i-STENTORE

innovative Energy Storage
TEchnologies TOwards increased
Renewables integration and
Efficient Operation

D3.4 – I-STENTORE DIGITAL ECOSYSTEM (DIGITAL TOOLS AND PLATFORMS, VIRTUAL POWER CONTROL, DATA GOVERNANCE, FLEXIBILITY SERVICES) (1ST TECHNOLOGY RELEASE)

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Abstract	This deliverable encompasses an initial overview of all demo-specific tools, detailing enhancements necessary for their seamless integration within the i-STENTORE framework. It also outlines the design of the horizontal tools and components to be developed, such as the VPP, IPT, data governance middleware, interface with existing infrastructure, and the implementation of flexibility services. Success criteria include achieving operational versions of both vertical and horizontal tools, ensuring their successful integration into the i-STENTORE digital platform with partial functionality for the first release.
Keywords	Virtual Power Plant, Investment Planning Tool, Data Governance Middleware, Integration Process, Semantic Interoperability, Energy Storage Systems, Flexibility Services.

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REVISION HISTORY

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Version 1.0	15/04/2024	Final peer-reviewed version

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TABLE OF ABBREVIATIONS AND ACRONYMS

Acronym	Definition
(A)PV	(Agriculture) PhotoVoltaic
aFRR	Automatic Frequency Restoration Reserve
(B)ESS	(Battery) Energy Storage Systems
(D)SO	(Distribution) System Operator
(H)ESS	Hybrid Energy Storage System
(I)IoT	(industial) Internet of Things
AI	Artificial Intelligence
API	Application Programming Interface
AWS	Amazon Web Services
BSPs	Balancing Service Providers
CEN	European Committee for Standardisation
CIM	Common Information Model
DC/DC	Direct Current to Direct Current
EDS	European Data Space
EEM	Empresa de Electricidade da Madeira
EM-ISA	e-mobility Information System Architecture
EMS	Energy Management System
EPES	Electric Power and Energy Systems
ERP	Enterprise Resource Planning
EU	European Union
EV	Electric Vehicles
IEGSA	Interoperable European Grid Services Architecture
FCR	Frequency Containment Reserves
FL	Flexible Loads
FMS	Furnace Monitoring System
FR	Flexibility Register
GDPR	General Data Protection Regulation
HTTP	Hypertext Transfer Protocol
HVDC	High Voltage Direct Current
ICT	Information and Computer Technologies
iDGM	i-STENTORE Data Governance Middleware
IDSA	International Data Spaces Association
IEGSA	Interoperable European Grid Services Architecture
IPT	Investment Planning Tool
LFP	Lithium Iron Phosphate
Li-Ion	Lithium-ion
MCDA	Multi-Criteria Decision Analysis
mFRR	Manual Frequency Restoration Reserves

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NGSI-LD	Next Generation Service Interface – Linked Data
OEO	Open Energy Ontology
OMIE	Operador del Mercado Ibérico de Energía
OWL	Web Ontology Language
PLC	Programmable Logic Controller
PV	Photovoltaic
RA	Reference Architecture
RAM	Random Access Memory
RDF	Resource Description Framework
RES	Renewable Energy Sources
REST	REpresentational State Transfer
SAREF	Smart Appliances REFerence ontology
SGAM	Smart energy Grid Architecture Model
SO	System Operator
SoC	State of Charge
SQL	Structured Query Language
TRL	Technology Readiness Level
TSO	Transmission System Operator
UI	User Interface
VESS	Virtual Energy Storage System
VPP	Virtual Power Plant
VPN	Virtual Private Network
VRFB	Vanadium Redox Flow Battery
XML	EXtensible Markup Language

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EXECUTIVE SUMMARY

The i-STENTORE project, focusing on pioneering energy storage technologies for enhanced integration of renewables and efficient operation, has reached a significant milestone with the release of Deliverable D3.4. This document, evolving from the foundational work established in D2.2, presents the first technology release of the i-STENTORE digital ecosystem. This ecosystem represents a critical advancement in optimizing the use of renewable energy within the European power grid, showcasing the project's commitment to fostering a sustainable and efficient energy future.

Central to this deliverable are key components that form the backbone of the i-STENTORE digital platform. These include the Virtual Power Plant (VPP), the Investment Planning Tool (IPT), and the Data Governance Middleware. The VPP stands out as a pivotal innovation, offering a model-based approach for supervisory control over various energy storage technologies. It is intricately designed to enhance portfolio management efficiency and is adaptable to a wide range of stationary applications integrating renewable energy sources and storage solutions. The IPT, a strategic asset for potential energy storage investors, enables detailed comparison and decision-making among different energy storage technologies. The Data Governance Middleware, on the other hand, ensures seamless semantic interoperability across diverse data stakeholders, playing a crucial role in the project's data management strategy.

The deliverable also includes a comprehensive deployment guide, detailing the steps for integrating these components into the i-STENTORE ecosystem. This guide is essential for understanding the practical aspects of deploying the digital platform, ensuring effective monitoring and control of energy storage systems. Additionally, the deliverable is enriched with various appendices that provide in-depth technical information and practical examples. These appendices encompass detailed models, and specific methods for interaction with the digital platform, offering a holistic view of the project's technical and practical dimensions.

Looking forward, i-STENTORE is set to continue refining and expanding the functionalities of these tools. Key areas of focus include enhancing data governance capabilities, improving the efficiency of energy storage monitoring, and integrating advanced decision-making algorithms within the VPP, IPT. The project also aims to explore and develop new business models and market opportunities, particularly in the context of the evolving energy landscape and the growing importance of renewable energy sources. In essence, Deliverable D3.4 lays a robust foundation for advancing energy storage technologies and their diverse applications in the energy sector. The next steps involve building upon this foundation to fully realize the innovative approach of the project, ensuring its long-term impact and contribution to the transition towards a more sustainable and efficient energy system.

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1 INTRODUCTION

1.1 PURPOSE OF THIS DOCUMENT

This is an integral document that presents a thorough description of the 1st technology release of the i-STENTORE framework. It includes a presentation of how the various components are being implemented for seamless integration within the i-STENTORE digital platform. Deliverable D3.4 highlights each component's functionality, delving into the Virtual Power Plant (VPP), the methodology behind the Investment Planning Tool (IPT), and the Data Governance Middleware. It also provides a Deployment Guide, detailing the steps for integrating these components. Further, it assesses the current proprietary digital platforms for optimized energy storage monitoring and control, leading to conclusions and subsequent steps. This deliverable serves as a comprehensive guide and the basis for evaluating the successful deployment and functionality of the i-STENTORE digital ecosystem's initial offering.

1.2 RELATED WP3 ACTIVITIES

The scope of Work Package 3 (WP3) in the i-STENTORE project encompasses a series of interrelated tasks aimed at developing and integrating digital tools and platforms for optimizing energy storage and enhancing grid flexibility. Task 3.2 focuses on extending demo-specific proprietary digital platforms for monitoring and controlling energy storage, emphasizing the development of APIs for seamless integration with the i-STENTORE system. The integration extends to Task 3.3, which aims to transform the IEGSA platform's Flexibility Register into an advanced Virtual Power Plant tool for supervisory control of Energy Storage Systems (ESS). It also involves creating a cost-efficient solution for asset health management and lifetime monitoring. Both tasks are fundamental for the successful implementation of the i-STENTORE digital ecosystem, aligning with the objectives of designing interoperable and harmonized operational tools. Further advancing the project's goals, Task 3.4 defines open semantic data models essential for data governance and interoperability across the energy system. These models support a robust Data Governance Middleware to interconnect local digital tools and platforms, facilitating end-user flexibility encapsulation for grid services. Task 3.5 complements this by developing flexibility services that accommodate user needs, identifying optimal storage technologies for various services, and outlining data requirements for system operators. Task 3.6 IPT offers strategic decision support for selecting energy storage solutions, integrating multicriteria decision analysis methods. Finally, Task 3.7' is committed to developing and integrating the i-STENTORE digital platform which will ensure the combination of processes, services, and tools from all tasks, leading to a secured, functional platform prototype ready for validation.

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1.3 DOCUMENT STRUCTURE

The remainder deliverable is structured as follows:

- **Chapter 2**, i.e. the "i-STENTORE Reference Architecture" chapter delves into the initial design and development of the i-STENTORE project's digital platform. It covers the conceptualization and design of horizontal tools and components into the digital platform. This chapter sets a foundational framework for operational versions of the tools, aiming for successful integration and interoperability within the i-STENTORE network.
- **Chapter 3**, i.e. the "i-STENTORE 1st Technology Release [MVP1]", focuses on the initial technology release of the i-STENTORE project. It describes in detail the components of the project, including the Virtual Power Plant, the Investment Planning Tool, and the Data Governance Middleware. The chapter provides an in-depth view of the functionalities, design, and operational aspects of these components, emphasizing their roles in enhancing the efficiency and management of energy storage systems and renewable assets.
- **Chapter 4,** i.e. the "Conclusions" chapter summarizes the key findings, progress, and insights gained from the development and initial deployment of the i-STENTORE project's digital ecosystem. It also outlines the next steps, potential improvements, and future direction for the project.
- The deliverable is ending with **Chapters 5 and 6** which include the references and appendices sections, respectively.

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2 I-STENTORE REFERENCE ARCHITECTURE (RA)

This deliverable is essentially a detailed exposition of the first concrete steps towards creating a unified digital platform for the i-STENTORE project. Its purpose is to document the preliminary designs and improvements of the various components, ensuring that they align well within the i-STENTORE RA, as detailed in D2.2. This document describes the intended design for horizontal tools and components to be developed, such as the Virtual Power Plant (VPP), data governance middleware, and interfaces with existing systems. Furthermore, it details the flexibility services provided by storage technologies and how these are designed to be integrated into the i-STENTORE digital platform. The deliverable serves as a foundation for operational versions of all tools and aims for successful integration into the overarching i-STENTORE digital platform, even with partial functionality at this early stage. It marks a pivotal step in reaching the envisioned interoperability and compatibility across the various tools and systems within the i-STENTORE network, aligning with the project's broader goals of enhancing renewables integration and efficient operation in the energy sector.

2.1 INTRODUCTION

This chapter introduces the foundational aspects of the i-STENTORE Reference Architecture, which is central to the project's technological framework.

Section 2.2 provides a brief overview on the Business models of the i-STENTORE project, as outlined in D2.2 in order to make a connection to the developed components of the 1st Technology release.

In Section 2.3, the document shifts to a detailed examination of the various system services conceptualized under i-STENTORE. This includes Generation Support Services, Services for Distribution Infrastructure, and Frequency Regulation Services, along with a comprehensive catalogue of services demonstrated in the i-STENTORE project. Each service is described with a focus on its technological parameters, operational characteristics, and the role it plays in enhancing grid stability and efficiency.

The chapter is completed with an overview of future deliverables and developments anticipated in the i-STENTORE project. This forward-looking perspective highlights the project's commitment to ongoing innovation and adaptation to emerging challenges and opportunities in the energy sector.

2.2 SERVICES & BUSINESS MODELS

In the i-STENTORE project a business model is defined as a conceptual structure that describes the operation and requirements for a functional application that delivers value, which, more particularly for the given ESS domain includes methods for employing resources and gaining financially viable solutions, and encapsulating parameters combined in function to determine operational gains. The project offers a thorough analysis of business models for energy storage systems, focusing on the interaction between different storage technologies

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and digital solutions. This approach is seen as pivotal for integrating renewable energy into the power grid, emphasizing energy storage's role beyond traditional buffering to active grid components providing valuable services for grid resilience, stability, and efficient operation.

The i-STENTORE project categorizes services into system services (like frequency control, voltage control, emergency supply, etc.) and trading services (including renewable energy shifting, operational management, energy market, and capacity market). This classification also extends to the operational point of storage (behind-the-meter and front-the-meter), with each having distinct implications on the electricity value chain, taxes, and charges. The distinction between these service categories underscores the project's focus on versatile and adaptable energy storage solutions, essential for a dynamic and sustainable energy sector.

The Operational requirements for these business models vary significantly across different use-cases. However, the flexibility to operate on several applications simultaneously presents opportunities for additional revenue streams. A versatile storage system can diversify market offerings, enhancing operational efficiency and market reach. This adaptability is crucial for the profitability and sustainability of energy storage systems, influencing everything from system design to market strategies. All business models under design pay special focus to the importance of rapid communication systems, the significance of the contracts for energy contributions, the prominence of their integration with energy trading platforms, and the necessity of high efficiency and safety standards for storage systems.

2.3 SYSTEM SERVICES

The services under development within the i-STENTORE demonstrators are generic grid support services and are addressed to the wide range of storage assets present at the demonstration sites. Each service is better suited to be provided by a specific storage technology or by a combination of at least two different technologies in the form of a hybrid energy storage system, depending on the technology mix. All different time scales are covered, from seconds to days, including generation support flexibility services, distribution infrastructure support services such as grid congestion management, fast-response ancillary services and behind-the-meter energy management services such as end-user peak shaving. In all cases, energy storage is used to balance power grids by providing flexibility to the power system, improving grid reliability and, in particular, supporting the integration of more renewable generation.

This chapter presents a high-level characterisation of the services, based on the specific capacities of each Hybrid Energy Storage System planned and applied to the application reality of each demo, resulting in the first version of the catalogue of services offered by all the demonstrators in the i-STENTORE project. The information was obtained through a survey to collect the main parameters of the flexibility services.

Figure 1 summarises the services identified in the demos that will be developed and connected to the common platform, i-STENTORE. These cover a wide range of flexibility services, from RES generation support to balancing and ancillary services:

- Energy arbitrage

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- Peak shaving
- Congestion Mitigation
- Synchronous Inertia
- Power smoothing
- Frequency regulation services:
- Frequency Containment Reserve
- Automatic Frequency Restoration Reserve
- Manual Frequency Restoration Reserve
- Fast Frequency Response

The services identified are described in general terms below and further, in more detail, in the context of each demonstrator.

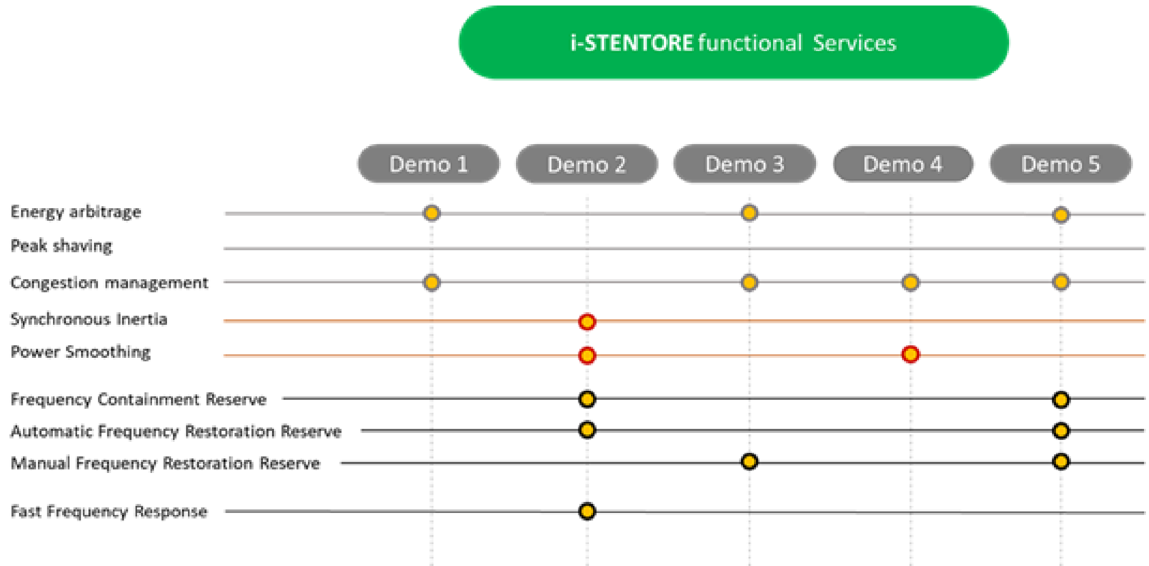

FIGURE 1: MATRIX CATALOGUE OF THE FUNCTIONAL FLEXIBILITY SERVICES WITHIN THE DEMOS.

2.3.1 Generation Support Services and Bulk Storage Services

2.3.1.1 Energy arbitrage

Making use of ESS for Energy arbitrage in support of renewable energy generation is a strategy that capitalises on the inherent variability of renewable energy production and the fluctuation of electricity market prices. This approach not only enhances the economic value of energy storage and renewable energy assets but also contributes to grid stability and efficiency.

2.3.1.2 Power smoothing

Synchronous inertia is a fundamental property of traditional power systems, primarily provided by large rotating generators, such as those found in coal, gas, and hydroelectric

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power plants. Inertia refers to the resistance of these rotating masses to changes in rotational speed, which, in the context of an electrical grid, translates to resistance against changes in the system's frequency. This property is crucial for maintaining grid stability, especially in the face of sudden changes in power supply or demand.

Energy storage systems do not inherently possess synchronous inertia in the traditional sense, but through advanced control technologies, they can provide critical stability services to modern power grids, effectively mimicking or supplementing the inertia that has been a cornerstone of grid stability in the era of conventional power generation. Energy storage systems can then provide a synthetic or virtual form of inertia. As more renewable energy sources are integrated into the grid, the availability of inertia from storage systems can compensate for the reduced physical inertia from traditional sources, facilitating a smoother transition to renewables.

For instance, Battery Energy Storage Systems (BESS) can provide a fast response to frequency deviations through power electronic interfaces. Although batteries do not have physical inertia, they can be controlled to mimic the inertial response of synchronous generators. In the case of detection of a change in frequency a BESS can instantaneously inject or absorb power from the grid, counteracting the frequency deviation much faster than conventional generators.

Pumped Hydro Storage (PHS) is another good example from the i-STENTORE Demos' technologies that is typically used for energy shifting and does not inherently provide inertia, but can be operated to supply grid inertia, e.g., by adjusting the speed of their turbines or compressors, they can offer a degree of inertial response under certain conditions. These types of storage systems can be particularly effective in combination with fast-acting controls that allow them to respond more quickly to changes in grid frequency. For these purposes, PHS is commonly combined with other storage technologies, such as utility scale BESSs.

2.3.1.3 Peak shaving

Peak shaving involves using energy storage devices to supply electricity during periods of high demand, thereby reducing the costs of access to electricity. It is particularly beneficial in supporting the integration of renewable energy sources by managing their variability and improving their economics, making them more cost effective.

2.3.2 Services to support distribution infrastructure

2.3.2.1 Congestion mitigation

Energy storage systems are particularly adequate in mitigating congestion in the power grid. Congestion is one critical challenge in the management and operation of modern electricity networks, particularly in the context of the current high rate of penetration of distributed energy resources. It occurs when the demand for electricity exceeds the transmission system's capacity to supply power from generators, e.g. peak production of RES, to consumers. Energy storage offers a flexible and efficient solution to this problem, with numerous benefits that enhance grid performance, reliability and security. The Energy storage

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systems act as a buffer, absorbing excess generation and releasing it as needed, thereby reducing instances of congestion caused by sudden surges in power supply.

2.3.3 Frequency regulation services

Frequency Ancillary Services are critical for the operation and stability of power systems. They help maintain the balance between electricity supply and demand, ensuring the system frequency remains within its normal operating range. These services are essential for the reliability and quality of the power system. Each service plays a distinct role in responding to frequency deviations, from immediate containment to gradual restoration and balance. The efficient functioning of these services is critical for the secure operation of the electric power system, especially in the context of increasing renewable energy sources and fluctuating demand patterns. These ancillary services are generally tendered by transmission and distribution system operators to ensure reliable power supply as most of them are already commonly tendered on the market and provided by storage operators, the case of Frequency Containment Reserves (FCR), automatic Frequency Restoration Reserves (aFRR), and manual Frequency Restoration Reserves (mFRR); and others are only now emerging in some EU markets, which is the case of the Fast Frequency Response (FFR).

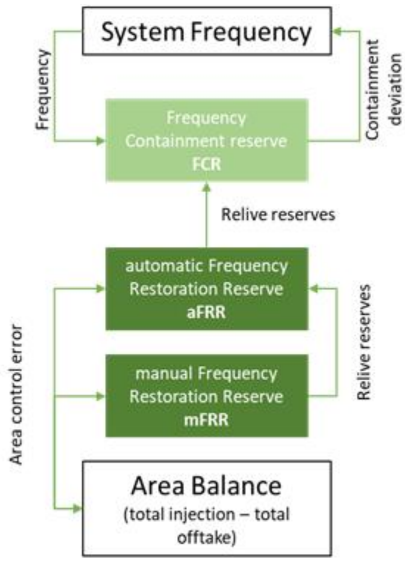

FIGURE 2: SCHEMATIC OVERVIEW OF THE ACTIVATION OF OPERATING RESERVES[1].

Figure 2 presents an overview of the traditional activation sequence of the operating reserves for frequency stability that is illustrated in Figure 3, in an example of an arbitrary incident with a large frequency drop. First, FCR is activated within seconds, then is followed up by aFRR,

[1] Elia Transmission Belgium SA/NV, PUBLIC CONSULTATION "Methodology for the dimensioning of the aFRR needs", June, 2020.

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within minutes, which is supported and followed by the mFRR. In Figure 3, the frequency profile is represented by the orange line[2].

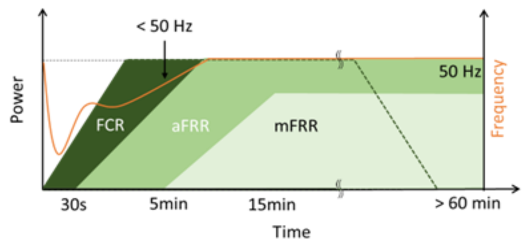

FIGURE 3: PRINCIPLE OF FREQ. DEVIATION AND SUBSEQUENT ACTIVATION OF OPER. RESERVES.

2.3.3.1 Frequency Containment Reserves (FCR)

Previously known as the "Primary Reserves", Frequency Containment Reserves are the first line of response in maintaining system frequency immediately after a disturbance, such as a sudden loss of generation or a significant increase in demand. FCR operates automatically and is typically activated within seconds of a deviation from the nominal frequency. The aim is to stabilise the frequency as quickly as possible to prevent further deterioration of the system condition. FCR providers are required to always have their resources available and to respond proportionally to the frequency deviation to contain it within a certain range.

2.3.3.2 Automatic Frequency Restoration Reserves (aFRR)

Automatic Frequency Restoration Reserves (or secondary reserves) is a centralised automatic function intended to replace FCR after the initial frequency deviation stabilisation and restore the frequency to the target frequency of 50.00Hz. This service is automatically activated through a control signal from the Transmission System Operator (TSO) and is usually deployed within minutes. aFRR uses the energy storage to adjust the active power production of the generating units to restore the frequency and the interchanges with other systems to their target values following an imbalance to match the current electricity demand, thus helping to bring the system frequency back to its target value.

2.3.3.3 Manual Frequency Restoration Reserves (mFRR)

Manual Frequency Restoration Reserves are used after the activation of aFRR to further restore the balance between supply and demand and bring the system back to its normal operating state. Unlike FCR and aFRR, mFRR is manually activated by the TSO and typically involves larger and longer adjustments. The deployment of mFRR can range from several minutes to several hours after the initial disturbance. mFRR resources can be either upward

[2] Kolenc, Mitja, et al. "Performance evaluation of a virtual power plant communication system providing ancillary services." Electric Power Systems Research 149 (2017): 46-54.

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(increasing generation or decreasing demand) or downward (decreasing generation or increasing demand), depending on the needs of the system.

2.3.3.4 Fast Frequency Response (FFR)

The Fast Frequency Response is a new service, provided by rapid active power increases or decreases in a timeframe of 2 seconds, to correct supply-demand imbalances and assist with managing frequency, and is sustained for at least 8 seconds. The fast response imposes particular requirements from the energy storage systems in terms of power and reaction time, the minimum capacity must be at least 1 MW and the ramp-up inferior to two seconds.

2.3.4 Conceptual catalogue of services in i-STENTORE Demos

The survey on the flexibility services (available in Appendix I) within the five demonstrations of the i-STENTORE project has been designed at this stage to collect high-level information, covering the following key points:

Service ID

- Service Description

Technical characterisation

- Technology used and maturity level
- Discharge time
- Reaction time
- Frequency of use
- Unit of measurement

Application characterisation

- Existence of the service
- Application Scale
- Beneficiaries of the service
- Procured volume definition
- Remuneration scheme
- Pricing method
- Deployment Process overview
- Settlement schemes

A more detailed characterization of each flexibility service within the demonstrators will be carried out later during the assessment of the data model requirements and the definition of

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the implementation details for each service, which will be the object of the second technical release as part of the deployment of the i-STENTORE platform services repository.

2.3.4.1 Demo 1, Molten glass thermal storage for an increased uptake of renewable electric energy – Slovenia

SERVICE 1 - CONGESTION MANAGEMENT

- **Technical characterisation**

Technology used and maturity level	Molten Glass Energy Storage (HESS); TRL 6à7
Discharge time	To be determined during trials
Reaction Time	Minimum of 60s for small power changes. Is unknown for higher load changes – assumption 24h+
Frequency of use	Every 8h, limited by the gas combustion system
Unit of measurement	MW and MWh

- **Application characterisation**

Existence of the service	new
Application scale	Site / Local segment of the network
Application beneficiaries	DSO and/or Aggregators (Hypothetical, as DSO is not part of the demonstration)
Procured volume definition	Volume to be offered is defined via a combination of technical limitations and prequalification tests
Unit of measurement	€/MW/h for capacity and €/MWh for energy delivered
Business case	Day-ahead congestion planning
Remuneration scheme	Capacity market has regulated tariff, while energy tariff is market based
Pricing method	Official DSO energy meter is used to account for delivered energy (or unofficial but of the same accuracy)

Process overview description (Hypothetical example, since TSO/DSO is not involved in DEMO 1, all steps will be executed and evaluated internally):

A. **Prequalification:** Done at TSO by the aggregator, with whom the client signs the contract. Bidding/Selection: Done at TSO by the aggregator, with whom the client signs the contract.

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B. **Delivery:** Requested by TSO from the aggregator. Aggregator then delegates signal to the clients.

C. **Settlement:** This service requires a settlement between a BRP and the service provider. It is requested by the aggregator, who sends the bill to TSO. Aggregator then pays his clients.

D. **Monitoring:** Done by aggregator and TSO independently.

SERVICE 2 – PEAK SHAVING

- **Technical characterisation**

Technology used and maturity level	Molten Glass Energy Storage (HESS); TRL 6à7
Discharge time	To be determined during trials
Reaction Time	Minimum of 60s for small power changes. Is unknown for higher load changes - assumption 24h+
Frequency of use	Every 8h, limited by the gas combustion system
Unit of measurement	MW and MWh

- **Application characterisation**

Existence of the service	New
Application scale	Site / Local segment of the network
Application beneficiaries	DSO and/or Aggregators
Procured volume definition	Volume to be offered is defined via a combination of technical limitations and prequalification tests
Unit of measurement	€/MW/h for capacity and €/MWh for energy delivered
Business case	Day-ahead congestion planning
Remuneration scheme	Capacity market has regulated tariff, while energy tariff is market based
Pricing method	Official TSO/DSO energy-meter is used to account for delivered energy (or unofficial but of the same accuracy)

Process overview description (Hypothetical example, since TSO/DSO is not involved in DEMO 1, all steps will be executed and evaluated internally):

A. **Prequalification:** Done at TSO by the aggregator, with whom the client signs the contract.

B. **Bidding/Selection:** Done at TSO by the aggregator, with whom the client signs the contract.

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C. **Delivery:** Requested by TSO from the aggregator. Aggregator then delegates signals to the clients.

D. **Settlement:** Requested by the aggregator, who sends the bill to TSO. Aggregator then pays his clients.

E. **Monitoring:** Done by aggregator and TSO independently.

2.3.4.2 Demo 2, Pump hydro Storage system combined with BESS – Portugal

Demo 2 is part of a small and isolated island with no electricity market. All the provided services will be implemented in the grid by the DSO. All the OPEX and CAPEX costs of the demonstration are supported by *Eletricidade da Madeira, S.A.* (EEM), the Island's grid operator. Also, no settlement with a third party is required for the provisioning of the foreseen services.

SERVICE 1 - SYNCHRONOUS INERTIA

- **Technical characterisation**

Technology used and maturity level	HESS: synchronous condenser, Li-ion battery. TRL 5 → 7
Discharge time	Discharge time varies, depending on the component of the HESS that is providing the service (e.g. synchronous condenser, Li-ion battery, etc.)
Reaction Time	Milliseconds (ms)
Frequency of use	Several times per day, depending on the operating conditions of the system
Unit of measurement	MW

- **Application characterisation**

Existence of the service	Existing
Application scale	Small island network (60, 30 and 6.6 kV)
Application beneficiaries	EEM (DSO) will provide the service
Procured volume definition	Defined according to the dispatch rules in practice, which considers several variables, such as, system load, forecasted renewable generation, etc.
Unit of measurement	MW
Business case	Day-ahead congestion planning
Remuneration scheme	N/A Specific functionality will be deployed by the DSO (EEM) in an isolated grid without market or regulated tariffs
Pricing method	N/A. The SO supports all the costs

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SERVICE 2 - FAST FREQUENCY RESPONSE (FFR)

The flexibility service offers a response to sudden changes in the system's frequency, maintaining a stable and consistent frequency.

- **Technical characterisation**

Technology used and maturity level	Demo 2; HESS TRL 5 → 7
Discharge time	Discharge time varies, depending on the component of the HESS that is providing the service (e.g. synchronous condenser, Li-ion battery, etc.)
Reaction Time	Milliseconds (ms)
Frequency of use	Several times per day, depending on the operating conditions of the system
Unit of measurement	MW

- **Application characterisation**

Existence of the service	Existing
Application scale	Small island network (60, 30 and 6.6 kV)
Application beneficiaries	EEM (DSO) will provide the service
Procured volume definition	Defined according to the dispatch rules in practice, which considers several variables, such as, system load, forecasted renewable generation, etc.
Unit of measurement	MW
Business case	Day-ahead congestion planning
Remuneration scheme	N/A Specific functionality will be deployed by the DSO (EEM) in an isolated grid without market or regulated tariffs
Pricing method	N/A. The SO supports all the costs

SERVICE 3- FREQUENCY CONTAINMENT RESERVE (FCR)

Frequency Containment Reserve – The primary frequency control which is part of the automatic generation control.

- **Technical characterisation**

Technology used and maturity level	Demo 2 HESS; TRL 5 → 7
Discharge time	Discharge time varies, depending on the component of the HESS that is providing the service (e.g. synchronous condenser, Li-ion battery, etc.)
Reaction Time	Milliseconds (ms)

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Frequency of use	Several times per day, depending on the operating conditions of the system
Unit of measurement	MW

- **Application characterisation**

Existence of the service	Existing
Application scale	Small island network (60, 30 and 6.6 kV)
Application beneficiaries	EEM (DSO) will provide the service
Procured volume definition	Defined according to the dispatch rules in practice, which considers several variables, such as, system load, forecasted renewable generation, etc.
Unit of measurement	MW
Business case	Day-ahead congestion planning
Remuneration scheme	N/A Specific functionality will be deployed by the DSO (EEM) in an isolated grid without market or regulated tariffs
Pricing method	N/A. The SO supports all the costs

SERVICE 4 - AUTOMATIC FREQUENCY RESTORATION RESERVE (AFRR)

Automatic Frequency Restoration Reserve – The secondary frequency control which is part of the automatic generation control.

- **Technical characterisation**

Technology used and maturity level	Demo 2 HESS; TRL 5 → 7
Discharge time	Discharge time varies, depending on the component of the HESS that is providing the service (e.g. synchronous condenser, Li-ion battery, etc.)
Reaction Time	Milliseconds (ms)
Frequency of use	Several times per day, depending on the operating conditions of the system
Unit of measurement	MW

- **Application characterisation**

Existence of the service	Existing
Application scale	Small island network (60, 30 and 6.6 kV)
Application beneficiaries	EEM (DSO) will provide the service

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Procured volume definition	Defined according to the dispatch rules in practice, which takes into account several variables, such as, system load, forecasted renewable generation, etc.
Unit of measurement	MW
Business case	Day-ahead congestion planning
Remuneration scheme	N/A Specific functionality will be deployed by the DSO (EEM) in an isolated grid without market or regulated tariffs
Pricing method	N/A. The SO supports all the costs

SERVICE 5 - POWER SMOOTHING

The service consists of reducing the fluctuations or variations in electrical power output, particularly from intermittent energy sources.

- **Technical characterisation**

Technology used and maturity level	Demo 2 HESS; TRL 5 → 7
Discharge time	Discharge time varies, depending on the component of the HESS that is providing the service (e.g. synchronous condenser, Li-ion battery, etc.)
Reaction Time	Milliseconds (ms)
Frequency of use	Several times per day, depending on the operating conditions of the system
Unit of measurement	MW

- **Application characterisation**

Existence of the service	New
Application scale	Small island network (60, 30 and 6.6 kV)
Application beneficiaries	EEM (DSO) will provide the service
Procured volume definition	Defined according to the dispatch rules in practice, which takes into account several variables, such as, system load, forecasted renewable generation, etc.
Unit of measurement	MW
Business case	Day-ahead congestion planning.
Remuneration scheme	N/A Specific functionality will be deployed by the DSO (EEM) in an isolated grid without market or regulated tariffs
Pricing method	N/A. The SO supports all the costs

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2.3.4.3 Demo 3, Virtual Energy Storage System for Renewable Energy Integration (VESS) – Spain

SERVICE 1 - ENERGY ARBITRAGE

A Virtual Energy Storage System will be formed, with renewable generation + storage. Offers will be optimised to maximise the benefits from the VESS participation in the market.

The process will optimise the participation based on the generation and price forecast sending an offer compatible with the operation of the battery. The charging and discharging behaviour will arise from the expected profits obtained in the market, maximising the benefits obtained from the renewable energy generation.

- **Technical characterisation**

Technology used and maturity level	Virtual Energy Storage System; TRL 6
Discharge time	Range of Hours
Reaction Time	12 hours
Frequency of use	Daily
Unit of measurement	MWh

- **Application characterisation**

Existence of the service	Existing
Application scale	National level
Application beneficiaries	MECSA (DSO)
Procured volume definition	The volume procured to the market is the one obtained from the participation in it. It will arise as a result of the VESS market participation, it will be given by the market operator (OMIE) to the VESS.
Unit of measurement	€/MWh
Business case	Day-ahead congestion planning
Remuneration scheme	Market-based
Pricing method	The pricing method of the offer will be made based on predictions of the day-ahead.

SERVICE 2 - AUTOMATIC FREQUENCY RESTORATION RESERVE (AFRR)

Automatic Frequency Restoration Reserve aFRR – The tertiary reserves are part of the frequency regulation system of Spain. It is regulated through the Operation Procedure 1.5, section 3.3, where it specifies that the tertiary reserve is constituted by the maximum power variation in upward or downward direction that can be scheduled in a timeframe not bigger than 15 min and that it can be maintained during, at least, 30 minutes. The objective is to

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reconstitute the secondary reserve. Since the Li battery would have 1 MW and 479 kWh, tests defined in Operation Procedure 3.8 could be met and the VESS could participate in it.

- **Technical characterisation**

Technology used and maturity level	Virtual Energy Storage System; TRL 6
Discharge time	~30 minutes
Reaction Time	~15 minutes
Frequency of use	Daily
Unit of measurement	Reserve: MW; Activation: MWh

- **Application characterisation**

Existence of the service	Existing
Application scale	National level (TSO)
Application beneficiaries	MECSA
Procured volume definition	Defined according to the dispatch rules in practice, which takes into account system load, forecasted renewable.
Unit of measurement	€/MW, €/MWh
Remuneration scheme	Market-based
Pricing method	Market-based

The settlement scheme foresees penalties for Energy Not Served (ENS).

SERVICE 3 – DSO SERVICES

DSO services (Congestion management, etc…) - Different capabilities of the VESS will be tested to showcase the potential of the use case to provide useful flexibility services to the DSO. This could eventually mitigate congestions or over-voltages. Further analysis will be required to analyse the full potential of the application.

- **Technical characterisation**

Technology used and maturity level	Virtual Energy Storage System; TRL 6
Discharge time	~15 minutes
Reaction Time	Milliseconds (ms)
Frequency of use	Not enough information
Unit of measurement	MWh

- **Application characterisation**

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Application scale	National level (TSO)
Application beneficiaries	MECSA (utility)
Procured volume definition	Defined according to the dispatch rules in practice, which takes into account system load, forecasted renewable.
Unit of measurement	MWh; €/MWh
Remuneration scheme*	Bilateral contract between DSO and MECSA
Pricing method	Under contract

*The settlement scheme is based on penalties if bilateral agreement is not fulfilled.

2.3.4.4 Demo 4, Cooperative Modular Multi Hybrid Energy Storage Systems based on Hybrid SuperCap /Li-NMC batteries for Smart DC MGs of E-mobility Service – Italy

SERVICE 1 - CONGESTION MANAGEMENT

The flexibility service aims to help the electricity grid when an unbalance occurs. The HESS power flow management system could provide this service, either supplying power to the grid or withdrawing power from the grid. The first operation would be implemented when an excess of power demand occurs; if HESS is not fully discharged it would supply power to grid. The second operation would be implemented when an excess of power supply occurs; if HESS is not fully charged it would withdraw power from the grid.

- **Technical characterisation**

Technology used and maturity level	Hybrid Energy Storage System; TRL 6
Discharge time	From 1 to 4 hours (depending on power supply or demand).
Reaction Time	Estimated 15 minutes, depending on time reaction of the transmission or distribution system operator.
Frequency of use	Estimated to be high.
Unit of measurement	MW

- **Application characterisation**

Existence of the service	Existing
Application scale	Distribution system area, which is represented by the primary substation area, belonged to the grid point of delivery of the HESS.
Application beneficiaries	Users of the service would be both consumers and producers whose point of delivery is in the same primary substation area.

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Procured volume definition	Defined according to the dispatch rules in practice, which considers system load, forecasted renewable.
Unit of measurement	€/MWh in function of power flow expressed in MW
Remuneration scheme	Market based
Pricing method	As defined by balancing market.

Process overview description:

A. **Prequalification:** Congestion management service.

B. **Bidding/Selection:** Balance Agreement will define bidding for congestion management service per MWh and MW dispatched.

C. **Delivery:** Throughout the distribution system to which HESS is connected.

D. **Settlement:** Balance Responsible Party (BRP) will exchange remotely information with HESS to enable balancing operation.

E. **Monitoring:** Smart meter will be installed to enable remote metering and monitoring of the HESS.

SERVICE 2 - POWER SMOOTHING

Power smoothing service consists of reducing power flow fluctuation generated by the photovoltaic power plant due to renewable source variability, such as solar irradiation, and climate conditions. The service is provided by the HESS, which absorbs the electricity power flow fluctuation thanks to its connection to PV power plant, getting output power and voltage smoothing for both electricity grid and Demo 4 technologies. The Power smoothing service improves technologies lifetime as well.

- **Technical characterisation**

Technology used and maturity level	Hybrid Energy Storage System; TRL 6
Discharge time	From 1 to 4 hours (depending on power supply or demand).
Reaction Time	Immediately
Frequency of use	Constant, depending on meteorological conditions.
Unit of measurement	PV Output Voltage (V); PV Output power (kW)

- **Application characterisation**

Existence of the service	Existing
Application scale	Both Demo 4 technologies and the distribution system area represented by the primary substation

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	area belonged to the grid point of delivery of the HESS.
Application beneficiaries	Users of the service would be both Demo 4 technologies and consumers whose point of delivery is located in the same primary substation area.
Procured volume definition	Procured volume is defined as the amount of energy generated by the PV power plant during power smoothing operation.
Unit of measurement	€/kWh
Remuneration scheme	Market based
Pricing method	Pricing method is related to reducing the power peak of PV power plant input into the electricity grid.

- Process overview description:

A. **Prequalification:** Power smoothing service.

B. **Bidding/Selection:** No bidding process forecasted.

C. **Delivery:** Throughout the distribution system to which HESS is connected.

D. **Settlement:** None.

E. **Monitoring:** Smart metres will be installed to enable remote metering and monitoring of both the PV power plant and the HESS.

2.3.4.5 Demo 5, Agri-PV Farm with Energy Storage Capabilities based on Hydrogen and BESS Technologies – Luxembourg

SERVICE 1 – ENERGY ARBITRAGE

The demo includes renewable generation, APV and Wind Power, and local storage provided by a BESS and an electrolyser combined with 2 sequential storage tanks with different pressure levels. The HESS management will be optimised to maximise the benefits from the participation in the market based on day-ahead price forecasting.

- **Technical characterisation**

Technology used and maturity level	Demo HESS and APVPP and WPP; TRL 5 -> 7
Discharge time	30 min to few hours
Reaction Time	Hours
Frequency of use	Daily
Unit of measurement	MWh

- **Application characterisation**

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Existence of the service	New
Application scale	National
Application beneficiaries	GPSS – APV plant operator
Procured volume definition	The volume procured according to the market participation. The planning is based on day-ahead forecasts of the market and RES generation.
Unit of measurement	Quantities: MWh, prices €/MWh
Remuneration scheme	Market based
Pricing method	Auction - Pay as bid

SERVICE 2 - CONGESTION MANAGEMENT

in the service will mitigate the unbalance created by excess electricity production that cannot be transported due to insufficient capacity of the physical power lines. The mitigation of congestion can be done through "redispatch" mechanisms. The Large-scale grid-forming battery storage system, will allow the curtailment of the excessive generation, e.g. from PPV and WPP, and return the electricity back into the grid with a time delay.

- **Technical characterisation**

Technology used and maturity level	Li-ion LFP BESS; TRL 7
Discharge time	30 min
Reaction Time	ms up to few seconds
Frequency of use	Expected to be high (several times per day)
Unit of measurement	MWh

- **Application characterisation**

Existence of the service	Existing
Application scale	Distribution system area
Application beneficiaries	DSO
Procured volume definition	Defined according to the dispatch rules
Unit of measurement	Quantities: MWh, prices €/MWh
Remuneration scheme	Accordingly with bilateral contracts or as defined by a future balancing market.
Pricing method	Defined by bilateral contract / market-based

Process overview description:

A. **Prequalification:** Congestion management service.

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B. **Bidding/Selection:** A balance agreement will define bidding for congestion management service per MWh and MW dispatched.

C. **Delivery:** Distribution system.

D. **Settlement:** Balance Responsible Party (BRP) will exchange remotely information with BESS controller to enable balancing operation.

E. **Monitoring:** A hierarchical control platform will receive smart metering measurement from all generation assets at the edge level for continuous management and operation of the grid-forming BESS.

SERVICE 3 - FREQUENCY CONTAINMENT RESERVE (FCR)

Luxembourg belongs to the Load-Frequency Control Area of Amprion (German TSO). The service uses the energy storage to maintain the balance between generation and consumption within the synchronous area in coordination with all interconnected parties ensuring the operational reliability of the power system by stabilising the system frequency at the stationary value of 50 Hz after a disturbance or incident in the timeframe of seconds. However, market participation in Luxembourg is still hampered by regulation constraints.

- **Technical characterisation**

Technology used and maturity level	Li-ion LFP BESS, TRL 7
Discharge time	> 15 minutes
Reaction Time	< 30 seconds
Frequency of use	Expected to be several times per day.
Unit of measurement	MW, MWh

- **Application characterisation**

Existence of the service	New
Application scale	Amprion's Load-Frequency Control Area (DE-LU)
Application beneficiaries	TSO. Procured through daily auctions in four-hour blocks from bids with a minimum size of 1 MW
Procured volume definition	Defined according to the dispatch rules in the control zone. The reserve availability is calculated based on renewable generation forecasting, and market day-ahead capacity and energy forecasting (with a minimum bid size of 1 MW).
Unit of measurement	Reserve: MW, activation MWh
Business case	Both capacity reserve and energy are procured through daily auctions in four-hour blocks from bids with a minimum size of 1 MW

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Remuneration scheme	Pay as bid Price. BRPs obtain a price for capacity reserve (including costs for energy).
Pricing method	Not defined yet. The demo has been designed pointing to Market-based (Auction - Pay as bid).

SERVICE 4 - AUTOMATIC FREQUENCY RESTORATION RESERVE (AFRR)

Luxembourg belongs to the Load-Frequency Control Area of Amprion (German TSO). aFRR is procured through day-ahead capacity and energy market-based mechanisms with a minimum bid size of 1 MW. Is open generation and to demand-side resources. Asymmetrical bids are allowed. Balancing energy is procured for 15 min. blocks and the full activation time is 5 min. Both availability and energy are remunerated. However, market participation in Luxembourg is still hampered by regulation constraints.

- **Technical characterisation**

Technology used and maturity level	Li-ion LFP BESS, TRL 7
Discharge time	30 minutes
Reaction Time	30 seconds to 15 minutes
Frequency of use	Expected to be several times per day.
Unit of measurement	Reserve: MW, activation MWh

- **Application characterisation**

Existence of the service	New Service (in Luxembourg).
Application scale	Amprion's Load-Frequency Control Area (DE-LU).
Application beneficiaries	TSO.
Procured volume definition	Defined according to the dispatch rules in the control zone. The reserve availability is calculated based on renewable generation forecasting, and market day-ahead capacity and energy forecasting (with a minimum bid size of 1 MW).
Unit of measurement	€/MW, €/MWh
Business case	Different auctions determine which Balancing Service Provider (BSP) holds back capacities and/or delivers the reserve in case of imbalances for each quarter hour.
Remuneration scheme	Pay as bid Price. BSPs obtain a price for capacity reserve (including costs for energy).
Pricing method	Not defined yet. The demo has been designed pointing to Market-based (Auction - Pay as bid).

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SERVICE 5 – MANUAL FREQUENCY RESTORATION RESERVE (MFRR)

The manual Frequency Restoration Reserve is used to restore the required grid frequency of 50 Hz when there are longer lasting deviations in the power grid that cannot be resolved solely by the other upstream balancing services (FCR or aFRR). Luxembourg belongs to the Load-Frequency Control Area of Amprion (German TSO). However, market participation in Luxembourg is still hampered by regulation constraints. In Amprion's LFC area mFRR is procured through day-ahead capacity and energy market-based mechanisms with a minimum bid size of 1 MW. Is open generation and to demand-side resources and asymmetrical bids are allowed and full activation time is 12.5 min. Both availability and energy are remunerated

- **Technical characterisation**

Technology used and maturity level	Li-ion LFP BESS, TRL 7
Discharge time	30 minutes
Reaction Time	12.5 minutes
Frequency of use	Expected to be several times per day.
Unit of measurement	Reserve: MW, activation MWh

- **Application characterisation**

Existence of the service	New Service (in Luxembourg).
Application scale	Amprion's Load-Frequency Control Area (DE-LU).
Application beneficiaries	TSO.
Procured volume definition	Defined according to the dispatch rules in the control zone. The reserve availability is calculated based on renewable generation forecasting, and market day-ahead capacity and energy forecasting (with a minimum bid size of 1 MW).
Unit of measurement	€/MW, €/MWh
Business case	Different auctions determine which Balancing Service Provider (BSP) holds back capacities and/or delivers the reserve in case of imbalances for each quarter hour.
Remuneration scheme	Pay as bid Price. BSPs obtain a price for capacity reserve (including costs for energy).
Pricing method	Not defined yet. The demo has been designed pointing to Market-based (Auction - Pay as bid).

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2.3.5 Outlook on Upcoming Deliverables

In the context of Task 3.5, a survey of the flexibility services to be provided by each of the project's demonstrations has been conducted, identifying their main specifications, considering the reality of each service from a technological point of view, considering the characteristics of each demonstrator's HESS, but also in the perspective of each use case development. As planned with the task programmatic workflow, the upcoming technical release (D3.5) will include the definition of the data models required for the operation of each service, together with the evaluation of the implementation details of the services in the demonstrators. These exercises will enable the co-creation of standard data models for service compatibility between the different demonstrators targeting their connection to the i-STENTORE platform.

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3 I-STENTORE 1ST TECHNOLOGY RELEASE [MVP1]

3.1 COMPONENTS DESCRIPTION

3.1.1 Virtual Power Plant

Implementation of the i-STENTORE Virtual Power Plant Tool will be focused on enhancing the Flexibility Register of the IEGSA platform, which was originally developed as part of the H2020 INTERRFACE project. The aim is to build upon the Flexibility Register and develop a complete Energy Storage System Virtual Power Plant (ESS-VPP) for supervisory control over various energy storage technologies. The upgraded Flexibility Register will incorporate detailed ontologies for various energy storage systems and renewable assets. This enhanced register will not only allow the registration of these assets but also provide near real-time operational data insights, enabling better operational planning for interconnected assets.

The ESS-VPP, once established, will significantly improve portfolio management efficiency. Its primary purpose will be to enable more efficient provisioning of grid-supporting services. The VPP itself will operate as a model-based supervisory and automated decision-making platform. It will be designed with replicability in mind, making it adaptable to a wide range of stationary integrated applications incorporating renewable energy sources (RES) and energy storage solutions. To connect with existing data acquisition systems, the modular supervisory system will integrate with the i-STENTORE Data Governance Middleware from Task 3.4, adhering to industrial-grade standards. Additionally, a cost-effective solution for health management and lifetime monitoring of these integrated applications will be provided. Furthermore, the VPP will deliver an automated approach covering the entire process from the design phase to the commissioning phase of the online supervisory system, encompassing the visualisation of information and data services. In summary, the VPP will be a robust, flexible, and efficient software tool that will play a pivotal role in managing and optimizing the operation of energy storage systems, renewable assets and loads.

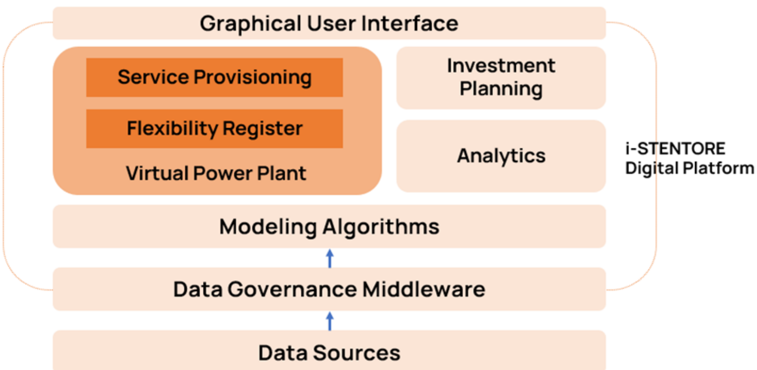

FIGURE 4: ESS-VPP COMPONENT STATIC VIEW.

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3.1.1.1 Asset Register Management

The I-STENTORE Asset Register Management module is a web-based CRUD (Create, Read, Update, Delete) application, which can be considered a base VPP distinct module. It is designed to streamline the registration of energy demo physical assets. Through a user-friendly interface it allows tracking and management of the aforementioned assets. Through the Data Access Policies module (part of the 2nd technology release) it caters based on access rules to the various I-STENTORE stakeholders, including Assets owners, operators, maintenance teams and/or regulatory authorities. As per the module functional specifications:

TABLE 1: ARM MODULE FUNCTIONAL SPECIFICATIONS.

ARM Functional Specifications Table		Current Release
FS_ARM_1	**Asset Registration (Create)**	
FS_ARM_1.1	Users can register new assets by providing detailed information such as asset type, location, capacity, technical specifications, and relevant details.	✓
FS_ARM_1.2	The registration process may include uploading relevant documents such as permits, certificates, and warranty information.	2^{nd} release
FS_ARM_2	**Asset Listing and Search (Read)**	
FS_ARM_2.1	The application provides a searchable list of all registered energy assets.	✓
FS_ARM_2.2	Users can filter assets based on criteria such as location, type, capacity, and status (operational, under maintenance, decommissioned, etc.).	✓ (partially)
FS_ARM_2.3	Detailed asset information including specifications, maintenance history, and performance data is accessible for viewing.	2^{nd} release
FS_ARM_3	**Asset Details and Editing (Update)**	
FS_ARM_3.1	Users can view and edit the details of registered assets as needed.	✓
FS_ARM_3.2	Updates may include changes to asset specifications, capacity details, maintenance schedules, and operational status.	✓ (partially)
FS_ARM_3.3	Revision history allows tracking of changes made to asset information over time.	2^{nd} release

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FS_ARM_4	Asset Maintenance Management (Update)	
FS_ARM_4.1	The application facilitates scheduling and management of maintenance activities for registered assets.	2nd release
FS_ARM_4.2	Users can create maintenance tasks, assign them to maintenance teams, set priority levels, and track progress.	2nd release
FS_ARM_4.3	Automated reminders and notifications ensure timely execution of scheduled maintenance activities.	2nd release
FS_ARM_5	Asset Decommissioning (Update and Delete)	
FS_ARM_5.1	An Asset can be deleted from registry.	✓
FS_ARM_5.2	When an asset reaches the end of its lifecycle or needs to be decommissioned for any reason, users can initiate the decommissioning process.	2nd release
FS_ARM_5.3	Decommissioning involves updating asset status, documenting decommissioning activities, and removing the asset from active inventory.	2nd release
FS_ARM_5.4	Deleted assets are archived for record-keeping purposes and can be retrieved if needed.	✓
FS_ARM_6	User Authentication and Authorization	
FS_ARM_6.1	Integration with Identity Management Tool.	✓
FS_ARM_6.2	The application supports User Registration capabilities.	✓
FS_ARM_6.3	The application supports user authentication to ensure secure access to sensitive asset information.	✓
FS_ARM_6.4	Role-based access control defines user permissions based on roles such as administrator, asset manager, maintenance personnel, etc.	2nd release

The benefits of the VPP ARM module can be summarized as follows:

- Centralized Asset Management: The application provides a centralized platform for managing all energy assets, improving visibility and control.

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- Efficient Maintenance: Scheduled maintenance tasks and automated notifications help ensure optimal asset performance and longevity.
- Compliance and Documentation: Users can maintain accurate records of asset information, maintenance activities, and regulatory compliance.
- Data-driven Decision Making: Access to real-time asset data and historical performance metrics enables informed decision making for asset optimization and planning.
- Enhanced Collaboration: Collaboration features facilitate communication and coordination among stakeholders involved in asset management and maintenance.

ASSET REGISTER MANAGEMENT USER INTERFACE

The user can access the available Assets in the system through the "Assets" screen (Fig. 5):

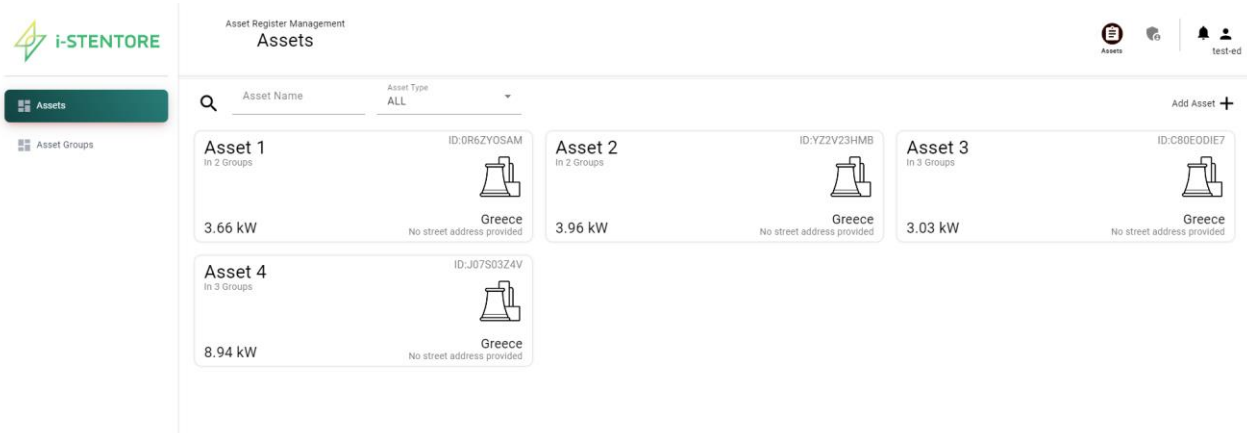

FIGURE 5: ASSETS.

An Asset contains a "Basic Info" tab (Fig. 6). Through this tab the user can access the base info about an asset like its type, the asset group it belongs etc.

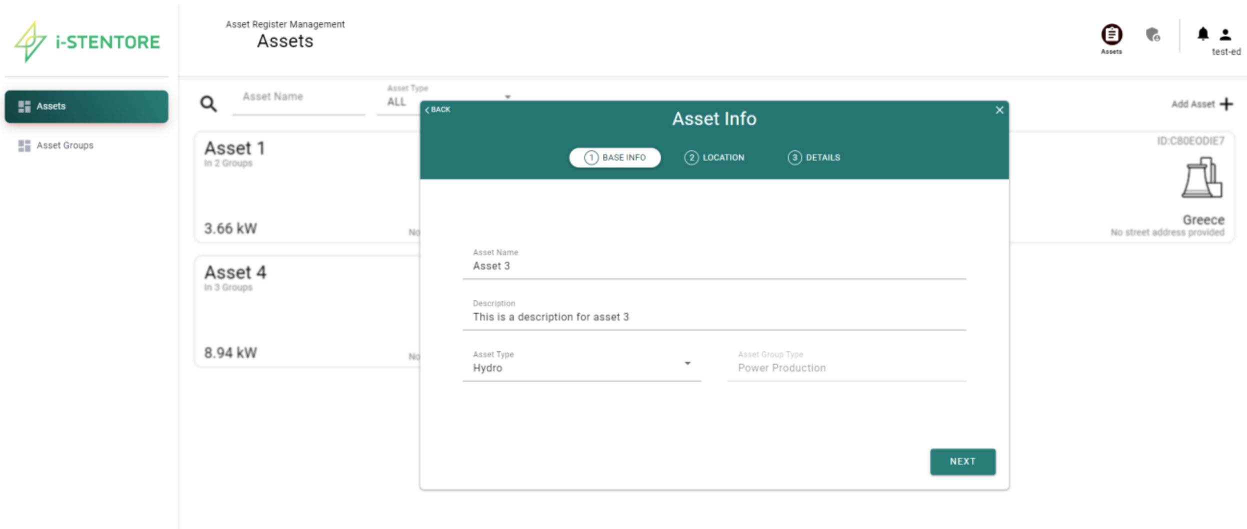

FIGURE 6: ASSET BASIC INFORMATION.

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An Asset contains a "Location" tab (Fig. 7). Through this tab the user can access the location information about the asset.

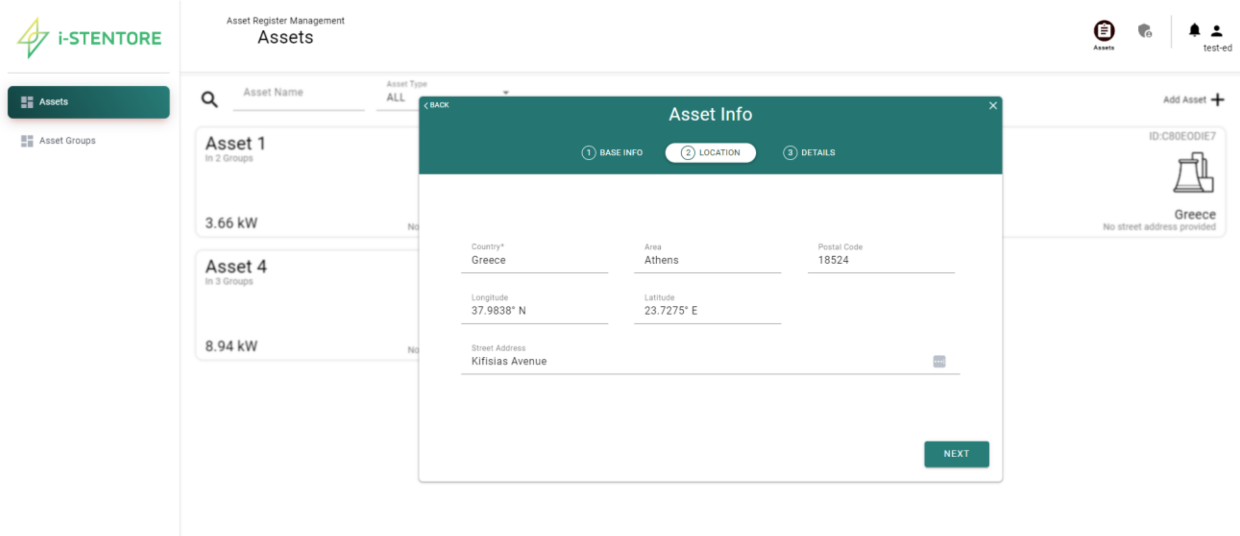

FIGURE 7: ASSET LOCATION TAB.

An Asset contains a "Details" tab (Fig. 8). Through this tab the user can access the detailed measurements information about the asset, based on the asset's type.

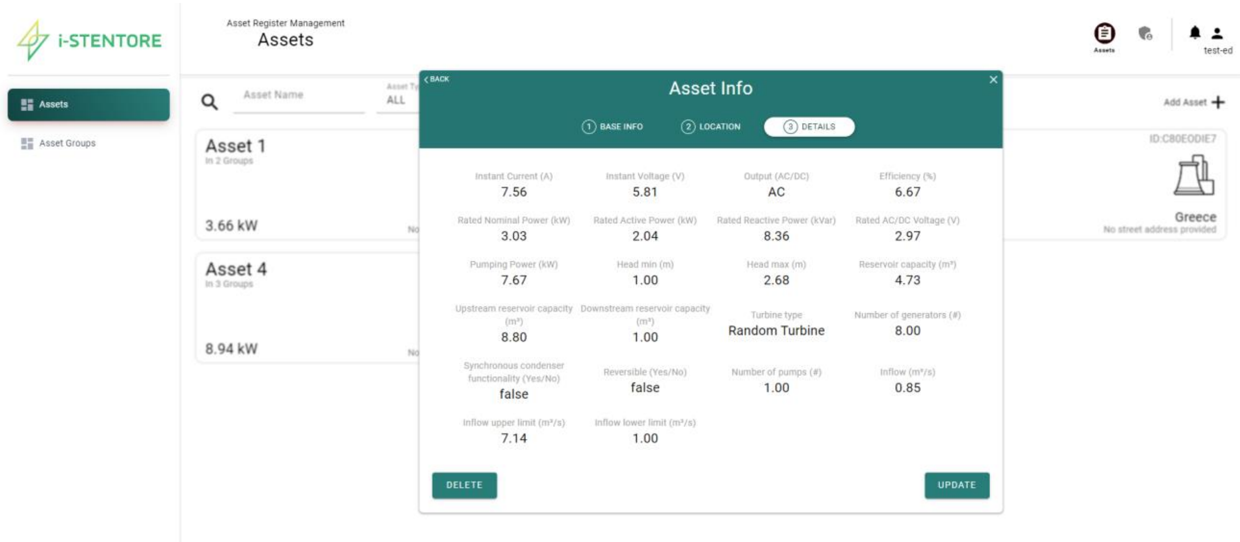

FIGURE 8: ASSET DETAIL MEASUREMENTS.

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Through the “Asset Groups” screen the user can see the available Asset Groups in the system (Fig. 9).

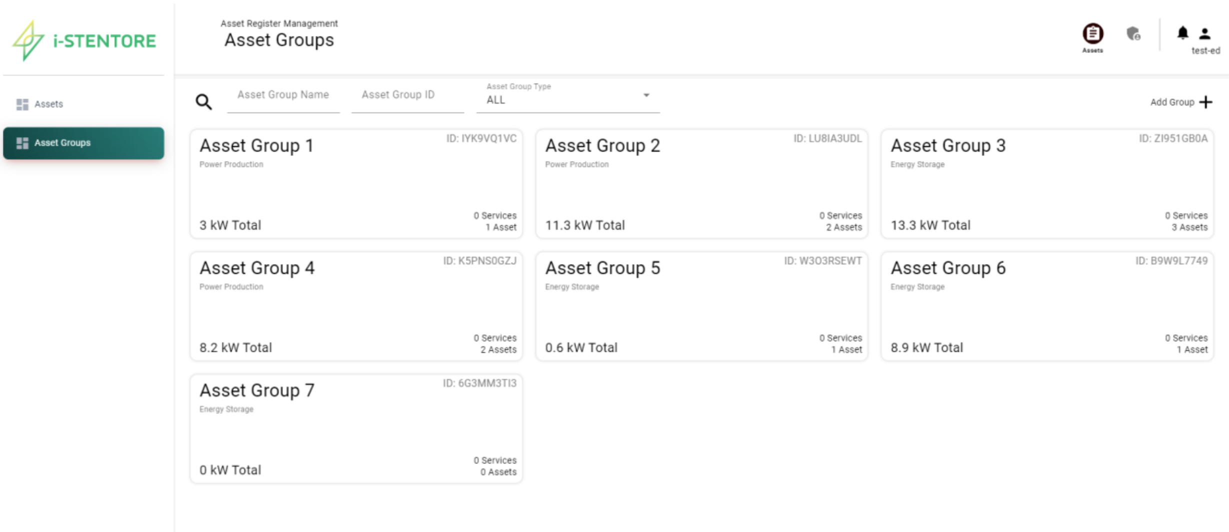

FIGURE 9: ASSET GROUPS.

This is the “Asset Group Info” tab of an Asset Group (Fig. 10). In this tab the user can see the base info about an asset group like its name, description and its asset group type.

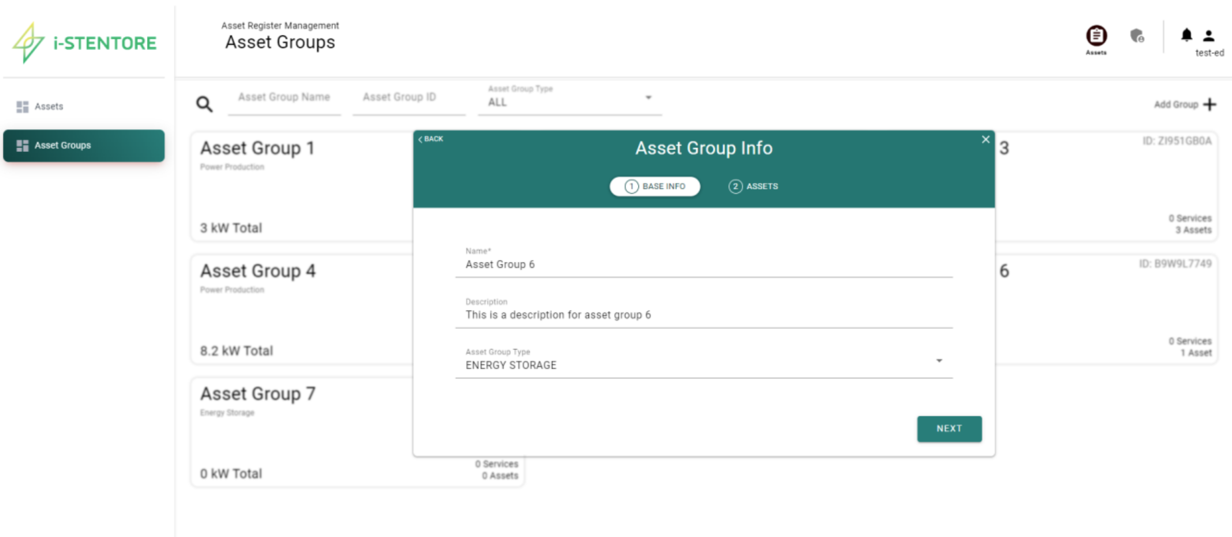

FIGURE 10: ASSET GROUP BASIC INFORMATION.

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The following Figure (Fig. 10) presents the "Asset Group Assets" tab of an Asset Group. In this tab the user can see the selected assets which belong to an Asset Group.

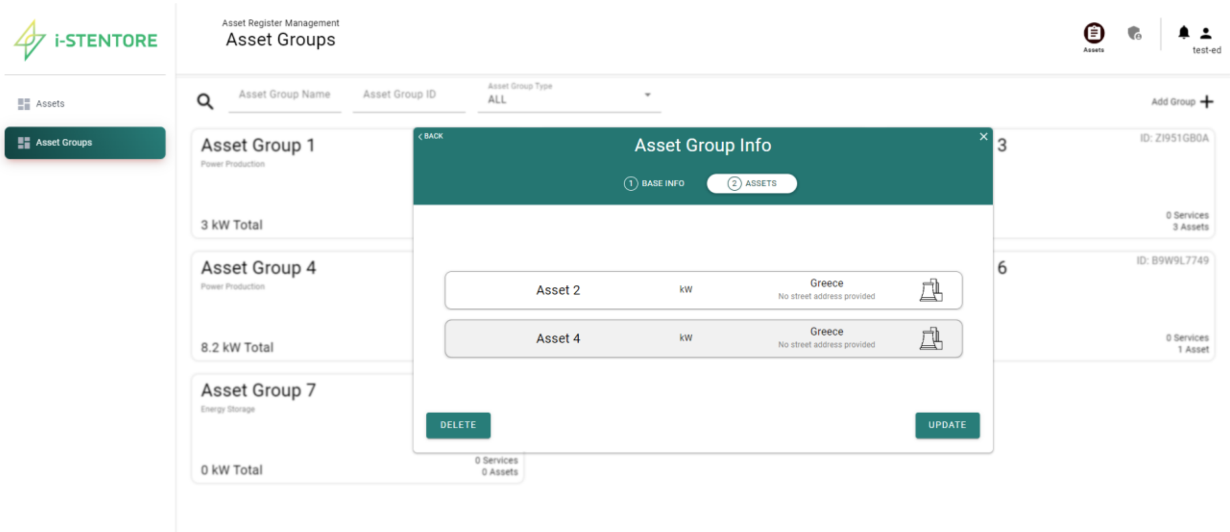

FIGURE 11: ASSET GROUP ASSETS.

Through the "Users" screen the user can see the registered users in the system (Fig. 12).

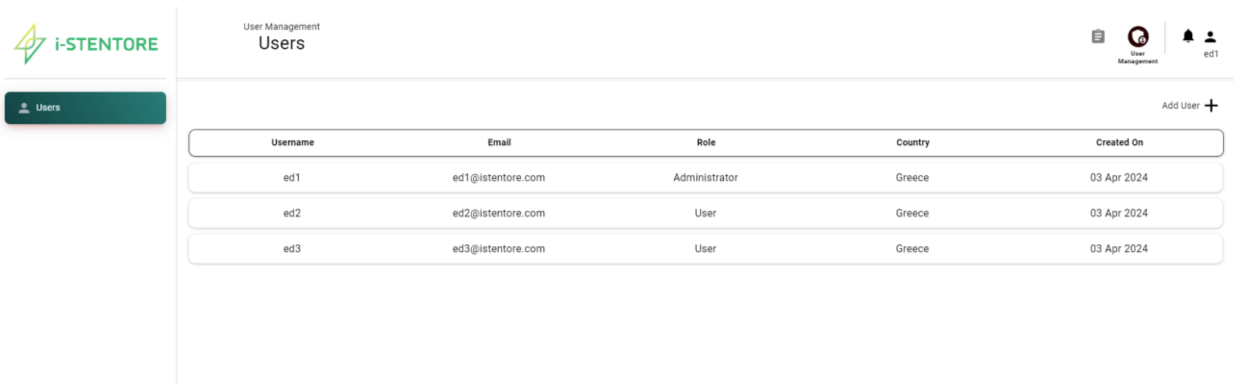

FIGURE 12: ASSET GROUP ASSETS.

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Through the "Edit User" popup window the user can see (or edit if he is administrator) the registered users details in the system (Fig. 13).

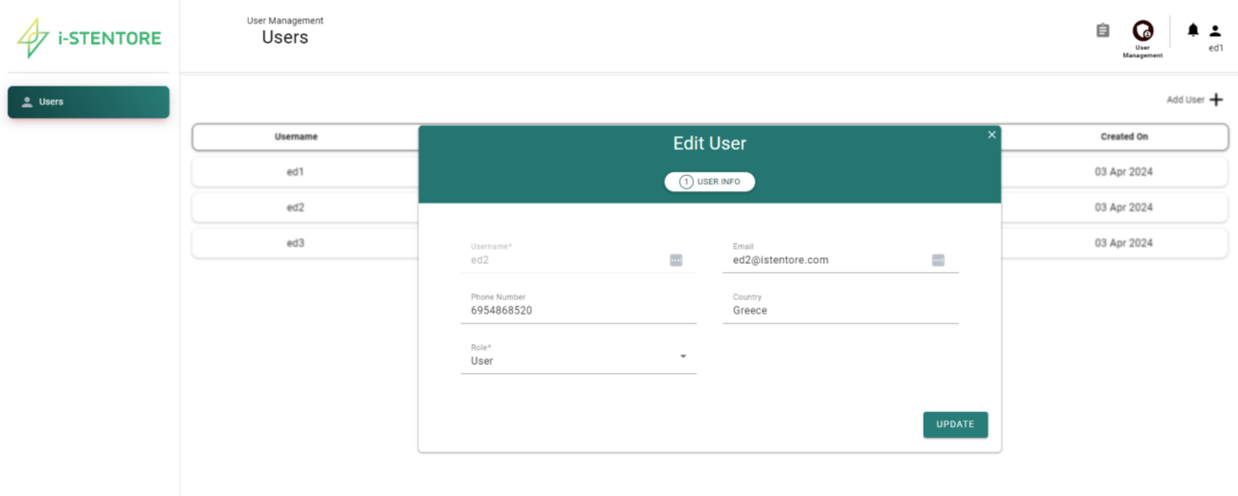

FIGURE 13: USER DETAILS.

3.1.1.2 Deployment and Future vision of the VPP

Overview: The current version of the VPP is operational and housed on a virtual machine (VM) leveraging the flexibility and scalability inherent to virtualized environments. At this stage, the deployment strategy provides an agile and adaptable platform, aligning with the dynamic requirements of the users as they progressively shape and refine the tool across diverse energy storage technologies. This approach not only enhances the tool's functionality but also opens avenues for users to co-shape and refine the existing ontology, offering valuable user feedback that inherently enriches the system's development.

Public Access and Credentials: Access to the VPP is designed to be publicly available, ensuring broader engagement and utility. External stakeholders can gain access upon receiving appropriate (anonymised) credentials, a process designed to uphold stringent data security and privacy standards, ensuring both transparency and confidentiality in operations.

Rationale for Dockerization: In the next releases ED intends to deliver a dockerised version. Dockerisation, known for its portability and ease of deployment, offers consistent performance across varied environments. This shift is anticipated to significantly enhance the operational efficiency, data security and deployment flexibility of the VPP.

3.1.2 Investment Planning Tool

The urgent need to advance the development and roll-out of innovative storage concepts, promote new technologies, and propose Hybrid Energy Storage System (HESS), has been translated, in market terms, into advancing the investments on innovative energy storage concepts. Considering that these efforts will facilitate the integration of renewables, improve power system management, and optimize grid operations, this section aims to lay out the main features of an Investment Planning Tool (IPT) that has been developed in the context of i-STENTORE, targeting potential energy storage investors, and enables the comparison among

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different options of standalone and hybrid energy storage technologies (alternatives of the problem) against a group of cross-sectoral criteria covering various dimensions of economic, technological, social, and environmental nature (restrictions of the problem).

From a methodological point of view, the tool gathers under a common conceptual umbrella a couple of advanced Multi-Criteria Decision Analysis (MCDA) methods and several extensions of them, structured in a way that enables solving complex decision-making problems, whilst also facilitating the in-depth elicitation of the users' knowledge and perspective. IPT constitutes a suite of distance-based MCDA methods, where VIKOR methodology [1] and various recent extensions of it [2, 3] have been in the spotlight, in order to enable solving complex decision-making problems in the presence of imprecise and/or uncertain input data. To enhance comprehensiveness and inclusiveness, another MCDA method called TOPSIS [4] has also been integrated in the tool, on top of the abovementioned ones, which, for the purpose of this first technological release is not accompanied by any extensions, as is the case for the VIKOR. However, this action is expected to be implemented in the scope of the second technological release, thus ending up in utilizing two MCDA methods and a few extensions for each of them [5, 6, 7]. From the end-users' perspective, they are able to insert their preferential profile, both in terms of their market engagement to the energy storage field (e.g., market role, revenue streams, applications, etc.) and methodologically (e.g., incomplete weights, interval data, etc.), and the tool is designed to prioritize the involved energy storage systems in an optimal and robust way. The tool brings significant added value providing solutions to decision-making problems that are closer to reality (augmented reification), while also allowing the users to express their preferences with enhanced freedom, in a way that extends beyond strictly defining numerical values to determining relative order and/or using linguistic terms.

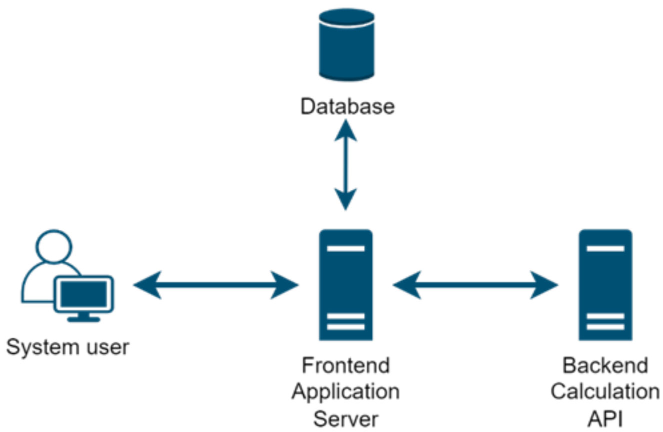

FIGURE 14: OVERALL ARCHITECTURAL APPROACH FOR THE DEVELOPMENT OF THE IPT.

IPT has been built on a foundation of cross-platform technologies, like Python and .NET Core, easily deployable on any sort of system through the use of containerisation. It comprises a dynamic web-based front-end application for the user interface and presentation layer, and a versatile backend API designed to serve multiple systems. The backend API operates independently of the front-end, making it adaptable to various user interfaces and applications. The front-end component, developed using a modern application development framework, incorporates the principles of Material Design and responsive UI elements. The backend component, implemented as a micro-service, is responsible for executing the MCDA methods on the provided data. In the next technological releases, there is a provision for an agnostic stateless API to be exposed, serving any client, be it the front-end application or another micro-service or system. This architectural approach allows for scalability, reusability, and ease of integration, making it an ideal choice for a versatile and modular system.

Technically speaking, IPT is available in the form of a web application and therefore does not require any additional installation actions by the users. To access it, the users just need to hit the address through a common web browser. The app has been tested on recent versions of Microsoft Edge, Google Chrome, and Safari, but in practice a recent version of any other browser based on Chromium or supporting WebAssembly technology can be used. Since the tool has been developed as a web application and runs in a web browser environment, there is not an established way to measure and define specific system requirements. It is estimated that approximately 200MB of RAM memory is required in addition to the requirements of the selected browser for its smooth operation. Internet access is equally important as well when loading the pages and when submitting data for calculation.

The above IPT has been released recently, following several validation tests that have been conducted to verify everything works as planned. Since these tests have been proven to be successful, an in-depth guidebook is presented below, to deploy the key functionalities and aspects of the tool. It should be highlighted here that part of the IPT's front-end is still under development including the introduction page, and as of this, the presented guidebook directly dives into the actual step-by-step application that a potential user should go through. Of course, as the project progresses, this guidebook will be constantly updated.

3.1.2.1 Step 1: Select your market role

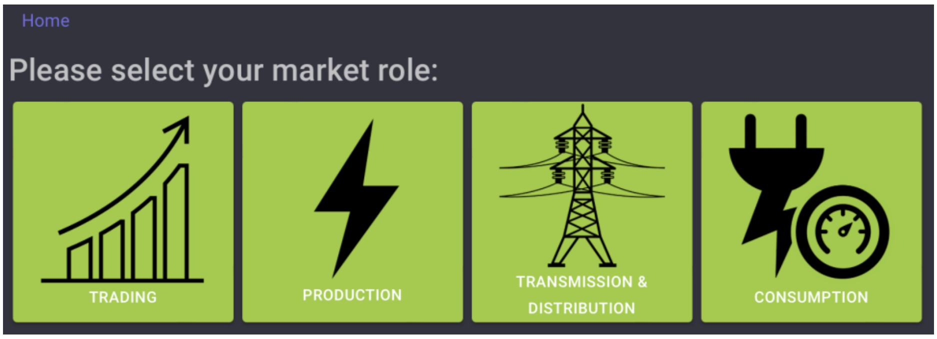

FIGURE 15: AVAILABLE MARKET ROLES INCLUDED IN THE IPT.

At the current version, the "Select your market role" page serves as the starting point once the tool is accessed, essentially asking the users to select their role in the energy storage market. In terms of market participation, we distinguish between four major categories with respect to the electricity supply chain: 1) trading, 2) production, 3) transmission and distribution (T&D), and 4) consumption [8]. In trading, investors procure electricity from producers or the market and then send it to consumers or back to the market. In production and consumption, things are quite straightforward since investors generate and sell electricity in the first case, whilst the exact opposite happens in the second case with the investors purchasing and consuming electricity. Within T&D, investors are in charge of monitoring the

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electricity transportation and the secure operation of the power grid overall. It is worth mentioning that the discrete responsibilities of transmission and distribution grid operators are aggregated into a single market role, to ease understanding.

It is important to emphasize that our perception of market roles does not necessarily align with typical depictions of individuals or organizations involved in the electricity market, even though there may be similarities. Our main goal for conducting such a clustering is driven solely by our pursuit to be compatible with the ontologies to be developed in the scope of i-STENTORE, which will be presented in Section 4.1.3.1. An investor, whether an individual or an organization, can assume multiple roles (not simultaneously) considering that applications may differentiate between market roles, or repeat the same role multiple times, each time including different energy storage technologies in the analysis. The final decision to invest in specific storage facilities is heavily dependent on each market role. The latter implies a direct link of the market roles to the revenue streams, applications, and energy storage technologies, as will be further elaborated in the following steps.

3.1.2.2 Step 2: Select your revenue stream

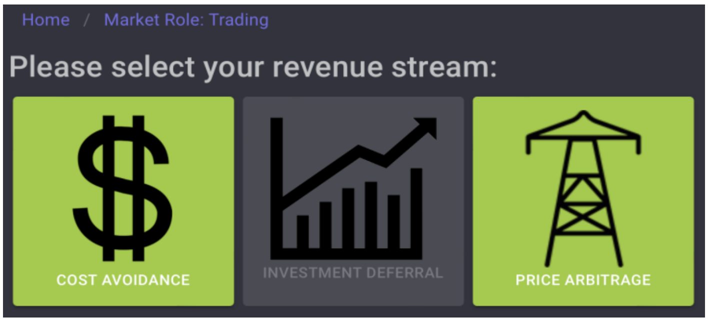

FIGURE 16: AVAILABLE REVENUE STREAMS INCLUDED IN THE IPT.

Once the market role is selected, then the users are requested to proceed with choosing the revenue stream for their case. The revenue stream describes the type of income a storage facility can trigger from its operation. In this version of the IPT, we have identified three distinct categories of revenue streams: 1) Cost avoidance, 2) Investment deferral, and 3) Price arbitrage. "Cost avoidance" refers to savings stemming from operational expenses, such as avoiding the need to adjust power generation capacity or penalties for deviations in electricity production [9]. "Investment deferral" denotes savings achieved by postponing investments in alternative generation or grid capacity [10]. Lastly, "Price arbitrage" involves exploiting disparities in electricity prices either between different markets simultaneously or over time within a single market [11]. This discrepancy may arise from additional costs such as taxes and fees incurred when purchasing electricity. For example, residential solar panel owners often are compensated in a lower price for the electricity they supply to the grid compared to what they pay for consuming grid electricity. The latter price gap emerges from fluctuations in electricity prices over time. It also encompasses savings for electricity consumers, like adjusting production facilities for industrial consumers or simply avoiding inconveniences for residential consumers.

It should be mentioned here that there is a mapping of the available market roles (Figure 6) to the revenue streams considering the real-life market operation. As of this, you may notice

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for example in Figure 7, where "Trading" has been selected as the market role of a user (marked in the upper left side of Figure 7 with an orange box), that cost avoidance and price arbitrage are eligible, in contrast to the investment deferral revenue stream which is prohibited from selecting. Following the same pattern, all of the involved market roles have been associated to particular revenue streams accordingly.

3.1.2.3 Step 3: Select your application

FIGURE 17: AVAILABLE APPLICATIONS INCLUDED IN THE IPT.

Moving on to the next step of inserting the users' preferential profile, a layer of applications is encountered. An application denotes the function fulfilled by an energy storage system to meet specific requirements for storing electricity over time within contemporary power systems. IPT currently incorporates 13 different applications [12, 13, 14]:

1. Frequency containment
2. Short-term frequency restoration
3. Long-term frequency restoration
4. Voltage control
5. Black start energy
6. Backup energy
7. Trading forecast
8. Production forecast
9. Schedule flexibility
10. Peak shaving
11. Trading arbitrage
12. Consumption arbitrage
13. Self-sufficiency

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The first four applications involve maintaining grid stability by either supplying or demanding power for specific durations to address frequency containment, short-/long-term frequency restoration, and voltage control issues. The subsequent two applications focus on ensuring continuous electricity availability at all times and during blackouts by providing black start energy and backup power. The remaining seven applications can be categorized as load shifting applications since they involve redistributing electricity over time. Applications 7. and 8. pertain to assisting in meeting committed selling/buying forecasts by compensating for unexpected changes in demand or generation profiles. In applications 9. and 10., energy storage aids in smoothing supply/demand peaks, potentially averting the need for transmission line expansions by reducing peak loads where deemed necessary. Last but not least, in applications 11., 12. and 13., storage facility owners capitalize on price discrepancies by selling electricity during high-price periods and purchasing energy during low-price periods.

Once again, a mapping of the available applications has been conducted to the revenue streams (and consequently to the market roles). For example, in Figure 8, where "cost avoidance" has been selected as the revenue stream of a user (marked in the upper left side of Figure 8), only four out of the 13 applications included in the IPT are eligible. Following the same pattern, all of the involved applications have been associated to particular revenue streams accordingly.

3.1.2.4 Step 4: Select the energy storage technologies for your application

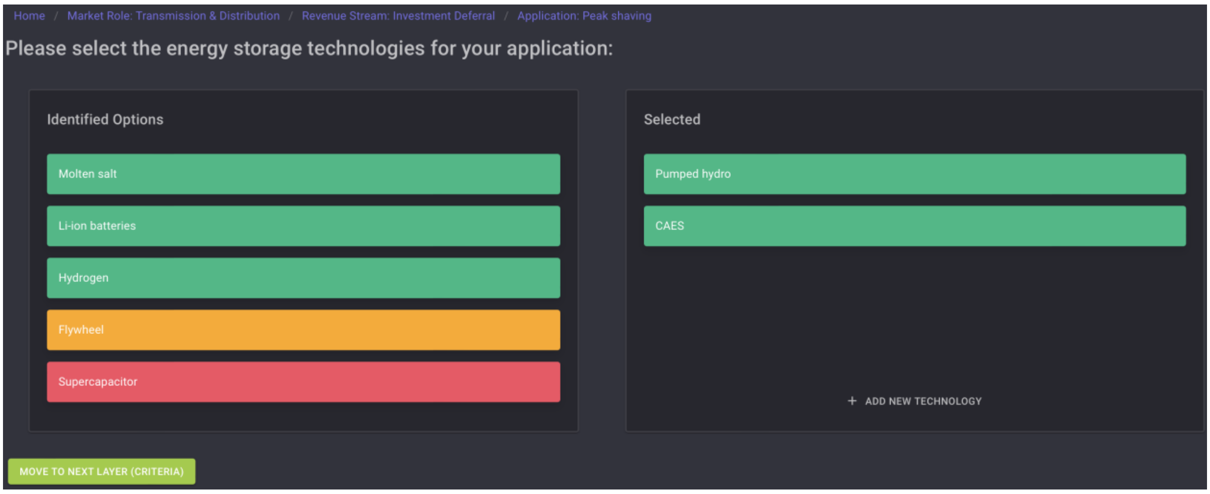

FIGURE 18: ENERGY STORAGE TECHNOLOGIES INCLUDED IN THE IPT.

In this step, the users are requested to select the energy storage technologies that will be analysed for the decision-making problem under examination. The current version of the IPT accommodates seven Energy Storage Systems (ESS), which are the following:

1. Flywheel
2. Pumped hydro
3. CAES
4. Molten salt

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5. Supercapacitor
6. Li-ion batteries
7. Hydrogen

Drawing from Figure 9, it is noticed that two separate panels have been developed. The left one lays out the ESS that have been gathered for the purpose of setting up the IPT, marked in different colours. The discrimination of the ESS according to their colour encompasses a different level of each storage system's deployment under the selected market role (in Step 1), revenue stream (in Step 2), and application (in Step 3). In other words, a mapping of the available ESS (Figure 9) to the applications (and thus to the revenue streams and the market roles) has been implemented. As of this, you may notice for example in Figure 9, where "Peak shaving" has been selected as the application, that only five ESS are 100% eligible (marked in green).

To elaborate more on the colouring, marked in green are the ESS that have been widely used for the built case under examination, whilst, on the other hand, marked in orange are the ESS that have been stress-tested only to some extent, and finally marked in red are the ESS that are still under investigation for the designated case. As of this, green and orange ESS are eligible, in contrary to the ones marked in red, which are prohibited from using. Once an ESS from the left panel is selected by the users, then it is automatically transferred to the right panel under "Selected". The selection is implemented upon double clicking of the desired ESS in the left panel or by dragging and dropping from the left panel to the right one. As an additional feature, the users are able to create new ESS on top of the existing ones by clicking on the "Add new technology", and include them in the upcoming analysis. Once the users are finished with the selection of the ESS, they need to press "Move to next layer (criteria)" in order to proceed to the next step.

As a side note in this step, it should be pinpointed that the dive into the operational framework of the above ESS is not part of this deliverable's objectives, and also taking into consideration that they have been thoroughly described in previous deliverables of the project, no further elaboration on their functionalities and features is provided here. Furthermore, the implicated energy storage technologies are standalone, with no Hybrid Energy Storage Systems (HESS) having been integrated yet. The reason for the latter lies in the fact that the MCDA methods require solid and concrete data in order to calculate accurate results for the decision-maker. However, when the case is for HESS, a profound lack of data availability has been encountered in the literature, both of static and dynamic nature. On that reflection, and following several internal discussion rounds with the partners, we are working intensively towards retrieving such data by combining literature-based and operational-driven pools of raw data from the partners' on-site ESS facilities, with an eye to integrating them in the tool, in the technological releases to follow.

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3.1.2.5 Step 5: Select the criteria for your application

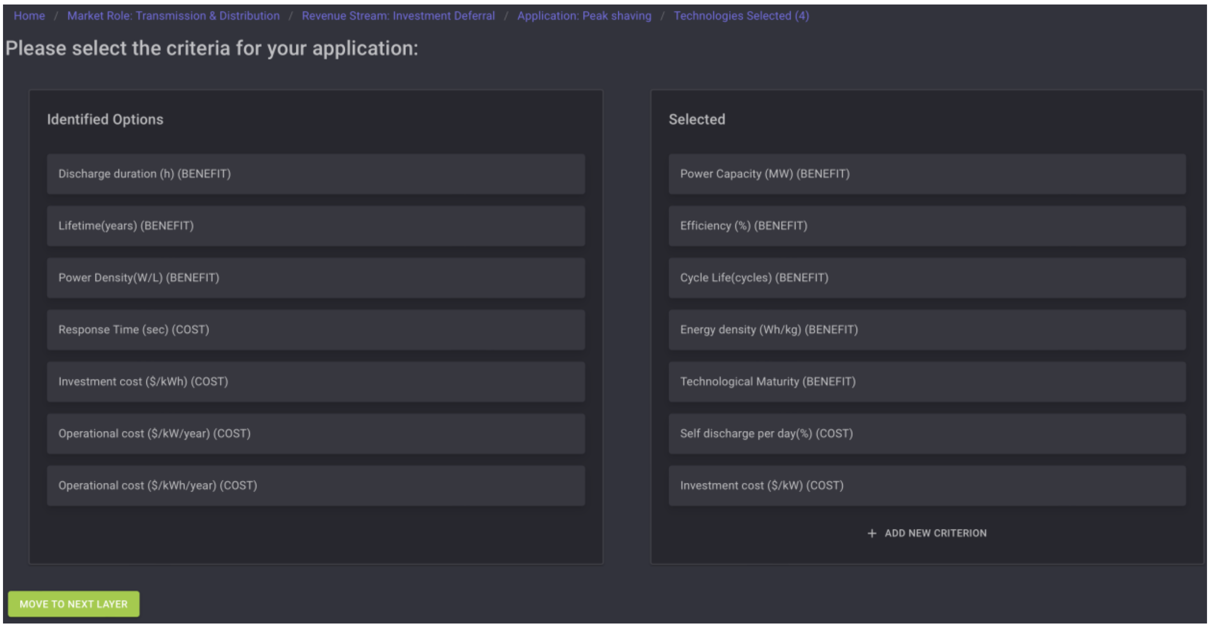

FIGURE 19: EVALUATION CRITERIA INCLUDED IN THE IPT.

After the energy storage technologies that will be included in the analysis have been selected in Step 4, the users need to choose the criteria against which the ESS will be assessed in terms of their performance. Based on extensive literature review and building on the insights drawn from previous deliverables of i-STENTORE, 14 criteria were identified:

1. Power capacity (MW)
2. Discharge duration (h)
3. Self-discharge per day (%)
4. Response time (sec)
5. Efficiency (%)
6. Lifetime (years)
7. Cycle life (cycles)
8. Investment cost ($/kW)
9. Investment cost ($/kWh)
10. Operational cost ($/kW/year)
11. Operational cost ($/kWh/year)
12. Energy density (Wh/kg)
13. Power density (W/L)
14. Technological maturity

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It worth noting that each criterion is attributed either a “cost” or a “benefit” label (Figure 10), which underlines the nature of the criteria’s impact on the rest of the methodological analysis. In particular, when a criterion is labelled with a “cost” sign, the methodological framework is structured to interpret it as a minimization problem. To simplify, the incorporated MCDA methodologies are designed to search for the minimum performance of the evaluated ESS, considering that this is the optimal solution for this specific criterion. The same applies to all criteria that are characterized as “cost”, namely, the minimum performances are considered to be the ideal ones. On the other hand, in the cases where a criterion is labelled as “benefit”, a maximization problem is internally formed, namely the maximum performance of the involved alternatives is sought for.

Another crucial characteristic of the identified criteria that should be highlighted is that some of them are of qualitative whilst some other of quantitative nature. In other words, the performances of the ESS under examination may be presented in the form of numerical values for the quantitative criteria, and in the form of linguistic terms for the qualitative criteria. For example, in our case all of the criteria are quantitative, except for the “technological maturity” which is assessed by the users based on the following scale: {Demonstration, Developing, Developed, Mature, Commercialized}. These terms are one-to-one matched to numerical values within the IPT, and the application of the methodology remains intact, regarding its ability to provide results.

As far as the visualization is concerned, two separate panels have been developed, applying the same technique used in Step 5. The left panel presents the criteria that have been gathered for the purpose of IPT, which are automatically transferred to the right panel under “Selected”, upon double clicking or dragging and dropping by the users. The users are able to create new additional criteria by clicking on the “Add new criterion”. Once the users are finished with the selection of the criteria, pressing “Move to next layer” will move the analysis on to the next step.

3.1.2.6 Step 6: Select the input data type

FIGURE 20: AVAILABLE DATA INPUT TYPES INCLUDED IN THE IPT.

The users are provided with the possibility to select their input data type, either on interval format, or by entering single values in terms of performance of the involved alternatives (Step 4) against the criteria (Step 5). The “intervals” option allows the users to insert imprecise data, by defining the upper and lower threshold of the performance values, with the respective lack of accuracy that such an approach may impose on the results of the analysis. On the contrary, the “single values” option appears to be more restrictive since it provides only for specific values to be entered. The latter implies higher data accuracy that will be reflected on the final results, but, at the same time, it burdens the users with limited flexibility, when the case is for difficult-to-retrieve data or alternatives that their performance cannot be easily translated

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into a single value. A third data input option, referred to as "mixed" has been incorporated to be the compromising solution to the abovementioned problem, since it allows users to provide performance data in both interval and single-value format, at criterion level. Relative descriptions regarding the background information of each input data type are presented to the user upon hovering over the potential options (Figure 11).

3.1.2.7 Step 7: Select the weighting type

FIGURE 21: AVAILABLE CRITERIA WEIGHTING TYPES INCLUDED IN THE IPT.

In this step, the users need to assign weights to the criteria, depending on their importance. To do so, there are two different pathways that the users could follow: 1) provide exact weights, or 2) provide relative weights. The reason behind this discrimination appears as a follow-up to the data input approach described in Step 6, andallows more flexibility to the users when accurate numerical values are difficult to be assigned to the criteria. To specify, the "exact weights" option prescribes for single numerical values to be entered, denoting the importance of each criterion compared to the rest. These weights can practically get any value, considering that a normalization process is carried out automatically (Figure 13). However, acknowledging that such a task may be challenging for a user or introduce uncertainty to the analysis, we come down to the second option, the "relative weights", where the users are free from providing strict numerical values and are requested to order the selected criteria (Step 5) in descending order (Figure 14). This is implemented by clicking on the up and down arrows next to each criterion's name, until the desired order is met.

FIGURE 22: NUMERICAL VALUES FOR THE "EXACT WEIGHTS" CRITERIA WEIGHTING TYPE.

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FIGURE 23: RELATIVE ORDER FOR THE "RELATIVE WEIGHTS" CRITERIA WEIGHTING TYPE.

Before moving on to the next step, it should be emphasized here that for each of the combination of the users' selection in Step 6 and Step 7, a dedicated MCDA methodological framework is expected to run in the backend of the IPT. In other words, these combinations define the methodological framework that will be employed for the analysis. Nevertheless, in this version of the IPT, there is not yet foreseen a one-to-one match of each combination to a particular MCDA framework, which, although will be integrated as feature in the next technological releases of the tool.

For the sake of clarity and inclusiveness, the mathematical background that will match each of the above combinations is presented below.

3.1.2.8 A. The VIKOR method

The VIKOR method has been developed as a multi-attribute decision-making method for solving decision-making problems with non-commensurable and conflicting criteria [1, 18]. This method is suitable for those situations where the goal is to maximize profit, while the risk of the decision is deemed to be less important.

Based on the L^p metric for the aggregation process, the method focuses on compromise ranking from a set of alternatives.

More precisely:

Let $A = (A_1, \ldots, A_m)$ be a set of alternatives which are evaluated across a set of criteria $C = (C_1, \ldots, C_n)$ with consequences $f_{ij}, i = 1, \ldots, m, j = 1, \ldots, n$, and criteria weights lying in the following set

$$W = \left\{ w \in \mathbb{R}^n : \sum_{j=1}^{n} w_j = 1, w_j \geq 0, j = 1, \ldots, n \right\}.$$

The VIKOR decision model includes the following steps:

Step 1. Determination of the positive and the negative ideal solution, as follows:

$$f_j^* = \max_i f_{ij}, \quad f_j^- = \min_i f_{ij},$$

if criterion C_j is of benefit type, and

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$$f_j^* = \min_j f_{ij}, \quad f_j^- = \min_j f_{ij},$$

if it is of cost type.

Step 2. Calculation of S and R metrics, defined as follows:

$$S_i = \sum_{j=1}^{n} w_j \left| \frac{f_j^* - f_{ij}}{f_j^* - f_j^-} \right|, i = 1, \dots, m,$$

$$R_i = \max_j w_j \left| \frac{f_j^* - f_{ij}}{f_j^* - f_j^-} \right|, i = 1, \dots, m,$$

Metrics S and R have specific interpretation in terms of decision theory. In particular, they correspond to two different decision-making perspectives regarding the level of conservativeness that decision-maker adopts. Metric S expresses the “majority of criteria” (or group utility) perspective, while metric R expresses the “individual regret” one.

Step 3. Calculation of metric Q, defined as follows:

$$Q_i = v \frac{S_i - S^*}{S^- - S^*} + (1 - v) \frac{R_i - R^*}{R^- - R^*}, i = 1, \dots, m,$$

where

$$S^* = \min_i S_i, \quad S^- = \max_i S_i,$$

$$R^* = \min_i R_i, \quad R^- = \max_i R_i,$$

and $v \in [0, 1]$ stands for the strategy coefficient of the VIKOR method weighting the group utility perspective against the individual regret one.

Step 4. Alternatives’ ranking in descending order based on metric Q.

3.1.2.9 B. The interval extension

In classical multi-criteria decision-making methods, consequences of the payoff table are expressed through crisp numbers, while, in real-world problems, it is not too realistic to assume that decision maker’s knowledge could be represented precisely [2]. On the other hand, interval numbers fit better to decision-making problems governed by uncertainty and impreciseness. Moreover, in contrast to stochastic and fuzzy approaches, interval numbers are more efficient, since they require the minimum amount of information regarding attributes’ values. In this section, we include the interval extension of the VIKOR MCDM method, developed in [2], to tackle with the case of interval values in the payoff table of the MCDM problem.

Considering that consequences of alternatives A against criteria C are of interval form, that is, $f_{ij} \in [f_{ij}^L, f_{ij}^U]$, the interval extension of the VIKOR decision model includes exactly the following steps:

Let I and J denote the set of indices associated with the benefit and cost type criteria.

Step 1. Determination of the positive and the negative ideal solution, as follows:

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$$\boldsymbol{f}^* = (f_1^*, \dots, f_n^*) = \left\{\left(\max_i f_{ij}^U : j \in I\right) \text{ or } \left(\min_i f_{ij}^L : j \in J\right)\right\},$$

$$\boldsymbol{f}^- = (f_1^-, \dots, f_n^-) = \left\{\left(\min_i f_{ij}^L : j \in I\right) \text{ or } \left(\max_i f_{ij}^U : j \in J\right)\right\}.$$

Step 2. Calculation of metrics $S_i = [S_i^L, S_i^U]$ and $R_i = [R_i^L, R_i^U]$, defined as follows:

$$S_i^L = \sum_{j \in I} w_j \left|\frac{f_j^* - f_{ij}^U}{f_j^* - f_j^-}\right| + \sum_{j \in J} w_j \left|\frac{f_{ij}^L - f_j^*}{f_j^- - f_j^*}\right|,$$

$$S_i^U = \sum_{j \in I} w_j \left|\frac{f_j^* - f_{ij}^L}{f_j^* - f_j^-}\right| + \sum_{j \in J} w_j \left|\frac{f_{ij}^U - f_j^*}{f_j^- - f_j^*}\right|,$$

$$R_i^L = \max\left\{w_j \left|\frac{f_j^* - f_{ij}^U}{f_j^* - f_j^-}\right| : j \in I,\ \ w_j \left|\frac{f_{ij}^L - f_j^*}{f_j^- - f_j^*}\right| : j \in J\right\},$$

$$R_i^U = \max\left\{w_j \left|\frac{f_j^* - f_{ij}^L}{f_j^* - f_j^-}\right| : j \in I,\ \ w_j \left|\frac{f_{ij}^U - f_j^*}{f_j^- - f_j^*}\right| : j \in J\right\}.$$

Step 3. Calculation of metric $Q_i = [Q_i^L, Q_i^U]$, defined as follows:

$$Q_i^L = v \frac{S_i^L - S^*}{S^- - S^*} + (1 - v) \frac{S_i^L - S^*}{S^- - S^*},$$

$$Q_i^U = v \frac{S_i^U - S^*}{S^- - S^*} + (1 - v) \frac{S_i^U - S^*}{S^- - S^*},$$

where

$$S^* = \min_i S_i^L, \quad S^- = \max_i S_i^U,$$

$$R^* = \min_i R_i^L, \quad R^- = \max_i R_i^L.$$

Step 4. Alternatives' ranking in descending order based on metric Q.

In Step 4, the alternatives ranking is not straightforward, since the values of metric Q are of interval type. To cope with this difficulty, various methods have been developed. In the context of i-STENTORE investment planning tool, three ranking methods have been integrated, each one corresponding to different profiles of the decision-maker. In particular, the tool's solution is based on (i) the arithmetic mean method, (ii) the degree of optimism method, and (iii) the degree of possibility one, described as follows.

B.I. ARITHMETIC MEAN METHOD

This method is quite straightforward and ranks the alternatives based on the following value:

$$Q_i^M = \frac{Q_i^L + Q_i^U}{2}.$$

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B.II. DEGREE OF OPTIMISM METHOD

Consider two interval numbers $Q_i = [Q_i^L, Q_i^U]$ and $Q_j = [Q_j^L, Q_j^U]$ that have to be compared. The following cases are distinguished:

- If Q_i and Q_j do not intersect, then the minimum interval number is the one with the lower values.
- If $Q_i = Q_j$, then the two interval numbers are of the same priority.
- Let $Q_i^L \le Q_j^L < Q_j^U \le Q_i^U$. If $K(Q_j^L - Q_i^L) \ge (1-K)(Q_i^U - Q_j^U)$, then Q_i is the minimum interval number, else Q_j is the minimum one, where $K \in (0,1]$ expresses decision maker's optimism level. Optimist decision-maker selects K close to one, while the pessimist decision-maker selected K close to zero.
- Let $Q_i^L < Q_j^L < Q_i^U < Q_j^U$. If $K\left(Q_j^L - Q_i^L\right) \ge (1-K)\left(Q_j^U - Q_i^U\right)$, then Q_i is the minimum interval number, else Q_j is the minimum one.

B.III. DEGREE OF POSSIBILITY METHOD

Let $l_i = Q_i^U - Q_i^L$ and $l_j = Q_j^U - Q_j^L$ for all $i,j = 1,\dots,m$. The degree of possibility of Q_i over Q_j is defined as follows:

$$p_{ij} = \max\left\{1 - \max\left\{\frac{Q_j^U - Q_i^L}{l_i + l_j}, 0\right\}, 0\right\},$$

while, the degree of possibility of Q_j over Q_i is defined as follows:

$$p_{ji} = \max\left\{1 - \max\left\{\frac{Q_i^U - Q_j^L}{l_i + l_j}, 0\right\}, 0\right\}.$$

Then, the degree of possibility of all intervals is expressed through a complementary matrix, defined as follows:

$$P = \begin{pmatrix} p_{11} & \cdots & p_{1m} \\ \vdots & \ddots & \vdots \\ p_{m1} & \cdots & p_{mm} \end{pmatrix}, p_{ij} \ge 0, p_{ij} + p_{ji} = 1, p_{ii} = \frac{1}{2}.$$

To rank the intervals, the aggregated degree of possibility is used, which is defined as follows:

$$p_i = \sum_{j=1}^{m} p_{ij}, \quad i = 1,\dots,m.$$

3.1.2.10 C. Incomplete information criteria

In MCDM problems, the criteria priority constitutes a crucial factor and affects the final solution. In the last years, incomplete information has been widely used whenever it is difficult to use precise data (e.g. though the Analytic Hierarchy Process (AHP) method [19]). In i-STETNORE investment planning tool, an extension of the VIKOR method has been integrated accommodating the use of incomplete criteria weights, thus allowing the decision-maker to express his/her preferences with enhanced freedom. This state-of-the-art extended method has been developed by [20]. For the needs of the present tool, one type of incomplete

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information has been adopted, i.e. the weak inequalities type, which could be perceived more handily by the user of the tool. In this section, we assume that consequences of the payoff table are crisp values. In this context, the criteria weights are defined as follows:

$$W = \left\{ \boldsymbol{w} \in \mathbb{R}^n : \sum_{j=1}^{n} w_j = 1, w_j \geq 0, j = 1, \dots, n \right\},$$

$$w_1 \geq w_2 \geq \cdots \geq w_n \geq 0.$$

Then, the adopted incomplete information decision model includes exactly the following steps:

Step 1. Determination of the positive and negative ideal solution, defined as in A, Step 1.

Step 2. Determination of the regret vectors $\boldsymbol{d_i} = (d_{i1}, \dots, d_{in})$, where its components are defined as follows:

$$d_{ij} = \begin{cases} \dfrac{f_j^* - f_{ij}}{f_j^* - f_j^-}, j \in I \\ \dfrac{f_{ij} - f_j^*}{f_j^- - f_j^*}, j \in J \end{cases}$$

Step 3. Calculation of metrics $S_i = [S_i^L, S_i^U]$ and $R_i = [R_i^L, R_i^U]$, defined as follows:

$$S_i^L = \min(\boldsymbol{d_i E}),$$

$$S_i^U = \max(\boldsymbol{d_i E}),$$

$$R_i^L = \min_k \max_j (d_{ij} \lambda_{kj}),$$

$$R_i^U = \max_k \max_j (d_{ij} \lambda_{kj}),$$

where

$$E = \begin{pmatrix} 1 & \cdots & 1/n \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 1/n \end{pmatrix},$$

is the matrix including as columns the extreme points of set W, and λ_{kj} is the jth component of extreme point λ_k.

Step 4. Calculation of metric Q, similar to B, Step 3.

Step 5. Alternatives' ranking in descending order based on metric Q.

3.1.2.11 D. Incomplete information criteria and interval payoff values

In this case, both criteria weights and consequences are allowed to be imprecise. In particular, weights are of weak inequalities type (similar to subsection B), while payoff values are of interval type (similar to subsection C). Then, the decision model for solving this MCDM problem includes exactly the following steps [20]:

Step 1. Determination of the positive and the negative ideal solution, defined as follows:

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$$\boldsymbol{f}^{*} = (f_1^*, \dots, f_n^*) = \left\{ \left(\max_i f_{ij}^U : j \in I \right) \text{ or } \left(\min_i f_{ij}^L : j \in J \right) \right\},$$

$$\boldsymbol{f}^{-} = (f_1^-, \dots, f_n^-) = \left\{ \left(\min_i f_{ij}^L : j \in I \right) \text{ or } \left(\max_i f_{ij}^U : j \in J \right) \right\}.$$

Step 2. Calculation of metrics $S_i = [S_i^L, S_i^U]$ and $R_i = [R_i^L, R_i^U]$, defined as follows:

$$S_i^L = \min\{\boldsymbol{d_i^L E}\},$$

$$S_i^U = \max\{\boldsymbol{d_i^U E}\},$$

$$R_i^L = \min_k \left\{ \max_j \{ d_{ij}^L \lambda_{kj} \} \right\},$$

$$R_i^U = \max_k \left\{ \max_j \{ d_{ij}^U \lambda_{kj} \} \right\},$$

where

$$\boldsymbol{d_i^L} = \left(\frac{f_j^* - f_{ij}^U}{f_j^* - f_j^-} \middle| j \in I, \frac{f_{ij}^L - f_j^*}{f_j^- - f_j^*} \middle| j \in J \right),$$

$$\boldsymbol{d_i^U} = \left(\frac{f_j^* - f_{ij}^L}{f_j^* - f_j^-} \middle| j \in I, \frac{f_{ij}^U - f_j^*}{f_j^- - f_j^*} \middle| j \in J \right),$$

and matrix E and λ_{kj} are as in subsection C.

Step 3. Calculation of metric $Q_i = [Q_i^L, Q_i^U]$, similar to subsection B, step 3.

Step 4. Alternatives' ranking in descending order based on metric Q.

3.1.2.12 E. TOPSIS method

The i-STENTORE investment planning tool integrates one more MCDM method, namely TOPSIS, appealing to more conservative decision-makers in terms of decision theory [5-7]. TOPSIS solves the same decision problem with the classical VIKOR, from a different point of view and, in many applications, they run together in pursuit of comparing the results. TOPSIS is based on the principle that the optimal point should have the shortest distance from the positive ideal solution and the farthest from the negative ideal solution. Therefore, this method is suitable for cautious (risk avoider) decision-makers, because they might like to have a decision which not only makes as much profit as possible, but also avoids as much risk as possible.

TOPSIS decision model includes exactly the following steps:

Step 1. Calculate the normalized payoff table. The normalized value r_{ij} is calculated as follows:

$$r_{ij} = \frac{f_{ij}}{\sqrt{\sum_{i=1}^m f_{ij}^2}}.$$

Step 2. Calculate the weighted normalized payoff table. The weighted normalized value v_{ij} is calculated as follows:

$$v_{ij} = w_j r_{ij}.$$

Step 3. Determine the positive and the negative ideal solution of the weighted normalized payoff table, similar to subsection A, Step 1.

Step 4. Calculate the L^2 distance from the positive ideal solution:

$$D_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2}.$$

Step 5. Calculate the L^2 distance from the negative ideal solution:

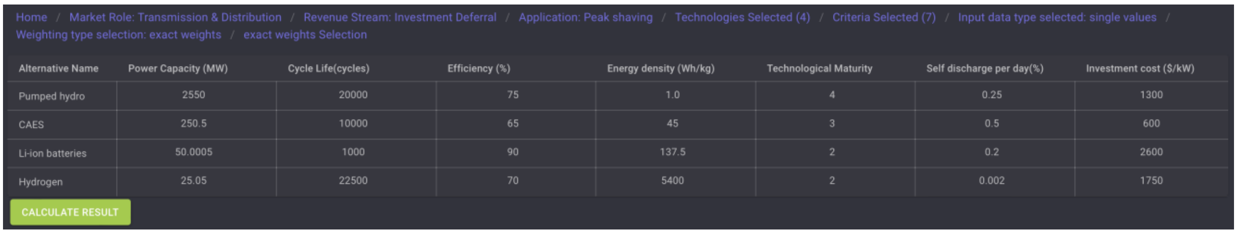
$$D_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2}.$$

Step 6. For each alternative, calculate the relative closeness:

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-}.$$

Step 7. Rank the decision alternatives with respect to metric C_i.

Step 8: Enter performance data



Alternative Name	Power Capacity (MW)	Cycle Life(cycles)	Efficiency (%)	Energy density (Wh/kg)	Technological Maturity	Self discharge per day(%)	Investment cost ($/kW)
Pumped hydro	2550	20000	75	1.0	4	0.25	1300
CAES	250.5	10000	65	45	3	0.5	600
Li-ion batteries	50.0005	1000	90	137.5	2	0.2	2600
Hydrogen	25.05	22500	70	5400	2	0.002	1750

FIGURE 24: PERFORMANCE DATA OF EACH ALTERNATIVE (ESS) AGAINST SELECTED CRITERIA.

In this step, the performance data of the ESS against the selected criteria are made available to the users for cross-checking and/or further elaboration. Pre-defined performance data have been drawn from literature [8, 15, 16, 17] and entered in the IPT to facilitate utilization of the tool and user experience.

Once the user has finished entering/checking the data, the whole form of selections so far is submitted for calculation, by pressing the "Calculate results" button. At this point, the last validity checks of the provided data are done. Specifically, the submission is blocked if the user has not added any criteria, if the number of alternatives is less than two, or if the performance of all alternatives against a criterion is absolutely the same. Especially in the latter case, the user has the option to click on a pop-up message that appears and automatically remove the criteria for which the above condition applies. As long as the final check does not detect any reason for not accepting the data, the process moves on to the calculation of the results.

Step 9: Extract visualized results

After the analysis is completed, the above screen will appear. The results present the final ranking of the implicated ESS, both graphically and in writing. Regarding the graphical presentation, it is pointed out that the lower the numerical value calculated for an energy

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storage system, the higher its position in the final ranking. Graphs can be also downloaded or printed or viewed in full screen.

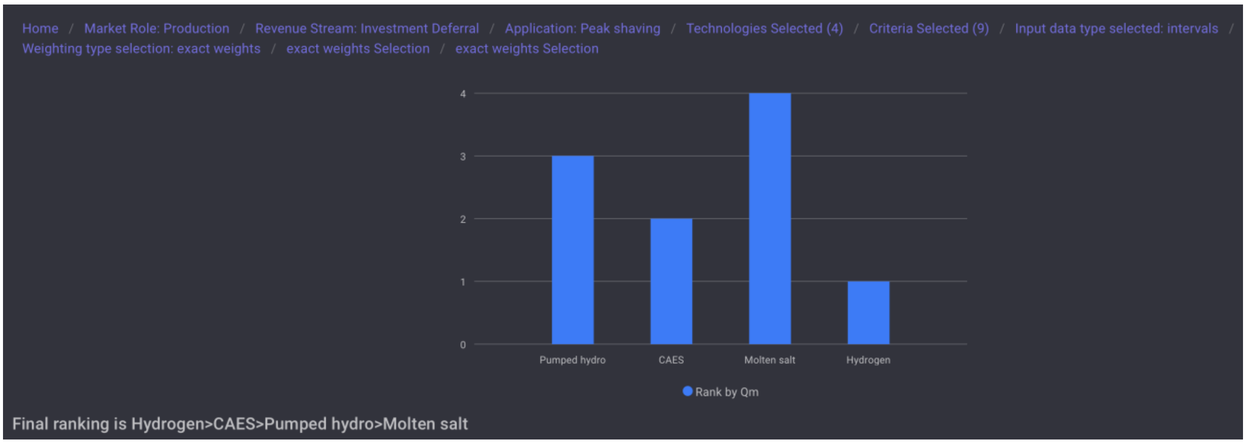

FIGURE 25: GRAPHICAL PRESENTATION OF THE MCDA RESULTS.

3.1.2.13 Deployment Guide

1. The user should install **Docker**. You may download Docker here.
2. Once the Docker is installed and running, open **PowerShell/Command Prompt** (Windows user) or open **Terminal** (Mac and Ubuntu users).
3. Execute the following command:

   docker run -d -v /var/run/docker.sock:/var/run/docker.sock -e FE_PORT=8002 istentore/mcdm-tool

Once the command is successfully executed, the user should get the following screen:

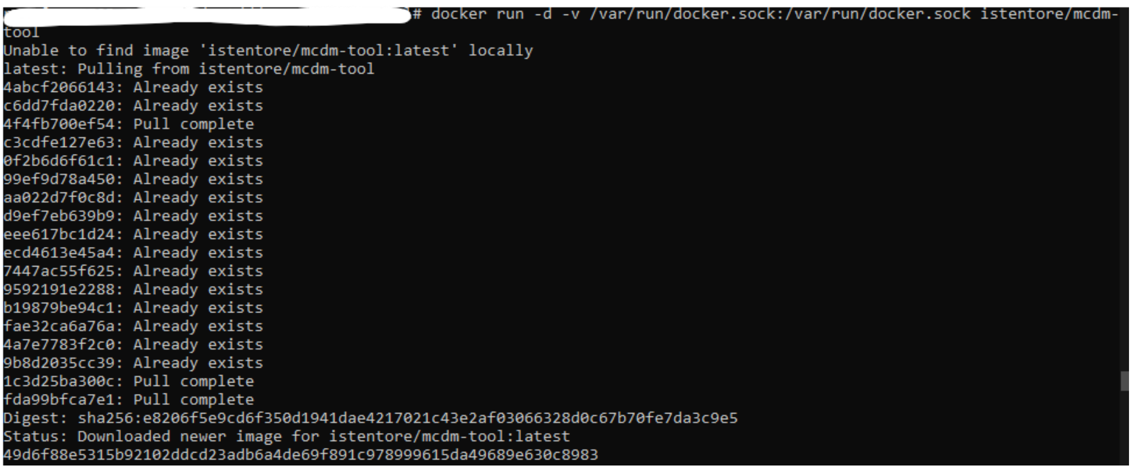

FIGURE 26: SCREENSHOT FROM PROCESS OF DEPLOYMENT.

Important note: Port 8002 can be any port the user prefers.

4. Once the previous screen appears, the user should open the browser and paste the link: http://localhost:8002/

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5. The user should be able to access the i-STENTORE Investment Planning Tool.
6. To stop the tool from running execute the following command:

   docker run -v /var/run/docker.sock:/var/run/docker.sock istentore/mcdm-tool down

Finally, when a new version of the tool is available, the user should follow the next steps:

1. First uninstall current version by executing the following command:
   docker run -v /var/run/docker.sock:/var/run/docker.sock istentore/mcdm-tool down --rmi all
2. Execute the command docker ps –a in the PowerShell/command prompt or terminal
3. Identify the CONTAINER ID. It should be found by the name istentore/mcdm-tool
4. If there is a container ID with this name, stop the container by executing the following command:
   docker stop <CONTAINER ID>
5. Delete the old version of by executing the following command:
   docker rmi istentore/mcdm-tool
6. Install the latest version of the tool by following the abovementioned steps, starting from Step 3.

3.1.3 Data Governance Middleware

The i-STENTORE Data Governance Middleware (iDGM), as its name suggests, is forming a layer between the underlying ESS and other interconnected assets and the i-STENTORE intelligent business layer (VPP, Investment Planning Tool, Asset Register, etc.). The primary and principal objective of the iDGM is the procurement of semantic interoperability across data providers and data consumers not only within the same i-STENTORE installation but to the whole energy and smart grid domain.

Semantic interoperability, in our case in the smart grid domain, refers to the ability of different systems to exchange and understand data in a meaningful way. Semantic interoperability is essential for the successful deployment and operation of the smart grid, which involves a wide range of heterogeneous devices and systems, all of which need to be able to communicate with each other to operate effectively.

To reach the envisioned interoperability objectives and achieve the desired functionality the iDGM includes the following internal modules and building blocks:

- i-STENTORE Ontology (iOntology)
- i-STENTORE Context Broker (iBroker)
- i-STENTORE Data Spaces Connector (iConnector)
- i-STENTORE Data Store (iDS)
- i-STENTORE Data Transformation Module (iDTM)

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Figure 27 presents the i-STENTORE Data Governance Middleware decomposition diagram (blocks in green background) with the abovementioned modules as well the related layers (in dark red background) in the i-STENTORE architecture. This is the first version of the iDGM and is subject to changes or updates subject to the next version of the i-STENTORE architecture and the system specifications related to the components.

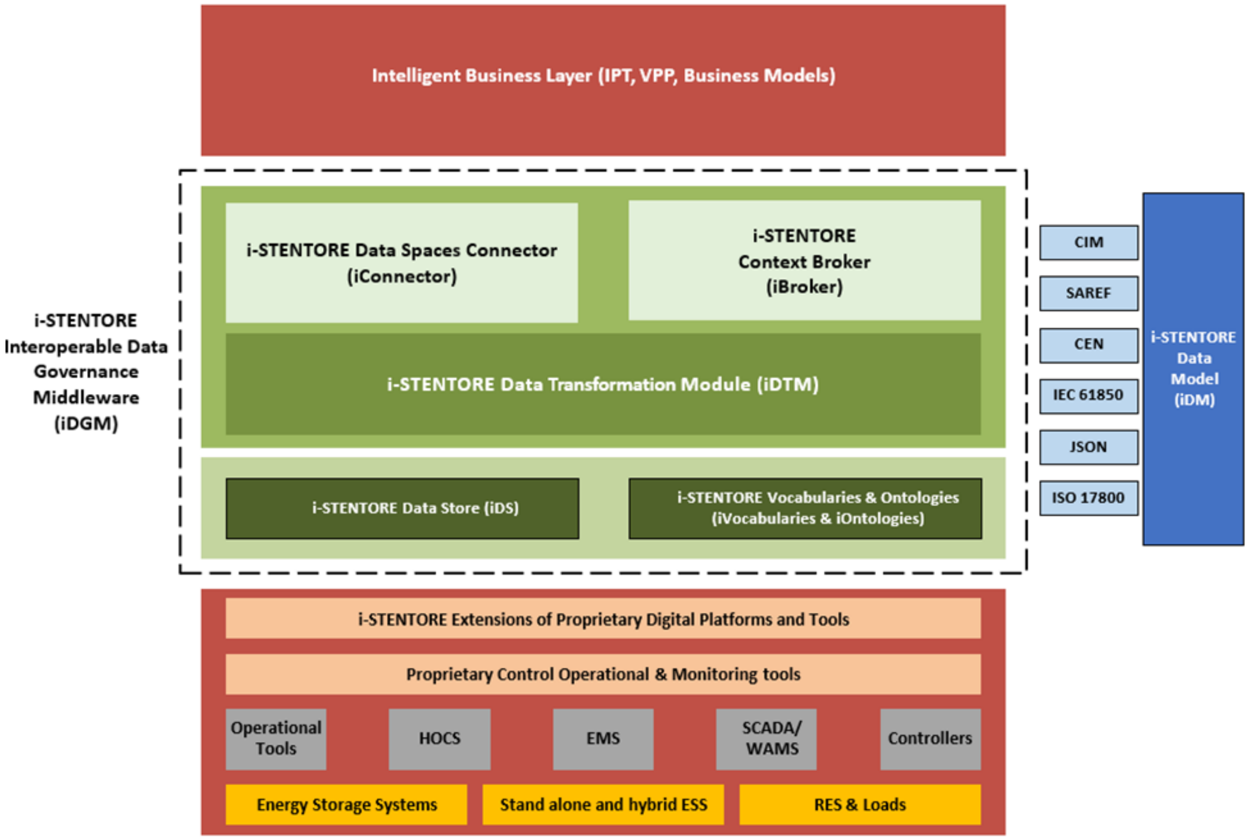

FIGURE 27: I-STENTORE DATA GOVERNANCE MIDDLEWARE DECOMPOSITION DIAGRAM (V2).

The envisioned result is a data governance middleware providing functional and data interoperability between all the underlying proprietary local digital tools and systems and the functionality and capabilities implemented at the i-STENTORE intelligent business layer. This compatibility is ensured by adhering to the guidelines and recommendations of European initiatives like the European Data Space (EDS)[3] domain-wide established related architectures, such as IEGSA and FIWARE[4] and of prominent Smart Grid Data Models IDSA[5]

[3] European Dynamics, “IEGSA (Interoperable European Grid Services Architecture),” [Online].
[4] FIWARE - Open APIs for Open Minds, [Online].
[5] IDSA, The Association - International Data Spaces, [Online].

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family of IEC CIM standards[6] and ontologies (SAREF)[7], SAREF4ENER[8] and the Open Energy Ontology[9] (OEO) as well as the potential extensions of them to fully cover the i-STENTORE user requirements. To this end, specific design decisions have been incorporated into the iDGM's modules and are analysed in the following subsections.

The iConnector will be provided as an additional feature providing data sharing capabilities among distributed local instances of the i-STENTORE Digital platform, to facilitate collaborative scenarios and knowledge diffusion. The iConnector will be based on the OneNet connector that was developed in the OneNet Horizon project.

3.1.3.1 i-STENTORE Ontology (iOntology)

Semantic models (conceptual data models including semantic information) are the cornerstone ingredient and perform a crucial role in achieving semantic interoperability by providing a formal representation of the concepts, relationships, and rules that govern the data being exchanged. More specifically, semantic models are the foundation for achieving semantic interoperability. They provide a shared understanding of data, enable consistent interpretation, facilitate machine-understandable processing, capture contextual information, and promote cross-domain compatibility.

i-STENTORE and the iDGM adopts semantic modelling to enable effective communication, collaboration, leveraging data across the different i-STENTORE tools and components as well external systems or applications in the energy domain or even different but relevant domains. The semantic modelling is achieved through the development and use of ontologies and vocabularies. Based on standard ontologies and vocabularies available for the smart grid domain, which will be extensively presented in the next chapters, the i-STENTORE Ontology (iOntology) has been developed to support and facilitate internal information exchange and compliance with external standards and initiatives. The iOntology features were extracted by the description of the detailed i-STENTORE use cases and the involved actors, roles, business entities and data requirements, based on related surveys that were distributed to the demo partners.

[6] IEC 61970-301:2020+AMD1:2022 CSV, "Consolidated version, Energy management system application program interface (EMS-API) - Part 301: Common information model (CIM)," [Online].
[7] "Smart Applications REFerence Ontology, and extensions," European Telecommunications Standards Institute, [Online].
[8] "SAREF4ENER: an extension of SAREF for the energy domain created in collaboration with Energy@Home and EEBus associations," European Telecommunications Standards Institute, [Online].
[9] Open Energy Ontology, [Online]. Last Access: 2024-02-28

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METHODOLOGY

The process for developing the i-STENTORE semantic data models (iOntology) is based on the methodology proposed by ISA (Interoperability Standards Advisory) in the published document "Process and methodology for developing semantic agreements" [10].

INTRODUCTION TO ISA

ISA (Interoperability Solutions for European Public Administrations), is a European Union programme (implemented by the Commission) contributing to a European Union free from electronic barriers at national borders. The ISA programme addresses the need for electronic cross-border public services by facilitating efficient and effective collaboration between European public administrations. ISA promotes the establishment of common approaches and solutions to enable electronic collaboration and to contribute to the implementation of community policies and activities. The ISA programme also promotes sharing and reuse of common tools and services – thus reducing costs and time to market. ISA ran from 2010 to 2015[11].

ISA² is the follow-up programme to ISA. The programme ran from 1 January 2016 until 31 December 2020. Its main purpose is to:

- ensure that interoperability activities are well coordinated at EU level;
- develop and operate solutions for the public administrations on the basis of businesses' and citizens' needs;
- put in place the necessary instruments to boost interoperability at EU and national level, such as:
  - ➢ a revised European Interoperability Framework (EIF);
  - ➢ a revised European Interoperability Strategy (EIS);
  - ➢ an Architecture, the European Interoperability Reference Architecture (EIRA);
  - ➢ a Cartography of solutions, the European Interoperability Cartography (EIC) [12].

INTRODUCTION TO PROCESS AND METHODOLOGY FOR DEVELOPING SEMANTIC AGREEMENTS PROPOSED BY ISA

The Chapters of the document "Process and methodology for developing semantic agreements" cover the following sections:

---

[10] Interoperability Standards Advisory, "Process and methodology for developing semantic agreements," 2013.
[11] European Union, "The ISA programme: Overcoming e-Barriers to European public services," Publications Office of the European Union, Luxembourg, 2011.
[12] European Commission, "ISA² - Interoperability solutions for public administrations, businesses and citizens," [Online].

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- **Stakeholders:** The several organisations and their interests in the interoperability that the semantic agreements would permit.
- **Specification Process:** The functions of the various groups involved in the specification process, along with the steps that must be taken in order to reach semantic agreements. These steps include forming the working group and its subgroups, drafting documents, reviewing and endorsing the model, and reviewing and endorsing each of its constituent parts.
- **Methodology:** The methodology used to construct the model and its elements, with special attention to the intellectual content of the job that the working group and its subgroups must do.
- **Implementation:** A number of concerns pertaining to the publication of the model and its components in machine-readable RDF and XML schemas as well as human-readable HTML documents.

<u>Stakeholders</u>

The process of developing and maintaining semantic agreements involves identifying various stakeholders who play distinct roles in the endeavour:

- **The Authority (Top-Level Oversight):** This stakeholder represents the higher governing body responsible for overseeing the entire activity. It could be the Board of Directors within a company, a funding agency managing a project or program, or a specific department or directorate in a governmental administration. This top-level entity is referred to as the "Authority" and holds the ultimate responsibility for the activity.
- **The Activity Members (Primary Stakeholders):** These stakeholders are the core entities engaged in the activity. They are a group of organisations collaborating to construct shared services that necessitate their information systems to interoperate. Typically, they function as data owners requiring semantic agreements to exchange data effectively and create unified services. They are termed as "Members" and are actively involved in the development and maintenance of these agreements.
- **The Wider Community (Extended Stakeholders):** Apart from the primary members directly involved in the activity, there exist other organisations interested in the agreements established by the activity. These entities see value in utilising these agreements to either join the shared services with the primary members or construct similar services within a different set of organisations. This broader set of interested organisations is collectively referred to as the "Community".

<u>Specification Process</u>

The specification process for achieving consensus among stakeholders involves several actors and roles, each contributing to distinct stages of development.

<u>Actors and Their Roles:</u>

- **Endorsement Group (EG):** A multidisciplinary ad-hoc group consisting of representatives from third parties interested in semantic agreements. It might include members from user communities, legal experts, and domain researchers.

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- **Secretariat:** This support unit facilitates communication between the main Activity and the EG. The Secretariat aids in identifying and inviting external experts to participate. If absent, the Activity Leader takes up these responsibilities.
- **Activity Leader (AL):** Responsible for managing and coordinating the work, the AL oversees the overall planning and execution. They invite working group members, appoint chairs and editors, and communicate outcomes to the relevant stakeholders.
- **Expert Pool (EP):** Comprised of experts possessing a deep understanding of existing implementations regarding data models, entities, and description approaches. External experts from the domain and application areas may be included. Working Group and Subgroup members are recruited from this pool.
- **Domain Model Working Group (DM-WG):** This group comprises experts from the EP with knowledge of data models and flows in existing implementations. External experts engaged in similar activities may also participate. Responsible for developing the Domain Model.
- **Data Entity Subgroups (DESG):** Multiple DESGs, one for each Data Entity defined in the Domain Model. Composed of experts familiar with how specific data entities are described in existing implementations. These subgroups discuss and agree upon core attributes and controlled vocabularies for each Data Entity.
- **Review Group (RG):** Monitors the work of various groups, receiving and reviewing interim and final results for feedback. Open for members of the Authority, EG, and EP. Members of DM-WG and DESGs automatically become members of the RG and participate in reviewing the work of other groups.

<u>Methodology</u>

The technical steps that an Activity must take in order to achieve a semantic agreement are outlined in this section.

1. Articulate the problems that the Domain Model intends to solve in the form of a series of Use Cases
2. Derive a set of Requirements from the Use Cases
3. Derive necessary elements from selected Use Cases and Requirements
4. Identify and analyse existing models
5. Identify and analyse models used elsewhere
6. Create cross-reference table for Data Entities and relationships
7. Select set of core Data Entities and core relationships.
8. Document Draft Domain Model
9. Identify attributes and controlled vocabularies used in local implementations
10. Derive necessary elements from Use Cases and Requirements
11. Identify and analyse Data Entity descriptions used or standardized elsewhere

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12. Create cross-reference table for attributes
13. Perform semantic clustering of attributes
14. Identify and compare controlled vocabularies
15. Choose recommended controlled vocabularies
16. Document core set of attributes and recommended vocabularies
17. Add Data Entity attributes to the Domain Model
18. Harmonise attributes across the Domain Model
19. Harmonise controlled vocabularies across the Domain Model
20. Finalise Domain Model
21. Decide on the conformance requirements and develop a Conformance Statement

Implementation

The final product of the semantic agreements' development phase is the Domain Model, or, in the event of a minimal implementation, the Data Entity decided upon in the earlier rounds. There are three ways to implement the model or entity, and they all contain the same data in different formats:

1. A human-readable version in HTML
2. An XML schema
3. An RDF schema[13].

I-STENTORE ONTOLOGIES DEVELOPMENT

In this chapter, we elaborate on the reasoning for adapting the methodology proposed by the ISA, specifically tailored for implementation within WebProtégé. By aligning the ISA methodology with the functionalities and capabilities of WebProtégé, we aim to enhance the efficiency, effectiveness, and standardisation of ontology development processes.

WEBPROTÉGÉ

WebProtégé is a web-based ontology development environment that allows users to create, edit, and share ontologies collaboratively. It is based on the Protégé platform, which is a free, open-source software for building intelligent systems with ontologies. It supports the latest OWL 2 Web Ontology Language, which is a standard for representing and reasoning with ontologies. Besides being free and open source, WebProtégé was chosen among different

[13] Interoperability Standards Advisory, "Process and methodology for developing semantic agreements," 2013.

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tools as it has a simple and customizable user interface, which allows you to edit ontologies using various features, such as visualisation, collaboration, change tracking, and web forms[14].

WebProtégé supports multiple formats for upload and download of ontologies, like **RDF/XML** (Resource Description Framework/EXtensible Markup Language) syntax and OWL/XML syntax (Web Ontology Language/EXtensible Markup Language). The iOntologies have been developed using the RDF/XML syntax.

PROCESS BASED ON ISA METHODOLOGY

In order to develop i-STENTORE semantic data models (iOntologies, iVocabularies) in a standardized way using the WebProtégé tool, the idea was to adjust the ISA-proposed methodology for developing semantic agreements, based on the capabilities of WebProtégé and the requirements of the use cases, in an efficient way.

At first, as ISA methodology suggests in the "Specification Process" sector, we need to identify the actors and the roles of each actor related to the iOntologies development. WebProtégé offers four access levels or roles that determine the permissions and capabilities users have within a project and can be configured by the project owner: manager, editor, commenter and viewer. Based on the above permission types, we suggest the following separation of the i-STENTORE actors:

- **Manager:** Managers typically have elevated privileges within a project. They have permissions to edit the ontology, create or modify classes, properties, individuals, manage user permissions within the project, and perform various administrative tasks.
- **Editors:** Editors can make changes to the ontology, add or modify classes, properties, individuals, etc. If an actor claims permission for editing, it refers to the Manager who can accept or reject the claim, based on clear justification.
- **Commenters:** Commenters have the ability to view the ontology and add comments but do not have permission to modify the structure or content of the ontology.
- **Viewers:** Viewers have read-only access to the ontology. They can view the content but cannot make any changes or comments[15].

Regarding the process of the preparation activities, at first there are some generic steps that need to be followed by each actor in order to have access to the WebProtégé platform:

- Each actor that plans to use the WebProtégé tool, has to create an account on the platform.

[14] Stanford Center for Biomedical Informatics Research at the Stanford University School of Medicine, Stanford University, 6 August 2019. [Online].
[15] Stanford Center for Biomedical Informatics Research at the Stanford University School of Medicine, Stanford University, 6 August 2019. [Online].

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- Once the WebProtégé project is shared by the Manager and project Owner, each actor connects to its account and can view or interact with the project, according to the permission provided.

Once all actors are provided with the WebProtégé project permission and are signed in, the process of the iOntologies development can be initiated. The following steps will be followed on each version of the iOntologies, as an iterative process:

- **Viewers** review the version of the iOntologies, have internal discussions on issues, proposals and generate points for discussion.
- **Commenters** collect the abovementioned points and consolidate them, providing specific comments on the WebProtégé project.
- **Editors** evaluate the comments, and respond back to the Commenters with arguments, questions.
- Internal discussion between **Editors** and **Commenters** and conclusion regarding corrections (if any).
- If there are corrections that need to be made, the **Editors** edit the project based on the produced corrections.
- Along with the editing based on the comments and corrections provided, the **Editors** proceed with the further development of the iOntologies, as new data emerge.
- When a new version of the iOntologies is ready, the **Editors** agree with the **Manager** and all actors are notified.
- If the produced version is not the final version of the iOntologies, the iterative process starts once again.

Figure 28 presents the flowchart of the iterative process.

There are two more Deliverables with the next versions of the technology released, D3.5 and D3.6 in months 20 and 29, respectively. As there is enough time between each deliverable, the idea is that the iterative process described above will occur two or three times in each period. In this way, the interaction between actors will be maximized and the result will be implemented most efficiently.

Implementation of Methodology

Regarding the implementation of the above methodology and the access levels distribution, T3.4 leaders were defined as the Managers of the iOntologies, as this task is responsible for developing the i-STENRORE Data Governance Middleware, which includes the iOntologies. Editors, Commenters, and Viewers access levels were distributed accordingly, based on the task responsibilities of each actor.

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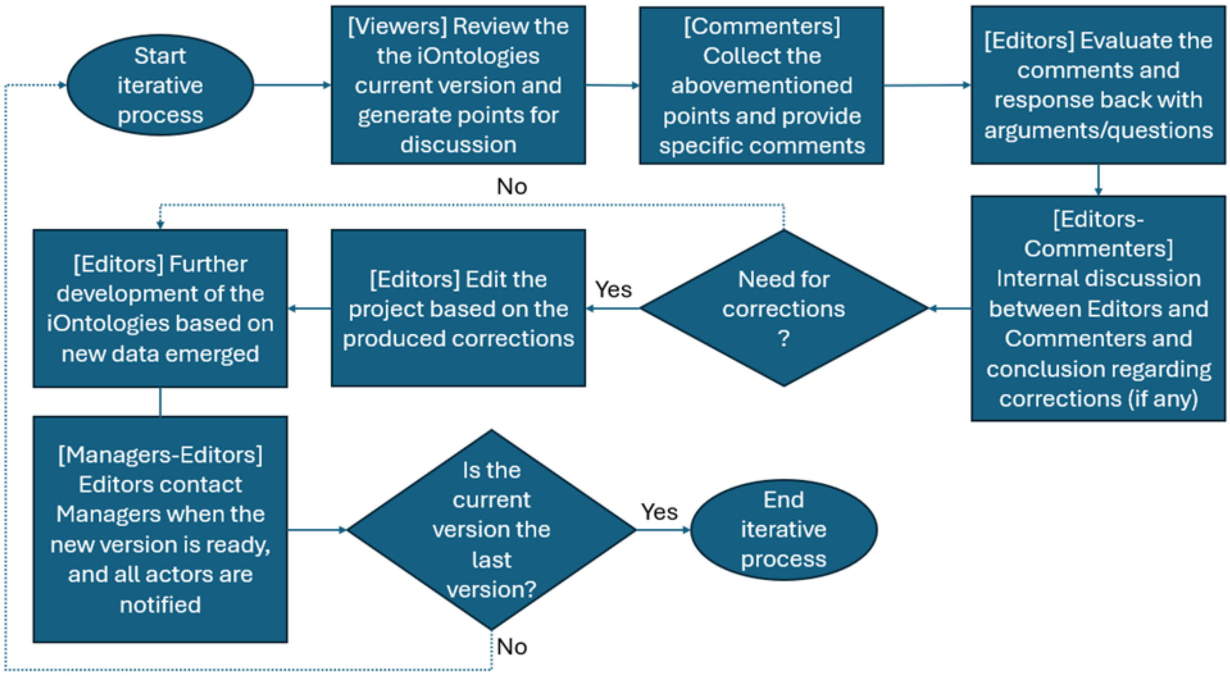

FIGURE 28: ITERATIVE PROCESS FOR THE DEVELOPMENT OF IONTOLOGIES.

EXTENDING RELATED ONTOLOGIES

Through iOntologies, the target is to use and extend some of the existing energy-related ontologies that will cover the i-STENTORE use cases. As of this version of the iOntologies, the ontologies that constitute the foundation are presented below.

SAREF

The Smart Appliances REFerence (SAREF) ontology is a consensus model that makes it easier to match existing assets (standards, protocols, data models, and so on) in the smart-appliances domain. The SAREF ontology provides building elements that enable the separation and recombination of various parts of the ontology based on specific requirements[16].

By leveraging the SAREF ontology, the project ensures interoperability, semantic representation, and alignment with existing standards, facilitating seamless communication and collaboration between different storage systems. This approach not only optimizes the reliability, cost-efficiency, and lifespan of assets but also promotes the multi-purpose use of storage as an active grid component, contributing to grid resilience and efficient operation.

[16] "Smart Applications REFerence Ontology, and extensions," European Telecommunications Standards Institute, [Online].

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SAREF 4 ENERGY (SAREF4ENER)

SAREF4ENER is an extension of SAREF for the Energy domain developed in partnership with Energy@Home (http://www.energy-home.it) and EEBus (http://www.eebus.org/en), the key industry associations in Italy and Germany, to allow the connectivity of their (different) data models. SAREF4ENER is focused on demand response situations in which consumers can provide flexibility to the Smart Grid by using a Customer Energy Manager (CEM) to manage their smart home devices. The CEM is a logical function for optimizing energy consumption and/or production that can be located in either the home gateway or the cloud. SAREF4ENER is an ETSI technical specification (ETSI TS 103 410-1)[17].

The SAREF4ENER ontology is highly beneficial for the semantic definition of the i-STENTORE project due to its specialized focus on energy-related concepts and systems. As i-STENTORE aims to integrate diverse storage solutions across various sectors and timeframes, SAREF4ENER provides a standardized vocabulary and structure for representing energy assets, storage systems, and their interactions. It also facilitates the optimization of reliability, power quality, and cost-efficient operation of storage systems, aligning with the project's objectives of maximizing asset lifetime and promoting purpose-specific Hybrid Energy Storage Systems (HESS). Furthermore, SAREF4ENER supports the exploration of versatile storage solutions in different applications, including mobility, agriculture, industry, household, and heating sectors, while also facilitating the integration of renewable energy sources (RES).

OPEN ENERGY ONTOLOGY (OEO)

Open Energy Ontology is a domain ontology is a collaborative effort to represent the context of energy system analysis using standard terminology used by human professionals in this field of study. Its goal is to promote transparency while also making energy system modelling and scenario analysis more comparable and transferable. This ontology uses the Basic Formal Ontology (BFO) and its principles[18].

The Open Energy Ontology's extensive coverage of energy-related concepts and systems makes it invaluable for the semantic characterization of the i-STENTORE project. Energy assets, storage systems, and their interactions can be represented using a common vocabulary and structure thanks to OEO, while i-STENTORE concentrates on integrating heterogeneous storage options across different industries and timeframes. Using OEO guarantees semantic interoperability, which makes it easier for various storage systems and integrated assets to collaborate and communicate with one another.

ONTOLOGY OF UNITS OF MEASURE (OM)

The OM ontology includes classes, instances, and properties that reflect the various concepts required to define and apply units, quantities, and related concepts. It comprises common

[17] "SAREF4ENER: an extension of SAREF for the energy domain created in collaboration with Energy@Home and EEBus associations," European Telecommunications Standards Institute, [Online].
[18] "Open Energy Ontology," [Online].

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units, as well as units from other systems of measurement. It also provides specialized units and numbers for a variety of application fields[19].

The Ontology of Units of Measure (OM) proves useful for the semantic definition of the i-STENTORE project due to its ability to standardize and specify units of measurement across diverse storage solutions and integrated assets. As i-STENTORE seeks to integrate various storage systems, OM provides a standardized framework for expressing and comparing quantitative data related to asset representation and parameters.

IONTOLOGIES SPECIFICATION

This section provides an overview of the i-STENTORE ontologies, how they relate to and extend the SAREF suite of ontologies, and how they reuse other existing ontologies, such as, Open Energy Ontology (OEO) and Ontology of units of Measurement (OM). It further presents the newly developed modules with the aid of diagrams and notes.

EXTENDED CLASSES AND PROPERTIES FROM EXISTING ONTOLOGIES

The iOntologies use a combination of classes, object properties, and data properties from the aforementioned existing ontologies, which are described below:

Classes

- saref:Device
- saref:Measurement
- saref:Service
- saref:Unit of Measure
- saref:Currency
- saref:Energy unit
- saref:Power unit
- saref:Pressure unit
- saref:Temperature unit
- s4ener:Device
- oeo:electric vehicle
- oeo:hydro power plant
- oeo:lithium-ion battery
- oeo:photovoltaic power plant
- oeo:thermal energy storage technology
- oeo:vehicle charging station
- oeo:wind farm
- oeo:areal solar power density
- oeo:efficiency value
- oeo:electricity price

[19] H. Rijgersberg, “OM – Ontology of units of Measure,” [Online].

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- oeo:electrical energy amount value
- oeo:electrical energy storage capacity
- oeo:power value
- om:angle
- om:cost
- om:electric charge
- om:irradiance
- om:length:
- om:mass
- om:percentage
- om:pressure
- om:speed
- om:tempetature
- om:time:
- om:Duration
- om:volume
- om:volumetric flow rate
- om:weight
- om:Celsius temperature unit
- om:angle unit
- om:electric charge unit
- om:force unit
- om:length unit
- om:mass unit
- om:percentage unit
- om:power density unit
- om:speed unit
- om:time unit
- om:volume unit
- om:volumetric flow rate unit

Object Properties

- saref:has time
- saref:is measured in
- saref:offers

Data Properties

- saref:has value

GENERAL OVERVIEW OF IONTOLOGIES

Figure 29 provides an overview of the basic classes and properties that compose the i-STENTORE set of ontologies developed in T3.4. Each basic class is required for the complete representation of i-STENTORE project and they will be analysed in the following sections.

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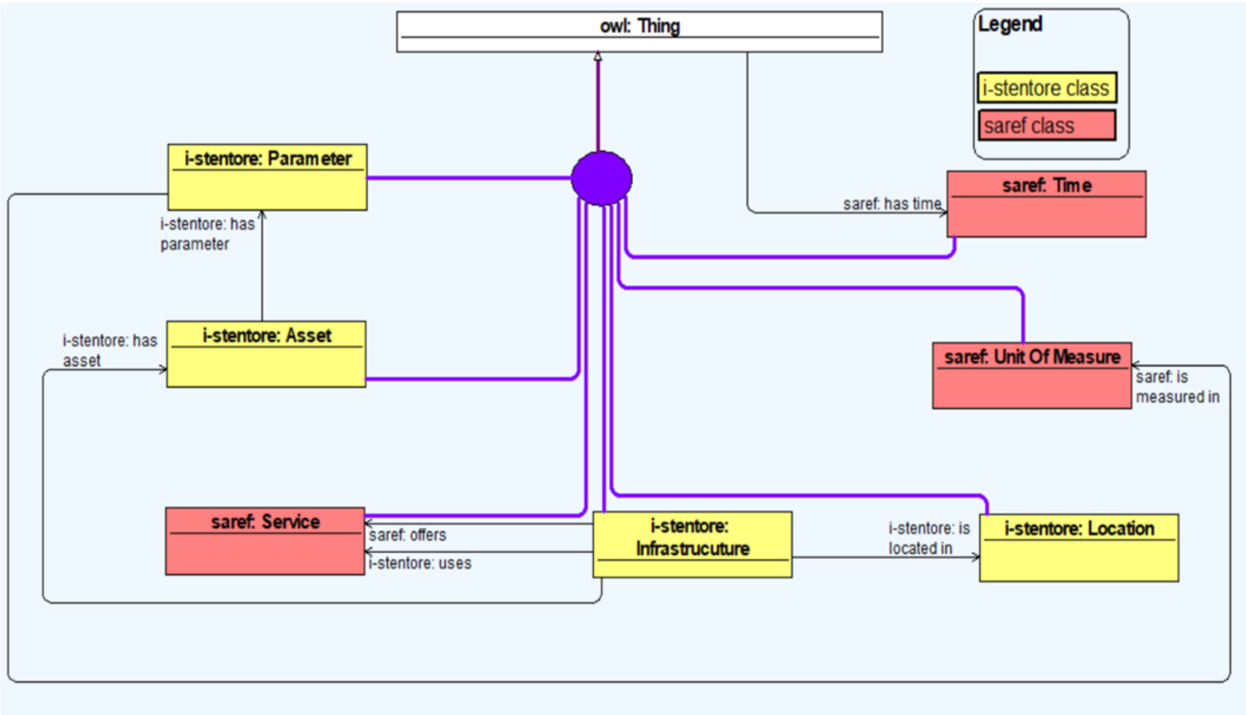

FIGURE 29: OVERVIEW OF THE BASIC CLASSES AND PROPERTIES OF IONTOLOGIES.

Classes

- **i-stentore:Asset:** An Asset typically refers to physical or tangible resources that are utilized in the generation, transmission, distribution, or storage of energy.
- **i-stentore:Parameter:** A Parameter typically refers to a measurable characteristic or attribute that describes the performance, condition, or functionality of the asset.
- **saref:Unit of Measure:** The unit of measure is a standard for measurement of a quantity, such as a Parameter.
- **saref:Service:** A service refers to a specific function or capability that the asset provides to the electrical grid or energy system. These services are essential for ensuring the reliable and efficient operation of the grid and may encompass various aspects of grid management, stability, and optimization. This class also refers to the non-energy services that an asset uses, like weather forecasting, load forecasting, and renewable energy sources production forecasting.
- **i-stentore:Infrastructure:** Infrastructure refers to the physical assets, facilities, and systems that are essential for the generation, transmission, distribution, storage, and consumption of energy resources. These infrastructure components play a crucial role in facilitating the production, delivery, and utilization of energy in various forms, such as electricity, natural gas, oil, and renewable energy sources.
- **i-stentore:Location:** The Location refers to the physical geographic site or area where the infrastructure is situated or deployed. The location of energy sector infrastructure is a critical consideration that can have significant implications for its design, construction, operation, and maintenance, as well as its accessibility, environmental impact, and relationship to other infrastructure components.
- **saref:Time:** A class that allows to specify the time concept.

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Object Properties

- **saref:has time:** A relationship to associate time information to an entity.
- **saref:is measured in:** A relationship identifying the Unit of Measure used for a certain Parameter.
- **saref:offers:** A relationship between an Infrastructure and the Services that it offers.
- **i-stentore:has asset:** A relationship between an Infrastructure and its Assets.
- **i-stentore:has parameter:** A relationship between an Asset and its Parameters.
- **i-stentore:is located in:** A relationship between an Infrastructure and its Location.
- **i-stentore:uses:** A relationship between an Infrastructure and the Non-Energy Services that it uses.

I-STENTORE:ASSET

Figure 30 shows the subclasses of the i-stentore:Asset class, which is a hyperclass of saref:Device and saref4ener:Device classes. In the energy sector, an asset typically refers to physical or tangible resources that are utilized in the generation, transmission, distribution, or storage of energy. In i-STENTORE project, we deal with two main categories of assets: the power production assets and the energy storage assets. The first category refers to the energy resources that are used for power generation, like wind power plants, photovoltaic power plants, and hydroelectric power plants. It also includes the Vehicle to Grid chargers that feed electricity to the power grid. The second one refers to the energy components which can store energy, like batteries. Examples include vanadium redox flow batteries (VRFBs), hydrogen storage technologies, lithium-ion batteries and thermal energy storage technologies. There is also a third asset category regarding different assets, like electrolysεers, electric vehicles and furnaces, which do not belong in the two main categories.

Subclasses

- **saref:Device:** A tangible object designed to accomplish a particular task. In order to accomplish this task, the device performs one or more functions. For example, a washing machine is designed to wash (task) and to accomplish this task it performs a start and stop function.
- **s4ener:Device:** A specialization of a saref:Device that exposes a power profile with power sequences to the CEM (note that a s4ee:Device can also be called 'power sequence server').
- **i-stentore:Power Production:** The Assets related to Power Production.
  - **oeo:wind farm:** A wind farm is a power plant that has wind energy converting units as parts.
  - **oeo:vehicle charging station:** A vehicle charging station is an electricity grid component that transfers electrical energy into the traction battery of a battery electric vehicle.
  - **oeo:hydro power plant:** A hydro power plant is a power plant having an aggregate of hydro power generating units as its power generating unit parts.
  - **oeo:photovoltaic power plant:** A photovoltaic power plant is a solar power plant that has PV panels as parts.

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- **i-stentore:Energy Storage:** The Assets related to Energy Storage.
  - **oeo:lithium-ion battery:** A lithium-ion battery is a battery that is rechargeable and in which lithium ions move from the negative electrode to the positive electrode during discharge, and back when charging. Li-ion batteries use an intercalated lithium compound as one electrode material.
  - **oeo:thermal energy storage technology:** A thermal energy storage technology is an energy storage technology that describes how to combine thermal energy storage objects and thermal energy in charging and decharging processes.
  - **i-stentore:Vanadium Redox Flow Battery (VRFB):** A Vanadium Redox Flow Battery is a type of rechargeable flow battery that employs vanadium ions as charge carriers.
  - **i-stentore:Hydrogen Energy Storage System (HESS):** A Hydrogen Energy Storage System (HESS) is a storage device in which it can be charged by injecting the hydrogen produced by redundant electricity generations.
- **i-stentore:Other Assets:** The Assets from different categories.
  - **oeo:electric vehicle:** An electric vehicle (abbreviated as EV) is a vehicle that uses one or more electric traction motors.
  - **i-stentore:Electrolyzer:** An electrolyzer is a system that uses the electrolysis of water to separate hydrogen and oxygen atoms.
  - **i-stentore:Furnace:** A furnace is an enclosed structure in which material can be heated to very high temperatures, e.g. for smelting metals.

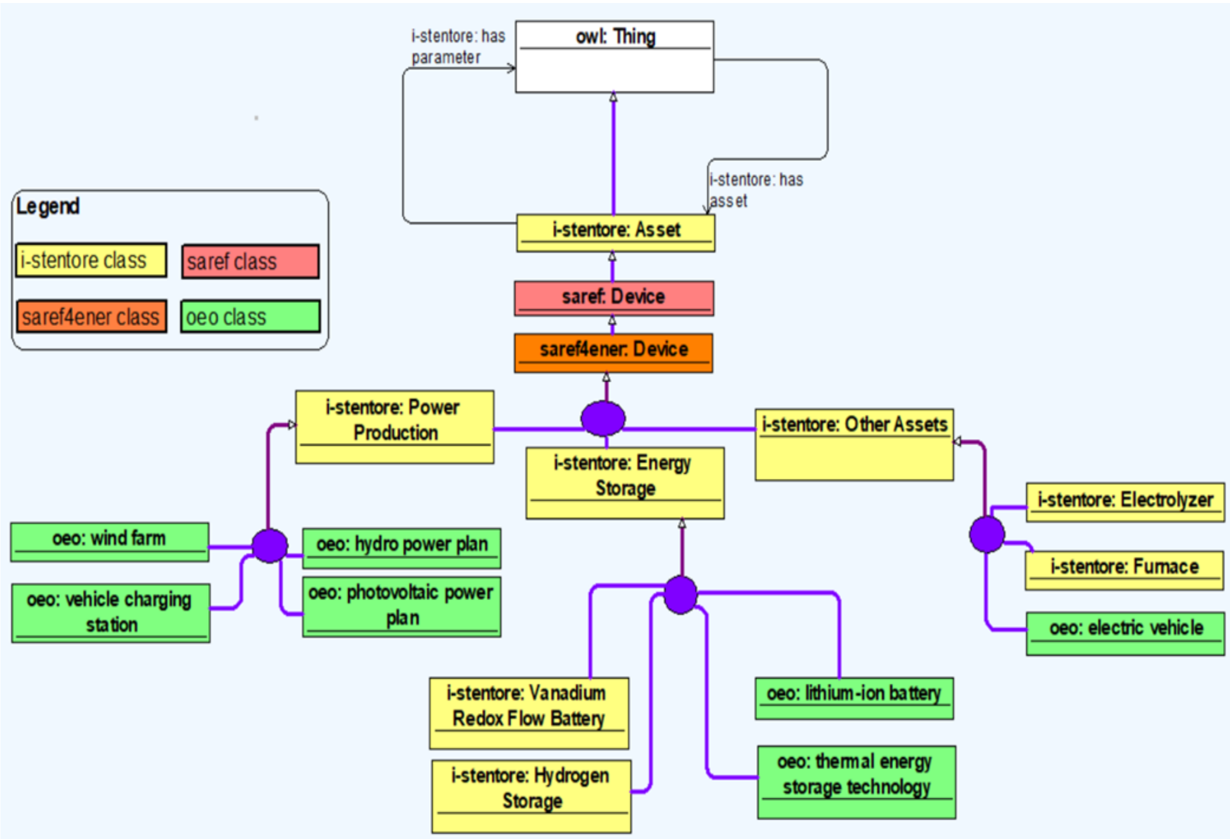

FIGURE 30: OVERVIEW OF I-STENTORE:ASSET CLASS.

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I-STENTORE:PARAMETER

Figure 31 shows the subclasses of the i-stentore:Parameter class. In the context of an energy sector, a parameter typically refers to a measurable characteristic or attribute that describes the performance, condition, or functionality of the asset. Parameters can vary depending on the type of asset and its specific role within the energy system. In the context of this project, we have identified two main categories of asset parameters: the general parameters, like turbine type, number of generators or number of pumps, and the measurements that are specific values. These values are either static (e.g. nominal power of a power plant) or dynamic (e.g. instantaneous voltage, current or power measurements) that change through the use of the assets.

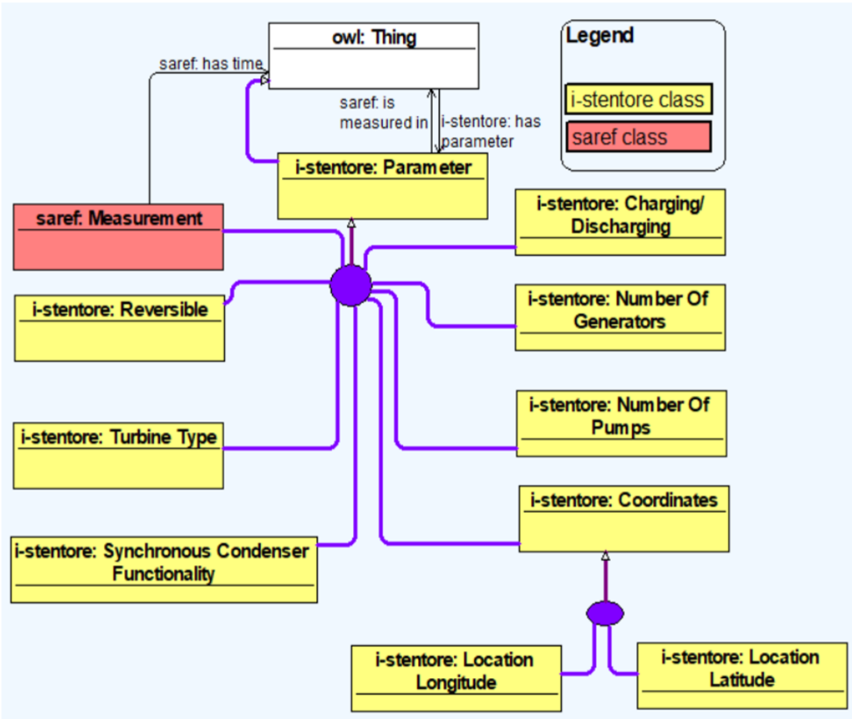

FIGURE 31: OVERVIEW OF I-STENTORE:PARAMETER CLASS.

Subclasses

- **saref:Measurement:** Represents the measured value made over a property. It is also linked to the unit of measure in which the value is expressed and the timestamp of the measurement. *(The subclasses of saref:Measurement will be presented in a distinct chapter)*
- **i-stentore:Reversible:** Defines whether a hydro power plant is reversible.
- **i-stentore: Turbine Type:** The turbine type of a power plant.
- **i-stentore:Synchronous Condenser Functionality:** **Defines** whether a hydro power plant has synchronous condenser functionality.
- **i-stentore:Charging/Discharging:** Defines whether a battery storage asset is charging or discharging.
- **i-stentore:Number of Generators:** The number of generators of a power plant.
- **i-stentore:Number of Pumps:** The number of pumps of a hydro power plant.

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- <u>i-stentore:Coordinates:</u> The coordinates are the pair of numbers and/or letters that show the exact position of a point on a map or graph.
  - ➢ **i-stentore:Location Latitude:** The location latitude of an asset.
  - ➢ **i-stentore:Location Longitude:** The location longitude of an asset.

I-STENTORE:MEASUREMENT

Figures 32 and 33 show the subclasses of the <u>i-stentore:Measurement</u> class. A measurement refers to a specific value or observation obtained through the use of instruments or techniques to quantify a particular parameter or characteristic of the asset. In the context of energy sector assets, measurements can encompass various aspects related to the asset's performance, condition, or functionality. Some basic measurements of an energy storage asset include the charging/discharging efficiency, the energy capacity, the charging power, and the battery output.

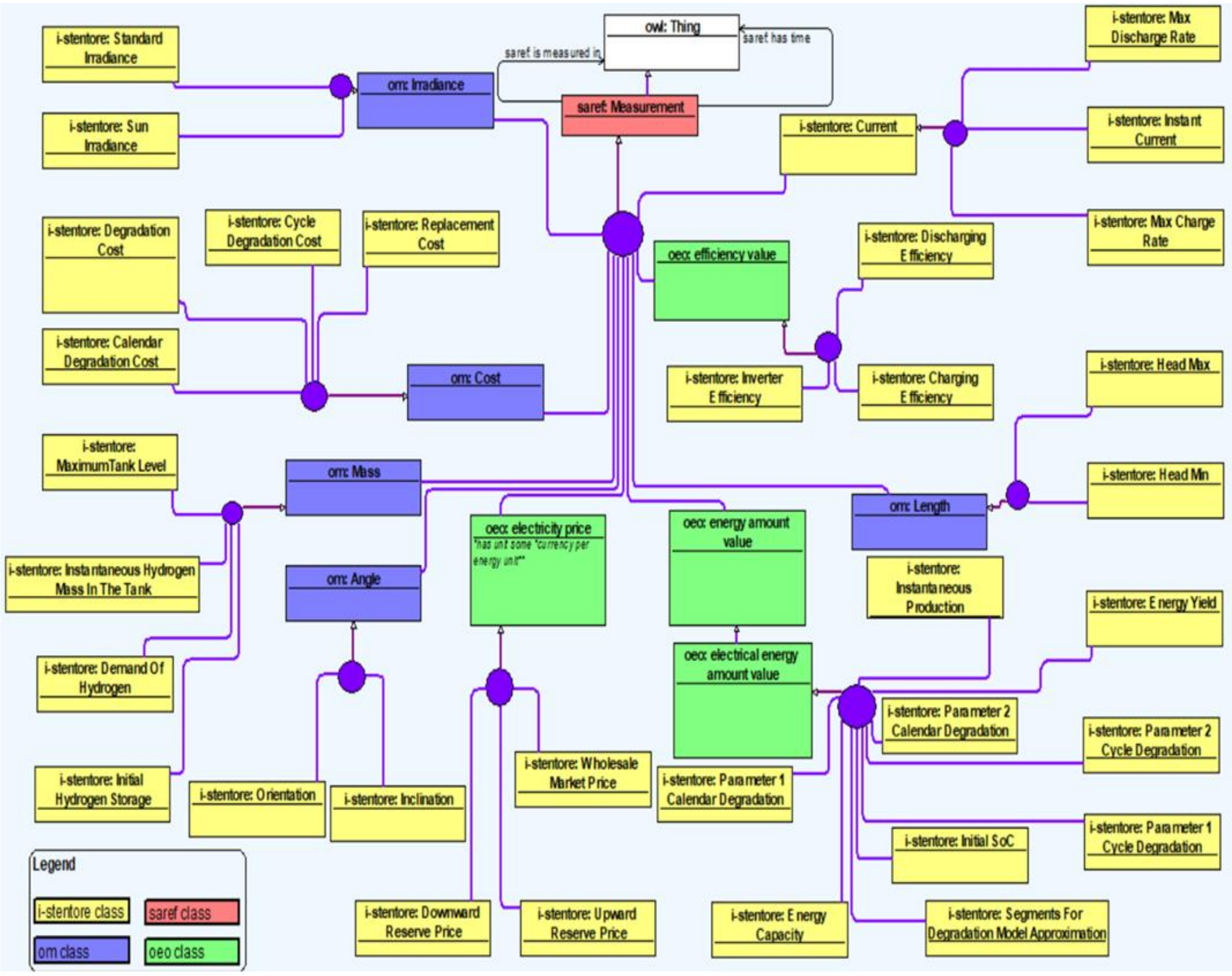

FIGURE 32: OVERVIEW OF I-STENTORE:MEASUREMENT CLASS [PT.1].

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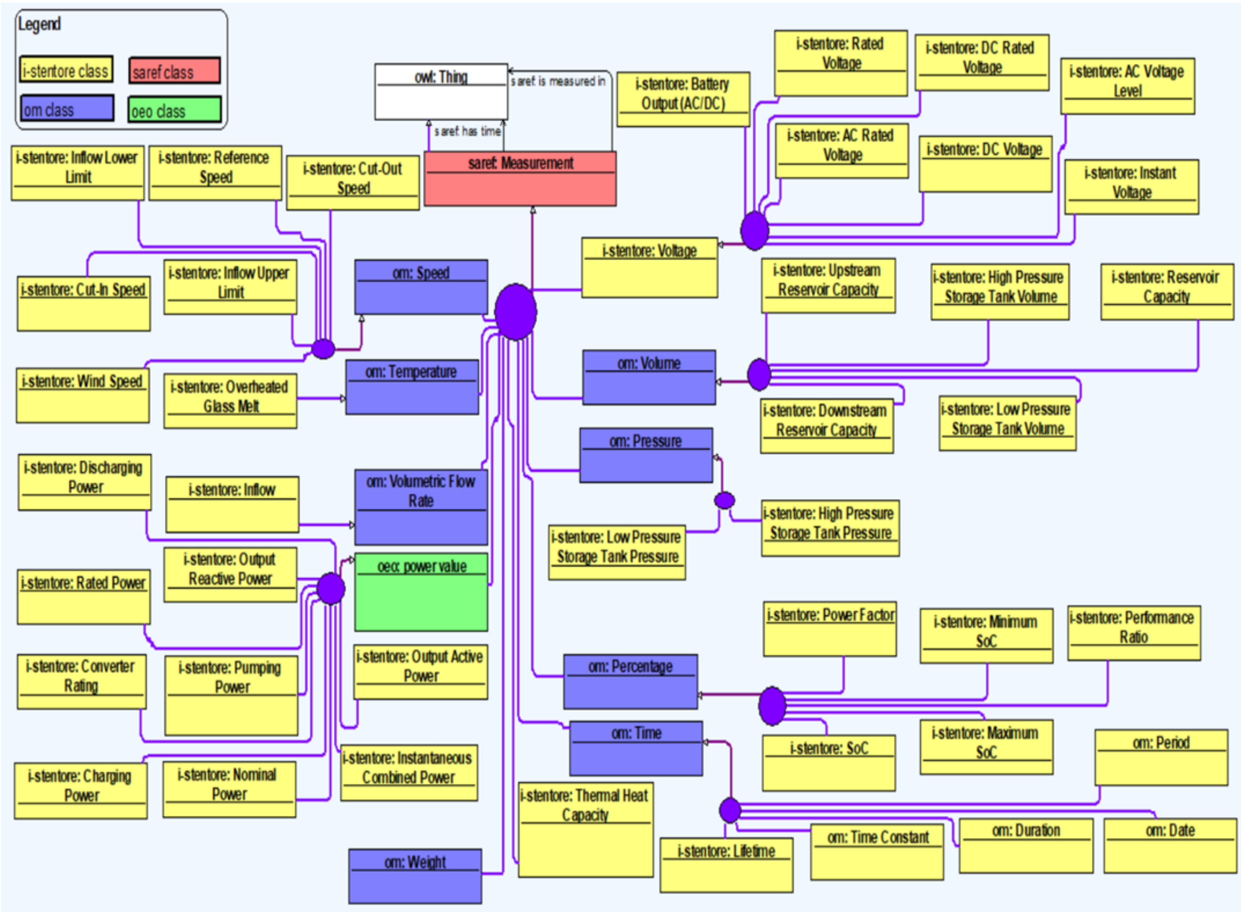

FIGURE 33: OVERVIEW OF I-STENTORE:MEASUREMENT CLASS [PT.2].

Subclasses

- **i-stentore:Current:** Current is a flow of electrical charge carriers, usually electrons or electron-deficient atoms.
- **i-stentore:Thermal Heat Capacity:** Thermal Heat Capacity is the quantity of heat necessary to produce a unit change of temperature in a unit mass of a material,
- **i-stentore:Voltage:** Voltage, also known as electric pressure, electric tension, or potential difference, is the difference in electric potential between two points.
- **oeo:efficiency value:** An efficiency value is a quantity value stating the ratio between a process's inputs and the outputs that are used.
- **oeo:electricity price:** Electricity price is the monetary price per energy unit of electricity.
- **oeo:energy amount value:** An energy amount value is a quantity value that has an energy unit as unit.
  - **oeo:electrical energy amount value:** An electrical energy amount value is an energy amount value that measures a quantity of electrical energy.
- **oeo:power value:** A power value is a quantity value that has a power unit as unit.
- **om:angle:** Angle is the ratio between an arc and its radius.
- **om:cost:** Cost refers to the monetary value of resources, goods, or services exchanged in a transaction or utilized to produce or acquire something.

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- **om:irradiance:** Irradiance is the power of electromagnetic radiation at a surface per unit area.
- **om:length:** Length is the amount of space between two geographical points along a curve. It is a base quantity in the International System of Units and other systems of units. Length is speed times time. The metre, a base unit of length in the International System of Units, is defined in terms of speed of light during a certain time interval.
- **om:mass:** Mass is the amount of matter of a phenomenon. It is a base quantity in the International System of Units. Mass is force divided by acceleration.
- **om:percentage:** Percentage is a term used to express a proportion or a fraction of a whole quantity, typically denoted by the symbol "%".
- **om:pressure:** Pressure is the force applied to or distributed over a surface. It is a derived quantity in the International System of Units. Pressure is force divided by area.
- **om:speed:** Speed is the time rate of motion measured by the distance moved over in unit time.
- **om:tempetature:** Temperature is the extent to which an object is hot.
- **om:time:** Time is a base quantity in the International System of Units and other systems of units. It is measured by numbers of repetitions of cyclical events.
- **om:volumetric flow rate:** Volumetric flow rate, often simply referred to as flow rate, is a measure of the volume of fluid (liquid or gas) that passes through a given cross-sectional area per unit of time. It quantifies the amount of fluid moving through a particular point in a system over a specific period.
- **om:weight:** Weight is a force that attracts a body towards another (reference) body.
- **om:volume:** Volume is a measure of how much three-dimensional space any phenomenon occupies. It is a derived quantity in the International System of Units. Volume is length to the power 3.

I-STENTORE:SERVICE

The subclasses of the i-stentore:Service class are presented in Figure 25. A service refers to a specific function or capability that the asset provides to the electrical grid or energy system. These services are essential for ensuring the reliable and efficient operation of the grid and may encompass various aspects of grid management, stability, and optimization. Examples of these services are frequency containment reserve, energy arbitrage and congestion management. This class also refers to the non-energy services that an asset uses, like weather forecasting, load forecasting, and renewable energy sources production forecasting.

Subclasses

- **i-stentore:Flexibility/Balancing/Ancillary Service:** Flexibility services are a range of existing and developing solutions that electricity system users can provide to help balance demand and supply in the electricity network and support its efficient use. Balancing services are the mechanisms in place to ensure the grid comfortably operates at the correct frequency. Ancillary services refer to functions that help grid operators maintain a reliable electricity system.
  - ➢ **i-stentore:DSO Services:** Flexibility/Balancing/Ancillary services offered to the DSO.

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- i-stentore:Energy Arbitrage: **i-stentore:Energy Arbitrage:** Energy arbitrage is a technique where power is bought during off-peak hours (when grid prices are cheapest). It is then stored and used during peak hours (when grid electricity prices are highest).
- **i-stentore:Congestion Management:** Congestion management is a strategy aimed at steering either the supply or demand of energy during peak periods, when the grid's capacity reaches its limit.
- **i-stentore:Synchronous Inertia:** Synchronous inertia supports grid operation by supporting the balancing of supply and demand during normal operations and by stabilizing the grid as a whole during disruptions.
- **i-stentore:Automatic Frequency Restoration Reserve (aFRR):** The automatic Frequency Restoration Reserve, also known as secondary reserve, is a reserve in the power grid that helps to keep the grid frequency stable.
- **i-stentore:Energy Community Services:** Flexibility/Balancing/Ancillary services offered to an Energy Community (Demand Response, Energy Storage etc.).
- **i-stentore:Fast Frequency Response (FFR):** Fast Frequency Response refers to the delivery of rapid active power increase or decrease by generation or load in a timeframe of 2 seconds or less, to correct a supply – demand imbalance and assist in managing power system frequency.
- **i-stentore:Frequency Containment Reserve (FCR):** Frequency Containment Reserve, also known as primary control reserve, is the first response to frequency disturbances. When frequency deviations occur, e.g. in consequence of a power plant outage, the Frequency Containment Reserve intervenes automatically within seconds in the entire synchronous area to restore the balance between supply and demand.
- **i-stentore:Power Smoothing (PS):** Power smoothing techniques are employed to mitigate the network problems caused by the variable output power of non-dispatchable renewable energy sources (RESs). Keystone of these techniques is the use of a battery energy storage system (BESS) acting as an intermediate energy buffer to smooth the RES output power.
- **i-stentore:Manual Frequency Restoration Reserve (mFRR):** The Manual Frequency Restoration Reserve (also R3 or tertiary reserve) helps to restore the required grid frequency of 50 Hz (or in some countries of 60 Hz). This tertiary control reserve intervenes when there are longer lasting deviations in the power grid that cannot be resolved solely by the other upstream balancing services (FCR or aFRR).

- <u>i-stentore:Non Energy Service:</u> The Non Energy Services that are needed in an Infrastructure.
  - **i-stentore:AC Charger Consumption Forecasting:** The forecasting of an AC Charger consumption.
  - **i-stentore:Battery Swapp Charger Consumption Forecasting:** The forecasting of an Battery Swappable Charger consumption.
  - **i-stentore:Hydro Forecasting:** The forecasting of a hydroelectric power plant production.
  - **i-stentore:Load Forecasting:** The forecasting of the electric load.

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- **i-stentore:PV Forecasting:** The forecasting of a photovoltaic power plant production.
- **i-stentore:Renewable Energy Community Users' Consumption:** The forecasting of the Renewable Energy Community users' consumption.
- **i-stentore:Reserve Prices Forecasting:** The forecasting of the Reserve Prices.
- **i-stentore:Unit Commitment:** The forecasting of the Unit Commitment.
- **i-stentore:V2G Charger Supply and Consumption Forecasting:** The forecasting of a V2G Charger supply and consumption.
- **i-stentore:Weather Forecasting:** The forecasting of the weather conditions.
- **i-stentore:Wholesale Market Price Forecasting:** The forecasting of the Wholesale Market Prices.
- **i-stentore:Wind Forecasting:** The forecasting of a wind turbine power plant production.

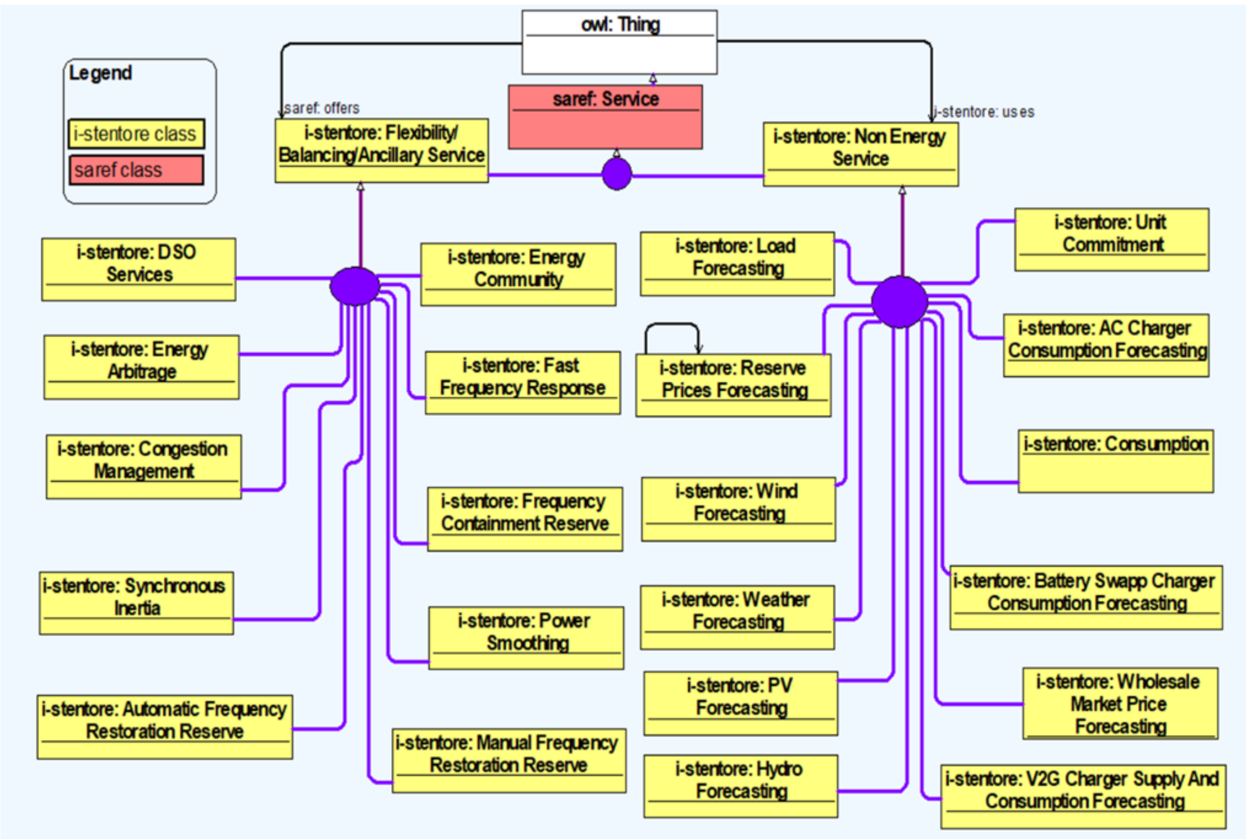

FIGURE 34: OVERVIEW OF I-STENTORE:PARAMETER CLASS.

I-STENTORE: UNIT OF MEASURE

Figure 35 displays the subclasses of the i-stentore:Unit of Measure class. A unit of measure refers to a standardized quantity or dimension used to quantify specific characteristics, parameters, or attributes of the asset. These units of measure provide a common framework for expressing and comparing the performance, capacity, efficiency, and other relevant metrics of energy sector assets.

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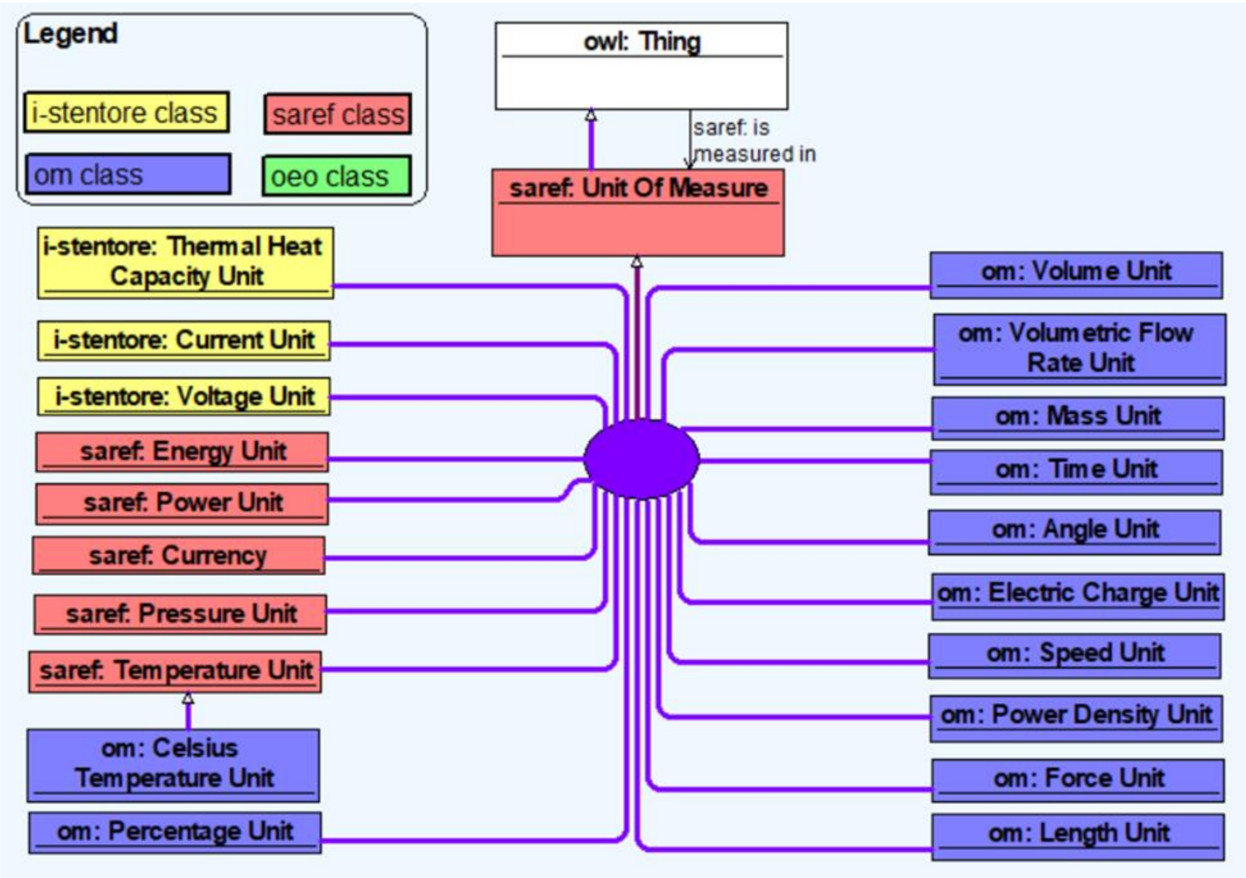

FIGURE 35: OVERVIEW OF I-STENTORE:UNIT OF MEASURE CLASS.

Subclasses

- **i-stentore:Thermal Heat Capacity Unit:** The unit of measure for thermal heat capacity.
- **i-stentore:Current Unit:** The unit of measure for current.
- **i-stentore:Voltage Unit:** The unit of measure for voltage.
- **saref:Energy Unit:** The unit of measure for energy.
- **saref:Power Unit:** The unit of measure for power.
- **saref:Currency:** The class of units of measure for price.
- **saref:Pressure Unit:** The unit of measure for pressure.
- **saref:Temperature Unit:** The unit of measure for temperature.
  - **om:Celsius temperature unit:** The unit of measure for temperature in degrees Celsius.
- **om:percentage unit:** The unit of measure for percentage.
- **om:volume unit:** The unit of measure for volume.
- **om:volumetric flow rate unit:** The unit of measure for volumetric flow rate.
- **om:mass unit:** The unit of measure for mass.
- **om:time unit:** The unit of measure for time.
- **om:angle unit:** The unit of measure for angle.
- **om:electric charge unit:** The unit of measure for electric charge.
- **om:speed unit:** The unit of measure for speed.

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- **om:power density unit:** The unit of measure for power density.
- **om:force unit:** The unit of measure for force.
- **om:length unit:** The unit of measure for length.

3.1.3.2 i-STENTORE IAM

Keycloak[20] is an open-source identity and access management tool with a focus on modern applications such as single-page applications, mobile applications, and REST APIs. As an IDM & IAM tool it adds authentication to applications and secures services with no need to deal with storing or authenticating users.

Features & Capabilities

- **Security:** Keycloak offers robust security features, including authentication and authorization mechanisms. By integrating Keycloak with Orion-LD, you can ensure secure access to your context data and APIs.
- **Single Sign-On (SSO):** Keycloak supports SSO, allowing users to authenticate once and access multiple applications and services without needing to log in again. This enhances user experience and simplifies authentication management.
- **Centralized User Management:** Keycloak provides a centralized user management system, allowing administrators to manage users, roles, and permissions from a single interface. This simplifies user administration and enhances security by enforcing consistent access controls across applications.
- **Token-based Authentication:** Keycloak uses tokens for authentication and authorization, including JSON Web Tokens (JWTs). By leveraging token-based authentication, Orion-LD can implement secure, stateless communication between clients and servers, reducing the risk of security vulnerabilities such as session hijacking.
- **Fine-grained Access Control:** Keycloak allows administrators to define fine-grained access control policies based on user roles, attributes, and other contextual information. By integrating Keycloak with Orion-LD, you can enforce access control policies at the API level, ensuring that only authorized users can access specific resources and perform permitted actions.

Keycloak provides user federation, strong authentication, user management, and fine-grained authorization. It also provides fully customizable login pages, recovery of passwords, and accepting terms. All of these features provided by Keycloak can easily integrated to a 3d party application without any coding. By delegating authentication of the user to Keycloak, we don't worry about authentication mechanisms, safely store passwords, etc. We can enable two-factor authentication without having to make changes to the application. This increases application security because in this situation an application doesn't have access to user credentials, it can only know tokens issued by Keycloak. Keycloak also provides single sign-

[20] Keycloak official website [Online].

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on with strong session management capabilities. It means allowing users to access multiple applications, while only having to authenticate once. Keycloak builds on industry standard protocols supporting OAuth 2.0, OpenID Connect (OAuth 2.0 + Authentication Layer), and SAML 2.0. Keycloak uses its own user database. It can also integrate with existing user directories, such as Active Directory and LDAP servers. Keycloak is a lightweight and easy-to-install solution. It can easily scale via its clustering capabilities. It has its own k8s operator.

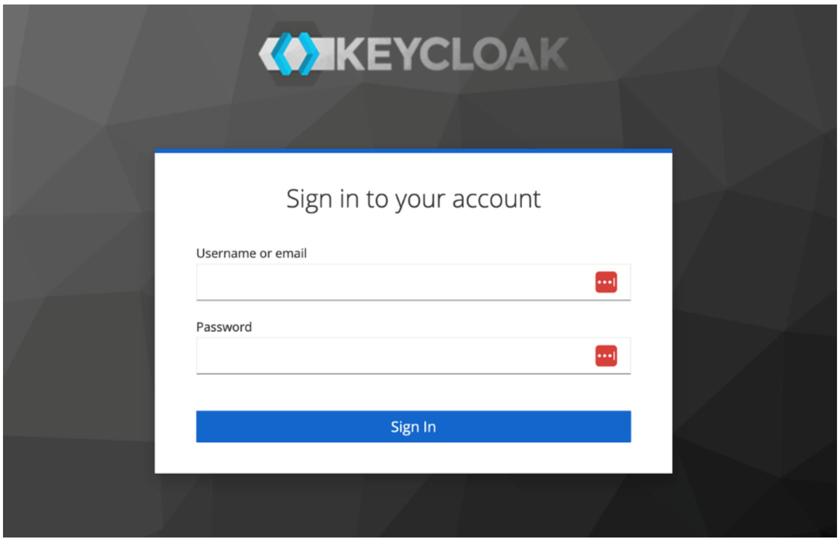

FIGURE 36: KEYCLOAK SIGN-IN UI SCREENSHOT.

SECURING APPLICATIONS AND SERVICES

As an OAuth2, OpenID Connect, and SAML compliant server, Keycloak can secure any application and service as long as the technology stack they are using supports any of these protocols. For more details about the security protocols supported are mentioned in the Keycloak Server Administration Guide[21]. Most of the support for some of these protocols is already available from the programming language, framework, or reverse proxy they are using. Leveraging the support already available from the application ecosystem is a key aspect to make your application fully compliant with security standards and best practices, so that you avoid vendor lock-in. For some programming languages, Keycloak provides libraries that try to fill the gap for the lack of support of a particular security protocol or to provide a richer and tightly coupled integration with the server. These libraries are known by Keycloak Client Adapters, and they should be used as a last resort if you cannot rely on what is available from the application ecosystem.

[21] Keycloak Server Administration Guide [Online].

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BASIC STEPS TO SECURE APPLICATIONS AND SERVICES

These are the basic steps for securing an application or a service in Keycloak.

1. Register a client to a realm using one of these options:
    - The Keycloak Admin Console.
    - The client registration service.
    - The CLI.
2. Enable OpenID Connect or SAML protocols in your application using one these options:
    - Leveraging existing OpenID Connect and SAML support from the application ecosystem.
    - Using a Keycloak Adapter.

TERMINOLOGY

These terms are used in this guide:

- **Clients** are entities that interact with Keycloak to authenticate users and obtain tokens. Most often, clients are applications and services acting on behalf of users that provide a single sign-on experience to their users and access other services using the tokens issued by the server. Clients can also be entities only interested in obtaining tokens and acting on their own behalf for accessing other services.
- **Applications** include a wide range of applications that work for specific platforms for each protocol.
- **Client adapters** are libraries that make it easy to secure applications and services with Keycloak. They provide a tight integration to the underlying platform and framework.
- **Creating a client** and **registering a client** are the same action. **Creating a client** is the term used to create a client by using the Admin Console. **Registering a client** is the term used to register a client by using the Keycloak Client Registration Service.
- **A service account** is a type of client that is able to obtain tokens on its own behalf.

I-STENTORE KEYCLOAK IDM

The authentication and authorization of the i-STENTORE platform relies on the Identity Provider service, based on the open-source package Keycloak as described above. This service[22] provides all the necessary parts to manage registration, authentication and roles of all i-STENTORE Users, and it is one of the central services of the IT infrastructure, providing the Single-Sign-On (SSO) system for almost all the services that require authentication. This

[22] https://istentore-server.eurodyn.com:20102/

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means that the services interfaced with the Identity Provider are accessed using the same credentials, while keeping the possibility for a user to have different roles in different services. Already the Virtual Power Plant interfaces with the Identity Provider Service and it will be extended for all authentication services in the frontend and backend whose description is not covered in this document. The SSO will cover the additional elements of the infrastructure as they will be developed, for example the Investment Planning interface.

3.1.3.3 i-STENTORE Datastore

MongoDB is an open-source NoSQL database management system designed for storing, retrieving, and managing document-oriented data. There are multiple reasons in why to use it in conjunction with the Orion-LD Context Broker (that is explained in the next section) and IoT-Related Data, some of which are explained below:

- **Schemaless Design:** MongoDB's schemaless design allows for flexible data storage, which can be beneficial when dealing with dynamic and evolving data structures, such as context information in IoT (Internet of Things) environments.
- **Scalability:** MongoDB is designed to scale horizontally across distributed systems, making it well-suited for handling large volumes of data and high-throughput applications. This scalability aligns well with the requirements of systems like Orion-LD, which may need to manage vast amounts of context data from various sources.
- **Performance:** MongoDB's architecture and indexing capabilities can provide efficient data retrieval and query performance, which is crucial for real-time applications like Orion-LD, where timely access to context information is essential.
- **Integration:** MongoDB integrates well with various programming languages, frameworks, and tools commonly used in web and application development. This flexibility makes it easier to integrate MongoDB with Orion-LD and other components of the FIWARE platform.
- **JSON Data Format:** MongoDB stores data in a format similar to JSON (BSON), which is native to many modern web and application development environments. Since JSON is also a common data format used in LD and IoT applications, using MongoDB can simplify data manipulation and exchange between different components of the system.

3.1.3.4 i-STENTORE Context Broker

- **Orion-LD** (Linked Data) Context Broker is a powerful tool used in the realm of the Internet of Things (IoT) and smart city solutions. It implements the NGSI-LD (Next Generation Service Interface for Linked Data) API[23]. The main reasons that it is the cornerstone of our middleware architecture are explained below:

[23] Context Information Management - Next Generation Service Interface for Linked Data API, [Online].

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- **Context Management:** Orion LD Context Broker manages and processes context information from various sources such as sensors, devices, and systems. It helps in aggregating, processing, and storing this information in a structured manner.
- **Real-time Updates:** Orion LD Context Broker provides real-time updates and notifications about changes in the context data. This real-time capability is crucial for applications that require timely responses to changing conditions.
- **Scalability and Performance:** Orion LD Context Broker is designed to be highly scalable and performant, capable of handling large volumes of context data from distributed sources. It can efficiently manage millions of context entities and handle high request rates.
- **Interoperability:** Orion LD Context Broker supports open standards and protocols for exchanging context information. This interoperability enables seamless integration with other IoT platforms, applications, and systems.
- **Flexible Data Model:** Orion LD Context Broker uses a flexible data model based on linked data principles. This allows developers to represent complex relationships and dependencies between context entities in a semantically rich manner, enabling more advanced data querying and analysis.
- **Support for Contextual Queries:** Orion LD Context Broker supports advanced querying capabilities, allowing developers to retrieve specific subsets of context information based on criteria such as location, time, and attribute values. This enables applications to make intelligent decisions and take appropriate actions based on the current context.

Some examples of our project's data models and interaction with the context broker (post and get request using the /ngsi-ld/v1/entities endpoint) are showcased in Appendices IV, V.

- **Kong Gateway** is an open-source, cloud-native API gateway and microservices management layer. It is designed to manage, secure, and scale APIs and microservices architectures. Kong Gateway provides various functionalities, including:
  - **API Gateway:** It acts as an intermediary between clients and our application's services, enabling us to manage traffic, enforce security policies, and apply transformations to incoming requests or outgoing responses.
  - **Load Balancing:** Kong Gateway can distribute incoming traffic across multiple instances of our services to ensure high availability and optimal performance.
  - **Security:** It offers features such as authentication, authorization, rate limiting, and encryption to secure our APIs and services from unauthorised access and attacks.
  - **Analytics and Monitoring:** Kong Gateway provides insights into API usage, performance metrics, and error rates, allowing us to monitor and optimise your services effectively.
  - **Plugin System:** Kong Gateway supports a wide range of plugins that extend its functionality, allowing us to customise and adapt it to our specific requirements without modifying the core codebase.
- **Kong Gateway** is meant to act as a reverse proxy between the clients and our middleware (Orion-LD and Keycloak). It will intercept the client requests to Orion-LD and will check if the client is authenticated by Keycloak. If and only if the client is authenticated, then it will

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forward the client request to Orion-LD and then distribute the response of Orion-LD back to the client.

3.2 INTEGRATING DIGITAL TOOLS AND PLATFORMS FOR ENHANCED ESS AND GRID SERVICES

This chapter focuses on Task 3.2 "Extensions of demo specific proprietary digital platforms and tools for monitoring and controlling energy storage optimizing performance".

The objective of the i-STENTORE project lies not only in exploring different solutions for energy storage systems but also in introducing an umbrella framework for their enhanced and optimal integration and interoperability. To this end, five different demos will be deployed, representing a wide variety of combinations of energy storage systems, grid services and business use cases. The implementation of the i-STENTORE demos not only aims to address technical and economic barriers specific to each demo site but also to establish a harmonized operational structure. To achieve this, a horizontal digital platform comprising various building blocks is being engineered based on the i-STENTORE Reference Architecture.

On the one hand, each pilot is developing a demo-specific platform tailored to its unique needs, hosting low-level controls that must be deployed locally, ensuring privacy and security. Nonetheless, these demo platforms will be integrated into the i-STENTORE concept, actively engaging with the Virtual Power Plant to enhance operational performance and facilitate more effective provision of grid-supporting services.

On the other hand, the i-STENTORE Data Governance Middleware (iDGM) constitutes a layer between the interconnected assets and the i-STENTORE intelligent business layer, ensuring semantic interoperability across different data stakeholders.

With this in mind, Task 3.2 aims to analyse the demo-specific platforms and tools in order to define their functional requirements and technological adaptations to ensure compatibility and interoperability with the i-STENTORE digital platform, in particular with the iDGM. Additionally, the results of this task will also be used as input to the middleware development process.

Therefore, as a final objective, the necessary extensions and APIs for machine-to-machine communication will be defined, along with the HMIs provided to the stakeholders.

3.2.1 Methodology

To achieve the ultimate objective of the task, the first crucial step is to analyse the specific platforms being developed by the demos. This involves examining the data, tools, formats, protocols, and other components that they plan to integrate into the information exchange mechanisms with i-STENTORE.

The input received from the pilots will be analysed to assess the limitations of the demo platforms and their adaptation capabilities. This analysis will provide a preliminary understanding of the extensions, adaptations, or APIs that may be required.

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Subsequently, these outcomes will be compared with the results of the 1st Technology Release presented in this document, with particular focus on the development of the i-STENTORE Data Governance Middleware and the Virtual Power Plant. By understanding the requirements from both sides, a refined definition of actions necessary to ensure interoperability and compatibility will be possible, and these will be presented in subsequent i-STENTORE Technology Releases.

Additionally, regarding HMIs, the preliminary HMIs of each demo will be analysed. Similarly, this information will be compared to the overall concept resulting from the 1st Technology Release in order to propose a harmonized demo HMI for the subsequent Technology Releases. The demo HMI will address the need to provide a multidisciplinary framework that encompasses different business use cases related to energy storage.

3.2.2 Analysis of i-STENTORE Demo Platforms

This section encompasses the analysis of the platforms developed by the demos within the i-STENTORE project. To initiate this analysis, a survey was devised and distributed to the demo partners, marking the initial iteration in defining the demo platforms and their subsequent integration into the i-STENTORE digital platform.

3.2.2.1 Survey on the Integration of Demos into the i-STENTORE Platform

The survey distributed to demo partners aims to analyse, from the pilot's perspective, how demo-specific platforms and tools are expected to interact with the i-STENTORE digital platform. This action is framed within a dual objective. On the one hand, it will allow an assessment of the limitations of demo platforms regarding communication protocols, data formats, accessibility, or any other constraining aspects that demos may identify. This information will be used to determine whether a technological adaptation or extension is needed for their proper integration into the i-STENTORE framework. On the other hand, this initiative also serves as a requirement definition from demos with regard to the i-STENTORE platform, presenting the functional specifications that demos will need from the project's ecosystem for their effective performance.

To provide the necessary context, the survey circulated to the demos is introduced first. Subsequently, the responses will be cross-referenced; that is, for each of the aspects inquired, the responses of all the demos will be presented together. This will enable a global analysis of the limitations and requirements of the demos, thereby allowing for a comprehensive and harmonized framework for their integration into the i-STENTORE architecture, as will be presented in subsequent sections.

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3.2.2.2 Survey content

The survey distributed to demo partners comprises the following points:

TABLE 2: DEMO SURVEY FOR TASK 3.2.

Survey on the Integration of Demos into the i-STENTORE Platform
1. **Please, list the information exchanges that your Demo will have with the i-STENTORE platform**. **For each data item or service**, please provide a **short description**, specify the **data format** (XML, JSON, etc.), expected **communication frequency**, and any other relevant characteristics. ▪ Data sent to i-STENTORE: ▪ Data requested from i-STENTORE: ▪ Services requested from i-STENTORE:
2. Please specify how the communication with the i-STENTORE platform is expected to take place: ▪ What type of device/cloud service will be in charge of the communication with the i-STENTORE platform (PLC, PC, cloud server, other)? ▪ What are the limitations of the device/cloud service regarding communication protocols, data formats, accessibility, if any? Will it be possible to reconfigure it to use the final protocols used by i-STENTORE when they are finally decided? ▪ Is the device/cloud service fully programmable by you? Is it a proprietary-closed solution? Can you request modifications?
3. Will your demo platform have an HMI? If so, please add a short description of the functionality. If possible, include screenshots if the HMI is already available:

3.2.2.3 Cross-referenced survey responses from demos

This section presents the survey results, organized by individual questions, facilitating their subsequent analysis.

TABLE 3: DEMO SURVEY FOR TASK 3.2: CROSS.REFERENCE RESULTS FOR SECTION 1.

Cross-referenced results for section 1: **1. Please, list the information exchanges that your Demo will have with the i-STENTORE platform. For each data item or service, please provide a short description, specify the data format (XML, JSON, etc.), expected communication frequency, and any other relevant characteristics.**	
Data sent to i-STENTORE	
Demo 1	○ Static data: Flexible asset definitions: ▪ PV, nominal power, orientation, inclination, location, power factor ▪ Furnace, SOC, maximal charge and discharge power, charge/discharge efficiency ▪ Grid location: MV, substation/meter id ▪ User account details.

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	○ Historical data: Historical information regarding weather conditions or any other information that is subject to forecast. The communication frequency for this data information will be around 15 minutes or 1h, to provide the i-STENTORE platform with updated data for accurate forecasting services. ○ Resulting schedules from the optimization engine: optimized profiles. The maximum expected communication frequency will be 15 minutes. The expected format for this data is JSON and interaction via HTTP requests.
Demo 2	○ Aggregated and anonymised time series of: ▪ Loads ▪ Reservoir inflows ▪ PV and wind generation and forecasts ▪ Thermal generation ▪ Hydro generation ▪ Li-ion battery SOC ▪ VRFB SOC ▪ Outputs of the predictive optimisation tool developed in i-STENTORE.
Demo 3	○ Static data: Component definitions; user account details; steady information that will not be updated on a daily basis. To manage the databases with the i-STENTORE Platform, Demo 3 will use SQL, NoSQL, relying on HTTP requests for the interaction. ○ Past data: This could involve historical information regarding weather conditions, past market clearing results, or any other information that is subject to forecast. The communication frequency for this data will be around 15 minutes, in order to provide the i-STENTORE platform with updated data for accurate forecasting services. ○ Resulting schedules from the optimization engine: market offers (energy and price), VESS charge and discharge setpoints and expected SOC profile. These results are stored in the *Future Database* of the demo platform. The maximum expected communication frequency will be 15 minutes. The expected format for this data is JSON and interaction via HTTP requests.
Demo 4	○ Static data: Component definitions; user account details; steady information that will not be updated daily. To manage the databases with the i-STENTORE Platform, Demo 4 will use SQL, NoSQL, relying on HTTP requests for the interaction. ○ Past data: This could involve historical information regarding weather conditions, past market clearing results, or any other information that is subject to forecast. The communication frequency for this data information will be around 15 minutes, to provide the i-STENTORE Platform with updated data for accurate forecasting services.
Demo 5	○ Day ahead - resolution: 1 hour, update frequency: 24 hours ▪ Battery active power schedule

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	▪ Battery state of charge schedule ▪ Battery capacity allocation for flexibility services (CM, FCR, aFRR, mFRR). o Intraday - resolution: up to 5-minute, update frequency: up to 5-minute (aggregates can be provide every 15 minutes or 60 minutes) ▪ Battery actual active power output per service: - Energy arbitrage - Congestion mitigation - FCR - aFRR - mFRR ▪ Battery actual state of charge ▪ Electrolyser demand ▪ Hydrogen demand ▪ PV actual active power output ▪ WPP actual active power output ▪ Actual capacity of transmission lines for congestion mitigation.
Data requested from i-STENTORE	
Demo 1	o PV Plant: ▪ Sun irradiance, temperature, PV production (power factor if it changes) ▪ Degradation of modules (optional). o Hybrid storage systems: ▪ Static parameters: converter rating, maximum and minimum SOC, charging and discharging efficiency ▪ Dynamic parameters: charging and discharging power, state of charge (related to hypothetical flexibility request, external to Demo 1). o Energy markets: ▪ Wholesale market price (prefer HUDEX). o Data format: Ideally JSON obtained through HTTP requests. o Flexibility activation signal, requested profile. o Communication frequency: every 15 minutes.
Demo 2	o No data needed, so far – PV/wind generation forecasts might be requested, if it is available on the i-STENTORE platform.
Demo 3	o Wind generator: ▪ Static parameters: rated power, cut-in and cut-out speeds, reference speed ▪ Dynamic parameters forecast: wind speed, output active and reactive power. o PV plant:

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	▪ Static parameters: rated power, standard irradiance, efficiency of the panel ▪ Dynamic parameters forecast: Sun irradiance, output active and reactive power. o Run-of-river hydroelectric plants: ▪ Static parameters: rated power, hydraulic head, plant efficiency, inflow upper and lower limits ▪ Dynamic parameters forecast: inflow. o Lithium and VRF battery energy storage systems: ▪ Static parameters: converter rating, maximum and minimum SOC, charging and discharging efficiency, calendar degradation, cycle degradation, replacement cost. ▪ Dynamic parameters: charging and discharging power, state of charge. o Energy markets: ▪ Wholesale market price ▪ Tertiary reserve market price: Upward and downward reserve prices. o Data format: Ideally JSON obtained through HTTP requests. o Communication frequency: every 15 minutes.
Demo 4	o PV Plant: ▪ Static parameters: rated power, standard irradiance, efficiency of the panel ▪ Dynamic parameters forecast: sun irradiance, output active and reactive power. o Hybrid energy storage systems: ▪ Static parameters: converter rating, maximum and minimum SOC, charging and discharging efficiency, calendar degradation, cycle degradation, and replacement cost ▪ Dynamic parameters: charging and discharging power, State of Charge. o Charging stations: ▪ Static parameters: rated power, rated capacity, maximum current, maximum power ▪ Dynamic parameters: available energy, available power, current, power.
Demo 5	o Actual wholesale electricity day ahead market prices (€/MWh) o Flexibility service activation signals if needed (TSO, DSO). For example, aFRR is triggered based on specific monitored system variables.
Services requested from i-STENTORE	
Demo 1	o Local weather forecast (irradiance, temperature, location). Ideally updated every hour or quarter-hour for the next 24/48 hours.

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	○ Power forecast for PV: Ideally updated every hour or quarter-hour for the next 24/48 hours. ○ Wholesale price forecast: wholesale market price forecast for the next 24-72 hours. ○ Common flexibility service.
Demo 2	○ No service needed so far, but PV/wind generation forecast might be integrated.
Demo 3	○ Local weather forecast (irradiance, wind speed, water inflow for a run-of-river hydroelectric plant). Ideally updated every hour or quarter-hour for the next 24 to 72 hours. ○ Power forecast for PV, wind turbine run-of-river hydroelectric plant. Ideally updated every hour or quarter-hour for the next 24 to 72 hours. ○ Wholesale price forecast: wholesale market price forecast for the next 24-72 hours. ○ Tertiary reserve forecast: price forecast for the next 24 hours. ○ These forecasts can be probabilistic (samples and probability) or simply return the expectancy of the value. Data format: Ideally JSON obtained through HTTP requests.
Demo 4	○ Local weather forecast. Ideally updated every hour or quarter-hour for the next 24 to 72 hours. ○ Power forecast for PV. Ideally updated every hour or quarter-hour for the next 24 to 72 hours. ○ EVs: Number of vehicles to recharge, initial State of Charge, final State of Charge. ○ These forecasts can be probabilistic (samples and probability) or simply return the expectancy of the value. Data format: Ideally JSON obtained through HTTP requests.
Demo 5	○ PV production forecast ○ WPP production forecast ○ Wholesale Electricity Day ahead prices forecast ○ Congestion forecast ○ Frequency forecast (or power imbalance forecast) ○ The communication format is in JSON.

TABLE 4: DEMO SURVEY FOR TASK 3.2: CROSS.REFERENCE RESULTS FOR SECTION 2.

Cross-referenced results for section 2: 2. Please specify how the communication with the i-STENTORE platform is expected to take place:	
What type of device or cloud service will oversee the communication with the i-STENTORE platform (PLC, PC, cloud server, other)?	
Demo 1	One central or cloud server.

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Demo 2	INESC TEC virtual machine.
Demo 3	Cloud server: possibly AWS.
Demo 4	Cloud server: possibly AWS.
Demo 5	Cloud server: possibly AWS.
What are the limitations of the device/cloud service regarding communication protocols, data formats, accessibility, if any? Will it be possible to reconfigure it to use the final protocols used by i-STENTORE when they are finally decided?	
Demo 1	None, we can adjust the external communication to i-STENTORE.
Demo 2	At this stage, we believe it will not have significant limitations. If a remote connection i-STENTORE platform -> INESC TEC virtual machine is needed, a VPN access to the INESC TEC network is required.
Demo 3	None, it will be possible to reconfigure it to use the final protocol used by i-STENTORE platform.
Demo 4	None, it will be possible to reconfigure it to use the final protocol used by i-STENTORE platform.
Demo 5	There are no limitations of the communication platform. We can implement the desired protocols required to communicate with i-STENTORE.
Is the device/cloud service fully programmable by you? Is it a proprietary-closed solution? Can you request modifications?	
Demo 1	Yes, COMS will provide and adjust the services to be able to provide also the flexibility through i-STENTORE marketplace. We can also adjust external APIs so the cloud can communicate with Demo 1.
Demo 2	The server is fully programmable by INESC TEC.
Demo 3	Yes, the cloud service communications will be fully programmable by demo partners.
Demo 4	Yes, the cloud service communications will be fully programmable by demo partners.
Demo 5	It is programmed by us therefore we have full control of what can be implemented.

TABLE 5: DEMO SURVEY FOR TASK 3.2: CROSS.REFERENCE RESULTS FOR SECTION 3.

Cross-referenced results for section 3: 3. **Will your demo platform have an HMI? If so, please add a short description of the functionality. If possible, include screenshots if the HMI is already available.**	
Demo 1	Since Demo 1 is using the available flexibility for internal optimization, there will also be the HMI related to the Demo 1 service, where the user could select the type of optimization (e.g., price optimization, self-usage of energy from RES…). The idea is also to set the boundary condition to the furnace that might change during the first runs and is subject to throughput, quality of the melt and current process. This will be defined later. On the UI, the graphs related to production and schedules will also be shown.

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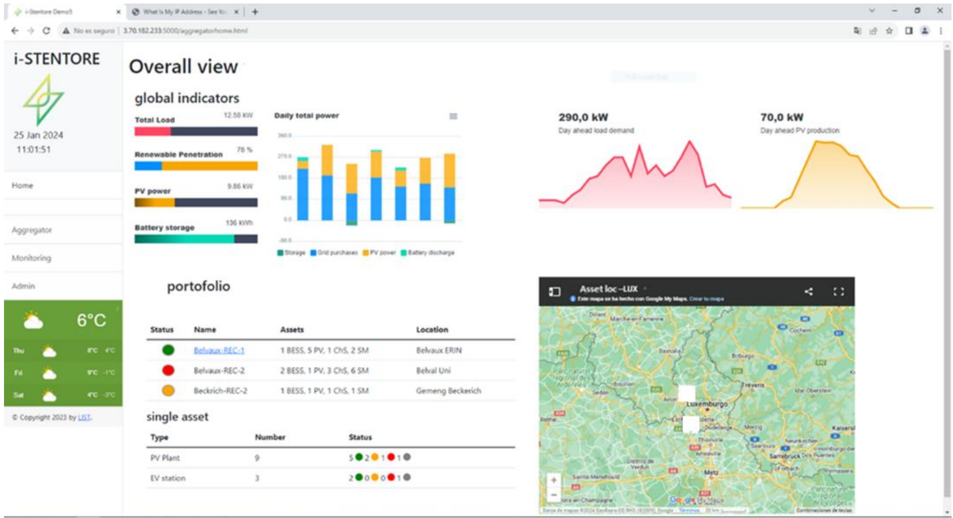
<table>
<tr><td>Demo 2</td><td>For now, no HMI is envisaged. The outputs of the optimisation tool developed in i-STENTORE will be provided to EEM (system operator) using a database.</td></tr>
<tr><td>Demo 3</td><td>Under definition.</td></tr>
<tr><td>Demo 4</td><td>Under definition.</td></tr>
<tr><td>Demo 5</td><td>The Demo 5 platform will have a complete HMI reflecting all asset status, historical and forecasted data flows. A first functional mock prototype has been developed and tested in a local development environment. Please, find the landing screen below:



</td></tr>
</table>

3.2.2.4 Survey analysis

This section aims to analyse the responses of the demos to the survey, highlighting common points and assessing whether limitations can be identified when integrating demo platforms into the i-STENTORE digital platform.

An important initial consideration is that the demos anticipate interfacing with the i-STENTORE platform via servers, eliminating the need for direct communication between the i-STENTORE framework and on-field devices such as PLCs, PCs, or proprietary devices. For reasons of security, privacy, and accessibility, each demo will manage the low-level control of its assets locally. Higher control, information and services exchange will occur at a higher level through a central server abstraction layer. Specifically, Demo 1 will use its own central server, as will Demo 2, which will use the INESC TEC virtual machine. The remaining demos are currently exploring the possibility of using cloud servers, with a focus on Amazon Web Services (AWS).

The flexibility of using these types of tools ensures that the demos encounter no limitations when it comes to adopting different communication protocols or data formats to align with the specifications of the i-STENTORE platform. Additionally, the demos have not identified any accessibility constraints, although a VPN connection may be required. Furthermore, the cloud servers will be fully controllable and programmable by the demo partners, enabling them to reconfigure the platforms, adjust necessary APIs, and perform data transformations if needed.

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However, although no adaptability limitations have been identified, the demos have indicated their initial plan to utilize the JSON format and conduct communication via HTTP requests as part of their data exchange mechanism. This approach allows for standardized and efficient data formats and communication protocols, facilitating their integration into the i-STENTORE digital platform. By utilizing these mechanisms, the demos aim to ensure reliable and secure data transmission, enhancing the interoperability within the project.

Additionally, some demos have specified the integration of various database technologies into their demo-specific platforms, including SQL and NoSQL, for effective data management. The integration of different database technologies will provide the demos with flexibility in handling various types of data and accommodating different data management requirements. SQL databases offer structured data storage and efficient querying capabilities, while NoSQL databases are suitable for handling unstructured and semi-structured data with high scalability and performance. By leveraging these technologies, the demos can effectively manage diverse data sets and optimize their performance within the i-STENTORE framework.

In relation to the envisaged data exchange from the demos' perspective, several aspects can be examined.

Regarding the frequency of communication between the demos and i-STENTORE, surveys have revealed that this will range from once a day to every 5 minutes, with a significant number of data exchanges occurring every hour or every fifteen minutes.

DATA SENT TO I-STENTORE

The examination of the data sets that the demos could transmit to the i-STENTORE platform uncovers several important points.

On the one hand, the demos could provide historical data on weather conditions, renewable generation, market clearing results, or any other information that is relevant to forecasting. This would provide i-STENTORE with updated and specific information from each demo to feed the forecast engine.

On the other hand, survey feedback indicates that the demos could also share the results of their specific optimization algorithms and the schedules of the demo assets. These schedules could be a direct result of the optimization algorithms or could result from their participation in the market. In addition, actual operational data from various pilot assets, such as the State of Charge of the energy storage systems, the actual power output of the renewable power plants, and the operational parameters of the grid status, could also be transmitted. These operational parameters may be communicated in an aggregated format.

This information will feed the i-STENTORE Analytics Engine & UI (iAnalytics), which aims to extract valuable insights, comprehend trends, identify patterns, and facilitate improved decision-making capabilities, thereby enhancing the existing functionality of the demo sites' digital platforms.

Finally, feedback from demos indicated that they could provide static data regarding component definitions or user account details. However, according to the conceptualization of the i-STENTORE framework, asset attributes are expected to be provided through the

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registration of assets in the Assets Management Register. In this manner, based on a common and detailed ontology for various energy storage systems, the interoperability of demo components and operational planning will be enhanced, ensuring efficient resource utilization across the i-STENTORE platform.

The analysis provided covers all the data items that could be transmitted from the demos according to the survey, though not all points are applicable across every demo. The accompanying table below correlates these aspects with the demos in this initial iteration with the pilots. However, this does not preclude the possibility of expanding or modifying specifications in future iterations, once the operational aspects of both the demos and their integration into i-STENTORE are fully delineated.

TABLE 6: SUMMARY OF THE DEMO SURVEYS REGARDING DATA TRANSMISSION.

	Demo 1	Demo 2	Demo 3	Demo 4	Demo 5
Past data to be used for generating forecasts	X	X	X	X	X
Demo-specific optimization engine results and asset schedules	X	X	X		X
Actual operational parameters of the assets and the grid		X			X
Static data	X		X	X	

DATA REQUESTED FROM I-STENTORE

Regarding the data flow from i-STENTORE to the demos, the survey indicates that demos will require various inputs. First, different attributes concerning the demo-specific assets, sites, and markets, which are hosted in the Flexibility Register and are necessary for running the algorithms governing each demo, will rely on i-STENTORE. This approach provides demos with a consistent framework to manage their assets based on a common ontology. Not only static parameters, such as rated powers, will be requested, but also dynamic ones, such as actual weather conditions or market prices. Additionally, activation signals for the delivery of flexibility services, triggered based on monitored system variables, will also be communicated via the i-STENTORE digital platform. Considering the particularities of each demo, their requirements are quite specific; however, these needs will be met in a harmonized manner within the i-STENTORE digital platform.

SERVICES REQUESTED FROM I-STENTORE

In relation to the services requested from i-STENTORE, a common requirement identified is forecasting. All demos will need various forecasts, and this service is intended to be provided by the i-STENTORE digital platform. Even if demos have their own internal forecasting engine, such as seen in Demo 2, they could integrate this service from the i-STENTORE system, thereby aligning with the interoperability objectives of the project.

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Essentially, the forecasts required encompasses local weather conditions, renewable generation production, market prices, and grid conditions, as well as specific details regarding each demo (for example, the number of EVs to recharge for Demo 4).

TABLE 7: SUMMARY OF THE DEMO SURVEYS REGARDING REQUIRED FORECASTS.

	Demo 1	Demo 2	Demo 3	Demo 4	Demo 5
Local weather forecast	X		X	X	
Renewable generation forecast	X		X	X	X
Market prices forecast	X		X		X
Grid condition forecast			X		X
Number and SOC of EVS				X	

HMIS

Regarding the demo-specific HMIs, as of the date of delivery of this document, all demos except demo 2 have planned the development of an HMI. For demos 3 and 4, the specification of their functionalities is still under definition. However, demos 1 and 5 already have more detailed specifications of their features. Demo 1 plans to incorporate an HMI to define the type of optimization and its parameters, displaying the resulting schedules and production profiles graphically. Demo 5 already has a preliminary version of its HMI and has provided a screenshot of it. It presents an overall view of the demo, with global indicators such as total load, renewable penetration, PV power, and battery storage, as well as detailed demand and generation profiles. Additionally, it includes a portfolio of assets, encompassing their identification, location, and status.

3.2.3 Conclusions and next steps

In this section, the platforms of the demos have been analysed, examining the data and signals they intend to manage in their interaction with the i-STENTORE digital platform. The tools to be used and the limitations of the demo platforms in terms of data formats, communication protocols and accessibility were also evaluated.

From this first iteration with the pilots, it is important to conclude that the demos will use flexible and reconfigurable servers that do not present any limitations to adapt to the i-STENTORE system, being able to integrate the necessary APIs, data formats and communication protocols. It should be noted that various demos are considering the utilization of the JSON data format and communicating via HTTP requests, which is coherent with the conceptualization of the i-STENTORE Context Broker.

These outcomes will be correlated with the consolidated specifications of the 1st Technology Release regarding the iDGM, the VPP, and the definition of the i-STENTORE Set of Vocabularies & Ontologies to align the requirements of the demos with the overall project framework. This will determine whether it is necessary to perform data transformations in order to harmonize and ensure compatibility, thereby obtaining data in a clean, consistent, and meaningful format.

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In addition, building on the 1st Technology Release, a harmonized HMI will be proposed for the demos to facilitate decision making and intuitive interaction. This harmonized HMI will provide a consistent interface for the pilots, including the ability to present real-time data in a clear and concise manner, provide integrated analysis tools to extract meaningful information from the data, and enable the management of connected devices within the i-STENTORE framework.

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4 CONCLUSIONS

The i-STENTORE project, dedicated to innovating energy storage integration and enhancing grid flexibility, has achieved significant milestones with the development and initial deployment of its digital ecosystem. A crucial accomplishment has been completed with this deliverable, initially supported by establishment of the work in D2.2, now effectively stepping into the preliminary integration of diverse energy storage solutions, thus representing a substantial advancement in optimizing renewable energy use within the European power grid.

The objective of the i-STENTORE Deliverable D3.4 is multifaceted, encompassing the presentation and enhancement of demo-specific tools within the broader i-STENTORE digital platform. This deliverable focuses on the first technology release, which has introduced key components like the Virtual Power Plant (VPP), Investment Planning Tool (IPT), and Data Governance Middleware. These components enhance the operational efficiency of the i-STENTORE platform, ensuring effective monitoring and control of energy storage systems. The integration of these components within the i-STENTORE digital platform is a step towards realizing the envisioned interoperability and compatibility across various tools and systems.

A portion of this deliverable is dedicated to outlining a deployment guide, showcasing the steps required for integrating parts of these vital components. On that note, the deliverable includes various appendices which provide a comprehensive view of the technical and practical aspects of this i-STENTORE deliverable, encompassing everything from standard templates and data models to specific examples and methods for interacting with the project's digital platform.

As the project moves forward, the focus will shift towards refining these tools and expanding their functionalities. Future directions include enhancing data governance capabilities, improving the efficiency of energy storage monitoring, and integrating more advanced decision-making algorithms within the VPP, IPT. The continual evolution of the Reference Architecture will ensure that it remains relevant and adaptable to new technologies and market conditions. Moreover, the project will explore new business models and market opportunities, particularly in the context of the evolving energy landscape and the increasing role of renewables.

In conclusion, D3.4, as a 1st technology release, has laid a solid foundation in advancing the state of energy storage technologies and their application as diverse storage solutions into the energy sector. The next steps will involve building on this foundation to realize the full potential of the project's innovative approach, ensuring its long-term impact and contribution to the transition towards a more sustainable and efficient energy system.

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5 REFERENCES

[1] Opricovic S., Tzeng G. H. (2004). Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS. European Journal of Operational Research, 156(2), 445-455.

[2] Sayadi M. K., Heydari M., Shahanaghi K. (2009). Extension of VIKOR method for decision making problem with interval numbers. Applied Mathematical Modelling, 33(5), 2257-2262.

[3] Kim J. H., Ahn B. S. (2019). Extended VIKOR method using incomplete criteria weights. Expert Systems with Applications, 126, 124-132.

[4] Hwang C. L., Yoon K. (1981). Multiple Attribute Decision Making: Methods and Applications. Springer-Verlag, New York.

[5] Chen C. T. (2000). Extensions of the TOPSIS for group decision-making under fuzzy environment. Fuzzy Sets and Systems, 114, 1-9.

[6] Chen T. Y., Tsao C. Y. (2008). The interval-valued fuzzy TOPSIS method and experimental analysis. Fuzzy Sets and Systems, 159, 1410-1428.

[7] Chen S. M., Lee L. W. (2010). Fuzzy multiple attributes group decision-making based on the interval type-2 TOPSIS method. Expert Systems with Applications. 37, 2790-2798.

[8] Baumgarte F., Glenk G., Rieger A. (2020). Business Models and Profitability of Energy Storage, iScience, 23, 101554.

[9] Martin N., Rice J. (2021). Solar Feed-In Tariffs: Examining fair and reasonable retail rates using cost avoidance estimates. Energy Policy, 112, 19-28.

[10] Spiliotis K., Claeys S., Gutierrez A. R., Driesen J. (2016). Utilizing local energy storage for congestion management and investment deferral in distribution networks. 13th International Conference on the European Energy Market (EEM), Porto, Portugal, 1-5.

[11] Zhang X., Qin C., Loth E., Xu Y., Zhou X. (2021). Arbitrage analysis for different energy storage technologies and strategies. Energy Reports, 7, 8198-8206.

[12] Castillo A., Gayme D. F. (2014). Grid-scale energy storage applications in renewable energy integration: a survey. Energy Conversion and Management 87, 885-894.

[13] Palizban O., Kauhaniemi K. (2016). Energy storage systems in modern grids – Matrix of technologies and applications. Journal of Energy Storage, 6, 248-259.

[14] Kousksou T., Bruel P., Jamil A., El Rhafiki T., Zeraouli Y. (2014). Energy storage: applications and challenges. Solar Energy Materials and Solar Cells 120 (Part A), 59-80.

[15] Hossain E., Faruque H. M. R., Sunny Md. S. H., Mohammad N., Nawar N. (2020). A Comprehensive Review on Energy Storage Systems: Types, Comparison, Current Scenario, Applications, Barriers, and Potential Solutions, Policies, and Future Prospects. Energies, 13(14), 3651.

[16] Chen H., Cong T. N., Yang W., Tan C., Li Y., Ding Y. (2009). Progress in electrical energy storage system: A critical review. Progress in Natural Science, 19(3), 291-312.

[17] Mitali J., Dhinakaran S., Mohamad A. A. (2022). Energy storage systems: a review. Energy Storage and Saving, 1(3), 166-216.

[18] Opricovic, S., & Tzeng, G. H. (2007). Extended VIKOR method in comparison with outranking methods. European journal of operational research, 178(2), 514-529.

[19] Saaty, R. W. (1987). The analytic hierarchy process — what it is and how it is used. Mathematical modelling, 9(3-5), 161-176.

[20] Kim, J. H., & Ahn, B. S. (2019). Extended VIKOR method using incomplete criteria weights. Expert Systems with Applications, 126, 124-132.

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6 APPENDICES

6.2 APPENDIX I: DEMO SERVICES DESCRIPTION TEMPLATES

Demo ID (#/country) :	
Demo Leader:	
Number or services froeseen	

Service 1		
Flexibility Service definition		
Description		
Existing or New Service?		
Technology used		
TRL level (1-9)		
Discharge time		
Reaction time		
Frequency of use		
Scale (site/Segment of the network/national/continental)		
Users of the service/short description of the Business case		
Market-based or regulated tariff?		
Unit of measurement		
Pricing method		
Procured volume definition		
Process overview description (if applicable)	1.Prequalification.	
	2.Bidding/Selection:	
	3.Delivery:	
	4.Settlement.	
	5.Monitoring:	
Settlement schemes	☐ TSO-TSO Settlement	☐ DSO- BRP Settlement
	☐ TSO-DSO Settlement	☐ DSO-Service Provider Settlement
	☐ TSO-BRP Settlement	☐ BRP- Service Provider Settlement
	☐ TSO-Service Provider Settlement	☐ No Settlement
	☐ DSO-DSO Settlement	☐ Other (describe)
Observations	e.g. : Is it limited by current market structure or regulation framework?	

6.3 APPENDIX II: THE I-STENTORE IONTOLOGY V.1 (RDF/XML SYNTAX)

```
<?xml version="1.0"?>
<rdf:RDF xmlns="http://www.hse.gr/i-stentore/ontology#"
     xml:base="http://www.hse.gr/i-stentore/ontology"
     xmlns:hse="http://www.hse.gr/i-stentore/ontology#"
     xmlns:obo="http://purl.obolibrary.org/obo/"
     xmlns:oeo="http://openenergy-platform.org/ontology/oeo/"
     xmlns:owl="http://www.w3.org/2002/07/owl#"
     xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
     xmlns:xml="http://www.w3.org/XML/1998/namespace"
     xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
     xmlns:core="https://saref.etsi.org/core/"
     xmlns:om-2="http://www.ontology-of-units-of-measure.org/resource/om-2/"
     xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
     xmlns:vann="http://purl.org/vocab/vann/"
     xmlns:terms="http://purl.org/dc/terms/">
    <owl:Ontology rdf:about="http://www.hse.gr/i-stentore/ontology">
        <owl:versionIRI rdf:resource="http://www.hse.gr/i-stentore/ontology"/>
    </owl:Ontology>


        <!--
    ///////////////////////////////////////////////////////////////////////////////////////
        //
        // Annotation properties
        //
    ///////////////////////////////////////////////////////////////////////////////////////
        -->
```


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```
    <!-- http://openenergy-platform.org/ontology/oeo/OEO_00110012 -->
<owl:AnnotationProperty rdf:about="http://openenergy-platform.org/ontology/oeo/OEO_00110012"/>
    <!-- http://purl.obolibrary.org/obo/IAO_0000112 -->
<owl:AnnotationProperty rdf:about="http://purl.obolibrary.org/obo/IAO_0000112"/>
    <!-- http://purl.obolibrary.org/obo/IAO_0000115 -->
<owl:AnnotationProperty rdf:about="http://purl.obolibrary.org/obo/IAO_0000115"/>
    <!-- http://purl.obolibrary.org/obo/IAO_0000116 -->
<owl:AnnotationProperty rdf:about="http://purl.obolibrary.org/obo/IAO_0000116"/>
    <!-- http://purl.obolibrary.org/obo/IAO_0000118 -->
<owl:AnnotationProperty rdf:about="http://purl.obolibrary.org/obo/IAO_0000118"/>
    <!-- http://purl.obolibrary.org/obo/IAO_0000119 -->
<owl:AnnotationProperty rdf:about="http://purl.obolibrary.org/obo/IAO_0000119"/>
    <!-- http://purl.obolibrary.org/obo/IAO_0000233 -->
<owl:AnnotationProperty rdf:about="http://purl.obolibrary.org/obo/IAO_0000233"/>
    <!-- http://purl.org/dc/terms/created -->
<owl:AnnotationProperty rdf:about="http://purl.org/dc/terms/created"/>
    <!-- http://purl.org/dc/terms/creator -->
<owl:AnnotationProperty rdf:about="http://purl.org/dc/terms/creator"/>
    <!-- http://purl.org/dc/terms/description -->
<owl:AnnotationProperty rdf:about="http://purl.org/dc/terms/description"/>
    <!-- http://purl.org/dc/terms/issued -->
<owl:AnnotationProperty rdf:about="http://purl.org/dc/terms/issued"/>
    <!-- http://purl.org/dc/terms/license -->
<owl:AnnotationProperty rdf:about="http://purl.org/dc/terms/license"/>
    <!-- http://purl.org/dc/terms/modified -->
<owl:AnnotationProperty rdf:about="http://purl.org/dc/terms/modified"/>
    <!-- http://purl.org/dc/terms/publisher -->
<owl:AnnotationProperty rdf:about="http://purl.org/dc/terms/publisher"/>
    <!-- http://purl.org/dc/terms/source -->
<owl:AnnotationProperty rdf:about="http://purl.org/dc/terms/source"/>
    <!-- http://purl.org/dc/terms/title -->
<owl:AnnotationProperty rdf:about="http://purl.org/dc/terms/title"/>
    <!-- http://purl.org/vocab/vann/preferredNamespacePrefix -->
<owl:AnnotationProperty rdf:about="http://purl.org/vocab/vann/preferredNamespacePrefix"/>
    <!-- http://purl.org/vocab/vann/preferredNamespaceUri -->
<owl:AnnotationProperty rdf:about="http://purl.org/vocab/vann/preferredNamespaceUri"/>
    <!-- http://www.ontology-of-units-of-measure.org/resource/om-2/alternativeLabel -->
<owl:AnnotationProperty rdf:about="http://www.ontology-of-units-of-measure.org/resource/om-2/alternativeLabel"/>
    <!-- http://www.ontology-of-units-of-measure.org/resource/om-2/alternativeSymbol -->
<owl:AnnotationProperty rdf:about="http://www.ontology-of-units-of-measure.org/resource/om-2/alternativeSymbol"/>
    <!-- http://www.ontology-of-units-of-measure.org/resource/om-2/symbol -->
<owl:AnnotationProperty rdf:about="http://www.ontology-of-units-of-measure.org/resource/om-2/symbol"/>
    <!-- http://www.ontology-of-units-of-measure.org/resource/om-2/unofficialAbbreviation -->
<owl:AnnotationProperty rdf:about="http://www.ontology-of-units-of-measure.org/resource/om-2/unofficialAbbreviation"/>
    <!-- http://www.ontology-of-units-of-measure.org/resource/om-2/unofficialLabel -->
<owl:AnnotationProperty rdf:about="http://www.ontology-of-units-of-measure.org/resource/om-2/unofficialLabel"/>

    <!--
///////////////////////////////////////////////////////////////////////////////////////
    //
    // Object Properties
    //
///////////////////////////////////////////////////////////////////////////////////////
    -->

    <!-- http://www.hse.gr/i-stentore/ontology#hasAssets -->
<owl:ObjectProperty rdf:about="http://www.hse.gr/i-stentore/ontology#hasAssets">
   <rdfs:subPropertyOf rdf:resource="http://www.w3.org/2002/07/owl#topObjectProperty"/>
   <rdfs:domain rdf:resource="http://www.hse.gr/i-stentore/ontology#Infrastrucuture"/>
   <rdfs:range rdf:resource="http://www.hse.gr/i-stentore/ontology#Asset"/>
   <rdfs:comment>A relationship between an Infrastructure and its Assets.</rdfs:comment>
   <rdfs:label xml:lang="en">has asset</rdfs:label>
</owl:ObjectProperty>

    <!-- http://www.hse.gr/i-stentore/ontology#hasParameters -->
<owl:ObjectProperty rdf:about="http://www.hse.gr/i-stentore/ontology#hasParameters">
   <rdfs:subPropertyOf rdf:resource="http://www.w3.org/2002/07/owl#topObjectProperty"/>
   <rdfs:domain rdf:resource="http://www.hse.gr/i-stentore/ontology#Asset"/>
   <rdfs:range rdf:resource="http://www.hse.gr/i-stentore/ontology#Parameters"/>
   <rdfs:comment>A relationship between an Asset and its Parameters.</rdfs:comment>
   <rdfs:label xml:lang="en">has parameter</rdfs:label>
```


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```
</owl:ObjectProperty>

        <!-- http://www.hse.gr/i-stentore/ontology#isLocatedIn -->
    <owl:ObjectProperty rdf:about="http://www.hse.gr/i-stentore/ontology#isLocatedIn">
        <rdfs:subPropertyOf rdf:resource="http://www.w3.org/2002/07/owl#topObjectProperty"/>
        <rdfs:comment>A relationship between an Infrastructure and its Location.</rdfs:comment>
        <rdfs:label xml:lang="en">is located in</rdfs:label>
    </owl:ObjectProperty>

        <!-- http://www.hse.gr/i-stentore/ontology#uses -->
    <owl:ObjectProperty rdf:about="http://www.hse.gr/i-stentore/ontology#uses">
        <rdfs:subPropertyOf rdf:resource="http://www.w3.org/2002/07/owl#topObjectProperty"/>
        <rdfs:domain rdf:resource="http://www.hse.gr/i-stentore/ontology#Infrastrucuture"/>
        <rdfs:range rdf:resource="http://www.hse.gr/i-stentore/ontology#NonEnergyService"/>
        <rdfs:comment>A relationship between an Infrastructure and the Non-Energy Services that it uses.</rdfs:comment>
        <rdfs:label xml:lang="en">uses</rdfs:label>
    </owl:ObjectProperty>

        <!-- https://saref.etsi.org/core/hasTime -->
    <owl:ObjectProperty rdf:about="https://saref.etsi.org/core/hasTime">
        <rdfs:domain rdf:resource="https://saref.etsi.org/core/Measurement"/>
        <rdfs:range rdf:resource="https://saref.etsi.org/core/Time"/>
        <rdfs:comment xml:lang="en">A relationship to associate time information to an entity</rdfs:comment>
        <rdfs:label xml:lang="en">has time</rdfs:label>
    </owl:ObjectProperty>

        <!-- https://saref.etsi.org/core/isMeasuredIn -->
    <owl:ObjectProperty rdf:about="https://saref.etsi.org/core/isMeasuredIn">
        <rdfs:domain rdf:resource="http://www.hse.gr/i-stentore/ontology#Parameters"/>
        <rdfs:range rdf:resource="https://saref.etsi.org/core/UnitOfMeasure"/>
        <rdfs:comment xml:lang="en">A relationship identifying the Unit of Measure used for a certain
Parameter.</rdfs:comment>
        <rdfs:label xml:lang="en">is measured in</rdfs:label>
    </owl:ObjectProperty>

        <!-- https://saref.etsi.org/core/offers -->
    <owl:ObjectProperty rdf:about="https://saref.etsi.org/core/offers">
        <rdfs:domain rdf:resource="http://www.hse.gr/i-stentore/ontology#Infrastrucuture"/>
        <rdfs:range rdf:resource="http://www.hse.gr/i-stentore/ontology#Flexibility%2FBalancing%2FAncillaryService"/>
        <rdfs:comment xml:lang="en">A relationship between an Infrastructure and the Services that it offers.</rdfs:comment>
        <rdfs:label xml:lang="en">offers</rdfs:label>
    </owl:ObjectProperty>

        <!--
    ///////////////////////////////////////////////////////////////////////////////////////
        //
        // Data properties
        //
    ///////////////////////////////////////////////////////////////////////////////////////
        -->

        <!-- https://saref.etsi.org/core/hasValue -->
    <owl:DatatypeProperty rdf:about="https://saref.etsi.org/core/hasValue">
        <rdfs:domain rdf:resource="https://saref.etsi.org/core/Measurement"/>
        <rdfs:comment xml:lang="en">A relationship defining the value of a certain property, e.g., energy or power. Note
that, even if numeric values are expected to enable reasoning, measurement values could use other datatypes.</rdfs:comment>
        <rdfs:label xml:lang="en">has value</rdfs:label>
    </owl:DatatypeProperty>

        <!--
    ///////////////////////////////////////////////////////////////////////////////////////
        //
        // Classes
        //
    ///////////////////////////////////////////////////////////////////////////////////////
        -->

        <!-- http://openenergy-platform.org/ontology/oeo/OEO_00000146 -->
        <owl:Class rdf:about="http://openenergy-platform.org/ontology/oeo/OEO_00000146">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#OtherAssets"/>
        <obo:IAO_0000115 xml:lang="en">An electric vehicle (abbreviated as EV) is a vehicle that uses one or more electric
traction motors.</obo:IAO_0000115>
```


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```
        <rdfs:label xml:lang="en">electric vehicle</rdfs:label>
    </owl:Class>

        <!-- http://openenergy-platform.org/ontology/oeo/OEO_00000248 -->
        <owl:Class rdf:about="http://openenergy-platform.org/ontology/oeo/OEO_00000248">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#EnergyStorage"/>
        <obo:IAO_0000115 xml:lang="en">A lithium-ion battery is a battery that is rechargeable and in which lithium ions
move from the negative electrode to the positive electrode during discharge, and back when charging. Li-ion batteries use an
intercalated lithium compound as one electrode material.</obo:IAO_0000115>
        <rdfs:label xml:lang="en">lithium-ion battery</rdfs:label>
    </owl:Class>

        <!-- http://openenergy-platform.org/ontology/oeo/OEO_00000324 -->
        <owl:Class rdf:about="http://openenergy-platform.org/ontology/oeo/OEO_00000324">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#PowerProduction"/>
        <obo:IAO_0000115 xml:lang="en">A photovoltaic power plant is a solar power plant that has PV panels as
parts.</obo:IAO_0000115>
        <rdfs:label xml:lang="en">photovoltaic power plant</rdfs:label>
    </owl:Class>

        <!-- http://openenergy-platform.org/ontology/oeo/OEO_00000447 -->
        <owl:Class rdf:about="http://openenergy-platform.org/ontology/oeo/OEO_00000447">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#PowerProduction"/>
        <obo:IAO_0000115 xml:lang="en">A wind farm is a power plant that has wind energy converting units as
parts.</obo:IAO_0000115>
        <rdfs:label xml:lang="en">wind farm</rdfs:label>
    </owl:Class>

        <!-- http://openenergy-platform.org/ontology/oeo/OEO_00010086 -->
        <owl:Class rdf:about="http://openenergy-platform.org/ontology/oeo/OEO_00010086">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#PowerProduction"/>
        <obo:IAO_0000115>A hydro power plant is a power plant having an aggregate of hydro power generating units as its
power generating unit parts.</obo:IAO_0000115>
        <rdfs:label xml:lang="en">hydro power plant</rdfs:label>
    </owl:Class>

        <!-- http://openenergy-platform.org/ontology/oeo/OEO_00010157 -->
        <owl:Class rdf:about="http://openenergy-platform.org/ontology/oeo/OEO_00010157">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/Measurement"/>
        <obo:IAO_0000115>A power value is a quantity value that has a power unit as unit.</obo:IAO_0000115>
        <rdfs:label xml:lang="en">power value</rdfs:label>
    </owl:Class>

        <!-- http://openenergy-platform.org/ontology/oeo/OEO_00020117 -->
        <owl:Class rdf:about="http://openenergy-platform.org/ontology/oeo/OEO_00020117">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/Measurement"/>
        <obo:IAO_0000115>Electricity price is the monetary price per energy unit of electricity.</obo:IAO_0000115>
        <rdfs:label xml:lang="en">electricity price</rdfs:label>
    </owl:Class>

        <!-- http://openenergy-platform.org/ontology/oeo/OEO_00020204 -->
        <owl:Class rdf:about="http://openenergy-platform.org/ontology/oeo/OEO_00020204">
        <rdfs:subClassOf rdf:resource="http://openenergy-platform.org/ontology/oeo/OEO_00050019"/>
        <obo:IAO_0000115>An electrical energy amount value is an energy amount value that measures a quantity of
electrical energy.</obo:IAO_0000115>
        <rdfs:label xml:lang="en">electrical energy amount value</rdfs:label>
    </owl:Class>

        <!-- http://openenergy-platform.org/ontology/oeo/OEO_00020369 -->
        <owl:Class rdf:about="http://openenergy-platform.org/ontology/oeo/OEO_00020369">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#EnergyStorage"/>
        <obo:IAO_0000115>A thermal energy storage technology is an energy storage technology that describes how to
combine thermal energy storage objects and thermal energy in charging and decharging processes.</obo:IAO_0000115>
        <rdfs:label xml:lang="en">thermal energy storage technology</rdfs:label>
    </owl:Class>

        <!-- http://openenergy-platform.org/ontology/oeo/OEO_00050019 -->
        <owl:Class rdf:about="http://openenergy-platform.org/ontology/oeo/OEO_00050019">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/Measurement"/>
        <obo:IAO_0000115 xml:lang="en">An energy amount value is a quantity value that has an energy unit as
unit.</obo:IAO_0000115>
```

```
        <rdfs:label xml:lang="en">energy amount value</rdfs:label>
    </owl:Class>

        <!-- http://openenergy-platform.org/ontology/oeo/OEO_00140050 -->
        <owl:Class rdf:about="http://openenergy-platform.org/ontology/oeo/OEO_00140050">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/Measurement"/>
        <obo:IAO_0000115>An efficiency value is a quantity value stating the ratio between a process&apos;s inputs and the
outputs that are used.</obo:IAO_0000115>
        <rdfs:label xml:lang="en">efficiency value</rdfs:label>
    </owl:Class>

        <!-- http://openenergy-platform.org/ontology/oeo/OEO_00320040 -->
        <owl:Class rdf:about="http://openenergy-platform.org/ontology/oeo/OEO_00320040">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#PowerProduction"/>
        <obo:IAO_0000115 xml:lang="en">A vehicle charging station is an electricity grid component that transfers electrical
energy into the traction battery of a battery electric vehicle.</obo:IAO_0000115>
        <rdfs:label xml:lang="en">vehicle charging station</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontologyDevice -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontologyDevice">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/Device"/>
        <rdfs:comment xml:lang="en">A specialization of a saref:Device that exposes a power profile with power sequences
to the CEM (note that a s4ee:Device can also be called &apos;power sequence server&apos;).</rdfs:comment>
        <rdfs:label xml:lang="en">Device</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#ACChargerConsumptionForecasting -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#ACChargerConsumptionForecasting">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#NonEnergyService"/>
        <rdfs:comment>The forecasting of an AC Charger consumption.</rdfs:comment>
        <rdfs:label xml:lang="en">AC Charger Consumption Forecasting</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#ACRatedVoltage -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#ACRatedVoltage">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#Voltage"/>
        <rdfs:label xml:lang="en">AC Rated Voltage</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#ACVoltageLevel -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#ACVoltageLevel">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#Voltage"/>
        <rdfs:label xml:lang="en">AC Voltage Level</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#Asset -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#Asset">
        <rdfs:comment>An Asset typically refers to physical or tangible resources that are utilized in the generation,
transmission, distribution, or storage of energy.</rdfs:comment>
        <rdfs:label xml:lang="en">Asset</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#AutomaticFrequencyRestorationReserve -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#AutomaticFrequencyRestorationReserve">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#Flexibility%2FBalancing%2FAncillaryService"/>
        <rdfs:comment>The automatic Frequency Restoration Reserve, also known as secondary reserve, is a reserve in the
power grid that helps to keep the grid frequency stable.</rdfs:comment>
        <rdfs:label xml:lang="en">Automatic Frequency Restoration Reserve (aFRR)</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#BatterySwappChargerConsumptionForecasting -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#BatterySwappChargerConsumptionForecasting">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#NonEnergyService"/>
        <rdfs:comment>The forecasting of an Battery Swappable Charger consumption.</rdfs:comment>
        <rdfs:label xml:lang="en">Battery Swapp Charger Consumption Forecasting</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#CalendarDegradationCost -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#CalendarDegradationCost">
        <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Cost"/>
```

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        <rdfs:label xml:lang="en">Calendar Degradation Cost</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#ChargingEfficiency -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#ChargingEfficiency">
        <rdfs:subClassOf rdf:resource="http://openenergy-platform.org/ontology/oeo/OEO_00140050"/>
        <rdfs:label xml:lang="en">Charging Efficiency</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#ChargingPower -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#ChargingPower">
        <rdfs:subClassOf rdf:resource="http://openenergy-platform.org/ontology/oeo/OEO_00010157"/>
        <rdfs:label xml:lang="en">Charging Power</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#CongestionManagement -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#CongestionManagement">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#Flexibility%2FBalancing%2FAncillaryService"/>
        <rdfs:comment>Congestion management is a strategy aimed at steering either the supply or demand of energy during
peak periods, when the grid&apos;s capacity reaches its limit.</rdfs:comment>
        <rdfs:label>Congestion Management</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#ConverterRating -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#ConverterRating">
        <rdfs:subClassOf rdf:resource="http://openenergy-platform.org/ontology/oeo/OEO_00010157"/>
        <rdfs:label xml:lang="en">Converter Rating</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#Coordinates -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#Coordinates">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#Parameters"/>
        <rdfs:comment>The Coordinates are the pair of numbers and/or letters that show the exact position of a point on a
map or graph.</rdfs:comment>
        <rdfs:label xml:lang="en">Coordinates</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#Current -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#Current">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/Measurement"/>
        <rdfs:comment>Current is a flow of electrical charge carriers, usually electrons or electron-deficient
atoms.</rdfs:comment>
        <rdfs:label xml:lang="en">Current</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#CurrentUnit -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#CurrentUnit">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/UnitOfMeasure"/>
        <rdfs:comment>The unit of measure for current.</rdfs:comment>
        <rdfs:label xml:lang="en">Current Unit</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#Cut-InSpeed -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#Cut-InSpeed">
        <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Speed"/>
        <rdfs:label xml:lang="en">Cut-In Speed</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#Cut-OutSpeed -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#Cut-OutSpeed">
        <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Speed"/>
        <rdfs:label xml:lang="en">Cut-Out Speed</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#CycleDegradationCost -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#CycleDegradationCost">
        <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Cost"/>
        <rdfs:label xml:lang="en">Cycle Degradation Cost</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#DCRatedVoltage -->
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        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#DCRatedVoltage">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#Voltage"/>
        <rdfs:label xml:lang="en">DC Rated Voltage</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#DCVoltage -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#DCVoltage">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#Voltage"/>
        <rdfs:label xml:lang="en">DC Output Voltage</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#DSOServices -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#DSOServices">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#Flexibility%2FBalancing%2FAncillaryService"/>
        <rdfs:comment>Flexibility/Balancing/Ancillary services offered to the DSO.</rdfs:comment>
        <rdfs:label xml:lang="en">DSO Services</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#DegradationCost -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#DegradationCost">
        <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Cost"/>
        <rdfs:label xml:lang="en">Degradation Cost</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#DemandOfHydrogen -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#DemandOfHydrogen">
        <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Mass"/>
        <rdfs:label xml:lang="en">Demand of Hydrogen</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#DischargingEfficiency -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#DischargingEfficiency">
        <rdfs:subClassOf rdf:resource="http://openenergy-platform.org/ontology/oeo/OEO_00140050"/>
        <rdfs:label xml:lang="en">Discharging Efficiency</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#DischargingPower -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#DischargingPower">
        <rdfs:subClassOf rdf:resource="http://openenergy-platform.org/ontology/oeo/OEO_00010157"/>
        <rdfs:label xml:lang="en">Discharging Power</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#DownstreamReservoirCapacity -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#DownstreamReservoirCapacity">
        <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Volume"/>
        <rdfs:label xml:lang="en">Downstream Reservoir Capacity</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#DownwardReservePrice -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#DownwardReservePrice">
        <rdfs:subClassOf rdf:resource="http://openenergy-platform.org/ontology/oeo/OEO_00020117"/>
        <rdfs:label xml:lang="en">Downward Reserve Price</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#Electrolyzer -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#Electrolyzer">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#OtherAssets"/>
        <rdfs:comment>An electrolyzer is a system that uses the electrolysis of water to separate hydrogen and oxygen
atoms.</rdfs:comment>
        <rdfs:label xml:lang="en">Electrolyzer</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#EnergyArbitrage -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#EnergyArbitrage">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#Flexibility%2FBalancing%2FAncillaryService"/>
        <rdfs:comment>Energy arbitrage is a technique where power is bought during off-peak hours (when grid prices are
cheapest). It is then stored and used during peak hours (when grid electricity prices are highest).</rdfs:comment>
        <rdfs:label xml:lang="en">Energy Arbitrage</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#EnergyCapacity -->
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    <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#EnergyCapacity">
        <rdfs:subClassOf rdf:resource="http://openenergy-platform.org/ontology/oeo/OEO_00020204"/>
        <rdfs:label xml:lang="en">Energy Capacity</rdfs:label>
    </owl:Class>

    <!-- http://www.hse.gr/i-stentore/ontology#EnergyCommunity -->
    <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#EnergyCommunity">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#Flexibility%2FBalancing%2FAncillaryService"/>
        <rdfs:comment>Flexibility/Balancing/Ancillary services offered to an Energy Community (Demand Response, Energy
Storage etc.).</rdfs:comment>
        <rdfs:label xml:lang="en">Energy Community Services</rdfs:label>
    </owl:Class>

    <!-- http://www.hse.gr/i-stentore/ontology#EnergyStorage -->
    <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#EnergyStorage">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontologyDevice"/>
        <rdfs:comment>The Assets related to Energy Storage.</rdfs:comment>
        <rdfs:label xml:lang="en">Energy Storage</rdfs:label>
    </owl:Class>

    <!-- http://www.hse.gr/i-stentore/ontology#EnergyYield -->
    <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#EnergyYield">
        <rdfs:subClassOf rdf:resource="http://openenergy-platform.org/ontology/oeo/OEO_00020204"/>
        <rdfs:label xml:lang="en">Energy Yield</rdfs:label>
    </owl:Class>

    <!-- http://www.hse.gr/i-stentore/ontology#EquivalentHour -->
    <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#EquivalentHour">
        <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Duration"/>
        <rdfs:label xml:lang="en">Equivalent Hour</rdfs:label>
    </owl:Class>

    <!-- http://www.hse.gr/i-stentore/ontology#FastFrequencyResponse -->
    <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#FastFrequencyResponse">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#Flexibility%2FBalancing%2FAncillaryService"/>
        <rdfs:comment>Fast Frequency Response refers to the delivery of rapid active power increase or decrease by
generation or load in a timeframe of 2 seconds or less, to correct a supply – demand imbalance and assist in managing
power system frequency.</rdfs:comment>
        <rdfs:label xml:lang="en">Fast Frequency Response (FFR)</rdfs:label>
    </owl:Class>

    <!-- http://www.hse.gr/i-stentore/ontology#FrequencyContainmentReserve -->
    <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#FrequencyContainmentReserve">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#Flexibility%2FBalancing%2FAncillaryService"/>
        <rdfs:comment>Frequency Containment Reserve, also known as primary control reserve, is the first response to
frequency disturbances. When frequency deviations occur, e.g. in consequence of a power plant outage, the Frequency
Containment Reserve intervenes automatically within seconds in the entire synchronous area to restore the balance between
supply and demand.</rdfs:comment>
        <rdfs:label xml:lang="en">Frequency Containment Reserve (FCR)</rdfs:label>
    </owl:Class>

    <!-- http://www.hse.gr/i-stentore/ontology#Furnace -->
    <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#Furnace">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#OtherAssets"/>
        <rdfs:comment>A furnace is an enclosed structure in which material can be heated to very high temperatures, e.g.
for smelting metals.</rdfs:comment>
        <rdfs:label>Furnace</rdfs:label>
    </owl:Class>

    <!-- http://www.hse.gr/i-stentore/ontology#HeadMax -->
    <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#HeadMax">
        <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Length"/>
        <rdfs:label xml:lang="en">Head Max</rdfs:label>
    </owl:Class>

    <!-- http://www.hse.gr/i-stentore/ontology#HeadMin -->
    <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#HeadMin">
        <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Length"/>
        <rdfs:label xml:lang="en">Head Min</rdfs:label>
    </owl:Class>
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    <!-- http://www.hse.gr/i-stentore/ontology#HighPressureStorageTankPressure -->
    <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#HighPressureStorageTankPressure">
        <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Pressure"/>
        <rdfs:label xml:lang="en">High Pressure Storage Tank Pressure</rdfs:label>
    </owl:Class>

    <!-- http://www.hse.gr/i-stentore/ontology#HighPressureStorageTankVolume -->
    <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#HighPressureStorageTankVolume">
        <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Volume"/>
        <rdfs:label xml:lang="en">High Pressure Storage Tank Volume</rdfs:label>
    </owl:Class>

    <!-- http://www.hse.gr/i-stentore/ontology#HydroForecasting -->
    <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#HydroForecasting">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#NonEnergyService"/>
        <rdfs:comment>The forecasting of a hydroelectric power plant production.</rdfs:comment>
        <rdfs:label xml:lang="en">Hydro Forecasting</rdfs:label>
    </owl:Class>

    <!-- http://www.hse.gr/i-stentore/ontology#HydrogenStorage -->
    <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#HydrogenStorage">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#EnergyStorage"/>
        <rdfs:comment>A Hydrogen Energy Storage System (HESS) is a storage device in which it can be charged by
injecting the hydrogen produced by redundant electricity generations.</rdfs:comment>
        <rdfs:label xml:lang="en">Hydrogen Energy Storage System (HESS)</rdfs:label>
    </owl:Class>

    <!-- http://www.hse.gr/i-stentore/ontology#Inclination -->
    <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#Inclination">
        <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Angle"/>
        <rdfs:label xml:lang="en">Inclination</rdfs:label>
    </owl:Class>

    <!-- http://www.hse.gr/i-stentore/ontology#Inflow -->
    <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#Inflow">
        <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/VolumetricFlowRate"/>
        <rdfs:label xml:lang="en">Inflow</rdfs:label>
    </owl:Class>

    <!-- http://www.hse.gr/i-stentore/ontology#InflowLowerLimit -->
    <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#InflowLowerLimit">
        <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Speed"/>
        <rdfs:label xml:lang="en">Inflow Lower Limit</rdfs:label>
    </owl:Class>

    <!-- http://www.hse.gr/i-stentore/ontology#InflowUpperLimit -->
    <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#InflowUpperLimit">
        <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Speed"/>
        <rdfs:label xml:lang="en">Inflow Upper Limit</rdfs:label>
    </owl:Class>

    <!-- http://www.hse.gr/i-stentore/ontology#Infrastrucuture -->
    <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#Infrastrucuture">
        <rdfs:comment>Infrastructure refers to the physical assets, facilities, and systems that are essential for the generation,
transmission, distribution, storage, and consumption of energy resources. These infrastructure components play a crucial role
in facilitating the production, delivery, and utilization of energy in various forms, such as electricity, natural gas, oil, and
renewable energy sources.</rdfs:comment>
        <rdfs:label xml:lang="en">Infrastructure</rdfs:label>
    </owl:Class>

    <!-- http://www.hse.gr/i-stentore/ontology#InitialHydrogenStorage -->
    <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#InitialHydrogenStorage">
        <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Mass"/>
        <rdfs:label xml:lang="en">Initial Hydrogen Storage</rdfs:label>
    </owl:Class>

    <!-- http://www.hse.gr/i-stentore/ontology#InitialSoC -->
    <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#InitialSoC">
        <rdfs:subClassOf rdf:resource="http://openenergy-platform.org/ontology/oeo/OEO_00020204"/>
        <rdfs:label xml:lang="en">Initial SoC</rdfs:label>
    </owl:Class>
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        <!-- http://www.hse.gr/i-stentore/ontology#InstantCurrent -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#InstantCurrent">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#Current"/>
        <rdfs:label xml:lang="en">Instant Current</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#InstantVoltage -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#InstantVoltage">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#Voltage"/>
        <rdfs:label xml:lang="en">Instant Voltage</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#InstantaneousCombinedPower -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#InstantaneousCombinedPower">
        <rdfs:subClassOf rdf:resource="http://openenergy-platform.org/ontology/oeo/OEO_00010157"/>
        <rdfs:label xml:lang="en">Instantaneous Combined Power</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#InstantaneousHydrogenMassInTheTank -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#InstantaneousHydrogenMassInTheTank">
        <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Mass"/>
        <rdfs:label xml:lang="en">Instantaneous Hydrogen Mass in the Tank</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#InstantaneousProduction -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#InstantaneousProduction">
        <rdfs:subClassOf rdf:resource="http://openenergy-platform.org/ontology/oeo/OEO_00020204"/>
        <rdfs:label xml:lang="en">Instantaneous Production</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#InverterEfficiency -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#InverterEfficiency">
        <rdfs:subClassOf rdf:resource="http://openenergy-platform.org/ontology/oeo/OEO_00140050"/>
        <rdfs:label xml:lang="en">Inverter Efficiency</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#Lifetime -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#Lifetime">
        <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Time"/>
        <rdfs:label xml:lang="en">Lifetime</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#LoadForecasting -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#LoadForecasting">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#NonEnergyService"/>
        <rdfs:comment>The forecasting of the electric load.</rdfs:comment>
        <rdfs:label xml:lang="en">Load Forecasting</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#Location -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#Location">
        <rdfs:comment>The Location refers to the physical geographic site or area where the infrastructure is situated or
deployed. The location of energy sector infrastructure is a critical consideration that can have significant implications for its
design, construction, operation, and maintenance, as well as its accessibility, environmental impact, and relationship to other
infrastructure components.</rdfs:comment>
        <rdfs:label>Location</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#LocationLatitude -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#LocationLatitude">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#Coordinates"/>
        <rdfs:comment>The Location Latitude of an Asset.</rdfs:comment>
        <rdfs:label xml:lang="en">Location Latitude</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#LocationLongitude -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#LocationLongitude">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#Coordinates"/>
        <rdfs:comment>The Location Longitude of an Asset.</rdfs:comment>
        <rdfs:label xml:lang="en">Location Longitude</rdfs:label>
```

```
</owl:Class>

    <!-- http://www.hse.gr/i-stentore/ontology#LowPressureStorageTankPressure -->
    <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#LowPressureStorageTankPressure">
    <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Pressure"/>
    <rdfs:label xml:lang="en">Low Pressure Storage Tank Pressure</rdfs:label>
</owl:Class>

    <!-- http://www.hse.gr/i-stentore/ontology#LowPressureStorageTankVolume -->
    <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#LowPressureStorageTankVolume">
    <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Volume"/>
    <rdfs:label xml:lang="en">Low Pressure Storage Tank Volume</rdfs:label>
</owl:Class>

    <!-- http://www.hse.gr/i-stentore/ontology#ManualFrequencyRestorationReserve -->
    <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#ManualFrequencyRestorationReserve">
    <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#Flexibility%2FBalancing%2FAncillaryService"/>
    <rdfs:comment>The Manual Frequency Restoration Reserve (also R3 or tertiary reserve) helps to restore the required
grid frequency of 50 Hz (or in some countries of 60 Hz). This tertiary control reserve intervenes when there are longer
lasting deviations in the power grid that cannot be resolved solely by the other upstream balancing services (FCR or
aFRR).</rdfs:comment>
    <rdfs:label xml:lang="en">Manual Frequency Restoration Reserve (mFRR)</rdfs:label>
</owl:Class>

    <!-- http://www.hse.gr/i-stentore/ontology#MaxChargeRate -->
    <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#MaxChargeRate">
    <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#Current"/>
    <rdfs:label xml:lang="en">Max Charge Rate</rdfs:label>
</owl:Class>

    <!-- http://www.hse.gr/i-stentore/ontology#MaxDischargeRate -->
    <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#MaxDischargeRate">
    <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#Current"/>
    <rdfs:label xml:lang="en">Max Discharge Rate</rdfs:label>
</owl:Class>

    <!-- http://www.hse.gr/i-stentore/ontology#MaximumSoC -->
    <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#MaximumSoC">
    <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Percentage"/>
    <rdfs:label xml:lang="en">Maximum SoC</rdfs:label>
</owl:Class>

    <!-- http://www.hse.gr/i-stentore/ontology#MaximumTankLevel -->
    <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#MaximumTankLevel">
    <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Mass"/>
    <rdfs:label xml:lang="en">Maximum Tank Level</rdfs:label>
</owl:Class>

    <!-- http://www.hse.gr/i-stentore/ontology#MinimumSoC -->
    <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#MinimumSoC">
    <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Percentage"/>
    <rdfs:label xml:lang="en">Minimum SoC</rdfs:label>
</owl:Class>

    <!-- http://www.hse.gr/i-stentore/ontology#NominalPower -->
    <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#NominalPower">
    <rdfs:subClassOf rdf:resource="http://openenergy-platform.org/ontology/oeo/OEO_00010157"/>
    <rdfs:label xml:lang="en">Nominal Power</rdfs:label>
</owl:Class>

    <!-- http://www.hse.gr/i-stentore/ontology#NonEnergyService -->
    <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#NonEnergyService">
    <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/Service"/>
    <rdfs:comment>The Non Energy Services that are needed in an Infrastructure.</rdfs:comment>
    <rdfs:label xml:lang="en">Non Energy Service</rdfs:label>
</owl:Class>

    <!-- http://www.hse.gr/i-stentore/ontology#NumberOfGenerators -->
    <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#NumberOfGenerators">
    <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#Parameters"/>
    <rdfs:comment>The number of generators of a power plant.</rdfs:comment>
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      <rdfs:label xml:lang="en">Number of Generators</rdfs:label>
</owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#NumberOfPumps -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#NumberOfPumps">
      <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#Parameters"/>
      <rdfs:comment>The number of pumps of a hydroelectric power plant.</rdfs:comment>
      <rdfs:label xml:lang="en">Number of Pumps</rdfs:label>
</owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#Orientation -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#Orientation">
      <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Angle"/>
      <rdfs:label xml:lang="en">Orientation</rdfs:label>
</owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#OtherAssets -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#OtherAssets">
      <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontologyDevice"/>
      <rdfs:comment>The Assets from different categories.</rdfs:comment>
      <rdfs:label xml:lang="en">Other Assets</rdfs:label>
</owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#OutputActivePower -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#OutputActivePower">
      <rdfs:subClassOf rdf:resource="http://openenergy-platform.org/ontology/oeo/OEO_00010157"/>
      <rdfs:label xml:lang="en">Output Active Power</rdfs:label>
</owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#OutputReactivePower -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#OutputReactivePower">
      <rdfs:subClassOf rdf:resource="http://openenergy-platform.org/ontology/oeo/OEO_00010157"/>
      <rdfs:label xml:lang="en">Output Reactive Power</rdfs:label>
</owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#OverheatedGlassMelt -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#OverheatedGlassMelt">
      <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Temperature"/>
      <rdfs:label xml:lang="en">Overheated Glass Melt</rdfs:label>
</owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#PVForecasting -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#PVForecasting">
      <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#NonEnergyService"/>
      <rdfs:comment>The forecasting of a photovoltaic power plant production.</rdfs:comment>
      <rdfs:label xml:lang="en">PV Forecasting</rdfs:label>
</owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#Parameter1CalendarDegradation -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#Parameter1CalendarDegradation">
      <rdfs:subClassOf rdf:resource="http://openenergy-platform.org/ontology/oeo/OEO_00020204"/>
      <rdfs:label xml:lang="en">Parameter 1 Calendar Degradation</rdfs:label>
</owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#Parameter1CycleDegradation -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#Parameter1CycleDegradation">
      <rdfs:subClassOf rdf:resource="http://openenergy-platform.org/ontology/oeo/OEO_00020204"/>
      <rdfs:label xml:lang="en">Parameter 1 Cycle Degradation</rdfs:label>
</owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#Parameter2CalendarDegradation -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#Parameter2CalendarDegradation">
      <rdfs:subClassOf rdf:resource="http://openenergy-platform.org/ontology/oeo/OEO_00020204"/>
      <rdfs:label>Parameter 2 Calendar Degradation</rdfs:label>
</owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#Parameter2CycleDegradation -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#Parameter2CycleDegradation">
      <rdfs:subClassOf rdf:resource="http://openenergy-platform.org/ontology/oeo/OEO_00020204"/>
      <rdfs:label xml:lang="en">Parameter 2 Cycle Degradation</rdfs:label>
</owl:Class>
```


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```xml
        <!-- http://www.hse.gr/i-stentore/ontology#Parameters -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#Parameters">
        <rdfs:subClassOf rdf:resource="http://www.w3.org/2002/07/owl#Thing"/>
        <rdfs:comment>A Parameter typically refers to a measurable characteristic or attribute that describes the performance, condition, or functionality of the asset.</rdfs:comment>
        <rdfs:label xml:lang="en">Parameter</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#PerformanceRatio -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#PerformanceRatio">
        <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Percentage"/>
        <rdfs:label xml:lang="en">Performance Ratio</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#PowerFactor -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#PowerFactor">
        <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Percentage"/>
        <rdfs:label xml:lang="en">Power Factor</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#PowerProduction -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#PowerProduction">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontologyDevice"/>
        <rdfs:comment>The Assets related to Power Production.</rdfs:comment>
        <rdfs:label xml:lang="en">Power Production</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#PowerSmoothing -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#PowerSmoothing">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#Flexibility%2FBalancing%2FAncillaryService"/>
        <rdfs:comment>Power smoothing techniques are employed to mitigate the network problems caused by the variable output power of non-dispatchable renewable energy sources (RESs). Keystone of these techniques is the use of a battery energy storage system (BESS) acting as an intermediate energy buffer to smooth the RES output power.</rdfs:comment>
        <rdfs:label xml:lang="en">Power Smoothing (PS)</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#PumpingPower -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#PumpingPower">
        <rdfs:subClassOf rdf:resource="http://openenergy-platform.org/ontology/oeo/OEO_00010157"/>
        <rdfs:label xml:lang="en">Pumping Power</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#RatedPower -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#RatedPower">
        <rdfs:subClassOf rdf:resource="http://openenergy-platform.org/ontology/oeo/OEO_00010157"/>
        <rdfs:label xml:lang="en">Rated Power</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#RatedVoltage -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#RatedVoltage">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#Voltage"/>
        <rdfs:label xml:lang="en">Rated Voltage</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#ReferenceSpeed -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#ReferenceSpeed">
        <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Speed"/>
        <rdfs:label xml:lang="en">Reference Speed</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#ReplacementCost -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#ReplacementCost">
        <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Cost"/>
        <rdfs:label xml:lang="en">Replacement Cost</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#ReservePricesForecasting -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#ReservePricesForecasting">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#NonEnergyService"/>
        <rdfs:comment>The forecasting of the Reserve Prices.</rdfs:comment>
        <rdfs:label xml:lang="en">Reserve Prices Forecasting</rdfs:label>
```


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    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#ReservoirCapacity -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#ReservoirCapacity">
        <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Volume"/>
        <rdfs:label xml:lang="en">Reservoir Capacity</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#Reversible -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#Reversible">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#Parameters"/>
        <rdfs:comment>Defines whether a hydro power plant is reversible.</rdfs:comment>
        <rdfs:label xml:lang="en">Reversible</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#SegmentsForDegradationModelApproximation -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#SegmentsForDegradationModelApproximation">
        <rdfs:subClassOf rdf:resource="http://openenergy-platform.org/ontology/oeo/OEO_00020204"/>
        <rdfs:label xml:lang="en">Segments for Degradation Model Approximation</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#SoC -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#SoC">
        <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Percentage"/>
        <rdfs:label xml:lang="en">SoC</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#StandardIrradiance -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#StandardIrradiance">
        <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Irradiance"/>
        <rdfs:label xml:lang="en">Standard Irradiance</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#SunIrradiance -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#SunIrradiance">
        <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Irradiance"/>
        <rdfs:label xml:lang="en">Sun Irradiance</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#SynchronousCondenserFunctionality -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#SynchronousCondenserFunctionality">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#Parameters"/>
        <rdfs:comment>Defines whether a hydro power plant has synchronous condenser functionality.</rdfs:comment>
        <rdfs:label xml:lang="en">Synchronous Condenser Functionality</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#SynchronousInertia -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#SynchronousInertia">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#Flexibility%2FBalancing%2FAncillaryService"/>
        <rdfs:comment>Synchronous inertia supports grid operation by supporting the balancing of supply and demand
during normal operations and by stabilizing the grid as a whole during disruptions.</rdfs:comment>
        <rdfs:label xml:lang="en">Synchronous Inertia</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#ThermalHeatCapacity -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#ThermalHeatCapacity">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/Measurement"/>
        <rdfs:comment>Thermal Heat Capacity is the quantity of heat necessary to produce a unit change of temperature in
a unit mass of a material.</rdfs:comment>
        <rdfs:label xml:lang="en">Thermal Heat Capacity</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#ThermalHeatCapacityUnit -->

        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#ThermalHeatCapacityUnit">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/UnitOfMeasure"/>
        <rdfs:comment>The unit of measure for thermal heat capacity.</rdfs:comment>
        <rdfs:label xml:lang="en">Thermal Heat Capacity Unit</rdfs:label>
    </owl:Class>

        <!-- http://www.hse.gr/i-stentore/ontology#TurbineType -->
        <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#TurbineType">
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        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#Parameters"/>
        <rdfs:comment>The turbine type of a power plant.</rdfs:comment>
        <rdfs:label xml:lang="en">Turbine Type</rdfs:label>
    </owl:Class>

         <!-- http://www.hse.gr/i-stentore/ontology#UnitCommitment -->
         <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#UnitCommitment">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#NonEnergyService"/>
        <rdfs:comment>The forecasting of the Unit Commitment.</rdfs:comment>
        <rdfs:label xml:lang="en">Unit Commitment</rdfs:label>
    </owl:Class>

         <!-- http://www.hse.gr/i-stentore/ontology#UpstreamReservoirCapacity -->
         <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#UpstreamReservoirCapacity">
        <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Volume"/>
        <rdfs:label xml:lang="en">Upstream Reservoir Capacity</rdfs:label>
    </owl:Class>

         <!-- http://www.hse.gr/i-stentore/ontology#UpwardReservePrice -->
         <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#UpwardReservePrice">
        <rdfs:subClassOf rdf:resource="http://openenergy-platform.org/ontology/oeo/OEO_00020117"/>
        <rdfs:label xml:lang="en">Upward Reserve Price</rdfs:label>
    </owl:Class>

         <!-- http://www.hse.gr/i-stentore/ontology#V2GChargerSupplyAndConsumptionForecasting -->
         <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#V2GChargerSupplyAndConsumptionForecasting">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#NonEnergyService"/>
        <rdfs:comment>The forecasting of a V2G Charger supply and consumption.</rdfs:comment>
        <rdfs:label xml:lang="en">V2G Charger Supply and Consumption Forecasting</rdfs:label>
    </owl:Class>

         <!-- http://www.hse.gr/i-stentore/ontology#VanadiumRedoxFlowBattery -->
         <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#VanadiumRedoxFlowBattery">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#EnergyStorage"/>
        <rdfs:comment>A Vanadium Redox Flow Battery is a type of rechargeable flow battery that employs vanadium ions
as charge carriers.</rdfs:comment>
        <rdfs:label xml:lang="en">Vanadium Redox Flow Battery (VRFB)</rdfs:label>
    </owl:Class>

         <!-- http://www.hse.gr/i-stentore/ontology#Voltage -->
         <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#Voltage">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/Measurement"/>
        <rdfs:comment>Voltage, also known as electric pressure, electric tension, or potential difference, is the difference in
electric potential between two points.</rdfs:comment>
        <rdfs:label xml:lang="en">Voltage</rdfs:label>
    </owl:Class>

         <!-- http://www.hse.gr/i-stentore/ontology#VoltageUnit -->
         <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#VoltageUnit">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/UnitOfMeasure"/>
        <rdfs:comment>The unit of measure for voltage.</rdfs:comment>
        <rdfs:label xml:lang="en">Voltage Unit</rdfs:label>
    </owl:Class>

         <!-- http://www.hse.gr/i-stentore/ontology#WeatherForecasting -->
         <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#WeatherForecasting">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#NonEnergyService"/>
        <rdfs:comment>The forecasting of the weather conditions.</rdfs:comment>
        <rdfs:label xml:lang="en">Weather Forecasting</rdfs:label>
    </owl:Class>

         <!-- http://www.hse.gr/i-stentore/ontology#WholesaleMarketPrice -->
         <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#WholesaleMarketPrice">
        <rdfs:subClassOf rdf:resource="http://openenergy-platform.org/ontology/oeo/OEO_00020117"/>
        <rdfs:label xml:lang="en">Wholesale Market Price</rdfs:label>
    </owl:Class>

         <!-- http://www.hse.gr/i-stentore/ontology#WholesaleMarketPriceForecasting -->
         <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#WholesaleMarketPriceForecasting">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#NonEnergyService"/>
        <rdfs:comment>The forecasting of the Wholesale Market Prices.</rdfs:comment>
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        <rdfs:label xml:lang="en">Wholesale Market Price Forecasting</rdfs:label>
    </owl:Class>

         <!-- http://www.hse.gr/i-stentore/ontology#WindForecasting -->
         <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#WindForecasting">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#NonEnergyService"/>
        <rdfs:comment>The forecasting of a wind turbine power plant production.</rdfs:comment>
        <rdfs:label xml:lang="en">Wind Forecasting</rdfs:label>
    </owl:Class>

         <!-- http://www.hse.gr/i-stentore/ontology#WindSpeed -->
         <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#WindSpeed">
        <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Speed"/>
        <rdfs:label xml:lang="en">Wind Speed</rdfs:label>
    </owl:Class>


         <!-- http://www.hse.gr/i-stentore/ontology#BatteryOutput%28AC%2FDC%29 -->
         <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#BatteryOutput%28AC%2FDC%29">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#Voltage"/>
        <rdfs:label xml:lang="en">Battery Output (AC/DC)</rdfs:label>
    </owl:Class>

         <!-- http://www.hse.gr/i-stentore/ontology#Charging%2FDischarging -->
         <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#Charging%2FDischarging">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#Parameters"/>
        <rdfs:comment>Defines whether a battery storage asset is charging or discharging.</rdfs:comment>
        <rdfs:label xml:lang="en">Charging/Discharging</rdfs:label>
    </owl:Class>

         <!-- http://www.hse.gr/i-stentore/ontology#Flexibility%2FBalancing%2FAncillaryService -->
         <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#Flexibility%2FBalancing%2FAncillaryService">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/Service"/>
        <rdfs:comment>Ancillary services refer to functions that help grid operators maintain a reliable electricity
system.</rdfs:comment>
        <rdfs:comment>Balancing services are the mechanisms in place to ensure the grid comfortably operates at the
correct frequency.</rdfs:comment>
        <rdfs:comment>Flexibility services are a range of existing and developing solutions that electricity system users can
provide to help balance demand and supply in the electricity network and support its efficient use.</rdfs:comment>
        <rdfs:comment>The Flexibility/Balancing/Ancillary Services offered by an Infrastructure.</rdfs:comment>
        <rdfs:label xml:lang="en">Flexibility/Balancing/Ancillary Service</rdfs:label>
    </owl:Class>

         <!-- http://www.hse.gr/i-stentore/ontology#RenewableEnergyCommunityUsers%27Consumption -->
         <owl:Class rdf:about="http://www.hse.gr/i-stentore/ontology#RenewableEnergyCommunityUsers%27Consumption">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#NonEnergyService"/>
        <rdfs:comment>The forecasting of the Renewable Energy Community users&apos; consumption.</rdfs:comment>
        <rdfs:label xml:lang="en">Renewable Energy Community Users&apos; Consumption</rdfs:label>
    </owl:Class>

         <!-- http://www.ontology-of-units-of-measure.org/resource/om-2/Angle -->
         <owl:Class rdf:about="http://www.ontology-of-units-of-measure.org/resource/om-2/Angle">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/Measurement"/>
        <rdfs:comment xml:lang="en">Angle is the ratio between an arc and its radius.</rdfs:comment>
        <rdfs:label xml:lang="en">angle</rdfs:label>
    </owl:Class>

         <!-- http://www.ontology-of-units-of-measure.org/resource/om-2/AngleUnit -->
         <owl:Class rdf:about="http://www.ontology-of-units-of-measure.org/resource/om-2/AngleUnit">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/UnitOfMeasure"/>
        <rdfs:comment>The unit of measure for angle.</rdfs:comment>
        <rdfs:label xml:lang="en">angle unit</rdfs:label>
    </owl:Class>

         <!-- http://www.ontology-of-units-of-measure.org/resource/om-2/CelsiusTemperatureUnit -->
         <owl:Class rdf:about="http://www.ontology-of-units-of-measure.org/resource/om-2/CelsiusTemperatureUnit">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/TemperatureUnit"/>
        <rdfs:comment>The unit of measure for temperature in degrees Celsius.</rdfs:comment>
        <rdfs:label xml:lang="en">Celsius temperature unit</rdfs:label>
    </owl:Class>
```


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```
        <!-- http://www.ontology-of-units-of-measure.org/resource/om-2/Cost -->
        <owl:Class rdf:about="http://www.ontology-of-units-of-measure.org/resource/om-2/Cost">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/Measurement"/>
        <rdfs:comment>Cost refers to the monetary value of resources, goods, or services exchanged in a transaction or
utilized to produce or acquire something.</rdfs:comment>
        <rdfs:label xml:lang="en">cost</rdfs:label>
    </owl:Class>

        <!-- http://www.ontology-of-units-of-measure.org/resource/om-2/Date -->
        <owl:Class rdf:about="http://www.ontology-of-units-of-measure.org/resource/om-2/Date">
        <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Time"/>
    </owl:Class>

        <!-- http://www.ontology-of-units-of-measure.org/resource/om-2/Duration -->
        <owl:Class rdf:about="http://www.ontology-of-units-of-measure.org/resource/om-2/Duration">
        <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Time"/>
    </owl:Class>

        <!-- http://www.ontology-of-units-of-measure.org/resource/om-2/ElectricChargeUnit -->
        <owl:Class rdf:about="http://www.ontology-of-units-of-measure.org/resource/om-2/ElectricChargeUnit">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/UnitOfMeasure"/>
        <rdfs:comment>The unit of measure for electric charge.</rdfs:comment>
        <rdfs:label xml:lang="en">electric charge unit</rdfs:label>
    </owl:Class>

        <!-- http://www.ontology-of-units-of-measure.org/resource/om-2/ForceUnit -->
        <owl:Class rdf:about="http://www.ontology-of-units-of-measure.org/resource/om-2/ForceUnit">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/UnitOfMeasure"/>
        <rdfs:comment>The unit of measure for force.</rdfs:comment>
        <rdfs:label xml:lang="en">force unit</rdfs:label>
    </owl:Class>

        <!-- http://www.ontology-of-units-of-measure.org/resource/om-2/Irradiance -->
        <owl:Class rdf:about="http://www.ontology-of-units-of-measure.org/resource/om-2/Irradiance">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/Measurement"/>
        <rdfs:comment xml:lang="en">Irradiance is the power of electromagnetic radiation at a surface per unit
area.</rdfs:comment>
        <rdfs:label xml:lang="en">irradiance</rdfs:label>
    </owl:Class>

        <!-- http://www.ontology-of-units-of-measure.org/resource/om-2/Length -->
        <owl:Class rdf:about="http://www.ontology-of-units-of-measure.org/resource/om-2/Length">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/Measurement"/>
        <rdfs:comment xml:lang="en">Length is the amount of space between two geographical points along a curve. It is a
base quantity in the International System of Units and other systems of units. Length is speed times time. The metre, a base
unit of length in the International System of Units, is defined in terms of speed of light during a certain time
interval.</rdfs:comment>
        <rdfs:label xml:lang="en">length</rdfs:label>
    </owl:Class>

        <!-- http://www.ontology-of-units-of-measure.org/resource/om-2/LengthUnit -->
        <owl:Class rdf:about="http://www.ontology-of-units-of-measure.org/resource/om-2/LengthUnit">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/UnitOfMeasure"/>
        <rdfs:comment>The unit of measure for length.</rdfs:comment>
        <rdfs:label xml:lang="en">length unit</rdfs:label>
    </owl:Class>

        <!-- http://www.ontology-of-units-of-measure.org/resource/om-2/Mass -->
        <owl:Class rdf:about="http://www.ontology-of-units-of-measure.org/resource/om-2/Mass">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/Measurement"/>
        <rdfs:comment xml:lang="en">Mass is the amount of matter of a phenomenon. It is a base quantity in the
International System of Units. Mass is force divided by acceleration.</rdfs:comment>
        <rdfs:label xml:lang="en">mass</rdfs:label>
    </owl:Class>

        <!-- http://www.ontology-of-units-of-measure.org/resource/om-2/MassUnit -->
        <owl:Class rdf:about="http://www.ontology-of-units-of-measure.org/resource/om-2/MassUnit">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/UnitOfMeasure"/>
        <rdfs:comment>The unit of measure for mass.</rdfs:comment>
        <rdfs:label xml:lang="en">mass unit</rdfs:label>
    </owl:Class>
```

```
    <!-- http://www.ontology-of-units-of-measure.org/resource/om-2/Percentage -->
    <owl:Class rdf:about="http://www.ontology-of-units-of-measure.org/resource/om-2/Percentage">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/Measurement"/>
        <rdfs:comment>Percentage is a term used to express a proportion or a fraction of a whole quantity, typically denoted by the symbol "%".</rdfs:comment>
        <rdfs:label xml:lang="en">percentage</rdfs:label>
    </owl:Class>

    <!-- http://www.ontology-of-units-of-measure.org/resource/om-2/PercentageUnit -->
    <owl:Class rdf:about="http://www.ontology-of-units-of-measure.org/resource/om-2/PercentageUnit">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/UnitOfMeasure"/>
        <rdfs:comment>The unit of measure for percentage.</rdfs:comment>
        <rdfs:label xml:lang="en">percentage unit</rdfs:label>
    </owl:Class>

    <!-- http://www.ontology-of-units-of-measure.org/resource/om-2/Period -->
    <owl:Class rdf:about="http://www.ontology-of-units-of-measure.org/resource/om-2/Period">
        <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Time"/>
    </owl:Class>

    <!-- http://www.ontology-of-units-of-measure.org/resource/om-2/PowerDensityUnit -->
    <owl:Class rdf:about="http://www.ontology-of-units-of-measure.org/resource/om-2/PowerDensityUnit">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/UnitOfMeasure"/>
        <rdfs:comment>The unit of measure for power density.</rdfs:comment>
        <rdfs:label xml:lang="en">power density unit</rdfs:label>
    </owl:Class>

    <!-- http://www.ontology-of-units-of-measure.org/resource/om-2/Pressure -->
    <owl:Class rdf:about="http://www.ontology-of-units-of-measure.org/resource/om-2/Pressure">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/Measurement"/>
        <rdfs:comment xml:lang="en">Pressure is the force applied to or distributed over a surface. It is a derived quantity in the International System of Units. Pressure is force divided by area.</rdfs:comment>
        <rdfs:label xml:lang="en">pressure</rdfs:label>
    </owl:Class>

    <!-- http://www.ontology-of-units-of-measure.org/resource/om-2/Speed -->
    <owl:Class rdf:about="http://www.ontology-of-units-of-measure.org/resource/om-2/Speed">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/Measurement"/>
        <rdfs:comment xml:lang="en">Speed is the time rate of motion measured by the distance moved over in unit time.</rdfs:comment>
        <rdfs:label xml:lang="en">speed</rdfs:label>
    </owl:Class>

    <!-- http://www.ontology-of-units-of-measure.org/resource/om-2/SpeedUnit -->
    <owl:Class rdf:about="http://www.ontology-of-units-of-measure.org/resource/om-2/SpeedUnit">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/UnitOfMeasure"/>
        <rdfs:comment>The unit of measure for speed.</rdfs:comment>
        <rdfs:label xml:lang="en">speed unit</rdfs:label>
    </owl:Class>

    <!-- http://www.ontology-of-units-of-measure.org/resource/om-2/Temperature -->
    <owl:Class rdf:about="http://www.ontology-of-units-of-measure.org/resource/om-2/Temperature">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/Measurement"/>
        <rdfs:comment xml:lang="en">Temperature is the extent to which an object is hot.</rdfs:comment>
        <rdfs:label xml:lang="en">temperature</rdfs:label>
    </owl:Class>

    <!-- http://www.ontology-of-units-of-measure.org/resource/om-2/Time -->
    <owl:Class rdf:about="http://www.ontology-of-units-of-measure.org/resource/om-2/Time">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/Measurement"/>
        <rdfs:comment xml:lang="en">Time is a base quantity in the International System of Units and other systems of units. It is measured by numbers of repetitions of cyclical events.</rdfs:comment>
        <rdfs:label xml:lang="en">time</rdfs:label>
    </owl:Class>

    <!-- http://www.ontology-of-units-of-measure.org/resource/om-2/TimeConstant -->
    <owl:Class rdf:about="http://www.ontology-of-units-of-measure.org/resource/om-2/TimeConstant">
        <rdfs:subClassOf rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/Time"/>
    </owl:Class>
```

```
        <!-- http://www.ontology-of-units-of-measure.org/resource/om-2/TimeUnit -->
        <owl:Class rdf:about="http://www.ontology-of-units-of-measure.org/resource/om-2/TimeUnit">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/UnitOfMeasure"/>
        <rdfs:comment>The unit of measure for time.</rdfs:comment>
        <rdfs:label xml:lang="en">time unit</rdfs:label>
    </owl:Class>

        <!-- http://www.ontology-of-units-of-measure.org/resource/om-2/Volume -->
        <owl:Class rdf:about="http://www.ontology-of-units-of-measure.org/resource/om-2/Volume">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/Measurement"/>
        <rdfs:comment xml:lang="en">Volume is a measure of how much three-dimensional space any phenomenon occupies.
It is a derived quantity in the International System of Units. Volume is length to the power 3.</rdfs:comment>
        <rdfs:label xml:lang="en">volume</rdfs:label>
    </owl:Class>

        <!-- http://www.ontology-of-units-of-measure.org/resource/om-2/VolumeUnit -->
        <owl:Class rdf:about="http://www.ontology-of-units-of-measure.org/resource/om-2/VolumeUnit">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/UnitOfMeasure"/>
        <rdfs:comment>The unit of measure for volume.</rdfs:comment>
        <rdfs:label xml:lang="en">volume unit</rdfs:label>
    </owl:Class>

        <!-- http://www.ontology-of-units-of-measure.org/resource/om-2/VolumetricFlowRate -->
        <owl:Class rdf:about="http://www.ontology-of-units-of-measure.org/resource/om-2/VolumetricFlowRate">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/Measurement"/>
        <rdfs:comment>Volumetric flow rate, often simply referred to as flow rate, is a measure of the volume of fluid
(liquid or gas) that passes through a given cross-sectional area per unit of time. It quantifies the amount of fluid moving
through a particular point in a system over a specific period.</rdfs:comment>
        <rdfs:label xml:lang="en">volumetric flow rate</rdfs:label>
    </owl:Class>

        <!-- http://www.ontology-of-units-of-measure.org/resource/om-2/VolumetricFlowRateUnit -->
        <owl:Class rdf:about="http://www.ontology-of-units-of-measure.org/resource/om-2/VolumetricFlowRateUnit">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/UnitOfMeasure"/>
        <rdfs:comment>The unit of measure for volumetric flow rate.</rdfs:comment>
        <rdfs:label xml:lang="en">volumetric flow rate unit</rdfs:label>
    </owl:Class>

        <!-- http://www.ontology-of-units-of-measure.org/resource/om-2/Weight -->
        <owl:Class rdf:about="http://www.ontology-of-units-of-measure.org/resource/om-2/Weight">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/Measurement"/>
        <rdfs:comment xml:lang="en">Weight is a force that attracts a body towards another (reference)
body.</rdfs:comment>
        <rdfs:label xml:lang="en">weight</rdfs:label>
    </owl:Class>

        <!-- https://saref.etsi.org/core/Currency -->
        <owl:Class rdf:about="https://saref.etsi.org/core/Currency">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/UnitOfMeasure"/>
        <rdfs:comment xml:lang="en">The class of units of measure for price</rdfs:comment>
        <rdfs:label xml:lang="en">Currency</rdfs:label>
    </owl:Class>

        <!-- https://saref.etsi.org/core/Device -->
        <owl:Class rdf:about="https://saref.etsi.org/core/Device">
        <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#Asset"/>
        <rdfs:subClassOf>
            <owl:Restriction>
                <owl:onProperty rdf:resource="https://saref.etsi.org/core/offers"/>
                <owl:allValuesFrom rdf:resource="https://saref.etsi.org/core/Service"/>
            </owl:Restriction>
        </rdfs:subClassOf>
        <rdfs:comment xml:lang="en">A tangible object designed to accomplish a particular task. In order to accomplish this
task, the device performs one or more functions. For example, a washing machine is designed to wash (task) and to
accomplish this task it performs a start and stop function.</rdfs:comment>
        <rdfs:label xml:lang="en">Device</rdfs:label>
    </owl:Class>

        <!-- https://saref.etsi.org/core/EnergyUnit -->
        <owl:Class rdf:about="https://saref.etsi.org/core/EnergyUnit">
        <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/UnitOfMeasure"/>
```

```
            <rdfs:comment xml:lang="en">The unit of measure for energy.</rdfs:comment>
            <rdfs:label xml:lang="en">Energy unit</rdfs:label>
      </owl:Class>

             <!-- https://saref.etsi.org/core/Measurement -->
             <owl:Class rdf:about="https://saref.etsi.org/core/Measurement">
            <rdfs:subClassOf rdf:resource="http://www.hse.gr/i-stentore/ontology#Parameters"/>
            <rdfs:subClassOf>
                  <owl:Restriction>
                        <owl:onProperty rdf:resource="https://saref.etsi.org/core/hasValue"/>
                        <owl:cardinality rdf:datatype="http://www.w3.org/2001/XMLSchema#nonNegativeInteger">1</owl:cardinality>
                  </owl:Restriction>
            </rdfs:subClassOf>
            <rdfs:comment xml:lang="en">Represents the measured value made over a property. It is also linked to the unit of
measure in which the value is expressed and the timestamp of the measurement.</rdfs:comment>
            <rdfs:label xml:lang="en">Measurement</rdfs:label>
      </owl:Class>

             <!-- https://saref.etsi.org/core/PowerUnit -->
             <owl:Class rdf:about="https://saref.etsi.org/core/PowerUnit">
            <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/UnitOfMeasure"/>
            <rdfs:comment xml:lang="en">The unit of measure for power</rdfs:comment>
            <rdfs:label xml:lang="en">Power unit</rdfs:label>
      </owl:Class>

             <!-- https://saref.etsi.org/core/PressureUnit -->
             <owl:Class rdf:about="https://saref.etsi.org/core/PressureUnit">
            <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/UnitOfMeasure"/>
            <rdfs:comment xml:lang="en">The unit of measure for pressure</rdfs:comment>
            <rdfs:label xml:lang="en">Pressure unit</rdfs:label>
      </owl:Class>

             <!-- https://saref.etsi.org/core/Service -->
             <owl:Class rdf:about="https://saref.etsi.org/core/Service">
            <rdfs:comment xml:lang="en">A service refers to a specific function or capability that the asset provides to the
electrical grid or energy system. These services are essential for ensuring the reliable and efficient operation of the grid and
may encompass various aspects of grid management, stability, and optimization. This class also refers to the non energy
services that an asset uses, like weather forecasting, load forecasting, and renewable energy sources production
forecasting.</rdfs:comment>
            <rdfs:label xml:lang="en">Service</rdfs:label>
      </owl:Class>

             <!-- https://saref.etsi.org/core/TemperatureUnit -->
             <owl:Class rdf:about="https://saref.etsi.org/core/TemperatureUnit">
            <rdfs:subClassOf rdf:resource="https://saref.etsi.org/core/UnitOfMeasure"/>
            <rdfs:comment xml:lang="en">The unit of measure for temperature</rdfs:comment>
            <rdfs:label xml:lang="en">Temperature unit</rdfs:label>
      </owl:Class>

             <!-- https://saref.etsi.org/core/Time -->
             <owl:Class rdf:about="https://saref.etsi.org/core/Time">
            <rdfs:comment xml:lang="en">A class that allows to specify the time concept.</rdfs:comment>
            <rdfs:label xml:lang="en">Time</rdfs:label>
      </owl:Class>

             <!-- https://saref.etsi.org/core/UnitOfMeasure -->
             <owl:Class rdf:about="https://saref.etsi.org/core/UnitOfMeasure">
            <rdfs:comment xml:lang="en">The unit of measure is a standard for measurement of a quantity, such as a
Parameter.</rdfs:comment>
            <rdfs:label xml:lang="en">Unit of measure</rdfs:label>
      </owl:Class>
</rdf:RDF>

<!-- Generated by the OWL API (version 4.5.26.2023-07-17T20:34:13Z) https://github.com/owlcs/owlapi -->
```


6.4 APPENDIX III: IONTOLOGY EXAMPLE BASED ON DEMO 1

Example for Demo 1:

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- The *Infrastructure* of *Demo 1: Molten Glass Thermal Storage For An Increased Uptake Of Renewable Electric Energy* uses the *Non Energy Services* of *PV Forecasting* and *Weather Forecasting*.
- It offers *Congestion Management* and *Power Smoothing*, as *Flexibility/Balancing/Ancillary Services*.
- Regarding the *Assets*, Demo 1 has (the) assets of a *PV Plant* and a *Thermal Storage System*.
- It is located in Zasavje, Slovenia.
- The ***PV Plant*** has parameters: *Inclination, Location Latitude, Location Longitude, Nominal Power, Orientation, Voltage Level* and *Output Active Power*.
  - ➢ The ***Nominal Power*** of the *PV Plant* (static parameter) is 521 (kWp) and *is measured in* kilowatt.
  - ➢ In this example, the ***Output Active Power*** of the *PV Plant* at the specific *Time* of **04/03/2024 11:23 am**, which *is measured in* kilowatt, *has* (the) *value* of 50 (kW).
- The ***Thermal Storage*** has parameters: *Charge Rate, Discharge Rate, Energy Capacity, Overheated Glass Melt (temperature), Rated Power and Round-Trip Efficiency*.
  - ➢ The ***Discharge Rate*** of the *Thermal Storage* (static parameter) is 0.1 C and *is measured in* C-rate.
  - ➢ In this example, the ***SOC (State of Charge)*** of the *Thermal Storage* at the specific *Time* of **04/03/2024 11:23 am**, which *is measured in* kilowattHour, *has* (the) *value* of 300 (kWh).

The RDF/XML syntax of the above example is shown below:


```
<?xml version="1.0"?>
<rdf:RDF xmlns="http://www.hse.gr/i-stentore/ontology#"
     xml:base="http://www.hse.gr/i-stentore/ontology"
     xmlns:hse="http://www.hse.gr/i-stentore/ontology#"
     xmlns:obo="http://purl.obolibrary.org/obo/"
     xmlns:oeo="http://openenergy-platform.org/ontology/oeo/"
     xmlns:owl="http://www.w3.org/2002/07/owl#"
         xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
     xmlns:xml="http://www.w3.org/XML/1998/namespace"
     xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
     xmlns:core="https://saref.etsi.org/core/"
     xmlns:om-2="http://www.ontology-of-units-of-measure.org/resource/om-2/"
     xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
     xmlns:vann="http://purl.org/vocab/vann/"
     xmlns:terms="http://purl.org/dc/terms/">
         <owl:Ontology rdf:about="http://www.hse.gr/i-stentore/ontology">
         <owl:versionIRI rdf:resource="http://www.hse.gr/i-stentore/ontology"/>
         </owl:Ontology>


         <!--
    ///////////////////////////////////////////////////////////////////////////////////////
         //
         // Individuals
         //
    ///////////////////////////////////////////////////////////////////////////////////////
         -->

<!-- http://www.hse.gr/i-stentore/ontology#Demo1%3AMoltenGlassThermalStorageForAnIncreasedUptakeOfRenewableElectricEnergy
-->

         <owl:NamedIndividual rdf:about="http://www.hse.gr/i-
stentore/ontology#Demo1%3AMoltenGlassThermalStorageForAnIncreasedUptakeOfRenewableElectricEnergy">
         <rdf:type rdf:resource="http://www.hse.gr/i-stentore/ontology#Infrastrucuture"/>
         <rdf:type>
```

```
<owl:Restriction>
        <owl:onProperty rdf:resource="http://www.hse.gr/i-stentore/ontology#uses"/>
        <owl:someValuesFrom rdf:resource="http://www.hse.gr/i-stentore/ontology#PVForecasting"/>
</owl:Restriction>
</rdf:type>
<rdf:type>
<owl:Restriction>
        <owl:onProperty rdf:resource="http://www.hse.gr/i-stentore/ontology#uses"/>
        <owl:someValuesFrom rdf:resource="http://www.hse.gr/i-stentore/ontology#WeatherForecasting"/>
</owl:Restriction>
</rdf:type>
<rdf:type>
<owl:Restriction>
        <owl:onProperty rdf:resource="https://saref.etsi.org/core/offers"/>
        <owl:someValuesFrom rdf:resource="http://www.hse.gr/i-stentore/ontology#CongestionManagement"/>
</owl:Restriction>
</rdf:type>
<rdf:type>
<owl:Restriction>
        <owl:onProperty rdf:resource="https://saref.etsi.org/core/offers"/>
        <owl:someValuesFrom rdf:resource="http://www.hse.gr/i-stentore/ontology#PowerSmoothing"/>
</owl:Restriction>
</rdf:type>
<hasAssets rdf:resource="http://www.hse.gr/i-stentore/ontology#Demo1%3APVPlant"/>
<hasAssets rdf:resource="http://www.hse.gr/i-stentore/ontology#Demo1%3AThermalStorage"/>
<isLocatedIn rdf:resource="http://www.hse.gr/i-stentore/ontology#Demo1%3AZasavje%2CSlovenia"/>
<rdfs:comment rdf:resource="http://www.hse.gr/i-
stentore/ontology#Demo1%3AMoltenGlassThermalStorageForAnIncreasedUptakeOfRenewableElectricEnergy"/>
<rdfs:label xml:lang="en">Demo 1: Molten glass thermal storage for an increased uptake of renewable electric
energy</rdfs:label>
</owl:NamedIndividual>

<!-- http://www.hse.gr/i-stentore/ontology#Demo1%3APVPlant -->
<owl:NamedIndividual rdf:about="http://www.hse.gr/i-stentore/ontology#Demo1%3APVPlant">
<rdf:type rdf:resource="http://openenergy-platform.org/ontology/oeo/OEO_00000324"/>
<hasParameters rdf:resource="http://www.hse.gr/i-stentore/ontology#Demo1%3APVPlantInclination"/>
<hasParameters rdf:resource="http://www.hse.gr/i-stentore/ontology#Demo1%3APVPlantLocationLatitude"/>
<hasParameters rdf:resource="http://www.hse.gr/i-stentore/ontology#Demo1%3APVPlantLocationLongitude"/>
<hasParameters rdf:resource="http://www.hse.gr/i-stentore/ontology#Demo1%3APVPlantNominalPower"/>
<hasParameters rdf:resource="http://www.hse.gr/i-stentore/ontology#Demo1%3APVPlantOrientation"/>
<hasParameters rdf:resource="http://www.hse.gr/i-stentore/ontology#Demo1%3APVPlantOutputActivePower"/>
<hasParameters rdf:resource="http://www.hse.gr/i-stentore/ontology#Demo1%3APVPlantVoltageLevel"/>
<rdfs:label xml:lang="en">Demo 1: PV Plant</rdfs:label>
</owl:NamedIndividual>

<!-- http://www.hse.gr/i-stentore/ontology#Demo1%3APVPlantNominalPower -->
<owl:NamedIndividual rdf:about="http://www.hse.gr/i-stentore/ontology#Demo1%3APVPlantNominalPower">
<rdf:type rdf:resource="http://www.hse.gr/i-stentore/ontology#NominalPower"/>
<core:isMeasuredIn rdf:resource="http://www.semanticweb.org/hse.gr/ontologies/2023/11/iSTENTORE_SAREF#kilowatt"/>
<core:hasValue rdf:datatype="http://www.w3.org/2001/XMLSchema#integer">521</core:hasValue>
<rdfs:label xml:lang="en">Demo 1: PV Plant Nominal Power</rdfs:label>
</owl:NamedIndividual>

<!-- http://www.hse.gr/i-stentore/ontology#Demo1%3APVPlantOutputActivePower -->
<owl:NamedIndividual rdf:about="http://www.hse.gr/i-stentore/ontology#Demo1%3APVPlantOutputActivePower">
<rdf:type rdf:resource="http://www.hse.gr/i-stentore/ontology#OutputActivePower"/>
<core:hasTime rdf:resource="http://www.hse.gr/i-stentore/ontology#04.03.202411%3A23Am"/>
<core:isMeasuredIn rdf:resource="http://www.semanticweb.org/hse.gr/ontologies/2023/11/iSTENTORE_SAREF#kilowatt"/>
<core:hasValue rdf:datatype="http://www.w3.org/2001/XMLSchema#integer">50</core:hasValue>
<rdfs:label xml:lang="en">Demo 1: PV Plant Output Active Power</rdfs:label>
</owl:NamedIndividual>

<!-- http://www.hse.gr/i-stentore/ontology#Demo1%3AThermalStorage -->
<owl:NamedIndividual rdf:about="http://www.hse.gr/i-stentore/ontology#Demo1%3AThermalStorage">
<rdf:type rdf:resource="http://openenergy-platform.org/ontology/oeo/OEO_00020369"/>
<hasParameters rdf:resource="http://www.hse.gr/i-stentore/ontology#Demo1%3AThermalStorageChargeRate"/>
<hasParameters rdf:resource="http://www.hse.gr/i-stentore/ontology#Demo1%3AThermalStorageDischargeRate"/>
<hasParameters rdf:resource="http://www.hse.gr/i-stentore/ontology#Demo1%3AThermalStorageEfficiency"/>
<hasParameters rdf:resource="http://www.hse.gr/i-stentore/ontology#Demo1%3AThermalStorageEnergyCapacity"/>
<hasParameters rdf:resource="http://www.hse.gr/i-stentore/ontology#Demo1%3AThermalStorageOverheatedGlassMelt"/>
<hasParameters rdf:resource="http://www.hse.gr/i-stentore/ontology#Demo1%3AThermalStorageRatedPower"/>
```


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```
<hasParameters rdf:resource="http://www.hse.gr/i-stentore/ontology#Demo1%3AThermalStorageSOC"/>
<rdfs:label xml:lang="en">Demo 1: Thermal Storage</rdfs:label>
</owl:NamedIndividual>

<!-- http://www.hse.gr/i-stentore/ontology#Demo1%3AThermalStorageDischargeRate -->
<owl:NamedIndividual rdf:about="http://www.hse.gr/i-stentore/ontology#Demo1%3AThermalStorageDischargeRate">
<rdf:type rdf:resource="http://www.hse.gr/i-stentore/ontology#MaxDischargeRate"/>
<core:isMeasuredIn rdf:resource="http://www.hse.gr/i-stentore/ontology#C-rate"/>
<core:hasValue rdf:datatype="http://www.w3.org/2001/XMLSchema#decimal">0.1</core:hasValue>
<rdfs:label xml:lang="en">Demo 1: Thermal Storage Discharge Rate</rdfs:label>
</owl:NamedIndividual>

<!-- http://www.hse.gr/i-stentore/ontology#Demo1%3AThermalStorageSOC -->
<owl:NamedIndividual rdf:about="http://www.hse.gr/i-stentore/ontology#Demo1%3AThermalStorageSOC">
<rdf:type rdf:resource="http://www.hse.gr/i-stentore/ontology#SoC"/>
<core:hasTime rdf:resource="http://www.hse.gr/i-stentore/ontology#04.03.202411%3A23Am"/>
<core:isMeasuredIn rdf:resource="http://www.ontology-of-units-of-measure.org/resource/om-2/kilowattHour"/>
<core:hasValue rdf:datatype="http://www.w3.org/2001/XMLSchema#integer">300</core:hasValue>
<rdfs:label xml:lang="en">Demo 1: Thermal Storage SOC</rdfs:label>
</owl:NamedIndividual>
```


6.5 APPENDIX IV: DEFINING DATA MODELS (FOR ORION-LD'S API)

This part shows the defining of the data models that will be used by the Orion-LD API. The .yaml file that generates a dummy API (the original NGSI-API is in the following link[24]) with the data models (or entities) to be used in this project is:


```
openapi: 3.0.3
info:
  title: i-STENTORE Assets
  description: |-
        Model Definitions for i-STENTORE Assets
  version: latest
servers:
  - url: https://idgm.istentore.eu
tags:
  - name: ngsi-ld

paths:
  /ngsi-ld/v1/entities:
        get:
        tags:
        - ngsi-ld

        responses:
        '200':
        description: successful operation
        content:
        application/json;application/ld+json:
                schema:
                type: array
                items:
                oneOf:
                - $ref: '#/components/schemas/EnergyStorage'
                - $ref: '#/components/schemas/PowerProduction'
        '400':
        description: Invalid status value

components:
  schemas:
```


[24] NGSI-API Link [Online].

EnergyStorage:
required:
- id
- type
type: object
properties:
id:
type: string
description: URN holding the id of the attribute
type:
type: string
description: The entity type
ratedpower:
type: number
description: (kW)
ratedvoltage:
type: number
description: (V)
energycapacity:
type: number
description: (kWh)
hasStorage:
type: object
description: The storage types that are used
oneOf:
- $ref: '#/components/schemas/Thermal'
- $ref: '#/components/schemas/Chemical'
- $ref: '#/components/schemas/Hydrogen'

Thermal:
required:
- id
- type
type: object
properties:
id:
type: string
description: URN holding the id of the attribute
type:
type: string
description: The entity type
overheatedglassmelt:
type: number
description: (Celcius)

Chemical:
required:
- id
- type
type: object
properties:
id:
type: string
description: URN holding the id of the attribute
type:
type: string
description: The entity type
output:
type: string
enum:
- AC
- DC
converterrating:
type: number
description: (kW)
soc:
type: number
description: (%)

Hydrogen:
required:

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- id
- type
type: object
properties:
id:
type: string
description: URN holding the id of the attribute
type:
type: string
description: The entity type
initialstorage:
type: number
description: (kg)
maxtanklevel:
type: number
description: (kg)
demand:
type: number
description: (kg)
lowpressuretankvolume:
type: number
description: (cubic meters)
highpressuretankvolume:
type: number
description: (cubic meters)

PowerProduction:
required:
- id
- type
type: object
properties:
id:
type: string
description: URN holding the id of the attribute
type:
type: string
description: The entity type
efficiency:
type: number
description: (%)
outputactivepower:
type: number
description: (kW)
outputreactivepower:
type: number
description: (kVar)
acvoltagelevel:
type: number
description: (V)
hasProduction:
type: object
description: The Power Production types that are used
oneOf:
- $ref: '#/components/schemas/Photovoltaic'
- $ref: '#/components/schemas/Hydroelectric'
- $ref: '#/components/schemas/Windturbine'

Photovoltaic:
required:
- id
- type
type: object
properties:
id:
type: string
description: URN holding the id of the attribute
type:
type: string
description: The entity type
inverterefficiency:

```
type: number
description: (%)
acratedvoltage:
type: number
description: (V)
dcvoltage:
type: number
description: (V)

Hydroelectric:
required:
- id
- type
type: object
properties:
id:
type: string
description: URN holding the id of the attribute
type:
type: string
description: The entity type
pumpingpower:
type: number
description: (kW)
reservoircapacity:
type: number
description: (cubic meters)
generators:
type: integer
pumps:
type: integer
reversible:
type: boolean
enum:
- true
- false
inflow:
type: number
description: (cubic meters / sec)

Windturbine:
required:
- id
- type
type: object
properties:
id:
type: string
description: URN holding the id of the attribute
type:
type: string
description: The entity type
windspeed:
type: number
description: (m/s)
cutinspeed:
type: number
description: (m/s)
cutoutspeed:
type: number
description: (m/s)
referencespeed:
type: number
description: (m/s)
```


6.6 APPENDIX V: EXAMPLE OF POST AND GET REQUEST

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This is an example of a POST and GET request of an entity using Orion-LD. The python script that was used for the post request is the following script (can be done with curl and javascript as well):

```
import json
import requests

payload={
   "@context": {
            "i-STENTORE": "https://istentore/models/",

            "EnergyStorage": "i-STENTORE:EnergyStorage",

            "ratedpower": "i-STENTORE:ratedpower",
            "ratedvoltage": "i-STENTORE:ratedvoltage",
            "energycapacity": "i-STENTORE:energycapacity"
   },

   "id": "urn:ngsi-ld:EnergyStorage:ES3",
   "type": "EnergyStorage",

   "ratedpower": {
            "type": "Property",
            "value": 10
   },

   "ratedvoltage": {
            "type": "Property",
            "value": 15
   },

   "energycapacity": {
            "type": "Property",
            "value": 200
   },

   "hasStorage": {
            "type": "Relationship",
            "object": [
            "urn:ngsi-id:Thermal:TS3"
            ]
   }
}
response = requests.post(url='https://idgm.istentore.eu/ngsi-ld/v1/entities', headers={
            "content-type": "application/ld+json"}, data=json.dumps(payload))
print(response.status_code)
```

The entity that has been posted in the database (as shown in MongoDB):


```
{
            "_id" : {
                        "id" : "urn:ngsi-ld:EnergyStorage:ES3",
                        "type" : "https://istentore/models/EnergyStorage",
                        "servicePath" : "/"
            },
            "attrNames" : [
                        "https://istentore/models/ratedpower",
                        "https://istentore/models/ratedvoltage",
                        "https://istentore/models/energycapacity",
                        "https://uri.etsi.org/ngsi-ld/default-context/hasThermal"
            ],
            "attrs" : {
                        "https://istentore/models/ratedpower" : {
                                    "type" : "Property",
                                    "creDate" : 1710164076.6774597,
                                    "modDate" : 1710164076.6774597,
                                    "value" : 10,
                                    "mdNames" : [ ]
                        },
```


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```
        "https://istentore/models/ratedvoltage" : {
            "type" : "Property",
            "creDate" : 1710164076.6774597,
            "modDate" : 1710164076.6774597,
            "value" : 15,
            "mdNames" : [ ]
        },
        "https://istentore/models/energycapacity" : {
            "type" : "Property",
            "creDate" : 1710164076.6774597,
            "modDate" : 1710164076.6774597,
            "value" : 200,
            "mdNames" : [ ]
        },
        "https://uri=etsi=org/ngsi-ld/default-context/hasStorage" : {
            "type" : "Relationship",
            "creDate" : 1710164076.6774597,
            "modDate" : 1710164076.6774597,
            "value" : [
                "urn:ngsi-id:Thermal:TS3"
            ],
            "mdNames" : [ ]
        }
    },
    "creDate" : 1710164076.6774597,
    "modDate" : 1710164076.6774597,
    "lastCorrelator" : ""
}
```


We use the following query to get all entities of "type=https://istentore/models/EnergyStorage":

```
curl 'https://idgm.istentore.eu/ngsi-ld/v1/entities?type=https://istentore/models/EnergyStorage&prettyPrint=yes&spaces=2'
```


```
[
  {
    "id": "urn:ngsi-ld:EnergyStorage:ES3",
    "type": "https://istentore/models/EnergyStorage",
    "https://istentore/models/energycapacity": {
    "type": "Property",
    "value": 200
    },
    "https://istentore/models/ratedpower": {
        "type": "Property",
        "value": 10
    },
    "https://istentore/models/ratedvoltage": {
        "type": "Property",
        "value": 15
    },
    "hasStorage": {
        "type": "Relationship",
        "object": [
            "urn:ngsi-id:Thermal:TS3"
        ]
    }
  }
]
```


Of course, there are many more endpoints and capabilities that the Orion-LD Context Broker implements, but it is best to consult the official FIWARE Orion-LD Context Broker State of the

Implementation[25] which explains what features of the NGSI-LD API are available in the Context Broker.

[25] Github link of the official FIWARE Orion-LD Context Broker [Online].

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