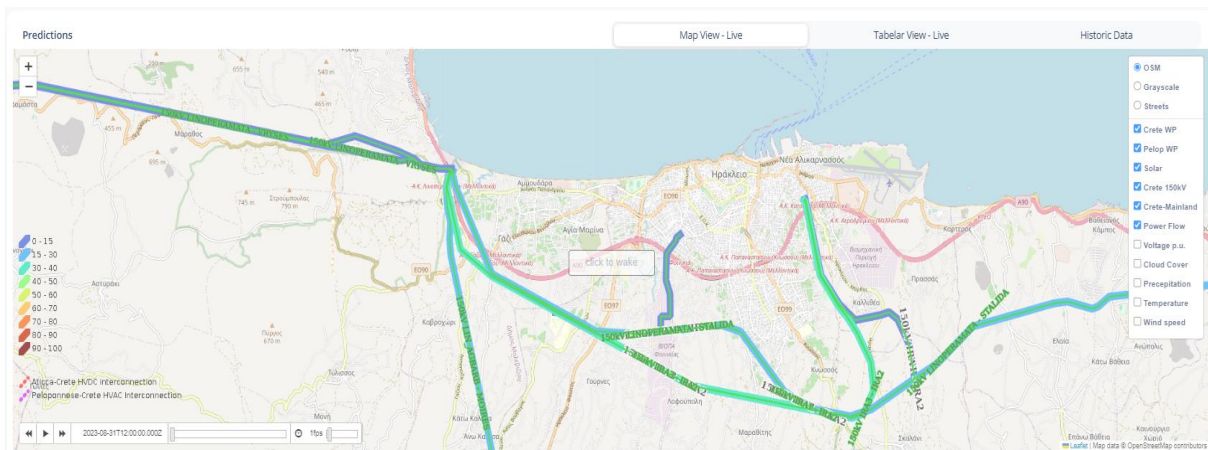
(b)

**Figure 3.7:** Production forecast of the renewable sources – unified (a) and for single unit (b).

System operators update the grid model with these parameters and perform the generation optimization process, with the results of the load flow calculation on the created model indicating that potential problems in the system could arise if no action is taken. The example of such a model, shown on the georeferenced map of Crete island, is given all the way back in Chapter 2, in Fig. 2.14. Of course, if another region is selected by the user for analysis, the map of Crete island and the grid on that island can be replaced by the chosen region, under the condition that there is a sufficient amount of input data at disposal of the user, so the model can be made properly. Depending on the nature of the mentioned issues in the grid and services that could help in relieving the situation, there were three individual scenarios defined and discussed within this BUC.

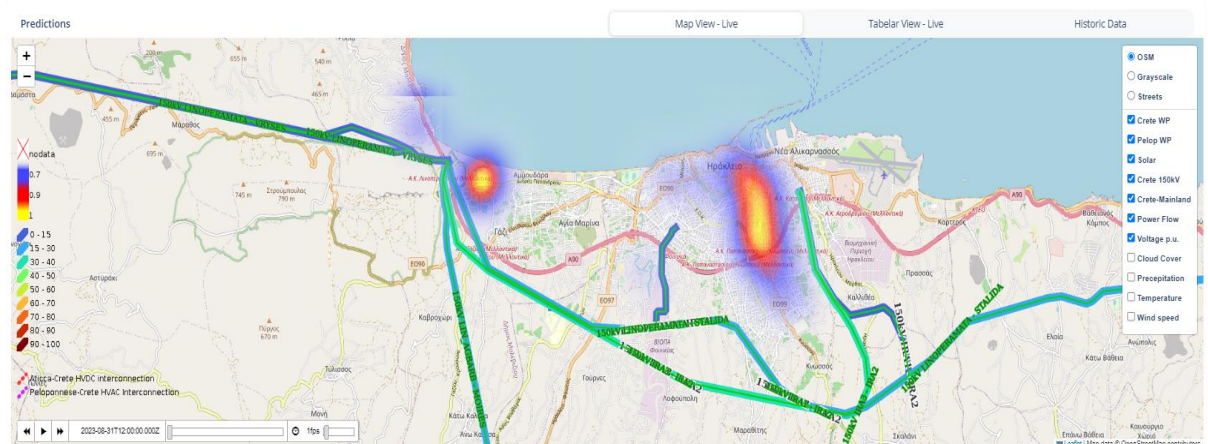
Those scenarios were the following:

- The one taking into account contingencies in the grid, where high loading or even overloading of the line is detected; this can easily be spotted as the GUI used for the presentation of the results uses the colour coding of the lines to show their loading. This can be seen in Fig. 3.8, in which a blue coloured line indicates that the loading of that line is less than half of its allowed limit (lower than 40% of maximal permitted transmission capacity). Different colours (such as yellow or red) would mean a higher loading and would potentially indicate a situation in which some action would need to be taken by the SO.



**Figure 3.8:** Georeferenced representation of the load flow results.

- The one considering occurrences of the voltages out of the predetermined boundaries (this could either be a warning of too high voltages or a warning of too low voltages). This can also be seen directly from the georeferenced map of the grid, in which the colour of the node indicates the value of its voltage, in line with the legend shown on the left-hand side of the map. This way of showing the voltages is seen in Fig. 3.9, in which it can be seen that higher voltages are marked in yellow and lower ones in blue shades.



**Figure 3.9:** Georeferenced representation of the voltage values.

- The one that is based on the state in which the system lacks the reserve capacities. This is indicated to the user in a tabular form in which the system needs for the reserves and the available values of those reserves are given. This can, depending on the selected timeframe, refer to real time, the day ahead or the week ahead.

Once the problem is identified, the flexibility services that could mitigate it are defined and forwarded to the market operator in order to initiate the process of acquiring the services. The view of the list of the defined flexibility resources that can provide the service is given in Fig. 3.10, the FSP register, populated only with the flexibility service providers that have passed the prequalification, is shown. As a reminder, the flow of the prequalification process can be seen in Fig. 2.36, back in Chapter 2 of this report.

ID	DATE	STATUS	FSP NAME	FSP TYPE	AREA	AFRR	MRRR	PAPS	PAFL	PRPS	APPROVED BY SO	APPROVED BY MO		
14	2023-08-20 21:07:19	Not Active	FSP Crete	333	Pelop	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	EDIT	DELETE
15	2023-08-20 21:07:51	Active	Protsener	fsp	Crete	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	EDIT	DELETE
17	2023-08-20 21:32:35	Not Active	Test	Fsr	Greece	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	EDIT	DELETE
18	2023-08-23 18:23:35	Not Active	test	type1	Greece	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	EDIT	DELETE
11	2023-08-20 20:29:47	Active	TSD Flex	static	Greece	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	EDIT	DELETE
12	2023-08-20 20:30:24	Active	TSD FSP	fud	Crete	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	EDIT	DELETE

Figure 3.10: FSP register

This list can easily be extended by adding the new flexibility resources, as illustrated in Fig. 3.11.

**Add FSP**

Name:

Area:

Type:

Status:

Check values:

AFRR

MRRR

PAPS

PAFL

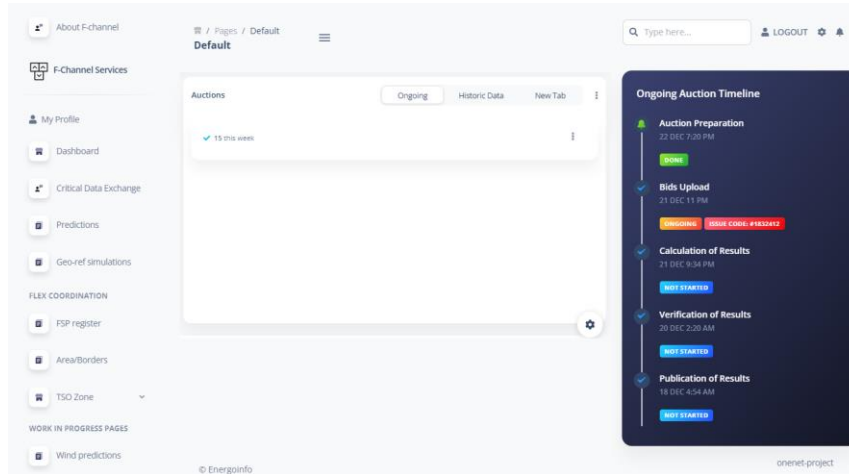
PRPS

Approved by SO

Approved by MO

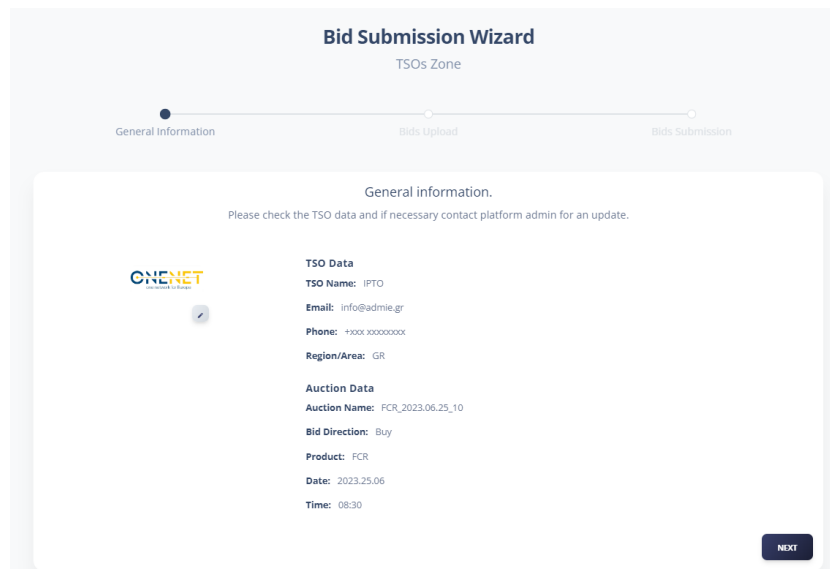
Figure 3.11: Addition of the new FSP to the register.

The market operator sets up an auction in which the system operators can pick the necessary services, along with the prices that can be paid for those services. This is done via the Auction Wizard, shown in Fig. 3.12.

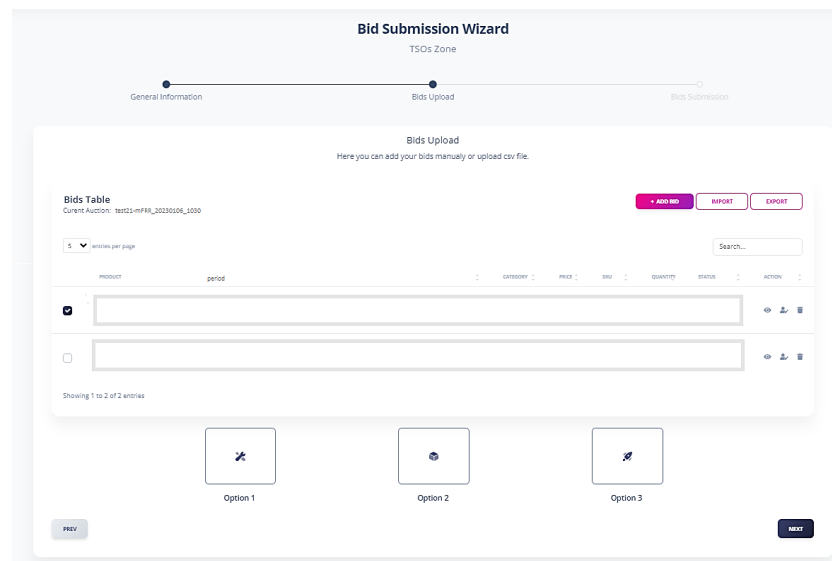


**Figure 3.12:** Auction Wizard sample screenshot.

The flexibility service providers or their aggregators prequalified for the requested service get the notification of the new auction and submit their bids, if any. The bids are also submitted in a simple manner, by utilizing the Bid Submission Wizard, the screenshots of which are given in parts (a) and (b) of Fig. 3.13.



(a)



(b)

**Figure 3.13:** Bid Submission Wizard sample screenshots – 1<sup>st</sup> window (a) and 2<sup>nd</sup> window (b).

Once the bid submission window closes, the bids that will be accepted in this auction get chosen, after which the information regarding the results of this auction gets forwarded to all of the participants in the procedure. These results are also visible to the potential guests (participants in the platform without any assigned role in the market). More about the actions that need to be taken by each of the participants can be read below.

As can be concluded from the given step-by-step analysis, the experiences of the users can vary dramatically, primarily based on the role that was assigned to them during the creation of their user account. Therefore:

- the system operators, alongside their part in the prequalification of the FSPs, participate in the majority of the process, starting from the time in which they receive the weather forecast, all the way to the moment in which they are informed of the auction results, during which they take care of numerous other parts of the process, such as the identification of problems in the grid and the suggestion of needed services;
- the market operator's part in the discussed scenario starts when it is informed of the need for setting up the new auction for obtaining the appropriate services, so it is included about halfway in the flow of the process; this operator sets up an auction by using the appropriate tools introduced in the F-channel platform of the Greek Demo (described in the previous chapters); its role ends once the auction ends;
- the responsibilities of the flexibility service providers start even later than the activities of the market operator, with their actions following the moment at which the auction is created and the window for submitting the corresponding bids is open; once the bids are submitted, the flexibility service providers, same as other participants, have to wait until the auction results are available to see if their offers are accepted or not;

- in line with what has been stated above, the guests (the users with no defined role in the energy market and, hence, no defined role within the F-channel platform) do not bear any particular responsibilities for the process of spotting the problems and obtaining the services needed for mitigating those issues, but can, nonetheless, be informed of the results of the conducted auctions once those become available.

Although this subchapter is primarily dedicated to the BUCs, it should also be clarified that all or some of the steps of the process given here largely match the users' experience related to almost all of the SUCs related to BUC 1. The example of this can be found in SUC 1 (covering the points until the completion of forecast) and SUCs 4, 7 and 8, differentiated by the type of spotted issue and, hence, the required type of flexibility resource.

#### **Users' experience when using the platform – BUC 2**

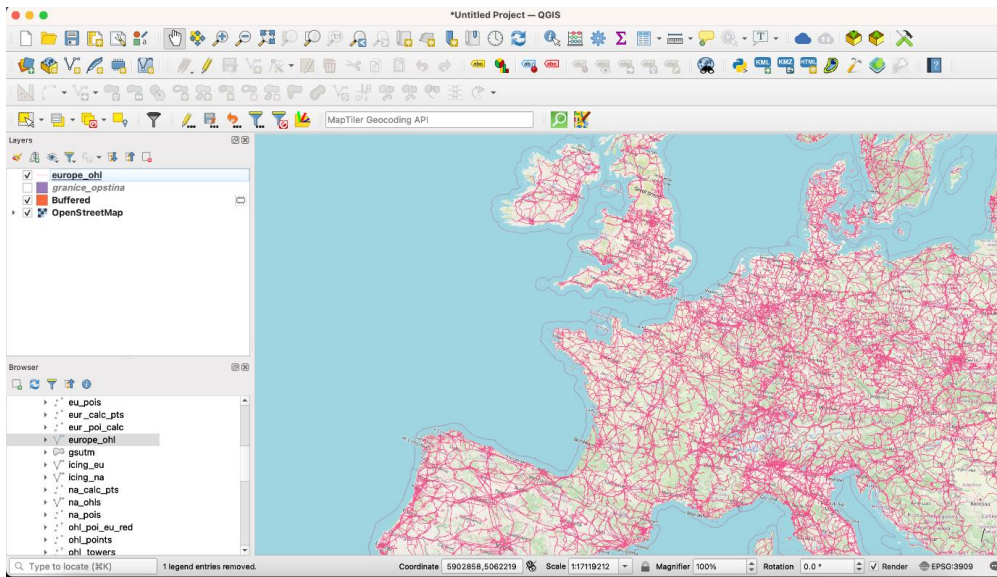
Even though the full description of the second BUC associated with the Greek Demo has been given in the previous subchapter, the opinion of the authors of this report was that it would be good to repeat at least some of the main points in order to make understanding the role of each user of the platform easier for the reader. It was mentioned that the second Business Use Case stemming from the OneNet Greek Demo is the one related to the enhanced severe weather condition handling and outage management for the operators of the different parts of the power system. The situation that is considered can be briefly summarized in the following lines: the weather service provider sends the high-resolution weather forecasts to the system operators, after which they convert those into the chosen power system parameters (similar to the description given for BUC 1, those are the demand power, the production powers of the renewable sources and the capacities of the lines in the selected area). Once again, parameters such as the renewable sources' production can either be unified or on the single unit level, allowing a greater flexibility of the platform and its application in different situations.

The platform allows the tracking of the critical weather parameters, such as, for example:

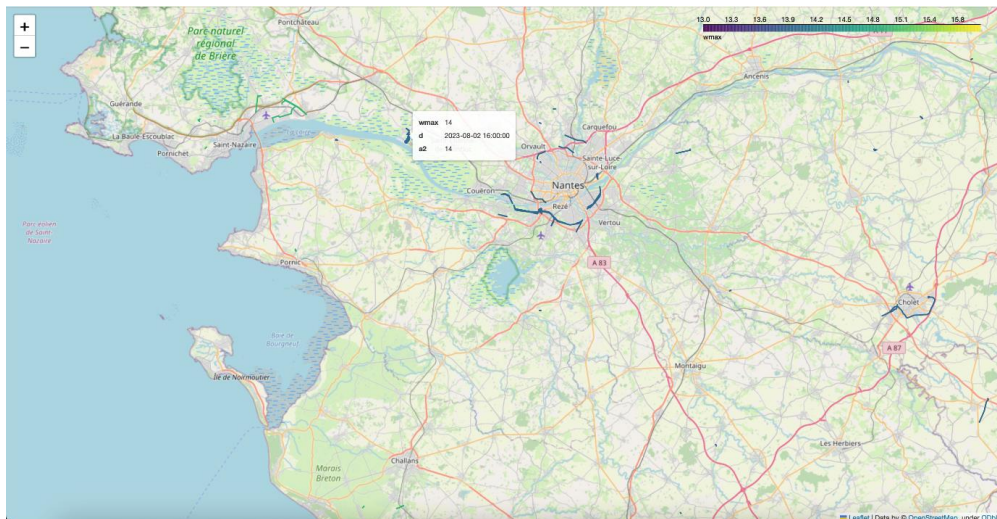
- wind speeds over 12 m/s;
- wind speeds under 5 m/s;
- appearance of icing on the lines;
- precipitation and storms.

In line with this list, parts (a) and (b) of Fig. 3.14 show all of the elements in Europe that are monitored for detection of critical weather conditions (a) and the severe conditions identified by F-channel platform (b).





(a)



(b)

**Figure 3.14:** Monitored elements in European grid (a) and identified critical weather conditions (b).

Data is further exchanged with other TSOs through the critical information exchange module built as an integral part of the F-channel platform (shown in Fig. 2.43 of this report). The screenshots from the wind report and the icing report, indicating the critical climatic conditions, can be seen in Fig. 3.15 (parts (a) and (b)).





In line with these descriptions, the part that each of the participants plays in this process also heavily depends on the nature of the spotted issue, with some of them even being left out in certain situations. More on this can be seen in the description provided below (listed in the user-by-user form once again, similar to the BUC 1 elaboration, but with clear separation between the two specified cases relevant for this Business Use Case):

- the system operators are the only participants active in both of the situations; in the first case, they are in charge of both noticing the issue in the grid and resolving it by conducting some of the actions from their repertoire, such as the modification of the maintenance schedule in order to avoid matching the times of the planned outages of the elements with the critical moments for the state of the grid; in the second case, their roles and experiences are similar to what was already described for the first BUC;
- the market operator does not participate in the first of the described cases at all, since the problems are resolved by the system operators and do not require any actions from the remaining actors in the energy market; in the second case, its role is the same as the one given to it in the description of the first BUC;
- the flexibility service provider also does not participate in the first described case, as the problems are resolved by the system operators and do not require any actions from the remaining actors in the energy market; in the second case, its role is the same as the one given to it in the description of the first BUC;
- in line with what has been already said, the guests (the users with no defined role in the energy market and, hence, no defined role within the F-channel platform) do not bear any particular responsibilities for the process of spotting the problems and obtaining the services needed for mitigating those issues, but can, nonetheless, be informed of the results of the conducted auctions once those become available.

In a similar fashion to what was already mentioned in the part of this subchapter related to BUC 1 of the Greek Demo, it should also be underlined that the procedure described for the second BUC of this demo fits the expected experiences of the users in the SUCs that are assigned to this BUC. This time, those are SUC 5 and SUC 6 of the Demo, with the fifth one, as a reminder, dealing with the storm and icing predictive maintenance of the different parts of the grid. On the same note, the sixth SUC covers the outage management process in order to increase the reliability of the outage and maintenance plans of the SOs. In continuation of this, the experiences given in the previous paragraphs also mimic those foreseen for the Regional BUC of the Southern Cluster (Regional critical infrastructure security awareness information exchange), with the most prominent difference being the fact that Regional BUC covers the issues of cyber-security in addition to what was described for BUC 2.

### 3.5 Users' Experience with the Platform (per SUC)

In order to improve the quality of the document and provide reader of this report with as much information as possible, it was also decided to shed some light on the users' experiences when dealing with the SUCs of the Greek Demo that do not resemble those elaborated in Subchapter 3.4. Therefore, brief descriptions of the ways in which the goals of SUCs 2 and 3 of the Greek Demo have been achieved can be found below.

#### **Users' experience when using the platform – SUC 2**

As stated in the first chapter of this report, SUC 2 of the Greek Demo covers the development of the user-friendly overview of the relevant characteristics of the regions of the system that are selected as critical or important for any other reason, focusing on the technical and the climatic parameters vital for the proper forecasts of chosen indicators, such as the RES production and the demand. From the point of view of the F-channel platform and the TSO-DSO coordination, stated as one of the most important goals of the platform's vision, this can be seen as a manner of saving the relevant information in order to enhance the accuracy of the conducted forecasts. From Subchapter 3.2, it can easily be concluded how much the existence and usage of the well-organized and reliable database improves the functioning of the ANN and reduces the possibility of errors. Thus, it would also be good to see what kind of roles the different participants in the energy market could play in the process of creating and maintaining this database. In the same fashion in which the similar descriptions were given for the BUC analysis, here, the user-by-user principle will again be applied. The roles are given below:

- the system operators can, this time, be treated as the only participants with active roles in this use case; since they are the ones responsible for the proper functioning of the different parts of the system, it is natural to give them the leading part in the safekeeping of the important data that can be used both for the analysis of the operation of the grid and for the forecasting of the predefined set of parameters on the appropriate time-horizons; what should, however, be stated here, is that the form in which the database will be formed and kept is left to each of the SOs to decide, for the sake of efficiency and also adaptability of the platform to the needs of the different potential users; the platform, of course, gives those users all of the values and information necessary for creation and maintenance of this database;
- the market operator does not participate in this case at all, since the part of the process covered by this SUC takes place before this user has any activities foreseen; the actions of this user are expected after the needs for the flexibility services are established and the auction is ready to be set up and take place;
- the flexibility service provider does not participate in this case at all, since the part of the process covered by this SUC takes place before this user has any activities; the actions of this user are expected after the needs for the flexibility services are established and the auction is set up, so the bids can be submitted;
- finally, the guests also have nothing to do with this SUC, with them only being able to see the results of the auction once that auction is done, which happens quite a bit after the process in this SUC is finished.

From this, it is clear that this SUC is all about the SOs and the way in which they are willing to keep the data relevant for them. As stated, this could vary from SO to SO, depending on the system for which the values need to be kept, the types of sources and the demand existing in that system, but also on the relevant legislation that could, in some cases, specify the type of information that the SOs need to keep at every moment. An example of the database that can be used for these purposes, focusing on the solar production units, is given in Fig. 3.16.

park_no	1	2	3	4	5	6	7	8	9	10
time hh:mm	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh
1.1.2018 00:00										
1.1.2018 01:00										
1.1.2018 02:00										
1.1.2018 03:00										
1.1.2018 04:00										
1.1.2018 05:00										
1.1.2018 06:00										
1.1.2018 07:00										
1.1.2018 08:00										
1.1.2018 09:00										
1.1.2018 10:00										
1.1.2018 11:00										
1.1.2018 12:00										

**Figure 3.16:** Example of the database for solar units.

Here, each of the columns correspond to one of the solar units in the observed part of the grid, with the rest of the base providing the information on the production power of that unit in each hour of the chosen period.

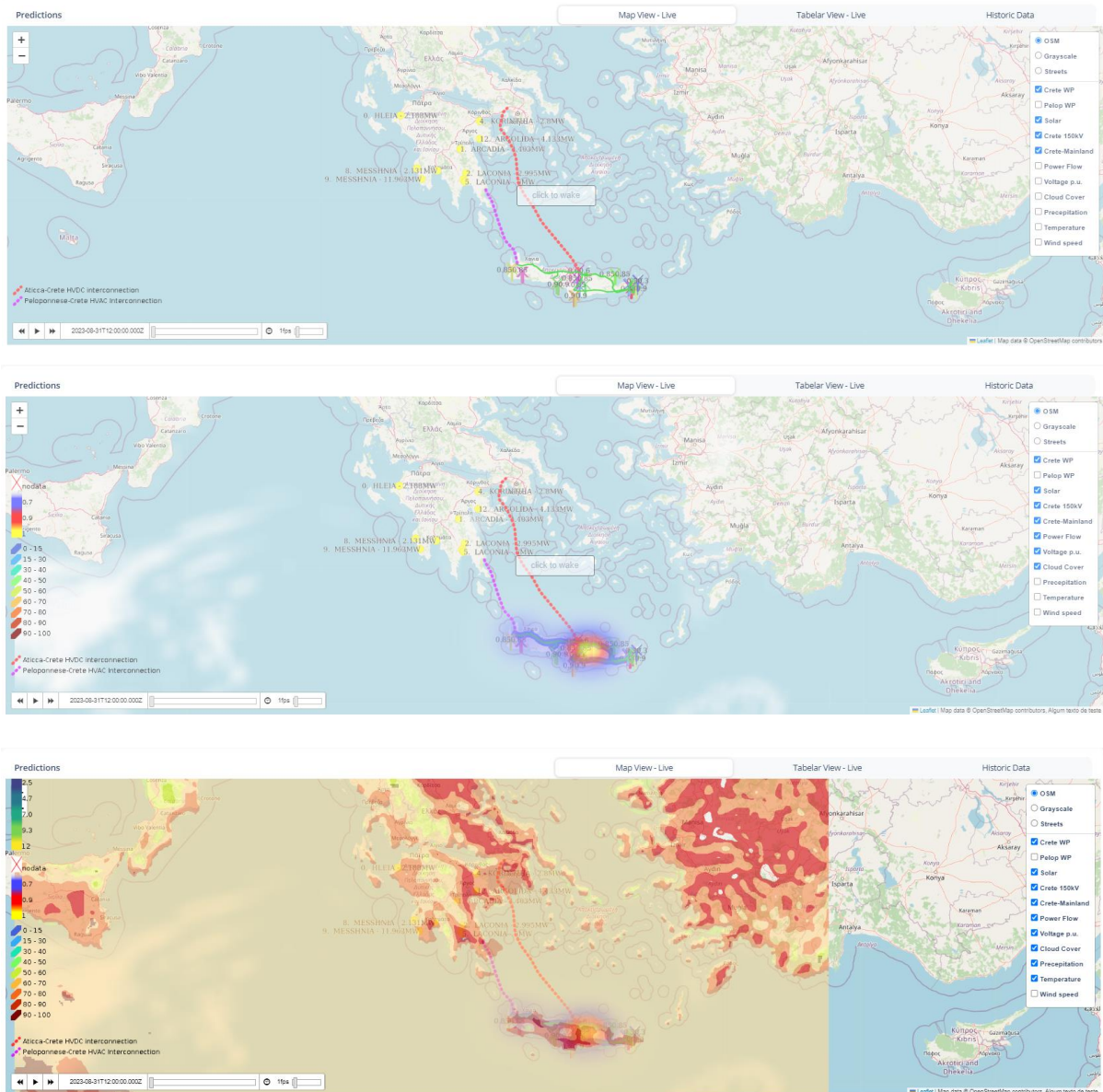
**Users’ experience when using the platform – SUC 3**

Finally, the third SUC related to the Greek Demo is the one primarily focusing on the readability of the data provided to the user and the freedom given to the user to manipulate the mapped view of the system in order to make the working environment less overwhelming and more dedicated to the current tasks and needs. Hence, the goal of this SUC was to develop the way in which the user can change the level of zoom of the georeferenced projection of the grid and filter the data in accordance to that. In other words, values shown to the user would only refer to the part of the grid that the user had specified through zooming in and out. It can, just from the given description, be concluded that this is another case in which only the SOs would have any role, but, for that to be confirmed, another analysis was conducted. So, the activities of the users in this SUC are the following:

- the system operators can, in line with their needs, specify the region of the map upon which the analysis that they are working on at the moment is based and filter out the results relevant only for that region; this is set to help them in reducing the possibility of a mistake due to the overbearing amount of values and increasing the reliability and efficiency of the conducted calculations in the process;
- none of the other participants in the energy market have any active role in this use case as they are not expected to actively interact neither with the entire map of the system, nor with any part of that map.

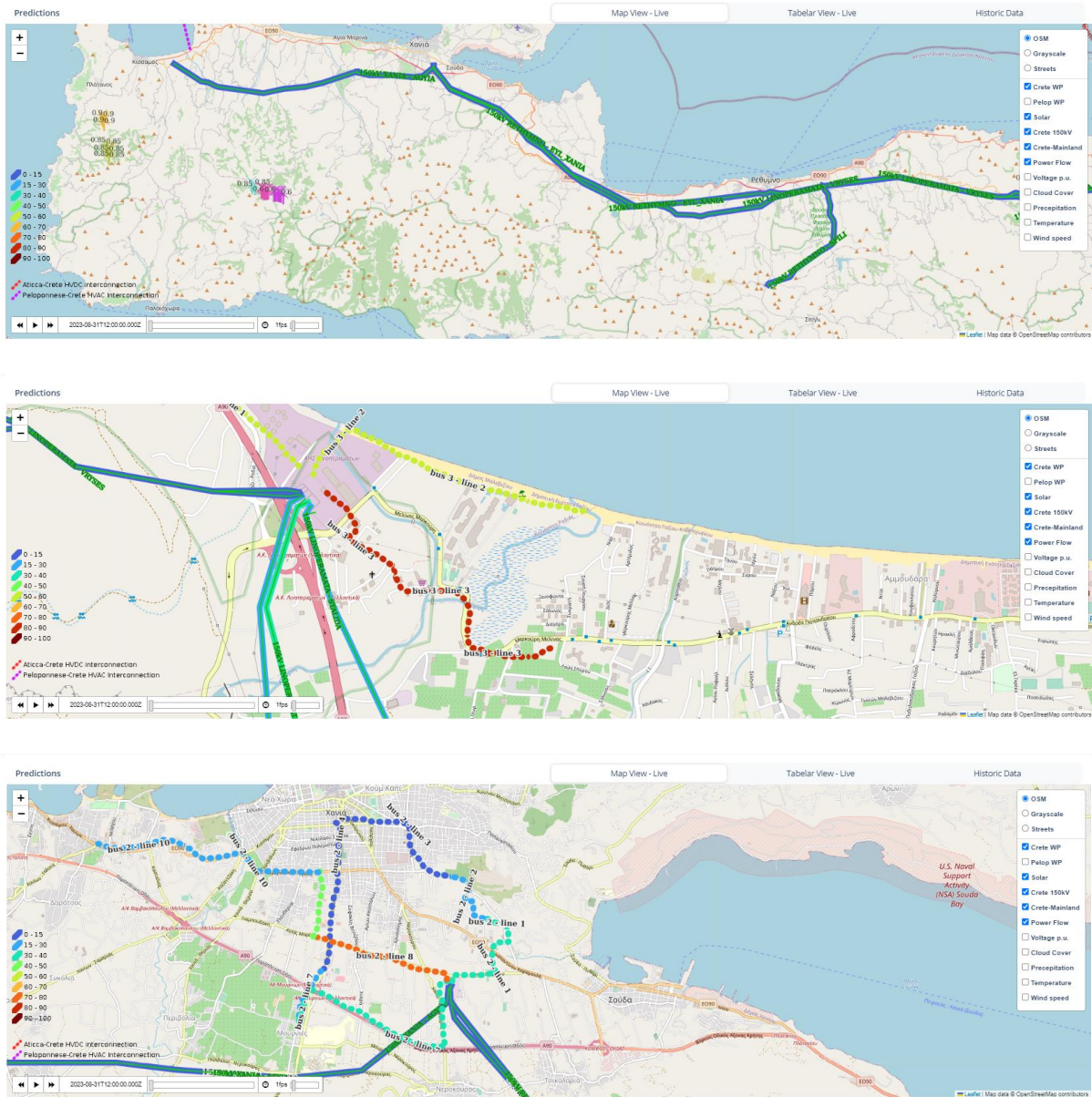


In order to illustrate the change of view that the system operator can come across by using the zoom-in and zoom-out functions, Fig. 3.17 shows a larger portion of the map of the area of interest in part (a). Part (b) of this figure shows how the zoomed-in part of the map looks like and what level of detail can be expected.



**Figure 3.17a:** GIS based map presentation of the entire area of interest with different weather and grid layers.





**Figure 3.17b:** GIS based map presentation of the local area of interest with different zoom levels.

It is clear how much the visibility of the parameters of interest for the potential users is increased in each case marked with (b) in this figure, thus confirming the theory of the zooming-in being able to aid with the data readability and comprehensiveness.

## 4 Conclusions

In this deliverable, the overview of the activities that had been done within the Greek Demo of the OneNet project has been provided. As a reminder, the Greek Demo belongs to the Southern Cluster of this project, along with the Cypriot Demo. The majority of these activities focused on the different aspects and functionalities of the F-channel platform, which is the main outcome of the conducted work. Basically, it is the web based, client server application for TSO-DSO coordination, aligning it with the general OneNet vision. It contains two modules, covering two major areas to which the effort was directed – the forecasts of the system state and the improved coordination between the participants in the energy market. As a significant addition to the Forecasting module, the part of the system of interest in Greece has been georeferenced, allowing for results to be given on the map. This was done in the scope of the GEOGRID solution (via the OneNet Open Call) and massively improved quality and user-friendliness of the platform in turn. The other aspects of user-friendliness were achieved by simulating the behaviour of different potential clients when testing the platform, making it easier for the partners in Greek Demo to remove any issues that each of the possible users could face while trying to work in the platform.

The testing of the forecasting method based on the ANN has been conducted by taking four units in the area of interest into consideration – two wind power plants and two solar power plants. After training the ANN, the forecasts indicated that the prediction errors can be substantially reduced compared to values typically expected today. For instance, the error indicator for the solar units was (for one of the units) reduced nearly five times if compared to the reference values. For the wind units, the new errors were about five times lower compared to the reference values. In addition to this, the graphical displays of the measured and forecasted hourly values of production have been made for all of these units for the one-week period. It turned out that the forecasts were successful in following the real-life production patterns almost completely, which is a major milestone that has been reached within this task. Finally, it has to be mentioned that all of the partners involved in this Demo found another benefit in expanding their knowledge, especially regarding the parts of the system for which they are not in charge. This aided them greatly in spotting the room for potential improvements, especially regarding the efficiency of some parts of the processes or even entire procedures that happen on the daily basis.

Finally, regarding the expected next steps of the process, it should be highlighted that the final six months of OneNet project should be dedicated to the evaluation of the Demos and the level in which the goals set for each of them have been achieved during the project. This will be performed through the analyses of the values of KPIs that were specified sometimes during the project via the combined effort of the team within the OneNet organization and partners involved in each of the Demos. The KPIs that will be taken into account here can be divided into two categories – the general ones, universal for every Demo, and the Demo-specific ones, designed to show the main advancements of each Demo. Evaluation will be conducted in a centralized manner, after which it will be shown in the separate deliverable. For the Southern Cluster, it will be marked as Deliverable 8.4, containing both the assessment of the Greek Demo and the assessment of the Cypriot Demo of OneNet project.

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## Appendix 1: List of Use Cases

Two Business Use Cases (BUCs) were identified regarding the Greek Demo. Those BUCs can be seen in the list below, together with the respective brief descriptions:

- BUC 1: Enhanced Active Power Management for TSO-DSO coordination. This BUC is based on improved identification of the available flexibility resources, focused primarily on the DSO voltage level, together with the enhanced identification of the power system flexibility needs, focused on the TSO voltage level grid. Along with that, this BUC considers the time horizon that is quite longer and the geographical scope that is wider than the respective ones that are commonly in use today, which is achieved through the simultaneous market and grid simulations backed up by AI based calculation engines. The objectives of this BUC, according to its official description, are the following:
  - Frequency stability;
  - Load flow and contingency monitoring and predictions;
  - Predictive congestion management;
  - Cost-effective operation of the system;
  - Early warning on the hazardous power system regimes;
  - Better flexibility service provider (FSP) planning and management;
  - Enhanced energy and power system state predictions;
  - Improved identification of the available FSPs;
  - Improved prediction of the system flexibility needs.
  
- BUC 2: Enhanced severe weather condition management and outage management for TSO, DSO and micro grid operator. This BUC is set to focus on enhanced severe weather condition management with predictive maintenance algorithms, combined with enhanced storm and icing predictions in order to prevent the power system from running into dangerous topological or operational regimes. The objectives of this BUC can be seen in the list that is provided below:
  - Predictive maintenance and outage management;
  - Enhanced severe weather condition management;
  - Outage management optimization for increased system adequacy;
  - Early warning on the potentially hazardous power system topology and regimes;
  - Avoidance of damages caused by the severe weather conditions.

These Business Use Cases have a total of eight System Use Cases (SUCs) that are directly related to them. The short insight into each one of those system use cases, together with the specification to which each of the BUC is related to, can be found in the following several paragraphs:

- SUC 1: Improved production and consumption prediction for DSO and microgrid voltage levels. This SUC is directly related to BUC 1, described in the previous part of this subchapter. The scope of this use case includes the improvement of the production and consumption predictions, focused mainly on the DSO voltage level, considering longer time span and wider geographical scope than any methodologies or tools that are commercially available today. This target is expected to be achieved through the simultaneous DSO and TSO grid simulations that are backed up by AI based analyses, all that while taking the reliable forecasts of the relevant weather conditions as the input. This shall allow improved observability of the results on the higher control and monitoring levels. Regarding the objectives of this SUC, the following prominent points have been underlined:
  - Frequency stability;
  - Load flow and contingency monitoring and predictions;
  - Cost-effective operation of the system;
  - Better FSPs planning and managing flexibility resources;
  - Better energy predictions and power system state predictions;
  - Improved identification of the available flexibility resources on all power system levels;
  - Improved prediction of the system flexibility needs.
  
- SUC 2: DSO, DG and PoI management. This SUC is also related to the goals of BUC 1, dealing with the enhancement of the TSO-DSO coordination. It is supposed to envelop the development of the user-friendly Register of PoIs that would contain the overview of the relevant characteristics of the regions of the system that are selected as critical or important for any other reason, while also focusing on the necessary regular periodic updates, technical, historic and forecasted data archiving, as well as on the analysis of the data for the future AI applications. It is important to state that, in line with its name, this use case is primarily set to concentrate on the DSO, DG and microgrid voltage levels. The objectives of this System Use Case have been defined as the following:
  - Load flow and contingency monitoring and predictions;
  - Predictive congestion management for maintaining secure and stable power system operation;
  - Cost-effective operation of the system;
  - Early warning on the hazardous power system regimes;
  - Better FSPs planning and managing flexibility resources;
  - Better energy predictions and power system state predictions;
  - Improved identification of the available flexibility resources on all power system levels;
  - Improved prediction of the system flexibility needs.

- SUC 3: Change View – different aggregation level simulations. This SUC is, similarly to the previous two, related to the first described BUC of the Greek Demo. It focuses on giving the user an option of manually defining the domain of the DSO/microgrid or TSO voltage level region of interest for which the simulations of the power production, flows and consumption will be conducted in order to avoid the unnecessary calculations and sub-optimal usage of the available resources. These calculations are set to include the contingency analyses, among other functionalities. Once the capability described in this SUC (performing the analyses solely for the part of the system determined by the user) is realized, it will guarantee the shorter computational times without putting their reliability at any kind of risk. The objectives of this SUC can be seen in the list provided below:
  - Frequency stability;
  - Load flow and contingency monitoring and predictions;
  - Predictive congestion management for maintaining secure and stable power system operation;
  - Cost-effective operation of the system;
  - Early warning on the hazardous power system conditions;
  - Better FSPs planning and managing flexibility resources;
  - Better energy predictions and power system state predictions;
  - Improved identification of the available flexibility resources on all power system levels;
  - Improved prediction of the system flexibility needs.
  
- SUC 4: Improved congestion management process on TSO and RSC side. This System Use Case is, once again, stemming directly from the foundation set by BUC 1. It will revolve around the improvement of the short-term predictions of the load, production and transmission capacities, based on the accurate weather forecasts. This will be followed by the contingency analysis and capacity calculations through the usage of the data obtained from DSO and/or local microgrid operators in the process of the constant and seamless exchange of information between all of the participants in the value chain. The primary objectives of the SUC, harmonized both with the specified objectives of the corresponding Business Use Case and the remainder of the SUCs connected to this BUC, are given below:
  - Frequency stability;
  - Load flow and contingency monitoring and predictions;
  - Predictive congestion management for maintaining secure and stable power system operation;
  - Cost-effective operation of the system;
  - Early warning on the hazardous power system regimes;
  - Better FSPs planning and managing flexibility resources;
  - Better energy predictions and power system state predictions;
  - Improved identification of the available flexibility resources on all power system levels;
  - Improved prediction of the system flexibility needs.

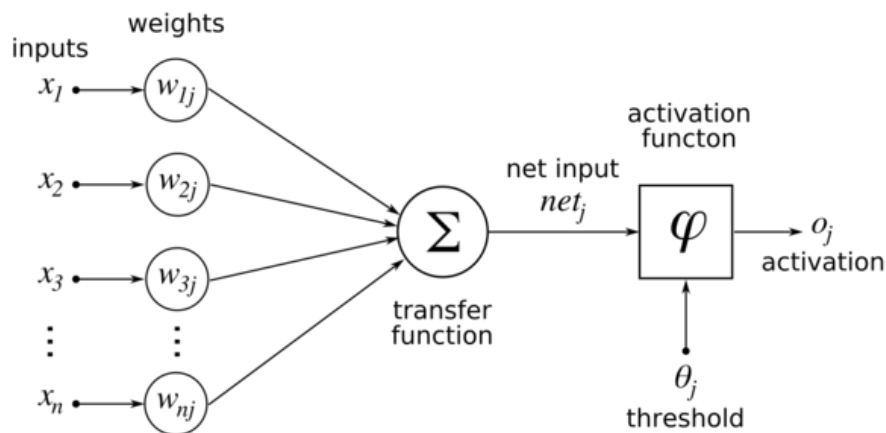
- SUC 5: Storm and Icing predictive maintenance process in TSO, DSO grid and local microgrid. This SUC pertains to BUC 2. Its scope envelopes the prediction of the severe weather conditions, such as the occurrences of the storms or the forming of ice, which will not only assist the operators of the system, regardless of the voltage level of the system in question, in scheduling the maintenance of the elements, such as the lines or distributed generators, but will also significantly aid in avoiding the consequences of those weather conditions, may those belong to the technical (potential black-outs) or the financial (damages that may happen to both the system elements and the consumers) category. Some of the more important objectives and goals of this System Use Case are provided in the list that is enclosed below:
  - Predictive outage management for ensuring the secure and stable power system operation;
  - Improved islanded operation of the parts of the system;
  - Improved system adequacy on both TSO and DSO sides;
  - Cost-effective operation of the system;
  - Optimal allocation of the available resources;
  - Voltage stability of the system;
  - Frequency stability of the system;
  - Early warning on the hazardous power system regimes.
  
- SUC 6: Outage management process in TSO/DSO grid and local micro grid. This use case is the second of two SUCs that are related to the second described BUC. It aims at the potential increase of the reliability of outage and maintenance plans of the SOs by granting them a more accurate insight into the conditions under which the system may be forced to operate in upcoming periods and the challenges that it might face based on those conditions. By that, the application of methodology encompassed by the case could, via the AI-driven data exchange and analyses, help SOs in changing the maintenance and outage plan so the potential grave consequences for the system can be avoided. As the input for these actions, the system operators will have at their disposal the accurate forecasts of the relevant weather parameters that will be utilized in order to achieve the set targets. Regarding the objectives of this use case and the improvements that can be expected from it, the following can be emphasized:
  - Predictive outage management for ensuring the secure and stable power system operation;
  - Improved islanded operation of the parts of the system;
  - Improved system adequacy on both TSO and DSO sides;
  - Cost-effective operation of the system;
  - Optimal allocation of the available resources;
  - Voltage stability of the system;
  - Frequency stability of the system;
  - Early warning on the hazardous power system regimes.

- SUC 7: Improved frequency control on TSO side. This SUC is, in the fashion same as the initial four SUCs included in this chapter, related to BUC 1 of the Greek Demo. It is envisaged to consider the situation in which the imbalance of such proportions is noticed in the system that jeopardizes the frequency stability, thus requiring immediate response. This action is composed of the optimal identification and activation of the available flexibility resources that could be used to mitigate the consequences of such an event. Active power flexibility products provided within this use case will enhance the frequency stability, relieve the congestions in the system and enable a cost-effective operation of the system, while simultaneously exploiting the flexible sources through mFRR and aFRR. The objectives that were stated in the moment of the definition of this System Use Case were the following:
  - Frequency stability;
  - Load flow and contingency monitoring and predictions;
  - Predictive congestion management for maintaining secure and stable power system operation;
  - Cost-effective operation of the system;
  - Early warning on the hazardous power system regimes;
  - Better FSPs planning and managing flexibility resources;
  - Better energy predictions and power system state predictions;
  - Improved identification of the available flexibility resources on all power system levels;
  - Improved prediction of the system flexibility needs.
  
- SUC 8: Improved Voltage control on DSO and TSO side. The eighth and final SUC related to the BUCs of the Greek Demo is heavily entwined with the specifications of the first of those BUCs. It considers the situation in which the potential overvoltages or undervoltages are predicted well up front, with enough time remaining for the proper reaction. As such events can easily trigger the voltage instability of the system, it is necessary for the concerned system operator to coordinate the relevant FSPs in order to provide the needed reactive power flexibility, with the FSPs connected both to the DSO grid levels and the TSO grid levels (mainly through the power transformers with the tap-change option). The objectives that were assigned to this System Use Case are provided below:
  - Voltage stability;
  - Load flow and contingency monitoring and predictions;
  - Predictive congestion management for maintaining secure and stable power system operation;
  - Cost-effective operation of the system;
  - Early warning on the hazardous power system regimes;
  - Better FSPs planning and managing flexibility resources;
  - Better energy predictions and power system state predictions;
  - Improved identification of the available flexibility resources on all power system levels;
  - Improved prediction of the system flexibility needs.

## Appendix 2: General ANN theory

Artificial Neural Networks (ANN) represent an application that is based on machine learning which aims to determine the output of a system based on its inputs. It is the most useful in cases of stochastic systems for which it is quite difficult to define the relation between the input and output values. Therefore, it is necessary to utilize a method that could estimate the output of the system without knowing the exact definition of the system's transfer function. The working principle of ANN is based on the work of the human nervous system. The human nervous system's capability of learning and implementing past experiences in new situations is the most important inspiration for the work of ANN. The human nervous system contains a huge number of neurons with the goal of processing and transmitting the information through chemical and electrical signals. Neurons are connected by synapses. Each neuron processes the information it gets from other neurons, based on which it makes a decision on whether it will forward that information to the following neurons in the same row. In that way, human nervous system processes the information from the outer world, which initiates human reactions.

ANN represent the mathematical model of the human neural network that can, based on the relevant input data and transferring information between artificial neurons, determine the output information that represents the solution of the analysed problem. Fig. A2.1 shows the mathematical representation of a neuron in ANN.



**Figure A2.1:** Mathematical representation of a neuron in ANN.

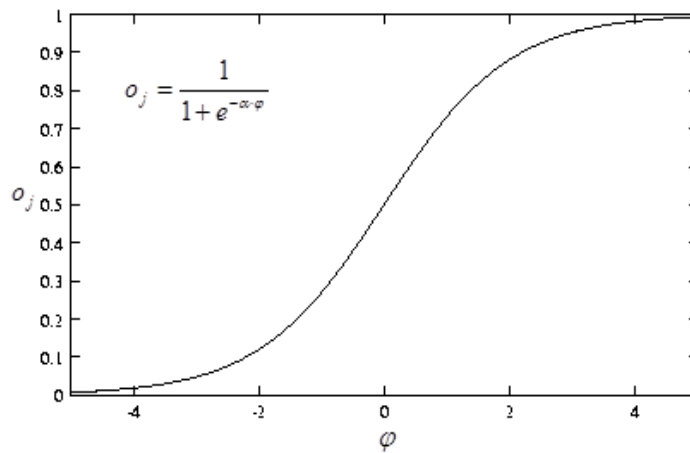
Each neuron has inputs that are connected to it through synapses. Those inputs can either be from the outer world or from the neurons that belong to the previous layer. In Fig. A2.1,  $x_j$  represents the  $j$ -th input,  $j=1\dots n$ , with  $n$  being the total number of inputs. The strength of synapses is defined through the synaptic weight  $w_{ij}$ , where the positive value of  $w_{ij}$  corresponds to the excitatory synapses, whereas the negative value corresponds to the inhibitory synapses. All inputs multiplied by the appropriate weighting factors are integrated in the transfer function. This value is compared to the value of the threshold. If the transfer function is greater than the threshold, the activation value would be 1, otherwise it would be 0. It can be written in the form given by (A.1)

$$\varphi = \varphi(\sum_{j=1}^n x_j * w_{ij} - \theta_j) \quad (\text{A.1})$$

The most commonly used activation function of a neuron is known as the sigmoid function, defined by (A.2):

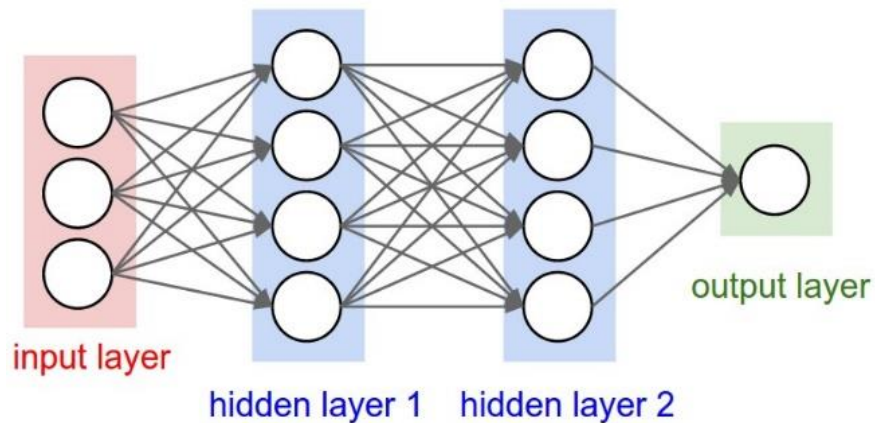
$$o_j = \frac{1}{1+e^{-\alpha\varphi}} \quad (\text{A.2})$$

Since the authors of this report are quite aware that this function can seem rather complex and not so easy to visualize, it was deemed useful to also provide the readers with the graphical representation of this function. Therefore, the diagram of this function, used by the MATLAB neural network toolbox, can be found in Fig. A2.2.



**Figure A2.2:** Diagram of the sigmoid activation function.

The information is, in line with the description of the logic and the process provided near the bottom of the previous page, forwarded from one layer of the neurons to the next one. In order to make this clearer, it should be highlighted that the ANN is organized in layers. The first layer is called input layer and its only purpose is to transmit the signals down the path. The final layer is called output layer. Its purpose is to determine the output of the whole ANN. The pathway between the input and output layers goes through hidden layers. The hidden layers form an ANN and their number directly affects the accuracy of the ANN. The organization of an ANN is shown in Fig. A2.3.



**Figure A2.3:** Internal structure of the ANN.