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Forecasting Transmission and Distribution System Flexibility Needs for Severe Weather Condition Resilience and Outage Management

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Abstract: With the increase in the complexity of the topology of transmission and distribution systems, associated with the predictability in the management of the dispatch of prosumers, new techniques for state estimation, and application of metaheuristics are necessary. In the current work a pilot project in Greece that addresses the difficulties of congestion and balancing management that system operators face in the renewable energy sources era, in accordance with the OneNet's architecture is described. Available resources of grid's flexibility are identified, and the implementation of an integrated monitoring system based on weather conditions with an energy control and dispatch system in the Greek electricity grid is addressed. The document suggests that flexibility resources will derive through predictions that have been improved and efficient forecasts from increased spatial resolution Numerical Weather Predictions and integration of Artificial Intelligence preventing the power system of entering dangerous topological or operational states.

Keywords: transmission system; distribution system; flexibility; Greek electricity market; business use cases; system use cases; key performance indicators; balancing market; target model

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1. Introduction

The Greek electricity market was reformed in 2020, and the Target Model was implemented [1]. Balancing and congestion management are critical operations because decarbonization targets are ambitious and system operators must manage a large volume of variable renewable generation. Efficient generation and demand forecast, congestion management, voltage, and frequency control are all areas of high interest where the respective network models are being developed in close collaboration with system operators.

Wind energy is highly variable and weather-dependent by nature. To ensure system stability and the detection of these significant variations, transmission system operators (TSOs) require accurate wind power forecasts. The accuracy of the underlying Numerical Weather Prediction (NWP) models is also considered. TSOs face difficulties, because some weather conditions are extremely difficult to forecast. As the electrical grid transitions to a system with a high degree of decentralization, the business models of the grid operators must change to allow rapid responses and adaptable flexibility. Due to the unique nature of the issue, an unprecedented response is required. As a result, the European Network of

Transmission System Operators for Electricity (ENTSO-E) and the European Distribution System Operators (EDSO) have encouraged their members to form a special consortium.

A new generation of grid services is what OneNet (One Network for Europe) [2] seeks to develop, capable of utilizing distributed generation, storage, and the demand response while also ensuring fair, open, and transparent consumer conditions. The OneNet is funded by the project Horizon 2020 [3], the EU's eighth framework program. This extremely ambitious perspective is realized by proposing new markets, products, and services, as well as developing a one-of-a-kind IT architecture to support innovative platform federation mechanisms. The project also aims to achieve broad agreement on the solution by launching a number of initiatives, including a large-scale discussion forum within the international energy community.

1.1. Target Model and the Integrated Energy Market in the EU

Market codes are the most relevant codes for electricity markets. These codes describe the "Target Model", which is a totally new design for the internal electricity market of Europe. Corresponding legislation includes: (i) the European Union's Directives 2009/72/EC [4], 2019/944 [5], and 2019/943 [6], which define common rules for the internal market of electricity; (ii) Regulation (EC) 714/2009 [7] defining cross-border electricity exchanges; (iii) Regulation (EC) 713/2009 [8] establishing the Agency for the Cooperation of Energy Regulators (ACER); (iv) Commission Regulation (EU) 2017/2195 [9] outlining specific guidelines for integrating the European balancing energy markets; (v) Commission Regulation (EU) 2017/1485 [10], which establishes harmonized rules for TSOs, DSOs, and Significant Grid Users (SGUs), with the goal of providing the proper legislation for the interconnected transmission system operation; (vi) Commission Regulation (EU) 2015/1222 [11], establishing a Capacity Allocation and Congestion Management (CACM) guideline; and (vii) Commission Regulation (EU) 2016/1719 establishing a Forward Capacity Allocation (FCA) guideline [12]. The Electricity Target Model seeks to integrate various national electricity markets into a common European electricity market [13]. These new markets are depicted in Figure 1.

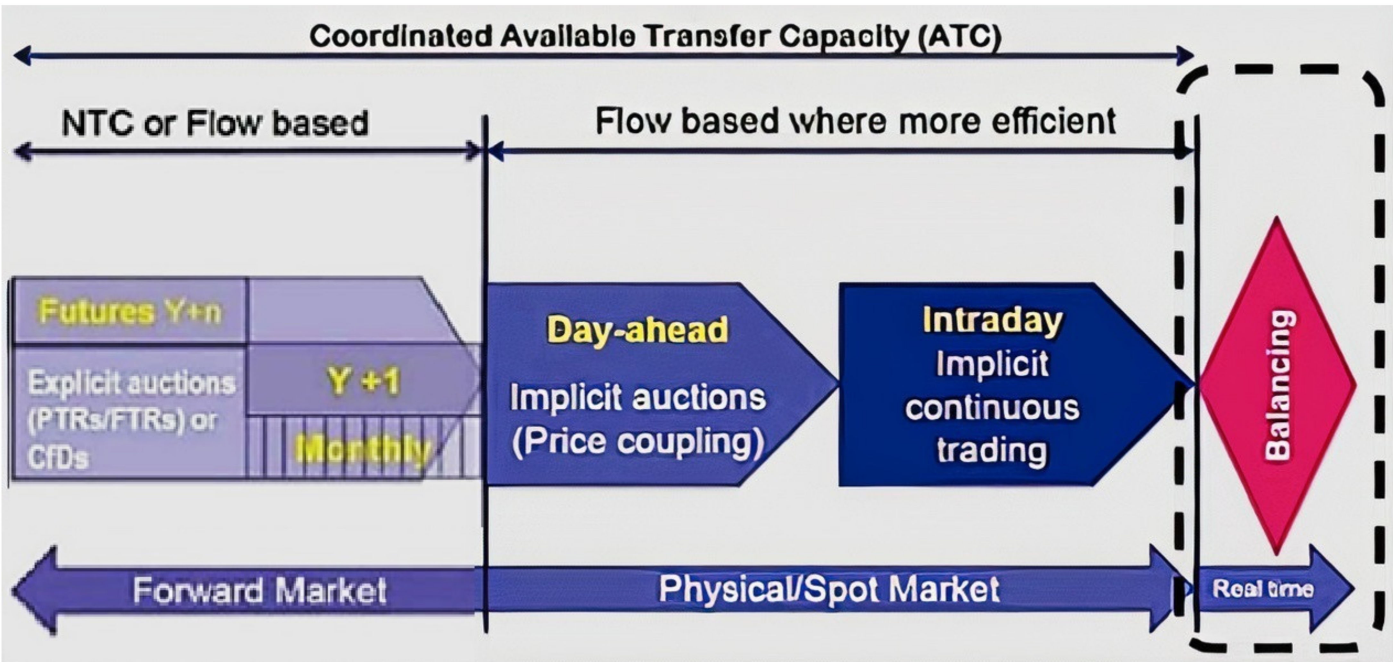


Figure 1. The different markets in the European electricity market [13].

The Forward and Future Markets react to events that occur years in advance, all the way up to the day of delivery. Forward and futures contracts are agreements to deliver a specific power amount at a future date for a price agreed upon today [14]. The Forward Market allows participants of the market to limit their exposure to the Intra-Day Market by ensuring their position when market prices are volatile [13]. Electricity can be traded in Forward and Future Markets between market zones, as well as within market zones [15].

Transactions of electricity with a requirement for physical delivery on a day (D) are auctioned in the Day-Ahead Market on day D-1. Since the market zone must be balanced at the end of the day, the Day-Ahead Market is critical [15], and after it has been cleared, the Intra-Day Market opens [16]. When deviations from their Day-Ahead Market offers occur, market participants can proceed with corrections. Unlike the Day-Ahead Market, which requires a balanced portfolio, the portfolio of the BRP can be unbalanced after the Intra-Day Market [16].

The Target Model is defined in Commission Regulation (EU) 2015/1222 [11] for the timeframes of the Intra-Day and the Day-Ahead. The Target Model of the Intra-Day Market is defined an implicit continuous trade-matching algorithm that enables the coupling of intra-day EU markets is defined as an implicit continuous trade-matching algorithm that allows the Intra-Day Markets' coupling in the EU [17]. After the Intra-Day Market closes, a balancing mechanism ensures that supply equals demand in real-time [18]. The primary goal of the Balancing Market is to make corrections of real-time imbalances in the electricity system between input and output [19]. TSOs must act in real time to secure balancing differences in demand and real-time production.

The TSO must contract three types of reserves in the Balancing Reserve Market (Figure 2). Frequency Containment Reserves (FCRs) are used to stabilize the frequency in seconds using reserves (locally activated or/and automatically controlled) [19]. Frequency Restoration Reserves (FRR), which are controlled and activated centrally, are used to restore system balance and are active for seconds to 15 min [19–21]. When FRR are insufficient to restore system balance, Replacement Reserves (RR) are used (i.e., in case of major imbalances). When frequency restoration reserves are insufficient to restore system balance, replacement reserves (RR) are used (i.e., in case of major imbalances).

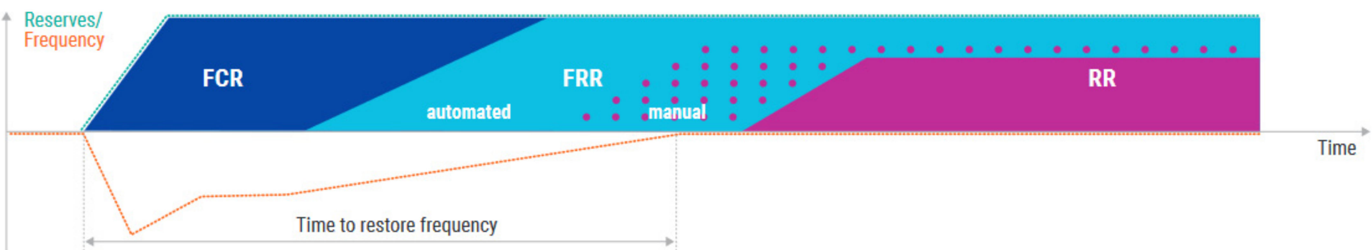


Figure 2. The Balancing Reserve Market [20].

Contractual Balancing Service Providers (BSPs) are paid a payment of availability in Balancing Capacity Markets [20]. The TSO is in charge of resolving imbalances by charging contacted parties for imbalances in their portfolios [6,21,22]. The amount of activated energy is determined by real-time imbalances [14]. The net quarter-hourly difference between the BRP's total injections and offtakes is the BRP's imbalance [14]. The net sum of all BRP imbalances in the control area equals the total imbalance in the control area [14,23]. By activating reserves, the TSO will keep the system balanced. The Net Regulation Volume (NRV) is the number of reserves that have been activated. A positive NRV indicates upward regulation, while a negative NRV indicates downward regulation [14,15].

The Imbalance Settlement Period (ISP) is a key feature in calculating an imbalance price [9,19–21]. By 1 January 2021, the ISP must be synchronized to 15 min [4,22]. The implementation of platforms for the exchange of balancing energy is a critical component [23–32]. These platforms are: (a) for the RR platform, the Trans-European Replacement Reserves Exchange (TERRE), (b) for the mFRR platform, the Manually Activated Reserves Initiative (MARI), (c) for the aFRR platform, the Platform for International Coordination of Automated Frequency Restoration and Stable System Operation (PICASSO), and (d) for the

IN platform, the International Grid Control Cooperation (IGCC). Redispatch is required when the results of the market's outcome in generation and consumption schedules that would potentially violate the limits of operation of a specific network element. Redispatch is typically accomplished by increasing or decreasing the output of a generator.

Electricity will have a crucial role in the economy of the EU [29]. To achieve this, the energy system must be more flexible, and the existing interconnections have to use their full capacity, while maintaining the system's security. The current bidding zone configuration is under strain at high voltage levels. Grid expansion could not keep up with the impressive capacities of installed renewables, and as a result, among other issues, redispatch costs are high and continuing to rise. Furthermore, at low-voltage levels, distribution networks would need to be expanded to accommodate increasing consumer PV installation, electrification of heating and transportation [16].

1.2. The Greek Electricity Market

In Greece, the Independent Power Transmission Operator S.A. (IPTO) is the transmission system's operator, which was established in 2011 [33] and is organized and operates according to EU Directive 2009/72/EC [4]. The Company operates the Hellenic Electricity Transmission System (HETS) in accordance with the provisions of Law 4001/2011, the National Grid Code, and the Operation License. The role of IPTO is to control, operate, maintain, and develop the Hellenic Electricity Transmission System ensuring the country's electricity supply adequately, safely, efficiently, and reliably, as well as to operate the Electricity Balancing Market.

HEDNO S.A. is in charge of the Hellenic Electricity Distribution Network (HEDN) development, operation, and maintenance. The role of HEDNO is to ensure its operation reliably, efficiently, and safely while considering the environment and energy efficiency. This also ensures that Users (Consumers, Producers, and Suppliers) have the most cost-effective, direct, transparent and nondiscriminatory access to the HEDN. Since there is no competition, the operation of the distribution network is a natural monopoly. As a result, the independent Regulatory Authority for Energy (RAE) supervises and regulates these business operations. Regulating is accomplished by approving the revenue that is permitted from such operations. HEDNO is also in charge of the management of the Electricity Systems of the Non-Interconnected Islands (NIIs).

RAE began implementing the "Target Model" in the Greek wholesale electricity market in 2018, based on European regulations, directives, and guidelines. Future targets include the Balancing, Intraday Day-Ahead, and Forward Markets. Since August 2021, HEDNO has transferred ownership of the transmission network in Crete to IPTO, and the transition of the electricity system of Crete into the National and European wholesale electricity market will be made through a specific regulatory framework.

1.3. Greece: The Southern Cluster Demonstrator

Greece-based pilot project implementation includes the Southern cluster demonstrator. In order to address the unique requirements of TSOs, DSOs, market participants, customers, and regulatory peculiarities, this project also offers a cutting-edge common method for TSO-DSO cooperation for flexibility and shared services.

The Peloponnese and Crete regions of Greece will gain the development and implementation of the F-platform, a sophisticated forecasting platform that assesses the requirements and flexibilities for congestion management and balancing. The island of Crete has recently been connected to mainland Greece as a result of which it is now a part of the pan-European integrated electrical network (Figure 3). In Crete and the Peloponnese, the high voltage level is currently 150 kV; however, new projects, consisting of new Overhead Lines (OHLs) at 400 kV and new HV substations, have been proposed and are currently being built. Since the Peloponnese region is mountainous and has a high wind capacity, many wind parks have been established despite the current network's capacity being insufficient to accommodate the installation of further wind power. Since diesel power units must be phased out in the next few years due to environmental regulations, the TSO included the AC connectivity with South Peloponnese. A second HVDC (scheduled for operation in the beginning of 2024) will connect Attica with Crete as well.

Figure 3. How Crete is connected to the mainland according to the National TYNDP 2021–2030.

In accordance with the OneNet overall design, the ultimate goal of the Southern demonstrator is to prescribe, develop, implement, and evaluate a research and development project in Greece that addresses the balancing and congestion management difficulties faced by system operators in the clean energy era. By utilizing grid services from prosumers, aggregators, suppliers, and producers, the TSO and DSO will cooperate in flexibility and coordination issues. Additionally, they will maximize the use of network assets and big data processing tools for network predictability and observability.

In order to assess particular approaches and market processes that will eventually be included in the OneNet platform, the Southern demonstrator will use effective algorithms for forecast, technologies for grid observability, algorithms for balancing, and congestion management. The outcomes of the demonstrator will be assessed in order to offer suggestions for upcoming reforms in the market structure and the forthcoming harmonization of an EU wide power market.

2. Challenges in the Market Structure

To achieve all of the Clean Energy Package goals, Greece must address several challenges that the current market and power system face. Domestic market liberalization poses a significant challenge to the Greek energy system. Unless additional market liberalization measures are implemented, effective competition is impossible in Greece, and the benefits of the electricity markets to consumers will be significantly reduced. Another issue that must be dealt is the target of 2030 for installed RES. Unfortunately, problems of decades associated with the RES implementation in the Greek power system have persisted. The time-consuming RES licensing procedures, the uncertainty of the future of the special RES account, and the lack of electrical interconnections with regions with high-RES potential, are typical examples of these problems. Apart from these issues here are new challenges for RES, such as the new auction-based Feed-in-Premium (FiP) system, the postponement of the full Target Model and electricity market regional coupling, which prevent new RES projects to participate in the electricity market.

Until now, the Greek electricity Market has been in a transient phase in which RES producers for the deviations they bring about in the Balancing Market; they simply bear balancing responsibility. At the end of 2022, the last phase of RES unit participation in the Target Model is anticipated to start. The goal of a RES aggregator is to guarantee the associated RES units' successful commercial operation. They represent for the fluctuation reduction between forecast and actual RES unit production and, as a result, keep the deviation charges imposed on RES producers to a minimum. Furthermore, traditional units are mostly responsible for stable energy generation at the moment, but as they fade away, concerns arise about RES units' ability to maintain this stability on their own and bear the cost.

The consumer's engagement in the energy system, both through flexibility in load operation and generation assets, is a crucial issue that the Greek electricity system must acknowledge [34–52]. Consumers, however, frequently are unable to take advantage of these new opportunities due to current market regulations. In order for consumers to profit financially from these new opportunities, they must have access to smart systems and electricity supply contracts with dynamic rates connected to the spot market. New demand services are currently developing, whereby new market actors offer to manage the electricity consumption of a number of consumers by compensating them for their flexibility [34,35]. The new market structure attempts to prevent any official involvement in supply prices and only allow for properly justified exceptions. However, the lack of standardized guidelines for "prosumers" continues to hinder self-generation. Appropriate rules could eliminate these obstacles by protecting users' rights to produce energy for their own use [18].

Information is a significant factor in both competition and customer involvement. According to studies, customers are less able to take advantage of competition and actively participate in markets because of the lack of transparency in the power markets. Consumers complain about the difficulty of offers and switching provider processes and feel under informed about alternative suppliers, the availability of new energy services, and these topics. A variety of energy data with significant economic value will be produced by the rising use of new technologies, especially smart metering systems, while data protection measures are applied. Therefore, in order to truly manage the electrical infrastructure as OneNet, we need new forms of cooperation among the actors.

OneNet proposes new, standardized products and services and makes them available through an open, interoperable, scalable, and standardized IT infrastructure. The development of GRIFOn platform (GRId FOrum), for the stakeholders that will be utilized to foster ongoing communication between the project and all other stakeholders, is a crucial component of this project's organizational structure.

Regarding the Greek demo, the "TSO-DSO Flexibility Channel" (F-Channel) is an online platform that may show how to set up a flexibility market with a variety of common items for TSO-DSO coordination (Figure 4). The coordination module, which will take into account data, and the functionality of IPTO-HEDNO key systems, will develop a flexibility platform, which will provide grid services for the balancing and congestion management challenges.

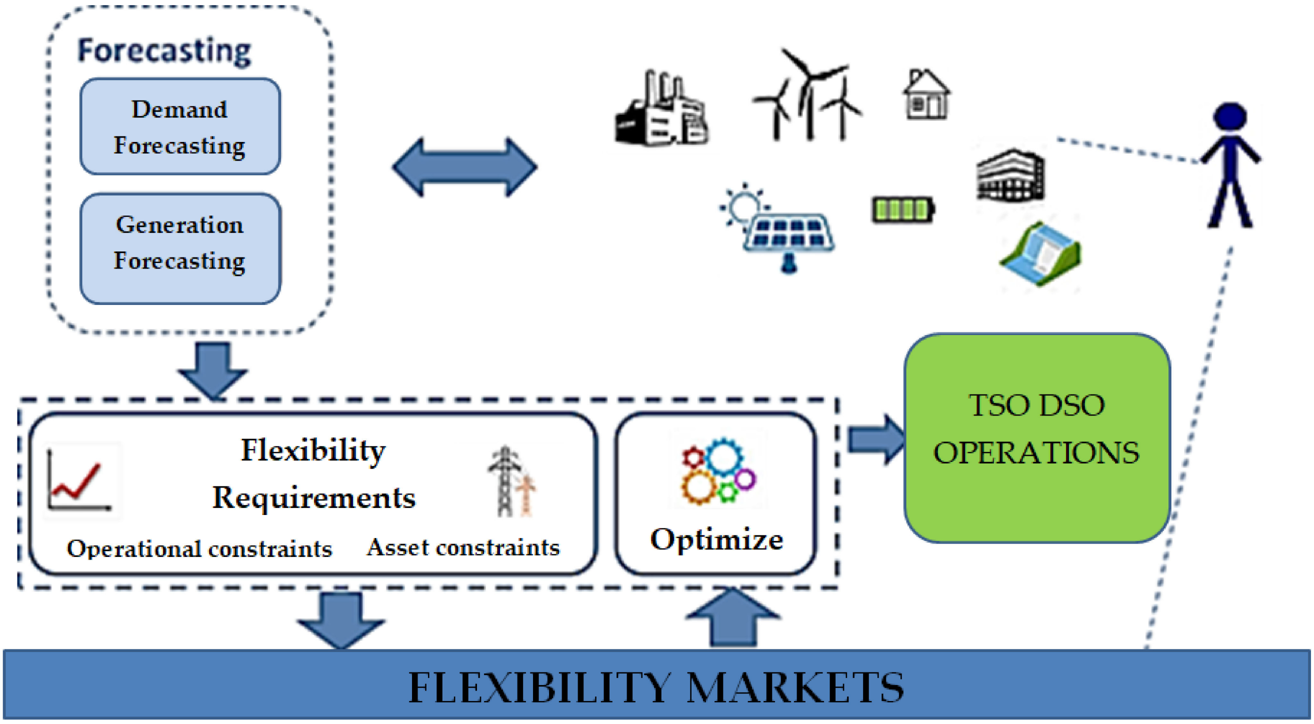


Figure 4. F-channel architecture.

Modules on forecasting and coordination will take into account all the various market participants in Greece who are currently or will be in the near future. Additionally, such modules will include "prosumers", "aggregators", and their participation in the energy mix and flexibility provision, flexibility providers/storage owners/EV charging station operators, and others (RAE is currently formulates EV regulation and grid storage).

Two scenarios will be examined in the Greek demo: (i) the current situation, dry-run testing of forecasting in various timeframes, balancing and congestion management processes, linkage with the present processes in IPTO and HEDNO, and (ii) examining near-term market reform scenarios and business prospects for flexibility services as a result of DERs, prosumers, storage owners, owners of EV charging stations, and new aggregator profiles, as well as extensive scenarios, such as markets in a local area, plans for new investments and interconnections, and reforms in regulation (Figure 5). It is important to note that all of the aforementioned events will occur near the Peloponnese-Crete AC link. The latter presents considerable operational challenges: the HVDC interconnection will be in operation in 2023, while the transmission network of Crete (owned by HEDNO) was linked with the mainland transmission backbone (run by IPTO) in 2021. High-RES penetration is already present in the area and is predicted to increase.

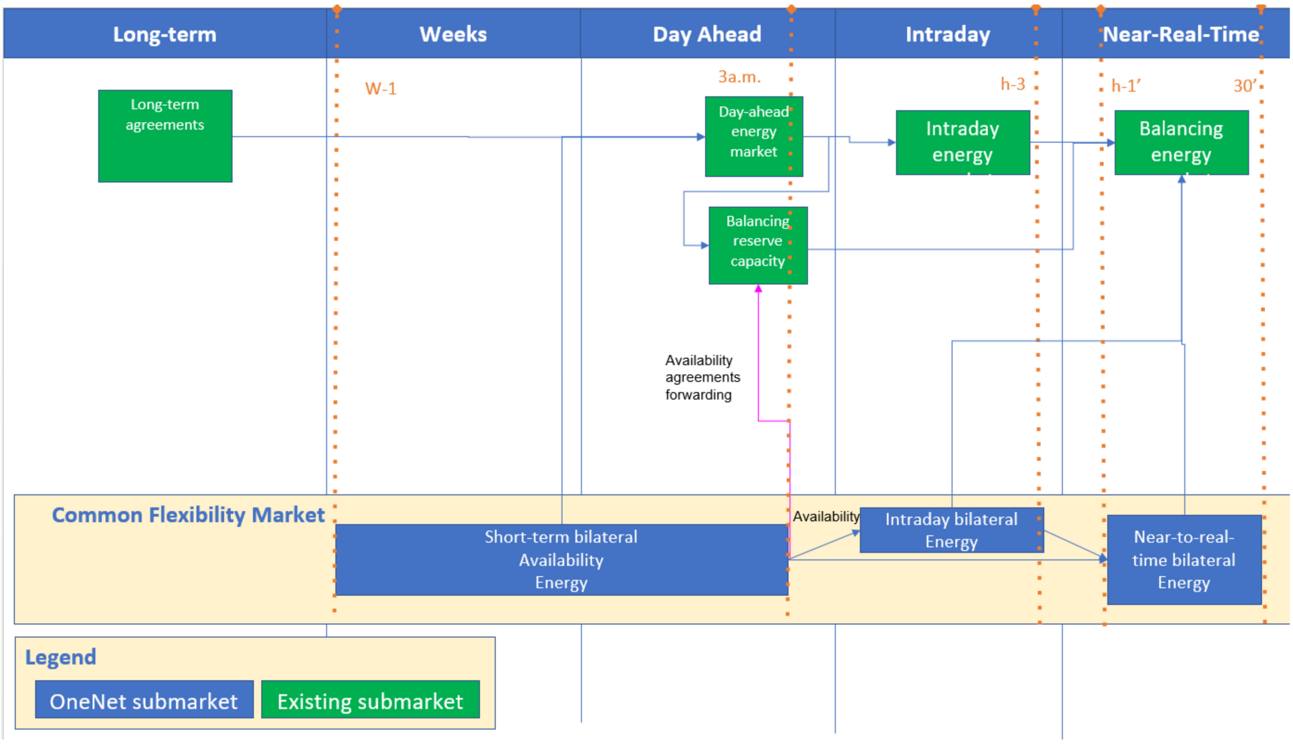


Figure 5. Visualization in a high level of the pilot project in Greece.

3. Platforms, Specifications, and Scenarios for the Pilot Projects for Flexibility Services to the Greek Transmission and Distribution System

3.1. Approach of the F-Channel

A web-based client-server application called F-channel is anticipated to improve Active Power Management for the coordination of TSO-DSO utilizing Artificial Intelligence (AI) techniques and a cloud computing method.

Today is possible to continuously predict a number of features that are crucial to the requirements of the power system, since meteorological data models have become more widely available. Wind speed and solar insolation patterns can be predicted with a high degree of precision over the course of the yearly season with the help of AI techniques and cloud computing environments. Aside from demand response forecasting, other notable advancements that can significantly help with the planning, flexibility, and reliability of the power grid include new projects to simulate icing on power lines and wind turbines using historical meteorological data models.

Similar techniques will be used towards the objectives of this project. After analyzing historical meteorological data with an hourly resolution, each set Point of Interest (POI) output will be appropriately predicted.

Once the model has been developed, its sensitivity must be assessed against real-time data, and modifications must be made using AI algorithms to maximize the model's efficiency. The model will also employ the most advanced NWP coming from external expert weather forecast to fine-tune and improve predicted outcomes. Later stages, after integration with weather data in real-time has been investigated, will consider and present the notion of developing a sustainable solution for industrial partners.

3.2. Approach to Active System Management (ASM) and Regulatory Framework

A crucial question that needs to be answered is to find ways to integrate the offered flexibility services in the energy market via these actors and new assets. Then, we will be able to use them for balancing and congestion management, ensuring the efficient and reliable system operation. This is due to the enormous growth of distributed generation from renewable sources and storage as well.

Congestion management and balancing are first supported by network codes and guidelines. Additionally, it is anticipated that the Clean Energy Package will allow DSOs the ability to acquire non-frequency auxiliary services and manage grid congestion. This is the most economical option, since DSOs must buy these services.

Ancillary services are those that DSOs and TSOs receive in order to maintain the grid's operation within reasonable limits for the security of supply. These services are typically provided by outside or by the TSOs and DSOs themselves [53]. Ancillary services are as follows:

(a) frequency ancillary services (mainly for balancing);
(b) services for congestion management;
(c) non-frequency ancillary services (e.g., voltage control).

Active power management is examined in the Active System Management (ASM) study from the standpoint of a close partnership between TSOs and DSOs. When such services are offered using a market-based approach by flexibilities owned and operated by outside companies [53], the congestion management in both distribution and transmission grids is also examined. The modification of generation injection and/or consumption patterns in response to an external signal (price signal or activation) to provide a service inside the energy system is referred to as flexibility in the context of the Greek demo [54]. The regulatory framework to these issues is:

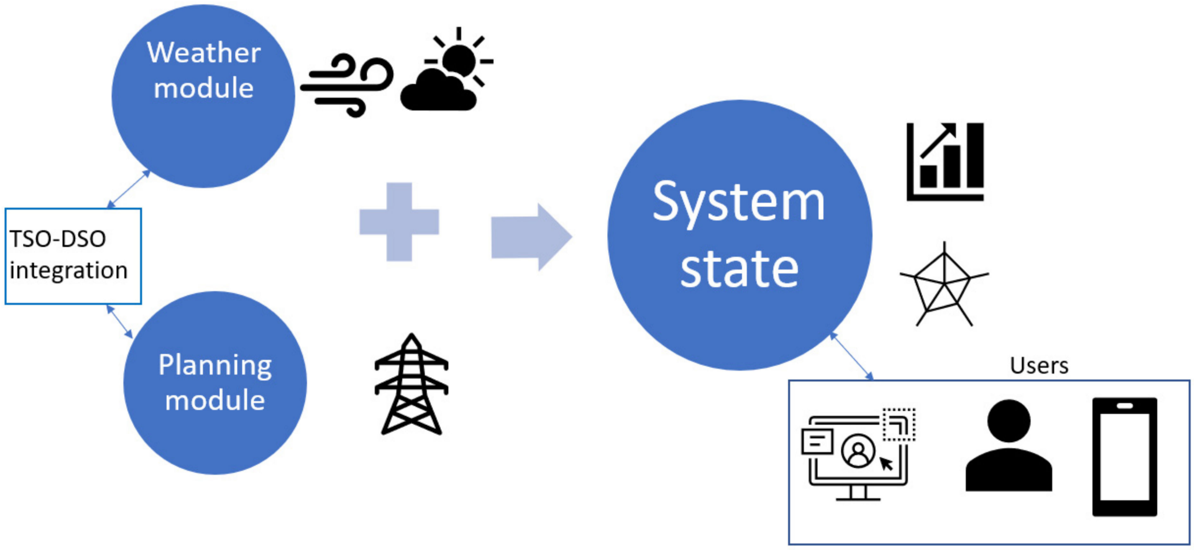
(a) Article 32.1 of (EU) 2019/944 Directive [5].
(b) System Operation Guide Lines (SOGL) [10].
(c) Electricity Balancing Guideline (EBGL) [9].
(d) Guideline on Capacity Allocation and Congestion Management (CACM) [11].
(e) Network Code on Requirements for Generators [54].
(f) Demand Connection [34].

3.3. Proposed Architecture and System Layout

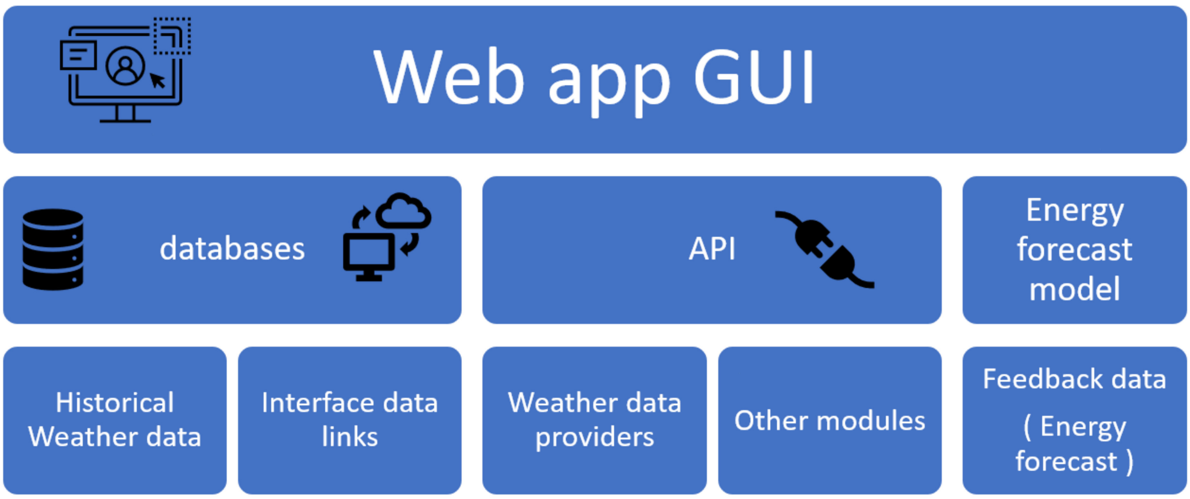
Figure 6 shows the basic planned system layout. To appropriately manage the weather variability in RES generation and demand, particular care must be given while establishing data communication between weather forecasting modules and planning modules.

A cloud computing system will be taken into consideration for this project and, if necessary, employed for modeling purposes based on the required computer resources for Energy projections. The basic architecture of the suggested web application is consisted of the following:

1. Additionally, a similar computing engine will be created for analysis of the grid and calculation. Databases and storage accounts are necessary for data storage. The two types of computing resources that have been allocated are continuously and per computation/transaction allocation. Power grid information and any necessary market data would be kept on a dedicated, secure server that was physically located at Energo Info Group (EIG) facilities or at another partner's facilities, as agreed. However, power system analysis calculations would also be done, making the application both incredibly fast and "light" in terms of the storage requirements.
2. The calculation engine will be powerful enough to handle calculations for transmission, distribution and any specialized microgrid architecture.
3. The database must be organized using the standard RDBM Rational model. Given that the primary datasets are geographically oriented, a spatial geographic component must be implemented. All datasets may now be represented, aggregated, and queried more easily. The development of Web Map Services (WMS) and Web Feature Services is required to display.
4. Infrastructure security for servers is given special attention. Secure Shell (SSH) keys must be used to encrypt server access codes for the development environment. Access must also be limited to certain IP address ranges. On the user side, access to the web application must be restricted to verified accounts made by the administrator.



(a)



(b)

Figure 6. (**a**) Proposed system layout for the F-channel. (**b**) Cloud computing engine.

3.4. Algorithms and Methods from Artificial Inteligence (AI)

In to identify the climatic parameter behavior patterns (daily, monthly, and season), historical weather data with a 1-h resolution must first be employed. Various ERA5 climate datasets will be employed, and AI techniques will be applied along with terrain orography data for this purpose. This information will be a starting point for developing various case studies, allowing for the monitoring of all RES locations throughout time and the identification of important scenarios using AI algorithms. Since ERA5 [55] models are capable of generating a variety of wind speed parameters (e.g., wind gust), these variables must be evaluated and adjusted as necessary to minimize bias when compared to operational data. The results of the models must be compared to operational data from TSO/DSO, and deep learning AI techniques must be used to calibrate the models appropriately.

The implementation model must be connected to the forecast weather Application Programming Interface (API) in the second stage of the project, when various climatic parameters important to production are being obtained. Data from stakeholders must be implemented based on a unique interface. Line rating can be calculated using projected data and is based on wind and temperature. Utilizing CPU-oriented, vectorized, highly efficient processes, all necessary calculations must be made. The primary programming languages to be used for implementation are Python and C, with a GUI created in Flask environment.

Calculation models must adhere to all applicable standards and procedures. For instance, the IEC 61400 series is used for predicting wind production and is followed when calculating conductor ampacity. Models can be updated at later stages of the project based on feedback from site measurements.

3.5. Distribution and Microgrid POIs

Through improved short-term power system planning in both system operators, the F-channel will model the transmission and distribution system, as well as microgrid levels, enabling DSO-TSO coordination in the areas of congestion management and flexibility services. In the meantime, it is allowed the prosumer's active inclusion and role as an equal market participant. All vertically connected entities would be covered by full vertical data and service flow.

3.6. Data Requirements

In order to develop and implement the F-channel, the following dataset was collected.

3.6.1. Network Models Data

IPTO has provided transmission system network models. The distribution system's network models will be created using the data that is already accessible, and appropriate equivalents will be applied for simulation needs.

3.6.2. Geospatial Data

For the examined Wind Power Plants (WPPs) and OHLs, the following GPS coordinates, of power system's components locations, including the routing of each tower's position, are provided:

- Substations.
- Wind parks.
- Solar parks.
- 400 kV HVAC lines.
- 150 kV HVAC lines.
- 20 kV HVAC lines.
- HVDC lines and cables of interest.

GPS data from the power system and GPS data from a few chosen POIs will be used for the visualization of GIS, energy forecasts, and weather localization:

- Start and finish GPS positions for cables lines and OHLs, together with the names of the corresponding substations. If the same POIs are connected in parallel lines, it is required to specify whether the circuit is single or double. Dimensions, weight, and rated ampacity of the conductor, as well as the conductor's bundle type arrangement (two or three-bundle, etc.).
- Substations' GPS points: specifying the ends of the substation's surface and describing the plant's surface.
- GPS points of every WP tower in the examined wind parks.
- GPS points of each OHL tower of the OHL that is analyzed.
- Proposed interconnection lines list (TSOs).

3.6.3. Technical Data for PV Parks and Wind Turbines

If available, TSOs and DSOs have to give technical specifications for every type of installed wind turbine after choosing the appropriate POIs. Otherwise, TSOs and DSOs will substitute generic standard data. To be more precise, the technical specification data required are presented in Figure 7:

- **For each turbine**: the turbine type, longitude, latitude, altitude, rotor diameter, tower height, rotor height, A-factor, form factor c, annual average wind speed, vertical average shear component, extreme wind speed (10 min average), survival wind speed (3 sec average), automatic stop limit (10 min average), rated power, rotor speed, rated wind speed (30 sec average), cut in wind speed (3 sec average), cut out wind speed (10 min average), restart wind speed (10 min average), power curves.
- **For each section of PV panels in solar parks:** longitude, latitude, altitude, tracking or static panels, power conversion factor, panel´s tilt angle.
- **For selected overhead lines:** longitude, latitude, altitude, tower type, tower total height and wire height. The overhead line route cross-section for the OHLs that will be covered by innovative forecasting must also be provided.
- The names of the two substations they connect, the voltage level, the number of circuits, and the parallel OHL index are all required for proposed critical lines (DSOs and TSOs).

Figure 7. Technical data for PV parks and wind turbines.

3.6.4. Historic Energy Data

- Historical production statistics for each of the concerned plants (wind and solar), including hourly production for the previous ten years.
- Historical data for energy consumption: hourly use for the previous ten years.

3.6.5. Historic Weather Data

Greek POIs were examined in terms of their energy production and consumption using historical weather data that measured and forecasted these variables. Greek authorities and/or TSO and DSO may be able to supply these statistics (measured and anticipated) over the previous 10 years.

3.6.6. Copernicus Climate Change Service Reanalysis Data

The European Centre for Medium-Range Weather Forecasts (ECMWF) implements and maintains Copernicus databases, which contain information accessible to the general public and scientific community [55]. Where accessible, the historical information about the chosen POIs will be gathered, as it can be seen in Figure 8.

3.6.7. Energy Policy Information

Energy policy information has been for the coordination of TSO DSO [4]. When necessary, the data is processed and saved on a separate database on the production server. The two categories of allocated computing resources are: (i) continuously allocated and (ii) allocated for each computation or transaction. During the demonstration/test period, calculations for power system analysis will be made using both cloud computing and other AI techniques.

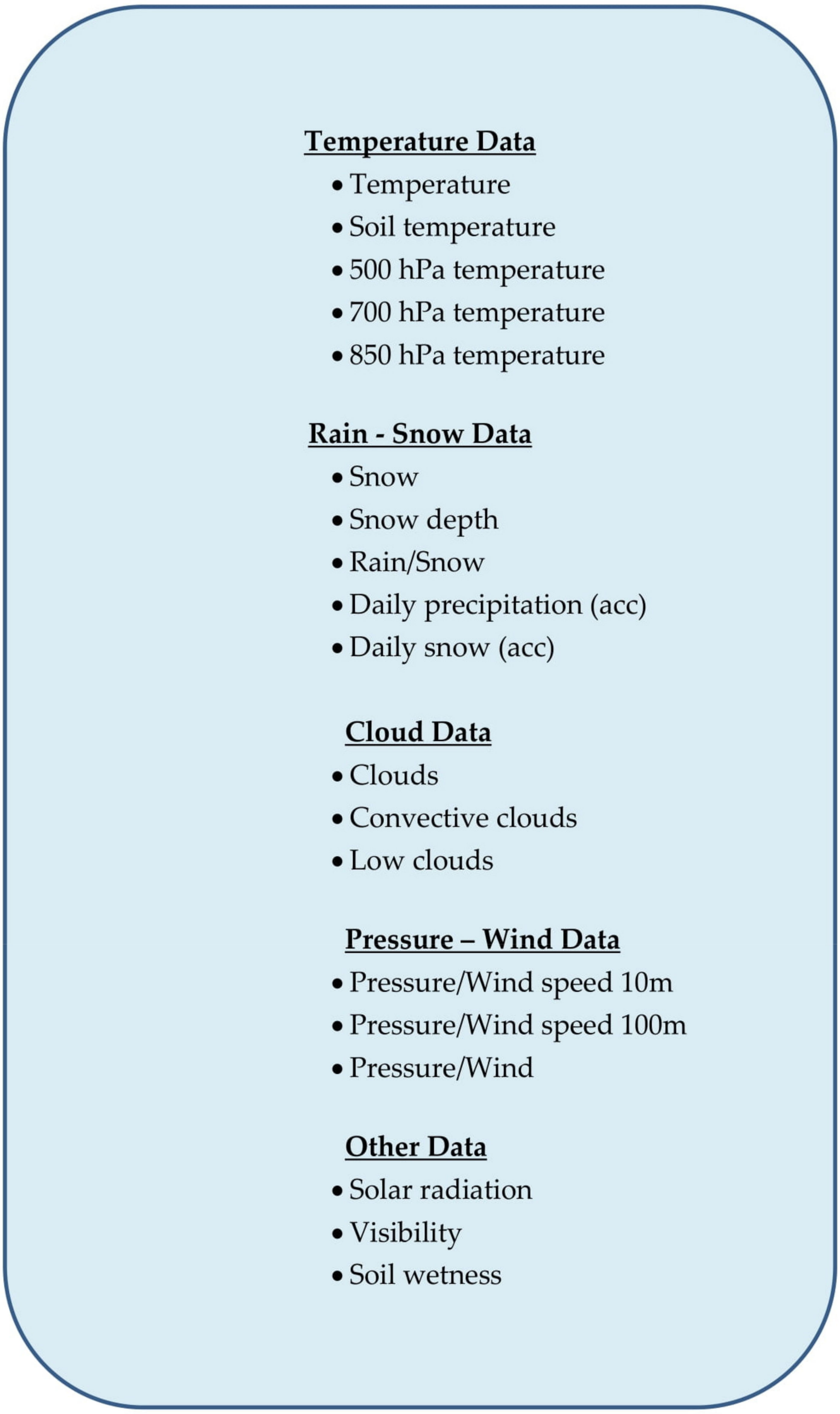


Figure 8. Data needed from Copernicus Climate Change Service reanalysis.

4. Southern Cluster's BUC, Products, and KPIs

Through grid simulations of the DSO and the TSO at the same time, supported by AI algorithms run by robust machines, F-channel aims to identify the available resources of flexibility, focused on the voltage level of the DSO. This also aims to identify the flexibility needs of the power system, focused on the voltage level of the TSO grid. This effort will be implemented for a longer period and for a wider geographical area of the one that is used until now.

4.1. BUC and KPIs for the Demonstration of the F-Channel in Greece

The Business Use Case (BUC) for the F-channel platform is "Enhanced severe weather condition management and outage management for TSO, DSO, and microgrid operator", and it will be shown through the Greek demonstration. In cooperation with OneNet partners, this BUC has been connected with products and System Use Cases (SUCs) (Table 1).

Table 1. Correlation of System Use Cases (SUCs) and Products.

SUC	Product/s Involved
DSO and TSO improved System adequacy (Processes for managing outages in the DSO grid and local microgrid and for doing storm and icing predictive maintenance).	Product to prevent or restore a severe system's state
DSO, DG and microgrid POI management (POIs updates, technical data, history data, data from forecasts, etc.).	N/A
Modified point of view simulations in different level of aggregation (Energy and system status forecasts for various DSO grid and local microgrid aggregation levels).	N/A

4.2. Description of the Business Use Case

The goal of this Business Use Case is to prevent the power system from entering risky topological or operational states by improving management in extreme weather conditions through algorithms on predictive maintenance and increased predictions of storms and icing. Additionally, the objectives of this Business Use Case are:

- Outage management and predictive maintenance.
- Improved management of extreme weather conditions.
- Optimization of outage management for better system performance.
- Prompt notification of potentially dangerous power system topologies and regimes.
- Preventing damage from extreme weather-related events.

Units of distributed generation, the OHLs of the DSO, TSO, and microgrids will all be included in the F-channel application that will be created. To prevent the power system from entering risky topological or operational states, algorithms on predictive maintenance with improved forecasts in storms and icing will be created. Additionally, for the optimum outage management of the grid (DSOs or microgrids), better forecasts from increased spatial resolution and AI techniques together with the early warning on a potentially dangerous power system topology and prevention of damage brought on by extreme weather conditions will be implemented.

The following are the primary anticipated advantages and features of this particular business case:

- Predictive maintenance for storms and icing in local microgrids, DSO grids, and TSO grids.
- The outage management of the grid (DSOs, TSOs, or micro-grids).

In Tables 2 and 3, there are the KPIs for this BUC and the conditions/assumptions/prerequisites for the BUC, respectively.

Table 2. Key performance indicators for the BUC.

Name	Objectives
Prediction error for ice appearance	• Utilize predictive congestion management to maintain a safe and reliable electrical grid. • Prompt notification of dangerous power system regimes
Prediction error for storm appearance	
Optimum operation of the power system because of optimization in the planned outages	
Early notification of dangerous power system regimes	

Table 3. Conditions/assumptions/prerequisites for the BUC.

Use Case Conditions	
Assumptions	
• Using simulation models of the power system, the use case shall be designed and presented in a non-intrusive, offline context. • In the demonstration, aggregators and prosumers will both be simulated. • If additional DERs are required to accurately portray the conditions in the immediate future, they will be simulated.	
Prerequisites	
Network accessibility and market data	• Data for network models of IPTO and HEDNO (voltage levels of 400 kV, 150 kV and 20 kV). • Geospatial data, such as locations of potential RES production POIs, GPS coordinates, and other crucial components of the power system, with the precise routing and tower positions for the examined OHLs and WPPs. • Technical information: Information about solar parks, wind farms, and OHLs. • Historical data on weather and the energy production and consumption of the examined locations in Greece, as measured and anticipated historically (Crete and Peloponnese). • For the tools used in TSO, DSO, and the producer/aggregator for forecasting, congestion management, and balancing, knowledge of current approaches and technology breakthroughs is required. • Energy-related policy details: Information regarding relevant EU Directives and Regulations for TSO DSO coordination.
Primary users participating actively (TSO, DSO, aggregator)	Departments for system operations and control, short-term planning of IPTO HEDNO and aggregators, as well as specialists for platform simulations and testing, should be heavily involved.

Figure 9 shows an interaction diagram for the BUC, while Figure 10 depicts the diagram of the market process.

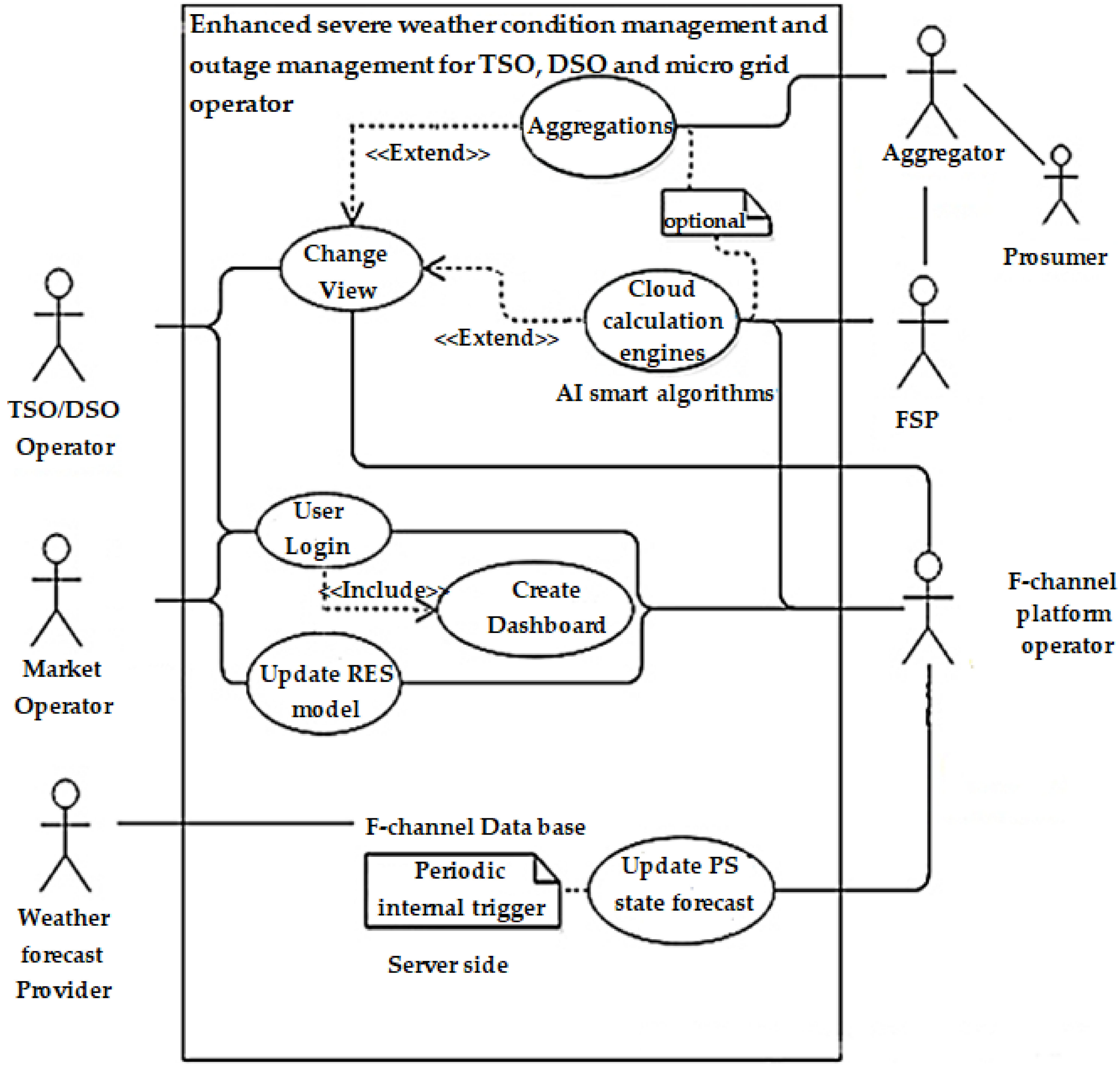


Figure 9. BUC's interactions.

4.3. A Scenario for the Developed Demo

The Greek demo has to test the scenario of Table 4. It is crucial to get the components of the power system ready for both the impending severe weather circumstances and the severe power system state conditions in order to prevent catastrophic equipment damage and load losses. This will be examined with enhanced identification of flexibility resources, flexibility demands and of severe system states and contingencies that can create severe system states. The activation period could be anywhere between 15 and 60 min. The scenario's step-by-step analysis is presented in Table 5. This scenario's exchanged information is shown in Table 6.

Figure 10. Diagram of the market process in the BUC.

Table 4. Information on the scenarios for BUC.

Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition
Warning system for early severe state/prevention and restoration	It is crucial to get the components of the power system ready for both the impending severe weather circumstances and the severe power system state conditions in order to prevent catastrophic equipment damage and load losses. Better identification with a longer time horizon of: (a) dangerous states of the power system, scenarios that can lead to severe system states, (b) flexibility resources and (c) improved identification of flexibility demands all. The activation period could be anywhere between 15 and 60 min.	TSO, DSO, Wind parks	Contingency prediction in the grid of IPTO or HEDNO	High resolution of NWP with a broad geographic range and a forward-looking perspective. Forecasted grid models for DSO and TSO voltage levels are available.

Table 5. Step-by-step analysis for the scenario.

Step No	Event	Name of Process/Activity	Description of Process/Activity	Service	Information Producer (Actor)	Information Receiver (Actor)
1.1	Weather predictions	Trigger of the scenario	Department inside IPTO/HEDNO or outsourced weather forecast provider. The weather forecasts will be conducted for specific weather parameters and specific locations of the grid.	CREATE	Provider of weather forecast	IPTO's and HEDNO's departments of short-term planning
1.2	Energy predictions	Energy production and consumption calculation	IPTO/HEDNO short term planning experts responsible for RES production. These data will be used under F-channel for IPTO's modelling: updates of IGM, DACF and 2DACF, Capacity Calculations and Contingency Analysis.	CREATE	HEDNO's and IPTO's production and load forecasting operator	IGM model operators
1.3	IGM updates	Individual Grid Models update	IPTO/HEDNO short term planning experts responsible for development, maintenance and updates of an IGM. This IGM will contain: consumption nodes, production nodes, voltage profile, power exchanges with the systems of neighboring States. IGM models will be further used by DACF, 2DACF and ATC calculators.	CREATE	Model operators of IGM	Operators of DACF and 2DACF in IPTO and HEDNO
1.4	Identification of severe power system state	Contingency analysis and system problem identification with an emphasis on extreme power system state circumstances	An IPTO's/HEDNO's expert from short term planning department, responsible for the congestion forecast simulation of the day ahead. The output will give both a list of critical outages and a list of possible mitigation measures. Based on predictions of energy production and consumption, grid simulation models are formed and identify potential grid's contingencies.	REPORT	Operators of DACF [1] and 2DACF [2] in IPTO and HEDNO	Expert of IPTO/HEDNO in the control of power systems
1.5	Mitigation measure identification	Identification of potential mitigation measures	A senior engineer from the TSO/DSO Short Term Planning Division, who is in charge of day-ahead congestion forecast simulation and analysis, which produces a list of potential mitigation methods	REPORT	DACF and 2DACF operators in TSO/DSO	Expert in power system control (TSO/DSO)

[1] Day Ahead Congestion Forecast. [2] Two Days Ahead Congestion Forecast.

Table 6. Information exchange for the scenario.

Name of Information	Description of Information Exchanged	Requirements
REPORT of weather forecast	High resolution weather forecasts for the predefined Points of Interest are provided in json files by the weather forecast vendor.	Exchange of files or creation of a special API. Communication between the TSO and DSO short-term planning teams and the weather forecasting vendor.
REPORT of energy production and load forecast	Energy production and load forecasting are performed by DSO and TSO operators utilizing internal AI computation engines for the F-channel.	Storage of the results in a Data Base.
Update of the Individual Grid Models	The most recent projection for energy and production is being added to IGM.	IGM is preserved in databases or CIM xml files.
REPORT of contingency analysis and severe state	The identification and registration of potential contingencies that could result in a severe power system state	Report is kept in TSO/DSO's database
REPORT of possible measures of mitigation	Identification of measures of mitigation.	Report is kept in TSO/DSO's database

4.4. Relationhip with other Use Cases

With the help of several System Use Cases (SUCs), which will be developed and implemented as part of the OneNet project, the F-channel application itself will show how valuable and superior it is to other, current tools and applications of a similar nature. The following system use cases show the direct connection.

4.4.1. SUC 1: Process for Storm and Icing-Related Preventive Maintenance in Local Microgrids, DSO Grids, and TSO Grids

The DGs, the OHLs of micro-grids and HEDNO, and the predictive maintenance and protection with better predictions of storms and icing are the scope of SUC 1. Its objectives are:

- Predictive congestion management to keep the functioning of the power system safe and stable.
- System functioning that is economical.
- Early notification of a risky power system regime.

The severe weather conditions that may trip power lines or induce DG outages, leading to brownouts or blackouts in the region we are interested will be recognized during this SUC. The following are the primary anticipated advantages and features for this specific use case:

- Better Islanded operation on the DSO and TSO sides.
- More adequate systems on both sides.

The key performance indicators are presented in Table 7.

Table 7. Key performance indicators for SUC 1.

Name	Reference to Mentioned Use Case Objectives
Rate of contingency identification	• Improved energy forecasts and power system state forecasts • Using predictive congestion management to keep the functioning of the power system safe and stable • Early notification of risky regimes in the power system
Early notification of a dangerous power system regimes	• More accurate predictions of the power's system state • Predictive congestion control for ensuring safe and reliable power system operation • Early notice of potentially dangerous power system regimes

4.4.2. SUC2: Process for Managing Outages in the IPTO Grid, the HEDNO Grid, and the Local Micro-Grid

The focus of SUC 2 is on the outage management of the IPTO/HEDNO grid and the local microgrid that accounts for better forecasts and forecasting effectiveness from integrated AI and NWPs with higher geographical resolution. Its objectives are:

- Predictive congestion management to keep the functioning of the power system safe and stable.
- System functioning that is economical.
- Early notification of a dangerous power system regime.
- The following are the main advantages and features for this specific use case:
- Increased IPTO and HEDNO system adequacy
- Improved IPTO and HEDNO side Islanded operation

The KPIs are the same with SUC 1 presented in Table 7.

5. Greek Demo Implementation Plan-Connecting with OneNet Architecture

5.1. IPTO-HEDNO-Consumer Value Chain Implementation Plan for the F-Channel Platform Demonstration

A thorough implementation plan was created early on in the project's development for the Greek Demo, and it has been methodically followed during this one year. The plan is illustrated in Figure 11.

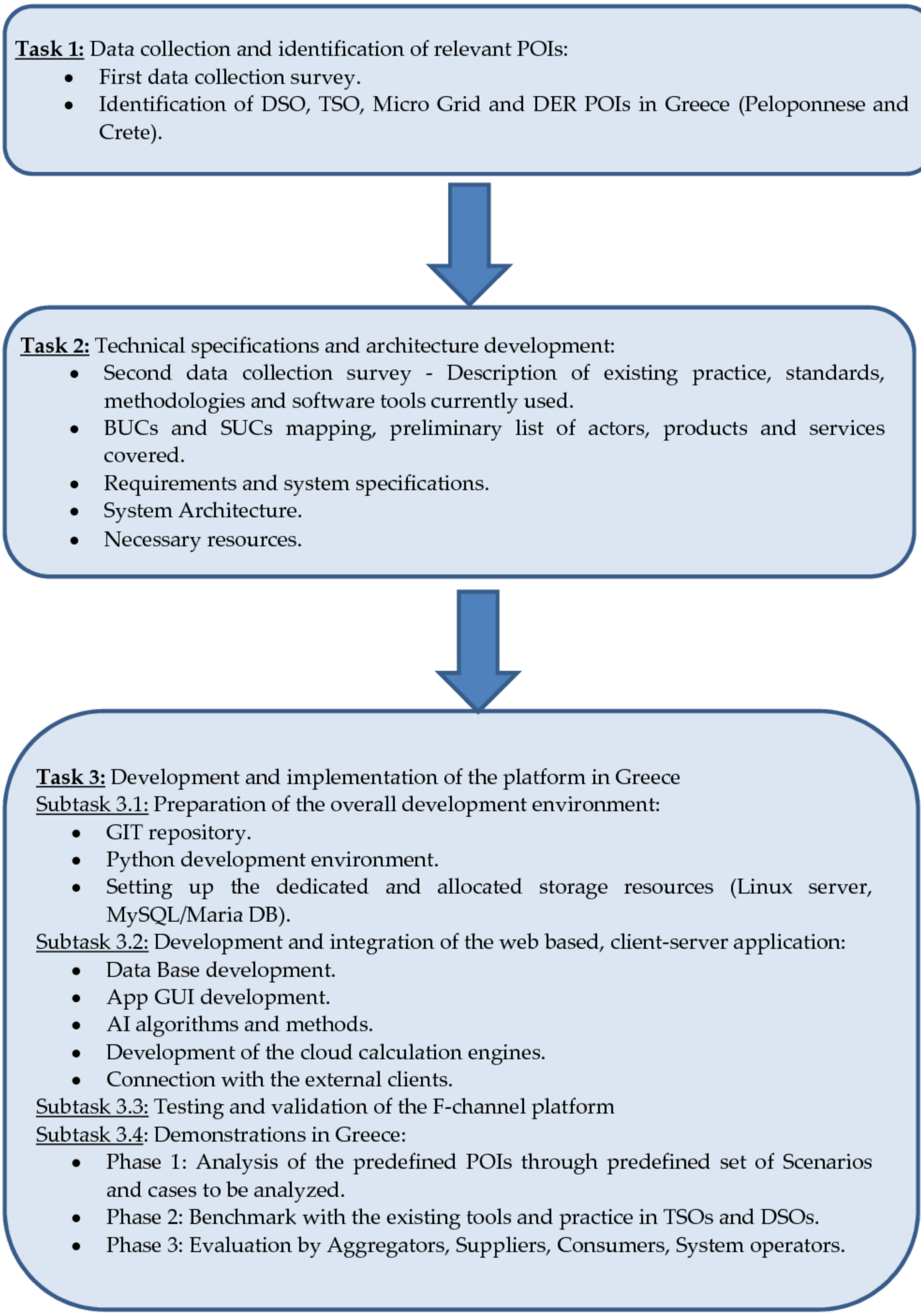


Figure 11. F-channel platform demonstration plan.

The following POIs were found for the analysis first steps:

- All of the Peloponnese's solar parks with the installed power of more than 2 MW.
- All 50 Peloponnese substations.
- Every wind park in the Peloponnese.
- Two potentially important lines are located in the Peloponnese region, according to IPTO.
- The OHL that connects the substations of Korinthos and Megalopolis is the first POI in particular, since it is a crucial line in terms of congestion problems. Certainly, another POI is the connection between the Peloponnese and Crete. The regions of Sklavouna-Neapoli and Chania are connected in the manner previously mentioned.

5.2. Connecting with OneNet Architecture

F-Channel's Integration Plan with OneNet

The OneNet System will offer guidelines for defining a special IT architecture that will completely support all data and services interchange with other project partners and modules. The plan for integrating F-channel with OneNet is currently being discussed.

The modular design of the F-channel platform will enable the use of a centralized register of FSPs or centralized clearing tool for the market offered by the central system of OneNet. F-channel will be based on technology of Geo Server [56], which will provide the rest of the OneNet partners/solutions with cutting-edge features related to spatial-geo referenced grid analysis, simulations, and presentation of all significant elements of the power system.

The integration with the OneNet platform of the platforms will be carried out in accordance with the European data exchange reference architecture presented by BRIDGE [57], as shown in Figures 12 and 13. As shown in Figure 14, a market clearing solution can potentially be linked to an F-channel platform.

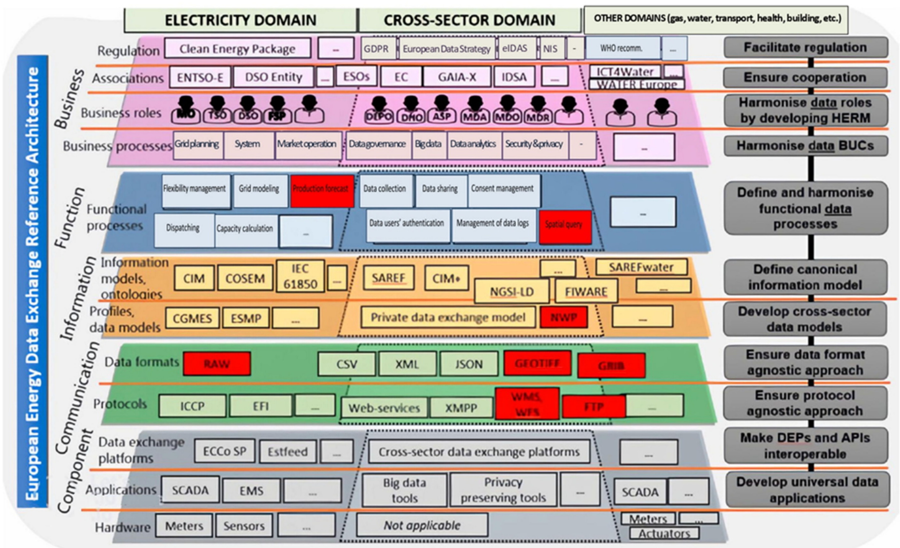


Figure 12. Reference Architecture for European Energy Data Exchange [40].

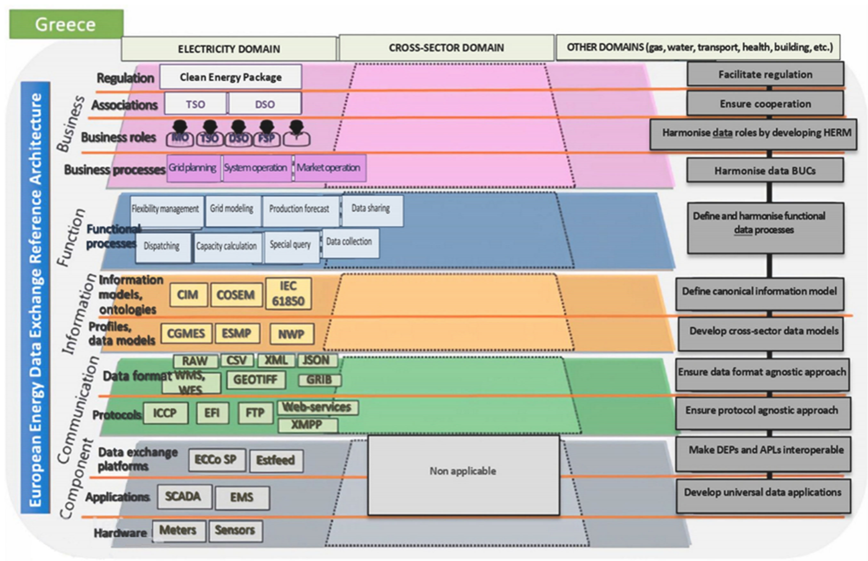


Figure 13. Domains have been identified to be integrated with F-channel.

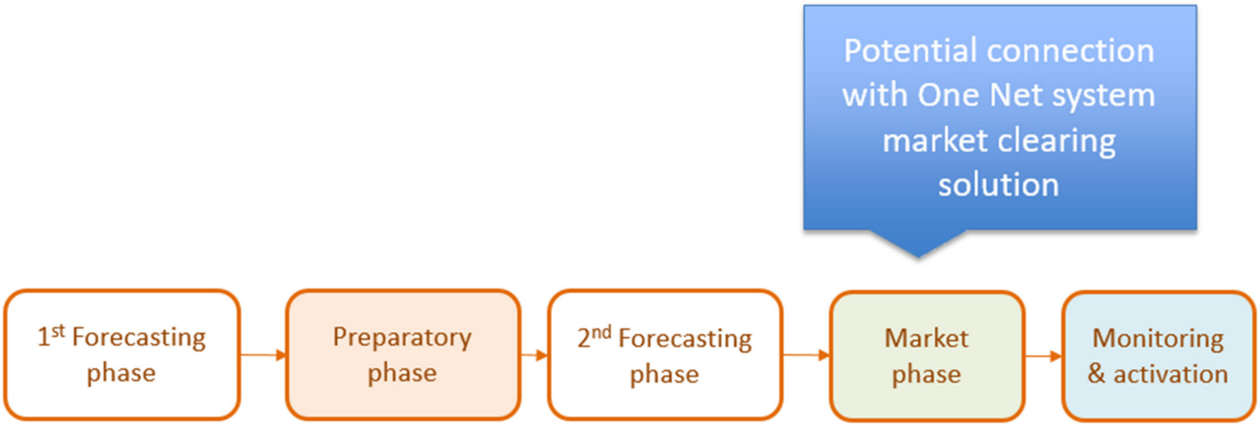


Figure 14. Clearing solution of the OneNet Market in the F-channel.

6. Conclusions

The overall goal of this work was to recommend, create, implement, and assess a pilot project in Greece that addresses the difficulties of congestion and balancing management that system operators face in the renewable energy sources era, in accordance with the OneNet's architecture. Flexibility resources that derive through improved predictions and efficient forecasts from increased spatial resolution Numerical Weather Predictions and the integration of Artificial Intelligence were presented. A Business Use Case in order to prevent the power system from entering risky topological or operational states by improving management in extreme weather conditions through algorithms on predictive maintenance and increased predictions of storms and icing was extendedly analyzed. Finally, an improved state estimation of the power system that has to be developed for the better prediction of the system's flexibility needs, having greater observability in various geographical areas and a longer "look into the future" was proposed.

The OneNet System will offer direction in defining a special IT architecture that completely supports all services and data interchange with other modules and project partners. In order to assure the effective, efficient, and high-power quality operation of the future distribution grids, it will give operators valuable tools to monitor the operation of the distribution grid in real time and automatically coordinate the flexible resources situated at the distribution grid. It is necessary for the TSO, DSO, market operator, and flexible resources to work together effectively. Through the OneNet system, which enables the standard interchange of data and information across the various entities, this collaboration will be made easier.

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