i-STENTORE

innovative Energy Storage TEchnologies TOwards increased Renewables integration and Efficient Operation

D2.3 – SERVICES CO-CREATION, BUSINESS MODELS, FUNCTIONAL SPECIFICATIONS, AND REFERENCE ARCHITECTURE (2nd VERSION)

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Abstract	This deliverable includes the first specification and design of the business models for i-STENTORE, the first identification of functional specifications for standardised data access and exchange and the first conceptual version of the i-STENTORE software Reference Architecture
Keywords	Business Models, Functional Specifications, Reference Architecture

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TABLE OF ABBREVIATIONS AND ACRONYMS

Acronym	Definition
(A)PV	(Agriculture) PhotoVoltaic
(B)ESS	(Battery) Energy Storage Systems
(B)UC	(Business) Use Case
(D)SO	(Distribution) System Operator
(H)ESS	Hybrid Energy Storage System
(I)IoT	(Industial) Internet of Things
API	Application Programming Interface
AWS	Amazon Web Services
CEN	European Committee for Standardisation
CP	Charging Point
CS	Central System
DB(S)	DataBase (System or Server)
DC/DC	Direct Current to Direct Current
DEI	Digitizing European Industry
DER(A)	Distributed Energy Resources (Architecture)
ELY	Electrolyser
EMS	Energy Management System
EU	European Union
EV	Electric Vehicles
FMS	Furnace Monitoring System
GDPR	General Data Protection Regulation
HOCS	Hierarchical Operation and Control System
HTTP	Hypertext Transfer Protocol
IDSA	International Data Spaces Association
IEGSA	Interoperable European Grid Services Architecture
IPT	Investment Planning Tool
LIB	Lithium-Ion Battery
Li-Ion	Lithium-ion
LTO	Lithium Titanate Oxide
MQTT	Message Queuing Telemetry Transport
NGSI-LD	Next Generation Service Interface – Linked Data
NMC	Nickel-Metal Hydride
OCPP	Open Charge Point Protocol
OLE	Object Linking and Embedding
OMIE	Operador del Mercado Ibérico de Energía – it is the operator of the Iberian electricity market, responsible for managing the wholesale electricity market in Spain and Portugal.
OPC	OLE for Process Control

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PLC	Programmable Logic Controller
PV	Photovoltaic
PVPP	Photovoltaic Power Plant
RA(M)	Reference Architecture (Model)
RAF	Reference Architecture Framework
RAMI	Reference Architecture Model for Industry
REST	REpresentational State Transfer
REE	Red Eléctrica de España - it is the transmission system operator (TSO) for the Spanish electricity grid.
RT-HIL	Real-Time Hardware-In-the-Loop
SCADA	Supervisory Control And Data Acquisition
SGAM	Smart energy Grid Architecture Model
SoC	State of Charge
SQL	Structured Query Language
SR	Spinning Reserves
TCP/IP	Transmission Control Protocol/Internet Protocol
TSO	Transmission System Operator
UI	User Interface
V2G	Vehicle to Grid
VESS	Virtual Energy Storage System
VPP	Virtual Power Plant
VPN	Virtual Private Network
VRFB	Vanadium Redox Flow Battery

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EXECUTIVE SUMMARY

The i-STENTORE project involves numerous stakeholders within the electricity sector. Its primary objective is to explore the integration and combinations of various storage solutions. By showcasing innovative storage systems, the project aims to co-optimise their cooperation with integrated assets, focusing on enhancing reliability, power quality, cost-efficiency, and asset longevity. Additionally, it seeks to implement a Reference implementation that integrates modern smart energy architecture models in the energy domain, involving diverse emerging roles, adopting also a Data Spaces (DS) compliant approach. This approach addresses issues of trust, security, sovereignty, and interoperability in data exchange and application services, with a particular emphasis on standardization, security, legal, and privacy matters.

In its innovative exploration, i-STENTORE delves into the complexities of developing business models for ESS, highlighting their multifaceted nature and critical role in integrating renewable energy sources and improving grid reliability. The document meticulously examines various business models, from single-use to multi-use applications, emphasizing their importance in the broader context of Europe's transition to a climate-neutral economy. The research also investigates the functional specifications for standardised data access and integration, which are crucial for establishing a harmonised framework for data exchange and facilitating the efficient and effective use of energy storage systems. It includes a thorough analysis of previous projects, providing a comprehensive understanding of the challenges and opportunities in data standardization within the energy sector.

i-STENTORE will introduce an overarching framework designed to showcase stand-alone and hybrid storage solutions, emphasizing the multipurpose use of storage not only as an energy buffer but also as an active grid component capable of providing services and enhancing grid resilience, stability, and efficient operation. To realise this vision, this deliverable outlines the process of deriving a requirements-based Reference Architecture, leveraging the experiences of numerous preceding and co-evolving European projects and initiatives. Initial drafts for Reference Architecture (RA) components are included.

This deliverable, D2.3, marks the second edition in this series and serves as an update to the initial version. While the fundamental principles and objectives outlined in the first deliverable remain applicable across the project, this edition introduces refinements where necessary. These refinements are based on our evolving understanding and the project's maturation since its inception. The updates are designed to provide a more precise framework, reflecting our progress and insights gained, ensuring the i-STENTORE project remains on the cutting edge of energy storage technology integration.

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1. INTRODUCTION

1.1 SCOPE

The purpose of this deliverable, titled "Services Co-Creation, Business Models, Functional Specifications, and Reference Architecture (2nd Version)", is to update and refine the initial findings and frameworks established in D2.2. This document delves into the advanced methodologies and strategic approaches required for the effective integration and operation of energy storage technologies within the i-STENTORE project. It aims to provide a comprehensive overview of the novel business models, functional specifications for data integration, and a tailored reference architecture to enhance the flexibility and interoperability of energy storage solutions in Europe's pursuit of climate neutrality.

1.2 TASK 2.3: NOVEL BUSINESS MODELS DESIGN FOR ESTABLISHMENT OF ENERGY STORAGE TECHNOLOGIES AS KEY ENABLER IN EUROPE'S CLIMATE NEUTRALITY

Task 2.3 focuses on developing and evaluating business models for Energy Storage Systems (ESS). This task involves a co-simulation environment to assess the deployment of storage using real data from laboratory equipment. This task employs a co-simulation environment to assess storage deployment using real data from laboratory equipment, allowing for a realistic simulation-based assessment. The task unfolds in three key steps:

- **Identifying Existing Opportunities and Barriers**: This involves a comprehensive analysis of current revenue streams and economic barriers for ESS. Markets, flexibility coordination schemes, and grid services are evaluated to understand the potential and limitations for large-scale storage adoption.
- **Assessing Future Use Cases and Business Models**: Future scenarios are created to evaluate potential single-use and multi-use storage deployments. This step focuses on reducing storage capacity investment needs and the overall environmental footprint by optimizing the usage of available storage.
- **Exploring Second-Life Applications**: The task also explores the second-life applications of ESS within a circular economy framework, aiming to extend the operational life and maximise the value of storage technologies.

The insights gained from these simulations are critical for understanding the practical challenges and opportunities in real-world deployments, ultimately contributing to the sustainable integration of ESS in Europe's energy infrastructure. These insights are integral to the overall development of viable business models and inform the approach outlined in this deliverable.

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1.3 TASK 2.5: FUNCTIONAL SPECIFICATIONS FOR STANDARDISED DATA ACCESS AND INTEGRATION

Task 2.5 aims to define the functional specifications required for standardised data access and exchange, ensuring interoperability within the i-STENTORE digital ecosystem. The task begins with an analysis of previous projects (e.g., INTERRFACE, PLATOON, BD4NRG, OneNet) and their findings on data access and integration. This analysis is followed by a detailed examination of the specific needs and data relevant to storage systems operation within the i-STENTORE project. Key activities include:

- **Evaluating Data Sharing Feasibility**: For each use case and data source, the feasibility of sharing raw data versus processed metadata is assessed. This includes consumer-centric use cases requiring data from devices like smart meters, NILM, and HEMS, which have varying formats and temporal granularity.
- **Ensuring Interoperability with Existing Standards**: The task ensures compliance and interoperability with standards such as SGAM, IEC61850, IEC CIM, COSEM, and ETSI TS 103673. These standards provide the framework for consistent and reliable data exchange across different platforms and systems.
- **Developing Specifications for Standardised Data Exchange**: The final output is a comprehensive set of specifications that facilitate standardised data access and exchange. These specifications are critical for the integration of data governance middleware and the successful implementation of the i-STENTORE digital platform.

The deliverables of Task 2.5 are pivotal for creating a robust and interoperable digital ecosystem, ensuring that all data flows within i-STENTORE adhere to the highest standards of interoperability and security.

1.4 TASK 2.6: REFERENCE ARCHITECTURE TAILORED TO AN OPEN AND MODULAR EUROPEAN ENERGY SYSTEM FOR OPTIMISED STORAGE TECHNOLOGIES USE LEADING TO INCREASED FLEXIBILITY

Task 2.6 is dedicated to developing the i-STENTORE Reference Architecture, designed to enhance flexibility and interoperability in a consumer-centric European energy system. This architecture builds on the work carried out within WP2, integrating novel technology tools, services, and business models aimed at optimizing energy storage technologies and managing available flexibility. The task involves:

- **Leveraging Existing Architectures:** Drawing from ongoing initiatives and projects like BRIDGE Data Management WG, H2020 BD4NRG, OneNet, INTERRFACE, and OpenDEI, the task extends and hybridises the SGAM model. This integration ensures that the architecture is versatile and can incorporate cross-sector roles and governance models.
- **Ensuring Standardization and Interoperability:** The reference architecture promotes the use of open standards and standardizable interfaces, facilitating seamless interoperability

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among different energy sectors. It emphasises data trust, sovereignty, and regulatory compliance in data sharing.

- **Developing Technological Connectors:** Translating the IDS architecture into technological connectors ensures secure, controlled, and efficient data exchange. These connectors are critical for enabling the multi-lateral, regulatory-preserving data sharing necessary for the i-STENTORE platform.

The comprehensive reference architecture developed in the frame of this task provides a detailed framework that guides the integration and operation of energy storage technologies, as outlined in the later sections to follow.

1.5 OUTLINE OF THE DELIVERABLE

This deliverable is structured to provide a detailed update on the progress and findings related to the development of business models, functional specifications, and the reference architecture within the i-STENTORE project.

- **The introduction** provides the scope, related tasks, and outline of the deliverable, the architectures & initiatives alignment, which describes the connection with the first version (D2.2) and outlines the pilot architectures and the novel business model design for ESS establishment which presents the methodologies and outcomes of designing business models for energy storage systems.
- **Chapter 2** connects the current deliverable with the first version (D2.2), detailing updates and refinements made to the initial frameworks. It provides a comparative analysis and updates from the previous deliverable, emphasizing enhancements in methodologies and frameworks to align with the latest technological and industry standards. It elaborates on the integration of innovative pilot architectures designed to demonstrate the applicability and benefits of the project's business models and technical specifications in real-world settings.
- **Chapter 3** delves into designing and evaluating innovative business models for ESS. It includes a co-simulation environment for testing models, identifying revenue opportunities and barriers, and developing multi-use storage deployment strategies. The chapter also addresses second-life applications of storage systems, providing economic and environmental insights.
- **Chapter 4** describes various business and system use cases within the i-STENTORE project. It outlines practical applications of the developed business models and technical specifications across different demonstrations within the i-STENTORE project. It details various scenarios, highlighting the implementation of the project's components in real-world environments to validate their effectiveness and efficiency.
- **Chapter 5** outlines the methodology for defining functional specifications for standardised data access and integration, including analysis of previous projects, planned demos, feasibility of data sharing, interoperability with existing standards, and developing coherent specifications.

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- **Chapter 6** covers the i-STENTORE reference architecture, including its vocabulary, concept architecture, and different versions. It discusses concept modelling, comparisons of demos, and the evolution of the architecture based on feedback and project needs. The comprehensive reference architecture outlined in this section serves as a blueprint for integrating diverse energy storage technologies and systems. It provides a detailed framework for implementing the project's technical aspects, ensuring consistency, scalability, and interoperability in its deployment.
- **Chapter 7** provides step-by-step integration guidelines for the various phases of the project, ensuring coherent and efficient implementation of the project's components. It serves as a practical guide for project participants, detailing the procedures and standards for integrating and testing the project's technological elements.
- Finally, **chapter 8** summarises the findings and progress made in the deliverable, emphasizing the refinements introduced in the second edition and the ongoing efforts to integrate advanced energy storage solutions within the European energy system.

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2. ARCHITECTURES & INITIATIVES ALIGNMENT

In this chapter we establish the continuity and enhancements made from the first version of the deliverable (D2.2). We detail how the initial frameworks and methodologies have been refined to address the evolving needs and findings of the project, ensuring that all updates align with the latest industry standards and technological advancements.

2.1 CONNECTION WITH 1ST VERSION (D2.2)

Enhancements and Refinements: D2.3 establishes continuity and improvements from D2.2 by refining the initial frameworks and methodologies to address the evolving needs and findings of the project. The updates ensure alignment with the latest industry standards and technological advancements, providing a robust foundation for energy storage integration and operation.

Reference Architecture: Both deliverables focus heavily on the development and evolution of the project's Reference Architecture. D2.2 presented the initial drafts and foundational concepts, while D2.3 refines these ideas, reflecting the project's progress and incorporating new insights gained since the inception. This refinement ensures the architecture stays relevant and effective for optimizing energy storage technologies and managing available flexibility.

Business Models and Functional Specifications: D2.2 included the early specifications and designs of business models, identifying functional specifications for standardised data access and exchange. D2.3 updates these components, offering more precise frameworks and methodologies for effective integration and operation of energy storage technologies within the project.

Pilot Architectures: Both deliverables discuss pilot architectures. D2.2 laid the groundwork by discussing initial pilot designs, while D2.3 elaborates on these designs, detailing operational specifics and demonstrating the practical applicability and benefits of the proposed business models and functional specifications.

Standardization and Interoperability: A key focus in both deliverables is the promotion of open standards and standardizable interfaces to facilitate seamless interoperability among different energy sectors. This is crucial for ensuring data trust, sovereignty, and regulatory compliance in data sharing.

Technological Connectors: D2.3 continues the work from D2.2 in developing technological connectors that ensure secure, controlled, and efficient data exchange, which are critical for enabling multi-lateral, regulatory-preserving data sharing necessary for the i-STENTORE platform.

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Detailed Framework: D2.3 provides a comprehensive update, including a detailed framework that guides the integration and operation of energy storage technologies, building on the initial concepts introduced in D2.2.

In summary, D2.3 aims to provide a more precise and effective framework for the integration and operation of energy storage technologies, reflecting the progress and insights gained throughout the project's development.

2.2 I-STENTORE PILOT ARCHITECTURES

This part of the document elaborates on the pilot architectures implemented within the project. It discusses the design and operational specifics of the pilot projects, highlighting how they contribute to achieving the overall objectives of enhanced grid flexibility and renewable energy integration. The architectures are tailored to demonstrate the practical applicability and benefits of the proposed business models and functional specifications. The key components of the pilot architectures include:

Integration of Different Storage Technologies: The pilot architectures integrate various storage technologies, generation assets, loads, business models, and services in an interoperable manner. This approach enables multipurpose use of storage, fosters the integration of renewable energy sources (RES), and optimises the use of available flexibility across different energy sectors.

Concept Modelling: The i-STENTORE model relies on established architectural initiatives and aims to extend the Smart Grid Architecture Model (SGAM) by aligning with key initiatives in Data Space architecture modelling such as IDSA and FIWARE. The model serves as a mediator ensuring seamless, technology-agnostic connections and integrations of various storage systems and interconnected assets.

Pilot Specifics: The pilot projects in D2.3 build upon the specific design and operational specifics detailed in D2.2. Detailed diagrams are provided to illustrate the different components involved in each pilot, their interconnections, and the communication protocols used.

Data Governance Middleware: D2.3 includes advancements in the Data Governance Middleware (iDGM) introduced in D2.2. This middleware is essential for achieving semantic interoperability across data providers and consumers within the energy and smart grid domains. Key components of iDGM include the i-STENTORE Data Store, Context Broker, Data Privacy & Security Module, Data Transformation Module, Analytics Engine, and Data Spaces Connector.

Technical Convergence: The technical convergence approach in D2.3 builds on the initial components outlined in D2.2, ensuring alignment with evolving project needs and technological advancements. Emphasis is placed on the use of standard APIs, common semantic models for data integration, and the interoperability of different systems and technologies.

What follows is the main objective and individual components of each pilot.

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Pilot 1 – Slovenia

The first Demo site is located in Hrastnik, Slovenia at partner HRAS facilities, and focuses on molten glass thermal storage. Additionally, the PV power plant (PVPP) is coupled to a hybrid energy storage system through the COMS flexibility platform to provide and manage flexibility. A more detailed architecture of Demo 1 is shown in Figure 1.

Objective: Integrate a molten glass thermal storage system with a rooftop PV power plant (PVPP) to optimize the use of solar energy and provide ancillary services.

Components:
The COMS flexibility platform is the core of the Demo 1 architecture, which integrates different systems and manages energy resources efficiently. The main components of the framework:

- **OPC Server:** Facilitates indirect control of the furnace, which is critical for the glass manufacturing process, ensuring safety and separation from direct external control.
- **Furnace Monitoring System (FMS):** Monitors the furnace operation, essential for maintaining glass batch quality and safety, but not directly controllable by external systems. This is connected to the flexibility platform through the VPN layer. OPC UA is used to communicate with the FMS. New tags were introduced into the OPC to control the available flexibility. The FMS has higher priority than any other component and can reject or limit the available flexibility to guarantee the quality of molten glass.
- **Programmable Logic Controller (PLC):** Manages furnace operations and interacts with the OPC server.
- **Historical and Real-Time PV Database:** Connects to SolarEdge monitoring server API to optimise solar power use in the glass melting process. The **Storage** is based on PostgreSQL Timescale, used to store historical and real-time data. It enables the creation of asset models and forecasting and is used to store the output of asset models and the scheduler service.
- **External Flexibility Service:** Developed by COMS, optimises PV energy usage and provides auxiliary services related to the molten glass thermal energy storage. **Asset models and scheduler service** are services necessary for forecasting the behaviour of the furnace and creating different optimizations. The output of the optimization is always a day-ahead schedule, which can be reevaluated in real time by changing different triggers (e.g., external DSO triggers, new production inputs, different optimization criteria).
- **PV solar system** Connected through the Solar Edge API for collecting historical production data, which is used for training the PV model. The live data is fed into the system and is used for monitoring, performance forecasting, and triggering necessary corrections.
- **i-STENTORE Platform:** A common component of all demos. It is an additional layer exposed to third parties. Flexibility will be offered to other partners using the I-STENTORE platform.
- **DSO/Marketplace:** A virtual component in our demo, as we do not have an external DSO partner. However, we will introduce an interface that could be used later for integrating DSO requests for flexibility activation. For demonstration purposes, this interface will be used to showcase services such as peak shaving and congestion management.

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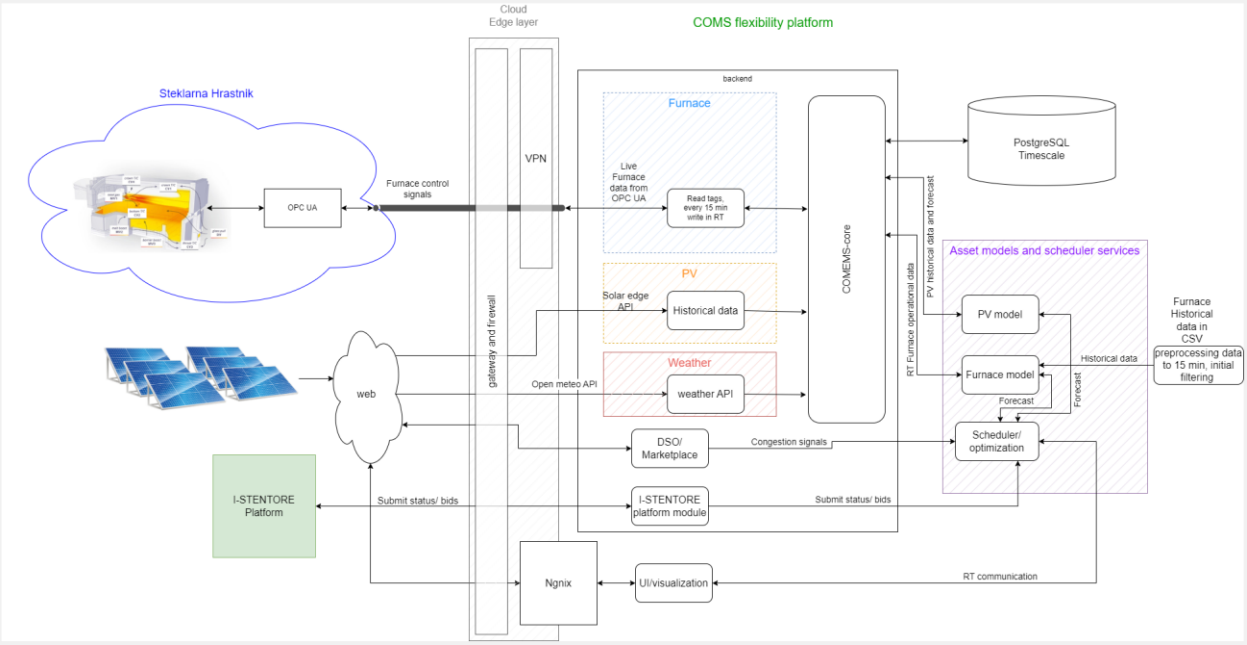

FIGURE 1: PILOT 1 ARCHITECTURE

Pilot 2 – Portugal

Objective: Utilising a Hybrid Energy Storage System (HESS) to manage renewable energy integration and grid stability on Madeira Island.

Components:

- **INESC TEC Virtual Machine:** Hosts the database, optimization algorithms, VRFB optimization algorithm, AI tool for water inflow forecast, and the front-end API.
    - **Database:** The database can store all the necessary data related to the Hybrid Energy Storage System (HESS), including historical and real-time data from the Li-ion battery, VRFB, and other integrated renewable energy sources like hydro-power, PV power, and wind power, it can hold the optimization results generated by the various algorithms, it can store inputs and outputs for the AI tool, it can log data related to the SCADA platform operations, and it can act as a central repository for data that needs to be accessed by different components of the system.
    - **Vanadium Redox Flow Battery (VRFB) optimisation algorithm:** This is the optimization algorithm for the 50 kW/100 kWh battery to be assembled in Porto and transported to Madeira.
    - **Optimization Algorithm and N-1 Dynamic Security Assessment:** Ensures system optimization and security.
    - **AI Tool for Water Inflow Forecast:** Predicts water inflow to optimize hydropower usage.
    - **Front-End API:** Provides an interface for optimization results and requests.

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- **i-STENTORE Platform:** Central platform for system data, optimization of results, and coordination.
- **EEM SFTP Server:** Facilitates data updates and dispatch set points between systems.
- **SCADA Platform:** Manages and monitors the HESS, integrating various renewable sources and optimizing their use for grid stability.
- **BESS → VRFB and Li-Ion battery storage system:** HESS composed of Li-ion and Vanadium Redox Flow Batteries (VRFB) and the battery management system.
- **RES (Renewable Energy Sources):** Integrates hydro-power with a reservoir, PV power, and wind power into the system.
- **Thermal Groups:** Conventional power generation units that produce electricity through the combustion of fossil fuels, such as natural gas, coal, or oil. These thermal power plants are included in the system to ensure grid stability and reliability.
- **Synchronous Condenser:** Provides grid stability and reactive power support.

The communication protocols utilise TCP/IP for data updates and MODBUS for point of operation communications.

Figure 2 illustrates all components and the details of data sharing within the Demo:

Update Regarding the software and algorithmic part of the Portuguese Pilot

An API is currently under development by INESC TEC, which EEM will use to request the execution of the dispatch algorithm and to access output data. This optimization algorithm is hosted on an INESC TEC virtual machine where all data provided by EEM via their SFTP server will be stored.

The objective of this dispatch algorithm is to define a general technology dispatch that is both economically optimal and dynamically viable. The process begins with a request from EEM through the API. The virtual machine will fetch updated data from the EEM server, which will then be used by the optimization algorithm. Subsequently, the results from the optimization algorithm will be evaluated using a dynamic-based procedure featuring the N-1 criterion.

If the algorithm's results indicate a safe and stable system, the data will be stored on both the EEM SFTP server and the INESC TEC virtual machine. If the output does not indicate a safe operational point, the algorithm will dispatch synchronous condensers and run again. This process will be repeated until a safe operational point is achieved. Once a stable operational point is determined, EEM will set their power generation and storage technologies to the defined point of operation.

A similar process is employed for the power smoothing service using the VRFB optimization algorithm. This process is initiated by EEM through a request via the aforementioned API. The INESC TEC virtual machine will then fetch updated data from the EEM server and run the VRFB optimization algorithm. Upon completion, the results will be stored on both the INESC TEC virtual machine and the EEM server, and the VRFB will be controlled accordingly.

Finally, system data and optimization results will be shared on the i-STENTORE platform.

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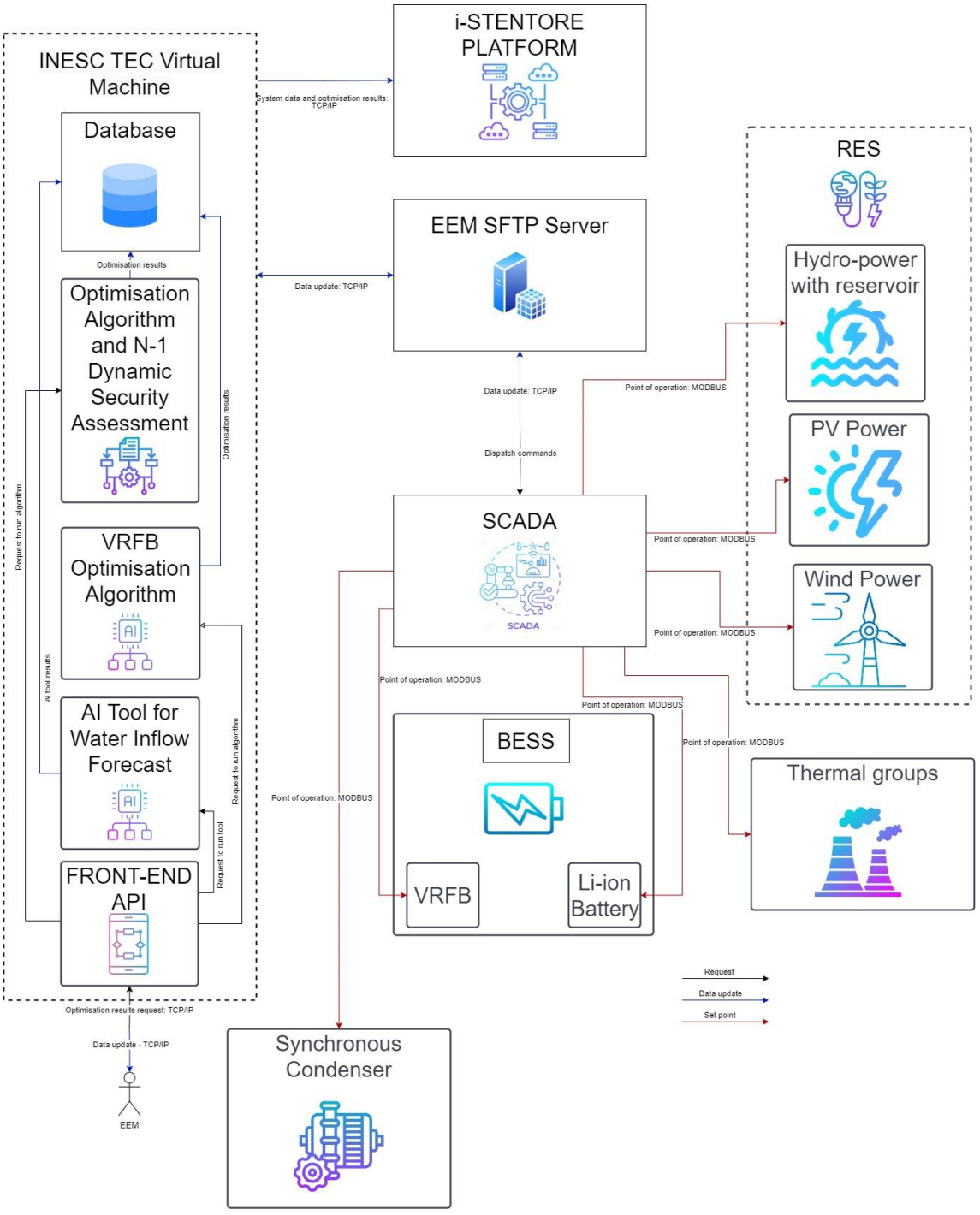

FIGURE 2: PILOT 2 ARCHITECTURE

Pilot 3 - Spain

Located in Spain, Demo 3 aims to bring together several storage and renewable generation components into a single large-scale VESS.

The separate storage technologies will be coordinated through a hierarchical operation and control system (HOCS) and an interoperable digital platform for energy and grid flexibility

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services management. After tests and evaluation regarding its quality and effectiveness as well as robustness in case of unexpected failures, the VESS-HOCS system will be integrated into the I-STENTORE digital platform, along with enabling the local DSO's interfaces to employ flexibility services for intelligent schedule generation for optimal asset exploitation.

Objective: Optimise the integration of renewable energy and enhance grid stability through a Virtual Energy Storage System (VESS) comprising different energy storage technologies.

Components:

- **Vanadium Redox Flow Battery (VRFB):** Located at a wind plant substation in Padul.
- **Lithium-ion Battery (LIB):** Situated at the "Parque Metropolitano Solar" PV power plant in Escúzar.
- **Hierarchical Operation and Control System (HOCS):** Manages the real-time coordination of energy assets, providing grid support services and managing battery degradation.

Regarding data access, several types of forecasting data are needed. Generation forecasting from solar and wind resources as well as the hydro schedule on one side, as well as energy demand forecasting data on the other have to be accessed as well as current market prices and historical market outcomes. On a local level, we retain battery data (SoC, SoH, voltage, current monitoring, etc.) as well as data from PMUs and from the DSO's SCADA.

Though data sources are generally not inventoried, the most relevant known sources are OMIE and REE data for historical market outcomes, along with the connected BESS, PV and Wind assets and the connected EMS. Data availability should be guaranteed at all times.

The details of data sharing within the Demo itself can be found in Figure 3.

The handled data is classified into confidential and publicly available data. Confidential data includes e.g., all plant operation and production data, models, layouts and other plant- and/or technology-specific know-how. Access to this information will be only given to specific persons for implementation purposes, and only after obtaining written permission.

Update Regarding the Current Situation of the Spanish Demo

As can be seen, the architecture presented in this deliverable for the Spanish Demo is the same as that reported in D2.2. Although significant progress has been made in defining the architecture and other specifications of the demo during this period, given the uncertainties facing Demo 3 at the time of writing, it is preferable to maintain this general description and report the final specifications once the uncertainties have been resolved. These uncertainties are since at the end of the first year of the i-STENTORE project, E22, the consortium partner responsible for supplying the VRFB for the demo, announced its intention to discontinue its participation in the project due to the closure of the VRFB production line for internal reasons. This means that the demo does not currently include the VRF battery, that was initially planned as part of the VESS.

At the time of writing, a final resolution of this situation has not been reached, so it is still uncertain whether the battery originally intended for the demo will ultimately be part of this pilot. Nevertheless, efforts have been made to explore alternative solutions that would preserve the core objectives of the demonstrator and the basic architecture.

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Once this situation has been definitively resolved and the characteristics of the demo have been adapted accordingly, the technical details and refinements of its architecture will be reported in subsequent versions of the deliverable. Nevertheless, all activities of the pilot regarding software development and optimization, as well as the procurement, assembly and deployment activities of the rest of the components and equipment are progressing normally in order to avoid further delays.

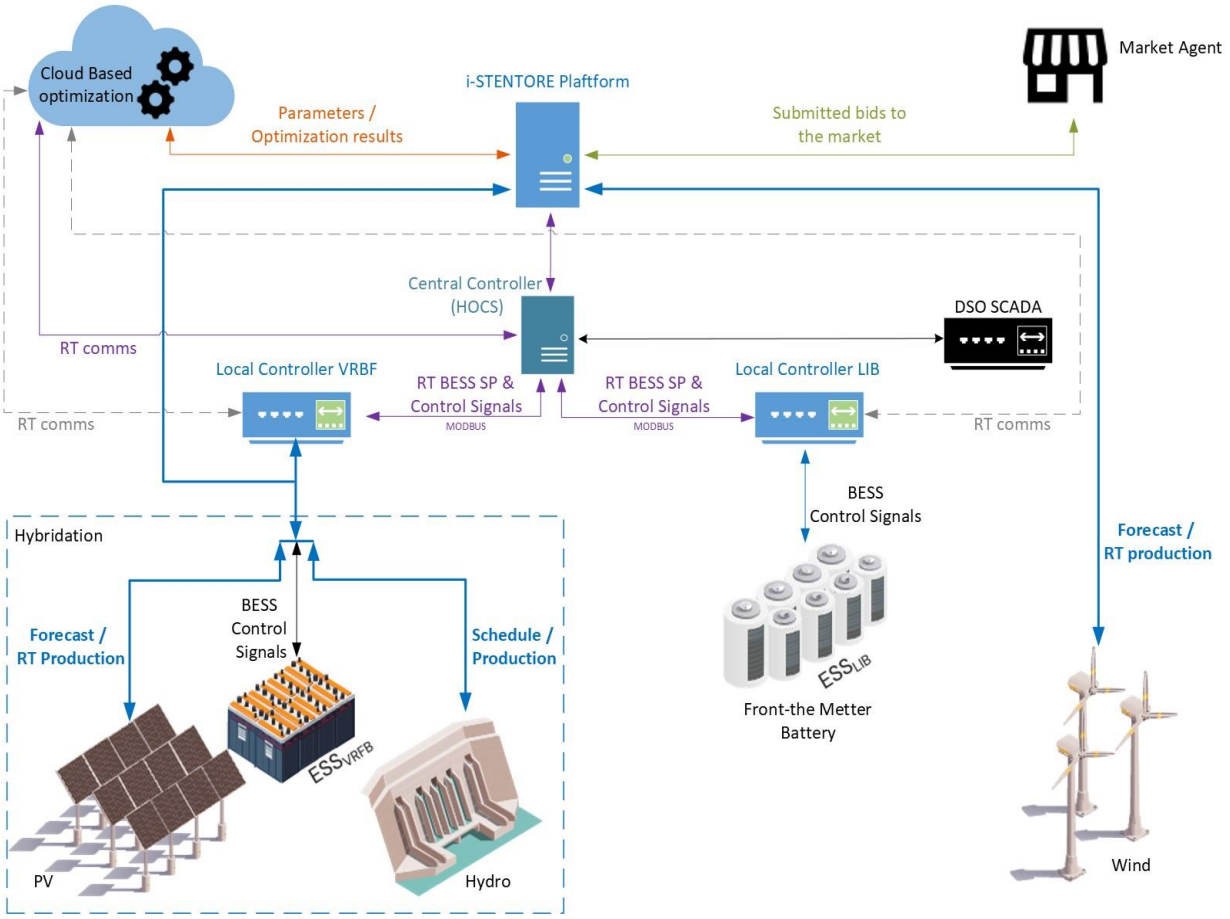

FIGURE 3: DATA SHARING IN PILOT 3

Pilot 4 – Italy

Demo site 4 is located in Italy at Pompei and Cava, covering two multi-charger hubs for EV-Mobility and Energy Services.

The Demo will set up and evaluate both hubs, and integrate storage systems based on PV sources, hybrid supercapacitor/battery technology, battery swap technology and a modular AC/DC Smart Microgrid architecture.

Objective: Demonstrate various ESS applications to improve Electric Vehicle (EV) charging services and grid support.

Components:

- **Hybrid Energy Storage System (HESS):** Composed of a lithium NMC battery and an LTO battery storage system, controlled by a DC/DC converter.

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- **Ultra-Fast Charging Station (UFCS):** Integrated with HESS for improved performance and reduced impact on the grid.
- **SCADA System:** Monitors PV implants, batteries, and micro-grid activities, optimizing energy distribution and recording data for energy saving calculations.

The main types of data that need to be accessed therefore are the PVPP power generation, and operation data from EVs and their charging stations. This includes EV state of charge, maximum charging / discharging power and energy demand, as well as charging station available power. The needed data is accessed via Open Charge Point Protocol (OCPP), which comes from a GES platform; data availability is not guaranteed at all times.

The handled data is classified into confidential and publicly available data. Confidential data includes e.g., all plant operation and production data, models, layouts and other plant and/or technology specific knowhow. Access to this information will be only given to specific persons for implementation purposes, and only after obtaining written permission.

At time of submission, some information regarding these questions are still unclear, however all open issues will have been resolved until the next release of this Deliverable. Figure 4 illustrates the internal architectures of the Italian pilot.

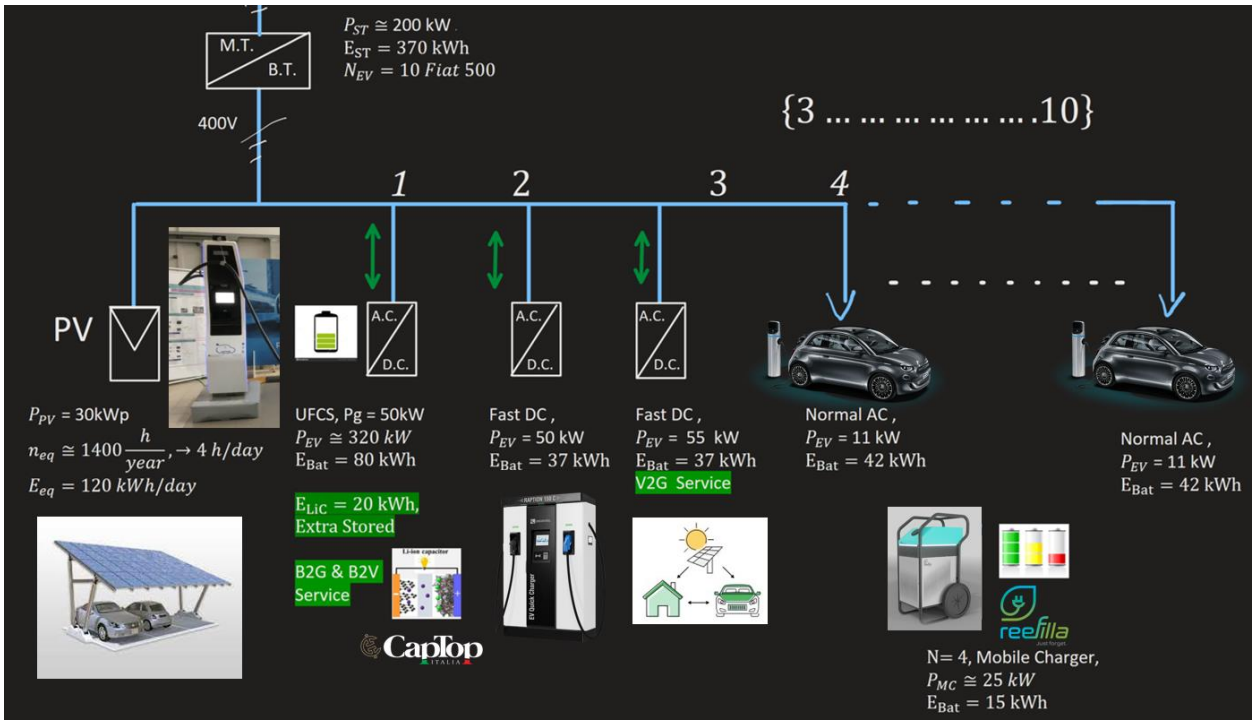

FIGURE 4: INTERNAL ARCHITECTURE OF THE ITALIAN PILOT

The composition of a Micro GRID EV charging hub can be outlined as follows:

Shelter with PV Roof

- Power Output: 30 kW
- Function: Provides renewable energy to the grid and charging stations, reducing dependency on external power sources.

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AC Quick Stations

- Number of Stations: 4
- Power Output per Station: 44 kW
- Connectors per Station: 2 Type 2 connectors
- Total Power Output: 176 kW

DC Ultra-Fast Station

- Power Output: 320 kW
- Power Source: Powered by HESS (Hybrid Energy Storage System)
- Function: Provides ultrafast charging for EVs, significantly reducing charging time.

DC V2G Bi-Directional Charger

- Power Output: 15 kW
- Function: Allows for vehicle to grid (V2G) technology, enabling EVs to discharge energy back into the grid, thus supporting grid stability and energy management.

Hybrid Energy Storage System (HESS)

- Lithium Battery: 150 kW
- Supercapacitor
- Function: Stores energy to manage the load, providing stability and supporting the ultrafast charging station. Supercapacitors handle short-term high-power demands, while lithium batteries provide longer term energy storage.

Figure 5 presents the details of data sharing within the Demo:

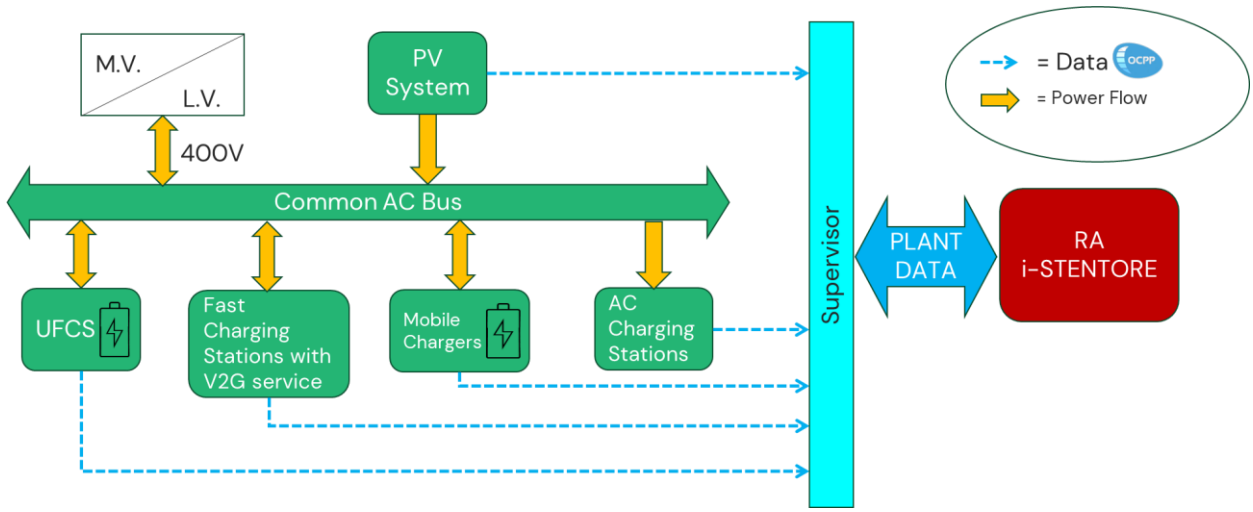

FIGURE 5: DATA SHARING WITHIN THE ITALIAN PILOT

Here are the details for data sharing at the Demo 4 charging hub:

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- **Communication Protocol**: The Demo 4 charging hub will utilize the Open Charge Point Protocol (OCPP) to facilitate communication between the electric vehicle (EV) charging stations and a central management system.
- **Management Platform**: The charging hub will be managed via a cloud platform and an associated app, enabling EV drivers to autonomously charge their vehicles and process payments.
- **Data to be Shared with the i-STENTORE Cloud Platform**:
  - Daily Production Amount: The amount of electrical energy produced daily by renewable sources.
  - Daily Auto-Consumption: The daily amount of renewable energy consumed by the charging station itself.
  - Renewable Energy for Mobility: Calculation of the amount of renewable energy utilised for EV charging.
  - Storage System Operation: Daily initial and final State of Charge (SoC) for all storage systems.

Pilot 5 - Luxembourg

Demo 5 focuses on an Agri-PV (APV) farm located in Luxembourg, which contains a multi-energy station combining several different resources to be used and expanded during the project.

The pilot integrates a hybrid energy storage system consisting of two different technologies, a large-scale electrolyser (ELY) for green hydrogen production and a utility-scale BESS with an agri-photovoltaic (APV) plant and wind power generation. The hydrogen produced by the electrolyser will be stored in trailers and transported over short distances to industrial users. The energy management of the farm's assets will be ensured by the optimal operation of the BESS. The high-capacity, grid-forming BESS will provide new flexibility functionalities to the APV system and will be designed to potentially provide ancillary and flexibility services to the distribution grid. A proprietary high-precision HOCS to dynamically control the different operation scenarios of all energy processes at the different levels. The HOCS operation planning will be continuously optimised accordingly with real-time multi-objective numerical models taking into account the potential degrees of the energy storage systems and the forecasts of the APV generation, local energy demand and wholesale market prices.

Objective: Integrate a hybrid energy storage system with agri-photovoltaic (APV) and wind power to optimise energy use and provide grid support (improve grid reliability).

Components:

- **Hybrid Energy Storage System (HESS):** Combines large-scale electrolyser for green hydrogen production and a utility-scale Battery Energy Storage System (BESS).
- **Hydrogen Production and Storage:** Electrolyser produces hydrogen stored in trailers and transported to industrial users.
- **High-Precision HOCS:** Manages energy processes dynamically, optimizing the operation of the BESS and integrating it with renewable sources for enhanced grid support.

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The conceptual diagram of the platform that will host the different databases, services and relevant processes is shown in the Figure 6. The platform consists of four databases grouping the data according to their temporal characteristics with respect to the services. These databases are called, management, operation, planning and historical.

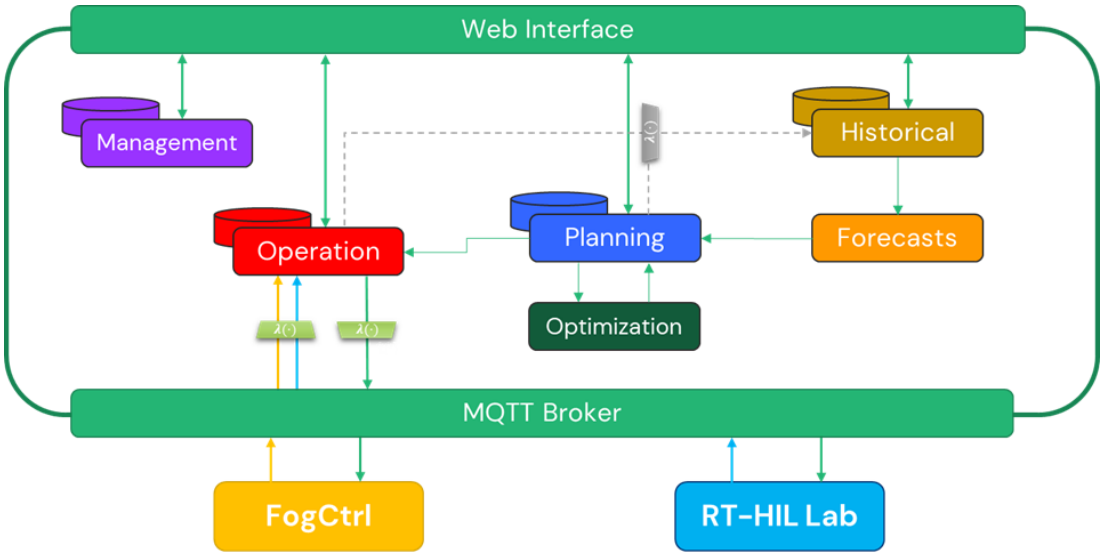

FIGURE 6: CONCEPTUAL FLOW DIAGRAM OF THE CONTROL PLATFORM OF DEMO

- **Management DB:** Stores information about user accounts (credentials and basic details), the characteristics and specifications of the energy components of this demo, i.e., the BESS, Electrolyser, Hydrogen tank, etc.
- **Operation DB:** Stores streaming data from sensors and metering devices from the different components in real-time. Also, it includes information about the active services.
- **Planning DB:** Stores information related to short term planning i.e., from 24 to 72 hours ahead. The planning of the demo is based on certain inputs, like forecasts of generation and wholesale market prices. This information is also stored in this database.
- **Historical DB:** Essentially keeps a record of all data from the operation and planning DBS for later analysis and evaluation. These data are used also from the forecast engine for fitting new more accurate models and provide the actual forecasts.

The 'Forecasts' block hosts processes that are required for retrieving relevant data from the historical database, loading the appropriate model, and providing the forecasts that are necessary for the 'Optimisation' block. The 'Optimisation' block hosts the optimisation models for the different services. This block will pull inputs and push outputs to the planning DB. The platform will interact with the demo components using the MQTT protocol through a message broker. During the design and development phase, these components will be simulated in the RT-HIL laboratory to enable message exchange between the platform and the real-time simulators. Later, communication with the real equipment will be established using the same structure as with the virtual equivalents. All the data resulting from the different processes will be accessible through dedicated dashboards hosted on a web-interface.

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The overall data exchange between the different components in this demo is shown in Figure 7. As discussed above, the optimizer determines the schedules for the electrolyser and the Battery Energy Storage System (Li-ion BESS) in the cloud. This information is sent to the fog control (Area Controller), which distributes the schedules to the corresponding components. In the case of the BESS, the schedule is first passed on to the edge control (Local Controller) that has direct communication with the battery's Battery Management System (BMS) or Converter. The communication protocol between the Fog and Edge Controllers, as well as between the Edge Controller and BESS, is Modbus TCP/IP. Apart from the schedules, command or parameter information is sent from the Cloud to the Fog Controller, Edge Controller, and Li-ion BESS. Upstream data packages include real-time measurements and alarms/warnings, which also contain information regarding the state of operation of the BESS. The Fog Controller receives information from a Phasor Data Concentrator (PDC), which in turn receives information from three Phasor Measurement Units (PMUs) installed at different locations in the grid.

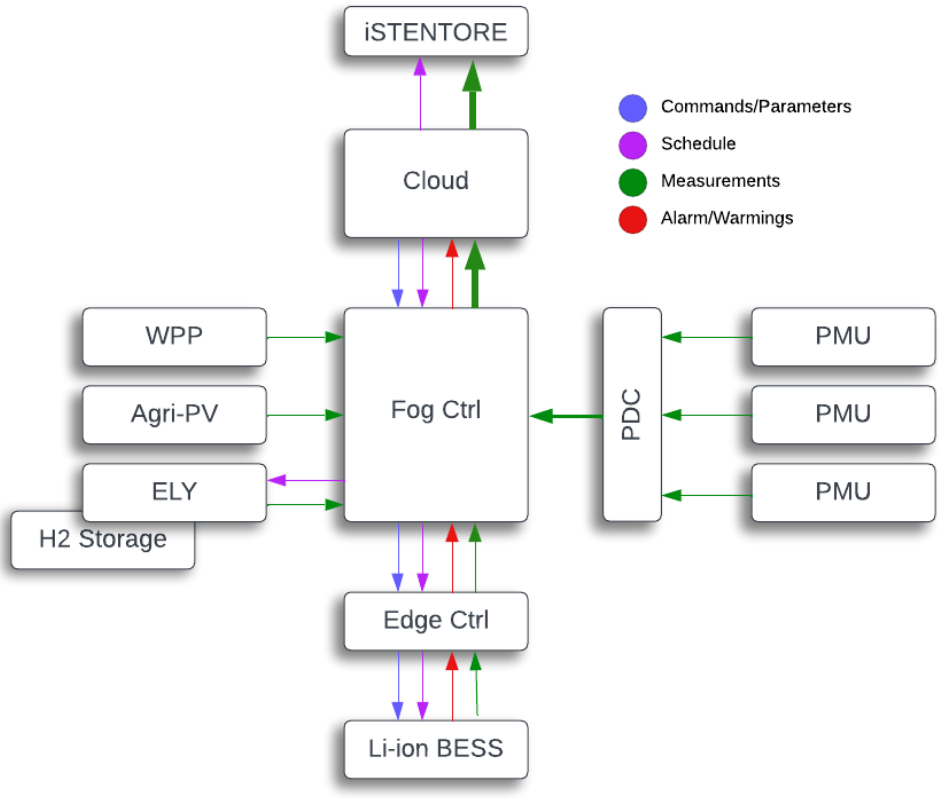

FIGURE 7: OVERAL DATA EXCHANGE OF DEMO 5 COMPONENTS

At this point, it is not clear whether the Wind Power Plant (WPP), Agri-PV, and ELY will transmit their measurements to the Fog Controller using Modbus TCP/IP or another protocol, or communicate directly with the Cloud. Assuming the former, all the information regarding their real-time measurements will be sent to the cloud through the Fog Controller. In such a design, there will be a single communication channel between the cloud and the assets, through the Fog Controller. Finally, information regarding the assets' performance and their schedules will be available to users through the i-STENTORE middleware.

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Interfacing and Data Management of the Luxembourgish Pilot

After modelling its energy processes, the farm's control functionalities will be designed and tested using a digital environment. This is followed by the installation of a utility-scale grid-forming 1MW/1MWh BESS, before i-STENTORE digital platform is deployed and used for managing energy and services in the APV plant.

In order to follow through with the Pilot's goals, access to and processing of several types of data is necessary. The overall most important types of data are the PVPP and wind power energy generation, hydrogen electrolyser process data, and battery metering. Accordingly, the main data sources within this use case are PMUs, Plant Controllers, Smart Meters, and the plant's EMS. In addition, day-ahead market data as well as weather data are required. Data availability should be guaranteed at all times. The User interface and data sharing of the pilot is shown in Figure 8.

Regarding governance, since the Pilot 5 platform we will be hosted in AWS, there is a plan to use services like AWS glue and AWS lambda. Usage of IAM policies for fine-grained access control is being discussed.

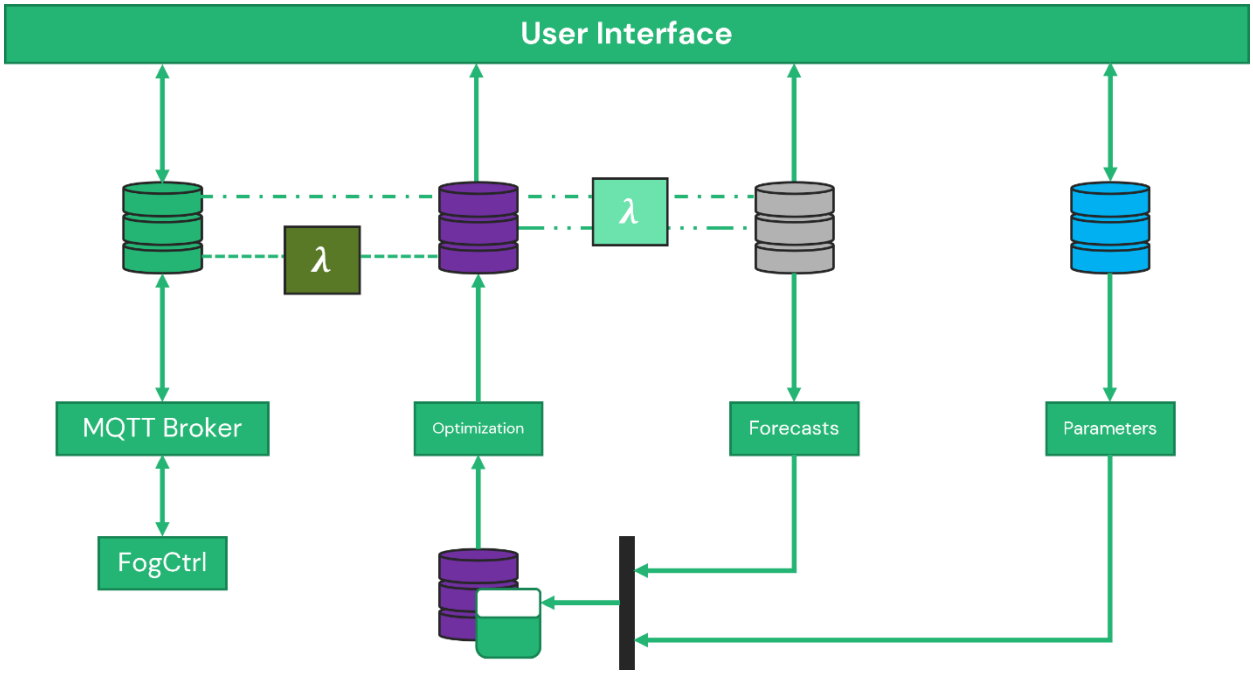

FIGURE 8: DATA SHARING IN PILOT 5

All operation data, including asset characteristics and parameters are classified as confidential within this Demo. Access to this information will be only given to specific persons or implementation purposes, and only after obtaining written permission.

Currently the Demo is facing uncertainties. The Electrolyser and the Wind Farm would have been implemented through a National Project, funded by the Luxembourgish Government and the Ministry of Energy. However, due to the Russian Invasion in Ukraine and the subsequent energy crisis, the Government revised its energy strategy, and the project was

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not funded after all. This means that parts of the equipment originally planned for the demo is not in place anymore. The consortium, in close collaboration with the EC, is currently looking for alternative solutions, one of which also include the change of the demo location and moving the demo to a site were the equipment originally envisioned, currently exists. We are also trying to ensure that the objectives, the scope and the impact created by the pilot will remain unaffected. Until a decision is reached, the partners continue working on software and hardware developments that remain unaffected by any potential changes in the pilot. This will minimize any potential delays introduced by these issues.

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3. NOVEL BUSINESS MODEL DESIGN FOR ESS ESTABLISHMENT

This chapter delves into the design and evaluation of innovative business models for energy storage systems. It outlines the co-simulation environment used for testing these models, the identification of revenue opportunities and barriers, and the development of multi-use storage deployment strategies. The chapter also addresses second-life applications of storage systems, providing insights into their economic and environmental impacts.

3.1 INNOVATIVE BUSINESS MODELS

As outlined in Deliverable 2.2. a business model can be defined as a conceptual structure to describe the operation and requirements for a functional application. In the realms of this work, functional applications are those being deployed on a BESS for a potential revenue gain from its operation. Towards the operation, the requirements for business models need to be investigated and carefully modelled at a later stage. The potential revenue gains could be derived from system or trading services. For system services, the European balancing markets allow a great potential for BESS to be operated on. In here, the implementation of the European Electricity Guideline (GL-EB) foresees a common market for control reserves. The balancing markets can be divided into frequency containment reserve (FCR), automatic Frequency restoration reserve (aFRR), and manual Frequency restoration reserve (mFRR). The requirements can be found in Deliverable 2.2. The application of operation on the FCR-market will later be taken into account. Another application for innovative business models is the application of peak shaving via BESS. In this operation mode, an electricity customer with high peak demand seeks to reduce these by a BESS. In periods of high demand, the BESS will withdraw power and recharge in periods of low demand. This will help to reduce the electricity bill, since industrial customers pay beside the normal electricity consumption a price for power withdrawn, that is oriented at the maximum power withdrawal over a year or month, depending on the grid operator. Despite the potential usage, the utilisation hours of the BESS remain small. Therefore, the potential for multi-use operation is high, since in the idle periods the BESS can be stacked with an additional application. Black starting capability, islanding operation and grid booster applications have also gained attention recently, however since there are no existing market schemes, the procurement is untransparent and cannot be analysed within this work.

For the trading service, the short-term energy arbitrage is suited for operation on a BESS, since the product length as well as the minimum energy bids allow the short-term trading.

3.2 CO-SIMULATION FRAMEWORK

For the identification of new business models for energy storage systems a co-simulation framework, mosaic [1], was used, which allows the coupling of several simulation models. Originally designed for smart grid scenarios, it can be furthermore used for the integration of

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different simulators into power systems. In this work, a simulator is a virtual BESS that is dispatched for optimized operation with different applications being stacked.

FIGURE 9: MOSAIK CO-SIMULATION FRAMEWORK

In Figure 9, the conceptual outline for the co-simulation framework is presented. In there, the mosaik is the core that couples the different simulators, which could be in this case the power system, a basic household, individual appliances such as PV plant or heat pumps and the possibility to control or monitor the different status. MOSAIK (shown in Figure 10) allows the coupling of either time-discrete or event-discrete simulators, however, for this work only a time-discrete simulator is needed. The virtual BESS is then implemented as an optimization problem, which seeks to maximize the revenue during the operation.

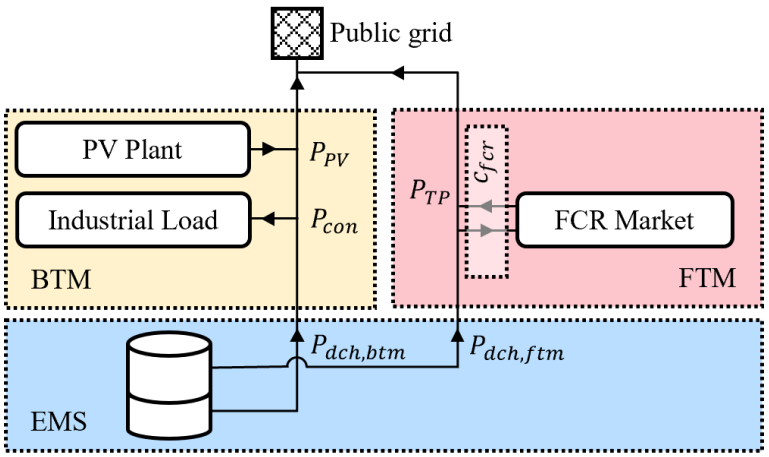

FIGURE 10: MOSAIK CO-SIMULATION FRAMEWORK

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During dispatch, the virtual BESS will report its operational state as well as the allocated or reserved power/energy for the different applications. This way the operational requirements and constraints are always satisfied. Additionally, a load flow analysis for a typical medium voltage grid is enabled, to check for violations on the power grid, however, this is only for monitoring purposes. The resulting optimization problem will be later reported for the individual applications.

3.3 MODELLING OF BUSINESS MODELS

In the following section, the business models will be modelled for the purpose of being used in optimization models. For the analysis of the revenue gains by the different applications a mathematical optimisation scheme is used.

3.3.1 BTM and FTM Splitting

Since the regulatory framework must also be considered during the operation of the BESS, we use the proposed BTM and FTM split by (Englberger et.al.,2022). In here, the battery is split virtually by FTM and BTM applications. This is translated as a constraint that no power will be exchanged between the operation for balancing power and the power consumption from the grid.

For this reason, a generic battery model is introduced.

Variables

$P_{ch}(t), P_{dch}(t)$	**Active charging and discharging power**
$X_{ch}(t), X_{dch}(t)$	**Complementary charging and discharging variables**

Set

$$\lambda = \{btm, ftm\}$$

$$t = \{1, \ldots, |T|\}$$

Subject to

$$P_{ch}(t) \leq X_{ch}(t) * P_{bat,max}$$

$$P_{dch}(t)\ X_{dch}(t) * P_{bat,max}$$

$$X_{ch}(t) + X_{dch}(t) \leq 1$$

$$P_{ch,bat} = P_{ch,btm}(t) + P_{ch,ftm}(t)$$

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$$P_{dch,bat} = P_{dch,btm}(t) + P_{dch,ftm}(t)$$

$$SoC_{bat}(t) = SoC_{btm}(t) + SoC_{ftm}(t)$$

$$SoC_{bat}(t) = SoC_{bat}(t-1) + P_{ch}(t) * -P_{dch}(t) * (2-) * \frac{\Delta t}{C_{bat}}$$

$$SoC_{bat}(0) = SoC_{bat}(T)$$

$$\forall\, t \in T$$

In the following the generic battery model will be used to expand the applications on it. Therefore, it will mark the baseline for the optimization, but individual applications must be modelled in accordance with the regulations as well as the physical limitations.

3.3.2 Peak Shaving

For instance, the application of peak shaving for a BESS yield at reducing the maximum peak power drawn from the grid in a certain period (e.g. monthly or yearly). An industrial utility can significantly reduce the price of electricity since the peak power increasing the need for grid reinforcement and distribution grid operators would be willing to reduce the electricity costs on the bill. Such an example is given in the Figure 11.

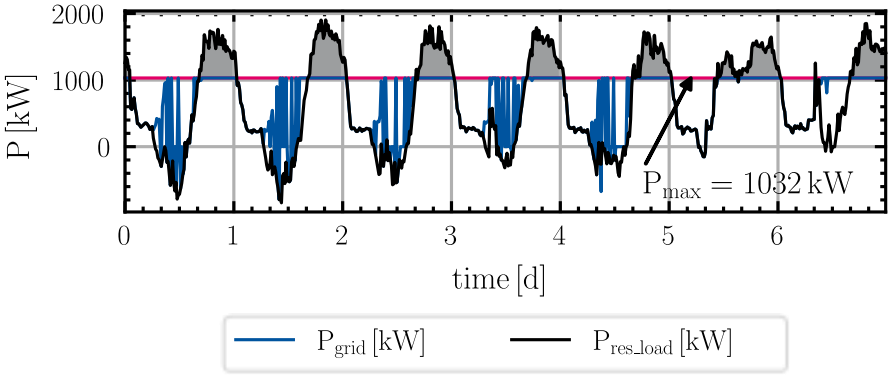

FIGURE 11: PEAK POWER REDUCTION BY PEAK SHAVING ON AN ELECTRICITY GRID

In Figure 11, the black line indicates the original load profile, and the purple line represents the peak power from which the battery shall be used for releasing power. The application of a BESS in peak shaving mode will need constant reconsideration of the peak power necessary to shave, because the once occurring peak power sets the price. Therefore, a controller needs to be aware of the actual maximum power, from which it should be used. Therefore, the energy levels of the BESS must be at specific limits, so that it can serve the requested dispatch. In operation mode, this will increase the complexity due to uncertain load profiles from industrial applications. An accurate forecasting will help to ensure an optimal operation, since a single point in time which surpasses the desired peak power would result in high costs. Nonetheless, for the purpose of this study, only an optimal operation will be considered for

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the quantification of peak power reduction. The generic battery model will be used and only the behind-the-meter branch of the battery is in use. The mathematical model reads as follows

Objective:

$$\min P_{max}$$

Subject to:

$$P(t) = P_{con}(t) - P_{PV}(t) + P_{ch}^{btm}(t) - P_{dch}^{btm}(t)$$

$$P_{max} \geq P(t)^2$$

$$P_{ch}^{btm}(t) \leq P_{PV}(t)$$

$$P_{dch}^{btm}(t) \leq P_{con}(t)$$

In this optimization problem, the objective function is to minimize the peak power drawn from the grid P_{max} for all periods, by setting a time-linked upper limit to the power $P(t)$ which represents the power drawn from the system for covering consumption $P_{con}(t)$, pv production $P_{PV}(t)$ and charge $P_{ch}^{btm}(t)$ and discharge $P_{dch}^{btm}(t)$ actions for the battery.

3.3.3 Frequency containment reserve

The application frequency containment reserve (FCR) complies with the offering of balancing power, which is offered by the BESS. FCR is then automatically activated without further requests by the TSO. Each operator for FCR has a controller that reacts to the local measured frequency. If a deviation of ±200 mHz from the normal frequency is measured, the participating power plants must provide the entire FCR within 30 seconds. The power output of the power plants is increased or decreased linearly and maintained for up to 15 minutes. A dead band of 49.99 - 50.01 Hertz is given, where no FCR must be provided.
This deadband and the linear power provision is also shown in the Figure 12.

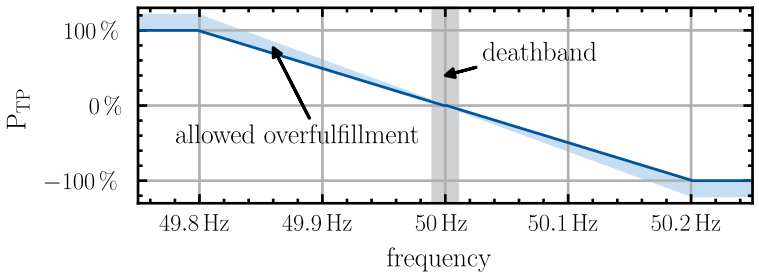

FIGURE 12: DEADBAND FOR BALACING POWER FROM FCR

In Figure 12, the deadband is shown as well as potential allowed overfulfillment for a given frequency deviation from the nominal frequency of 50 Hertz. The modelling of the application with FCR on a BESS will need to comply with the regulations. However, for the time granularity,

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using seconds or even milliseconds to regulate power is out of scope for mathematical optimization. Therefore, a mathematical optimization framework will account for the power reserved for FCR and for the amount of power withdrawn or consumed resulting in varying state-of-charge levels. Since the application of FCR results in capacity price for the allocated power paid, the optimization will seek to maximize allocated power.

Objective:

$$\max \sum_{t=0}^{T_{sim}} P_{TP}(t) \cdot c_{fcr}(t) \cdot \frac{\Delta t}{4h}$$

Subject to:

$$\forall t \in T: \text{ if } t_{sim} + t \neq 0 \bmod 4h \rightarrow P_{TP}(t) = P_{TP}(t + \Delta t)$$

$$P(t) \equiv 0 \bmod INK$$

$$1.25 \cdot P_{TP}(t) \leq P_{max}^{bat}$$

$$X_{buy}(t) + X_{sell}(t) \leq 1$$

$$P_{buy}(t) \leq X_{buy}(t) \cdot P_{max}^{bat}$$

$$P_{sell}(t) \leq X_{sell}(t) \cdot P_{max}^{bat}$$

$$P_{buy}(t) \geq X_{buy}(t) \cdot 100\ kW$$

$$P_{sell}(t) \geq X_{sell}(t) \cdot 100\ kW$$

$$\text{if } p_{fcr} < 0:$$

$$P_{buy}(t) - p_{fcr} \cdot P_{TP}(t) \leq P_{ch}^{ftm}(t) \leq P_{buy}(t) - 1.2 \cdot p_{fcr} \cdot P_{TP}(t)$$

$$P_{dch}^{ftm}(t) = P_{sell}(t)$$

$$\text{if } p_{fcr} = 0:$$

$$P_{ch}^{ftm}(t) = P_{buy}(t)$$

$$P_{dch}^{ftm}(t) = P_{sell}(t)$$

$$\forall\ t \in T$$

In the model, the optimization problem seeks to maximize the tendered power for FCR. It is ensured that the tendered power is reserved for 4 hours. Furthermore, the regulations foresee that over the entire period the BESS must be able to charge or discharge power, therefore ensuring an active SOC management. For this, the spot markets allow a minimum

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of 100 kWh. The overfulfillment is also satisfied with a constraint and in general the optimization problem can be used to find the optimal operation of a BESS for FCR provision.

3.3.4 Revenues from multi-use operation

With the two modelled applications, a multi-use operation can be obtained. In here, the model was tested for operation. The revenues are considered in Figure 13.

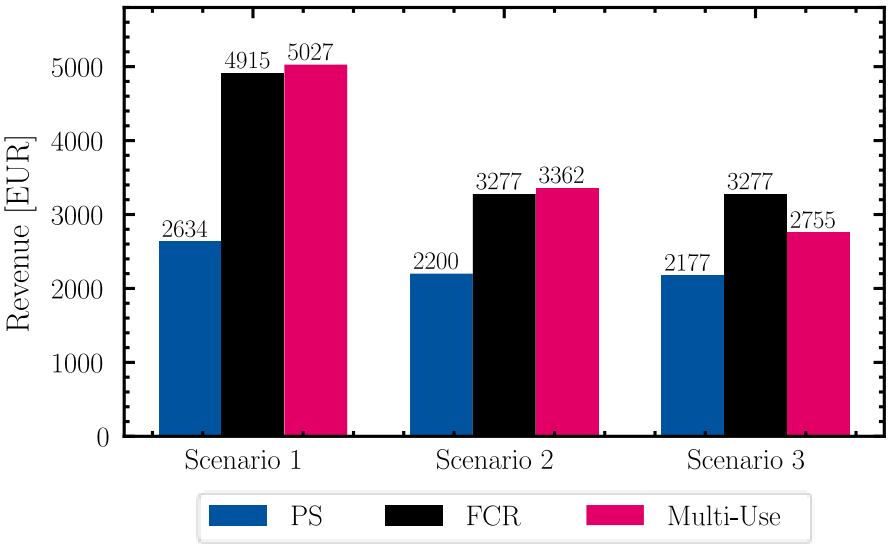

FIGURE 13: REVENUES FROM SINGLE AND MULTI-USE OPERATION

In Figure 13, exemplary revenues from single and multi-use operation are displayed. It can be observed that despite the multi-use operation yields mostly the highest revenues, but not in all scenarios. Each scenario represented a different configuration of the power-to-energy ratio but in the third scenario the application of peak-shaving was preferred and resulted in a lower revenue, since this would reserve too much power and reduce the potential revenues that can be gained from FCR operation.

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4. BUSINESS & SYSTEM USE CASES

This version of the document will cover the BUCs of Demos 1, 2 and 4 and SUCs of Demos 1 and 2, as a methodological approach that will be used eventually by all demos. Due to ongoing changes in the project as already explained in Section 2, Demos 3 and 5 will be further addressed in the final version D2.4. We present in this chapter the Sequence Diagrams and description of Actors for each UC. Some exemplary use cases following IEC 62559-2 standard can be found in Appendix A.

4.1 DEMO 1

Two UML diagrams present demo 1 (Figures 14 and 15). The first one presents the Business Use Case diagram, where the available flexibility from hybrid storage is offered to external actors outside the Demo 1 scope.

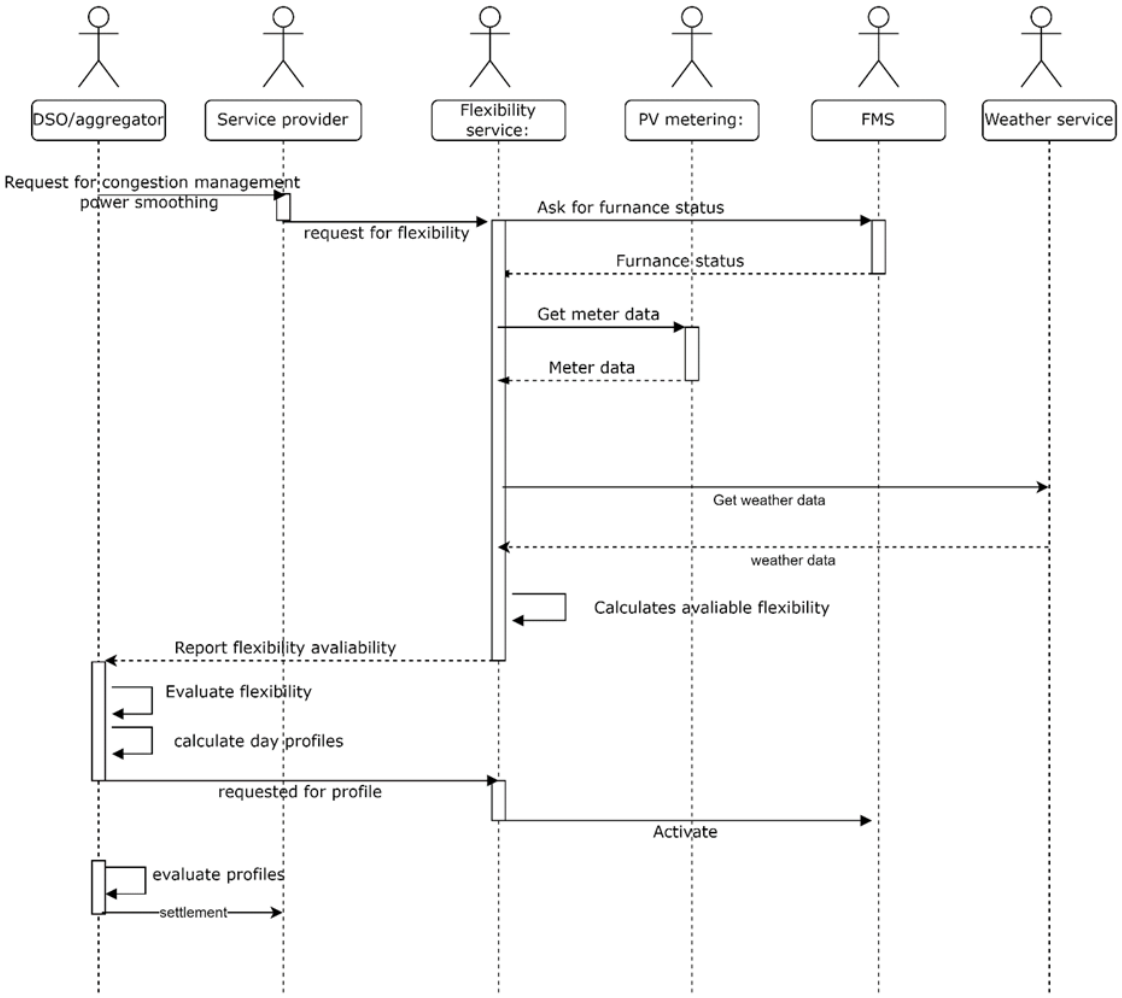

FIGURE 14: BUSINESS USE CASE OF DEMO 1

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The second diagram is a low-level or system use case diagram. It provides a detailed overview of interactions among different actors that will happen in Demo 1. This is also the basis for previous BUC, where the same flexibility can be offered through the marketplace.

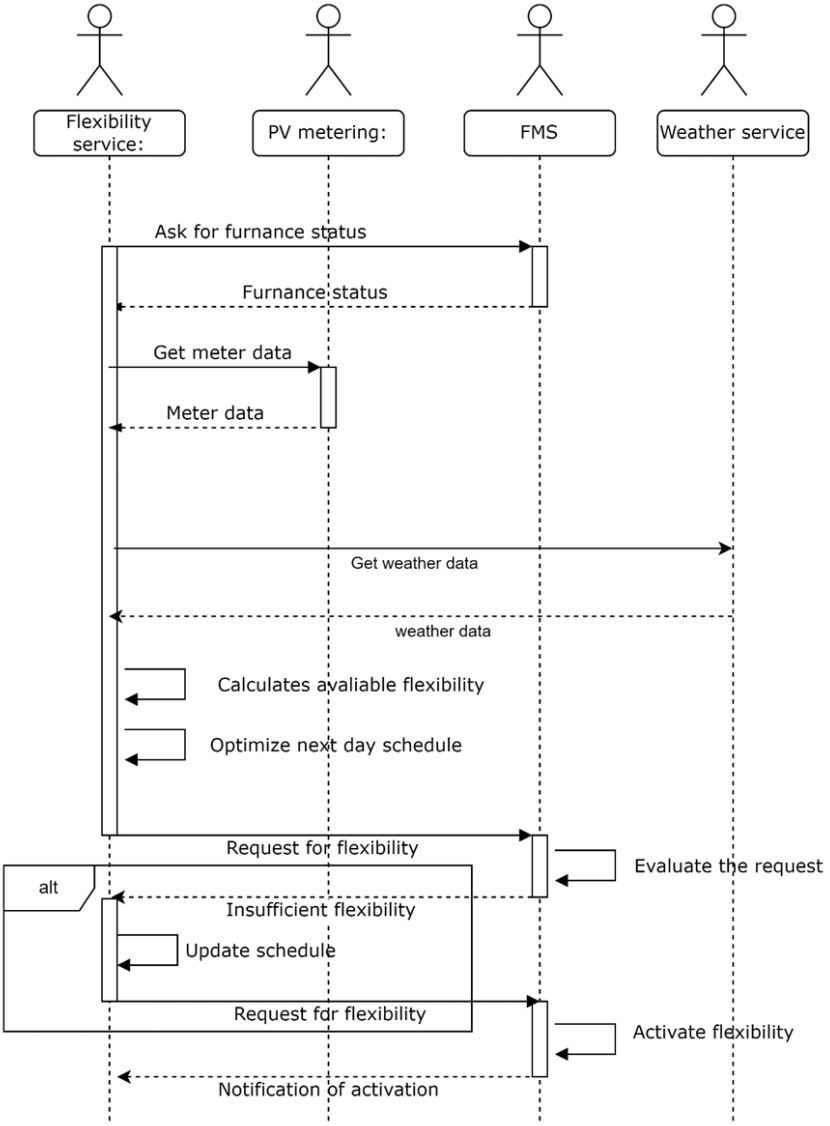

FIGURE 15: SYSTEM USE CASE OF DEMO 1

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The involved actors are introduced below:

TABLE 1: INVOLVED ACTORS OF DEMO 1 BUC

Actor name	Short description	Goal
Flexibility service	Entity responsible for calculating flexibility through forecasting process and creating the schedules.	Service responsible for creating schedules and evaluating the requests.
PV metering	A PV metering-related infrastructure with an API to access the historical and real-time data.	Provides historical and real-time data for other services.
FMS	Furnace Monitoring System is an integral part of hybrid storage.	The system responsible for controlling the furnace in connection to molten glass quality
Weather service	A third-party service providing weather predictions for the location of interest.	Service that provides historical and forecasted weather data.
Service provider	The entity that exposes the flexibility service to the third-party actors.	Exposes flexibility service to third-party actors.
DSO/aggregator	Distribution system operator/aggregator	Utilize the flexibility service.

The full Use Case description, following the IEC 62559-2 standard, can be found in Appendix A.1.

4.2 DEMO 2

Demo 2 on Madeira Island has two business use cases.

The first business use case features Electricidade da Madeira (EEM) as the primary actor, serving as the systems operator for the electrical grid on the island.
The ancillary services will be provided simultaneously by the optimisation process, represented in the sequence diagram bellow. The process consists in defining a general technology dispatch, optimal from an economic dispatch perspective and viable from a

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dynamic viewpoint. This optimisation process starts with a request from EEM through the API. The virtual machine will fetch updated data from the EEM server, which will then be used by the optimisation algorithm. Afterwards, the results from the optimisation algorithm will be assessed by a dynamic-based procedure featuring the N-1 criterion. If the algorithm outputs result in a safe and stable system, the data will be stored in EEM SFTP server and INESC TEC virtual machine. If the output does not result in a safe point of operation, then the algorithm will dispatch synchronous condensers and run again. This process is repeated until a safe point of operation is achieved. When a stable point of operation is calculated EEM will set their power generation technologies to the defined point of operation.

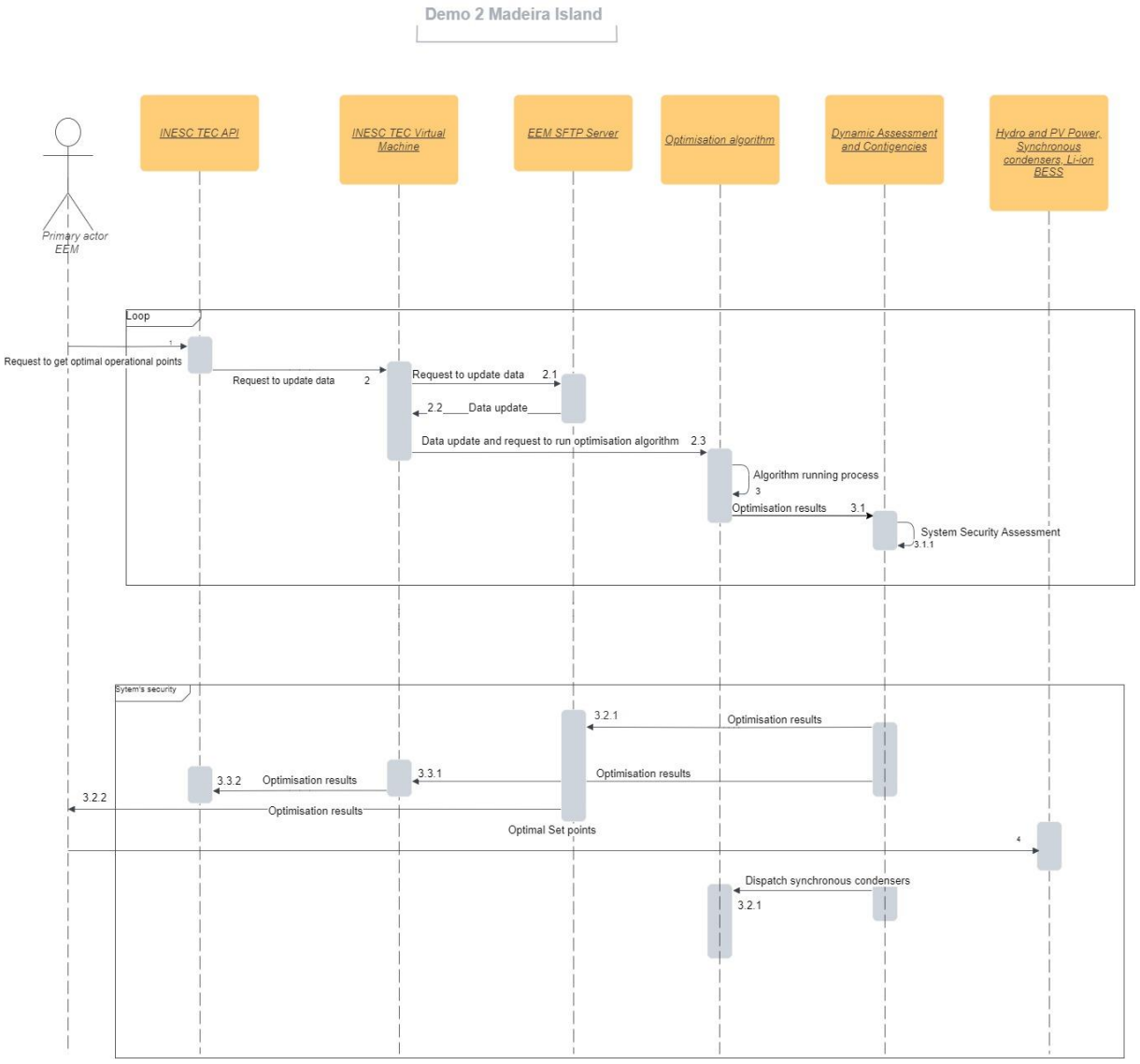

FIGURE 16: 1ST BUSINESS CASE OF DEMO 2

Figure 16 describes the first use case, Hybrid energy storage integration: synchronous condensers, pumped hydro, Li-Ion battery and VRFB for multiple services provision and increased RES integration in isolated power grids.

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TABLE 2: INVOLVED ACTORS OF DEMO 2 BUC

Actor name	Short description	Goal
EEM	Primary actor	EEM is the primary actor in this use case. As system operator, it is EEM that requests a service from the system under discussion and that aims at achieving the use case main objective.
Renewable energy companies	Secondary actors	Companies investing in renewable generation facilities are external actors as they are who provide the renewable curtailment service. They may also be regarded as external actors since they a stakeholder with a clear goal: minimise renewables curtailment.
Madeira regional government	External actor	The Madeira regional government is considered a stakeholder in this use case, as they have a significant interest in maximising local renewable generation to progressively decarbonise the island.
Electricity network clients	External actor	The customers of Madeira Island's electricity networks are considered stakeholders in this use case, as they have a significant interest in ensuring the resilience of the power grid.

The second use case regards the optimisation of the VRFB battery.

The VRFB will be used for power smoothing, the process is initiated by EEM through a request via the API previously mentioned, as shown in Figure 17. INESC TEC virtual machine will then fetch updated data from the EEM server and run the VRFB optimisation algorithm. The results will be stored in INESC TEC virtual machine and EEM server when the process is completed. EEM will control the VRFB accordingly.

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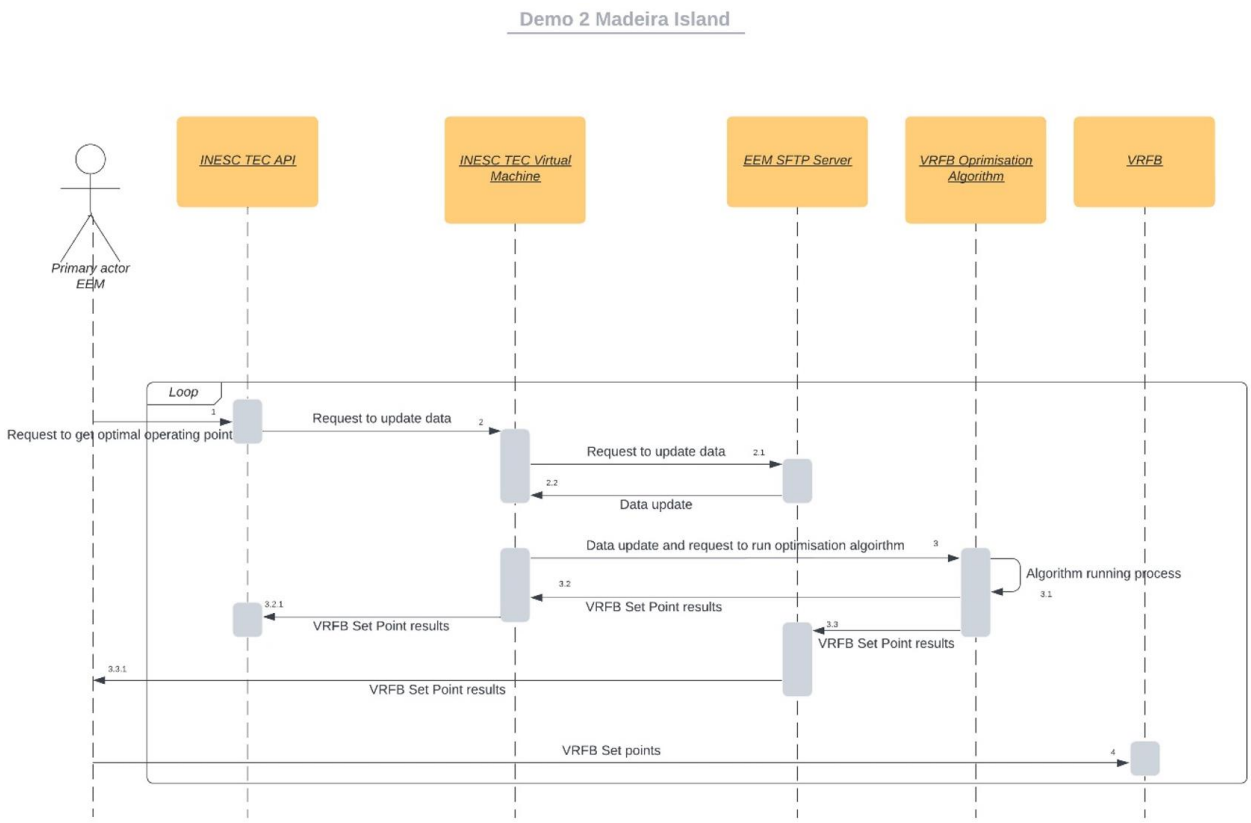

FIGURE 17: 2ND USE CASE OF DEMO 2

Figure 17, describes the second use case, Enhanced VRFB performance for power smoothing.

TABLE 3: INVOLVED ACTORS OF DEMO 3 BUC

Actor name	Short description	Goal
VRFB manufacturers	External Actor	VRFB manufacturers are primary actors in this use case. Manufacturers as VRFB providers will benefit directly from the project outcomes allowing to increase their system performance in terms of efficiency and lifespan.
Storage System Integrator	External Actor	Storage system integrators are primary actors in this use case as they will benefit from the hybridization system strategy and respective and project outcomes.

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EEM	Primary Actor	EEM is the primary actor in this use case. As system operator, it is EEM that requests a service from the system under discussion and benefit directly from the characteristics of the demo unit.
Renewable Energy Companies	Secondary Actor	Companies investing in renewable generation facilities are external actors as they are who provide the renewable curtailment service. They may also be regarded as external actors since they are stakeholders with a clear goal: minimise renewables curtailment.
Madeira Island Regional Government	Secondary Actor	The Madeira regional government is considered a stakeholder in this use case, as they have a significant interest in maximising local renewable generation to progressively decarbonise the island.
Electricity Network Clients	Secondary Actor	The customers of Madeira Island's electricity networks are considered stakeholders in this use case, as they have a significant interest in ensuring the resilience of the power grid.

4.3 DEMO 4

Demo site 4 is covering two multi-charger hubs for EV-Mobility and Energy Services.

The Demo will set up and evaluate both hubs, and integrate storage systems based on PV sources, hybrid supercapacitor/battery technology, battery swap technology and a modular AC/DC Smart Micro-Grid architecture, as shown in the diagram of Figure 18.

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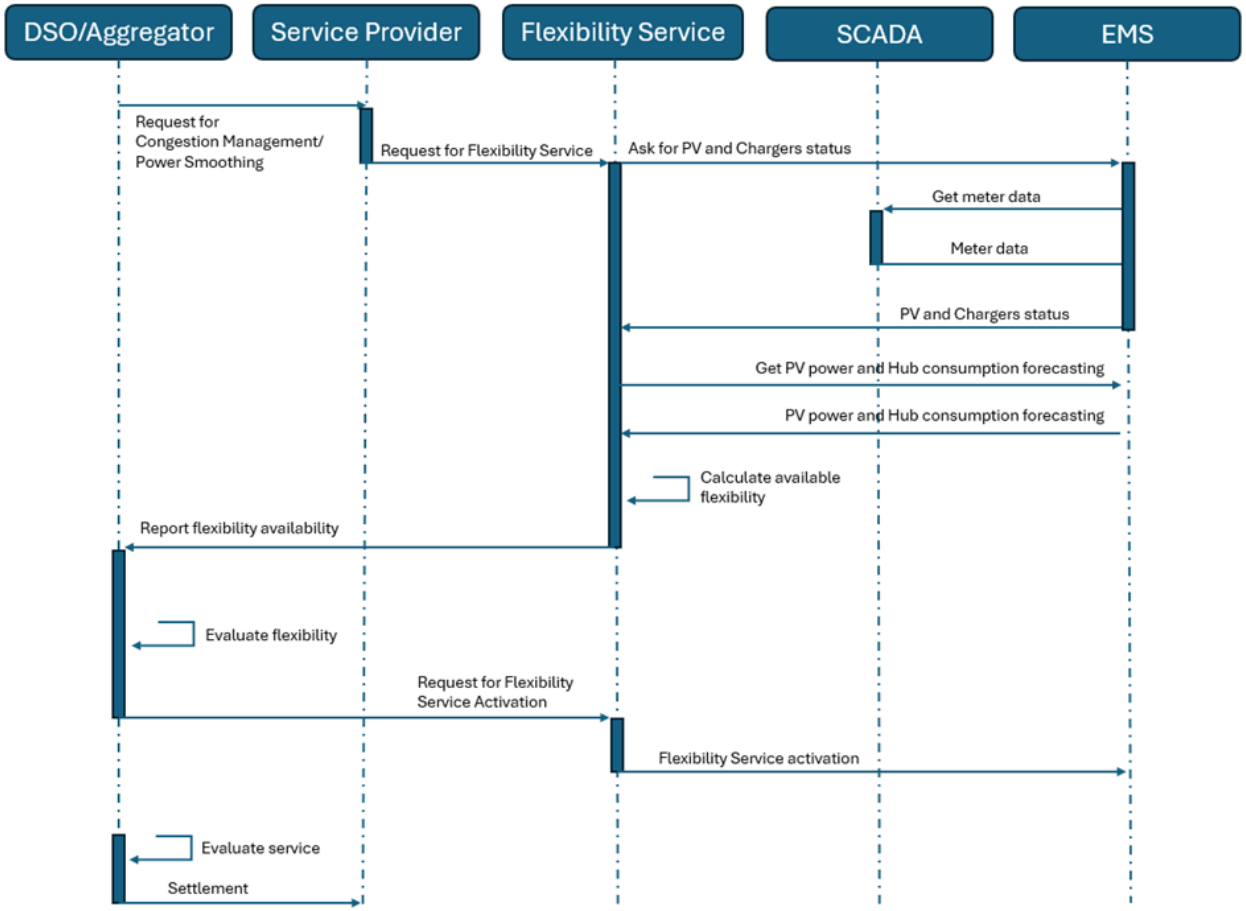

FIGURE 18: BUSINESS USE CASE OF DEMO 4

The involved actors are introduced below:

TABLE 4: INVOLVED ACTORS OF DEMO 4 BUC

Demo 4 Actor	Description
DSO/aggregator	Distribution System Operator (DSO) is the entities responsible for distributing and managing energy from the generation sources to the final consumers. Aggregator is an intermediate between DSO and prosumers/consumers.
Service Provider	Service Providers is an entity that offers electric service to customers within the service territory of an electric utility.

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Flexibility Service	Flexibility services are a range of existing and developing solutions that Service Provider can provide to help balance demand and supply in the electricity network and support its efficient use.
SCADA	Supervisory Control and Data Acquisition (SCADA) system is used for controlling, monitoring, and analysing devices and processes. SCADA system consists of both software and hardware components and enables remote and on-site gathering of data from the equipment.
EMS	Energy Management System: • Collects Hub technologies data. • Stores Chargers and weather forecasting. • Stores REC users' consumption forecasting. • Implements optimization algorithms. • Plans control operation to be carried out.

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5. FUNCTIONAL SPECIFICATIONS FOR STANDARISED DATA ACCESS & INTEGRATION

5.1 METHODOLOGY

The Methodology for Task 2.5 includes five stages:

1. Analysis of previous projects which have addressed similar matters
   a. INTERRFACE, PLATOON, BD4NRG, OneNet
2. Analysis of planned demos regarding data relevant to storage systems operation
3. Evaluation of feasibility of data sharing
   a. By use case and source
   b. Check feasibility of / need for sharing raw data or processed metadata
4. Define interoperability with SGAM and IEC family of standards
   a. (Such as IEC61850, IEC CIM (IEC61968, IEC61970, IEC62325), COSEM and ETSI TS 103673)
5. Bring together results into coherent specifications

Steps 1 and 2 have been completed, and documented in D2.1 and D2.2. The following section concerns step 3: Evaluation of feasibility of data sharing. This work firstly consisted of collecting the project's BUC and SUC information given in Chapter 4 of this document. An assessment was then made for each demo regarding the necessity and feasibility of sharing raw data as well as processed metadata. In the following, some initial functional requirements are extracted, which will be finalized in D2.4.

The maturity of this information is dependent on the level of input available from each Demo and can therefore vary. Any gaps will be closed in D2.4.

5.2 FEASIBILITY AND REQUIREMENTS OF DATA SHARING

Each Demo has their own internal data exchange needs. These differ by use case and are crucial for the demonstrator's individual setup, but not universally relevant for the I-STENTORE project's overall development. They are nonetheless introduced here. However, primarily relevant for WP3 implementation is each demo's need to communicate with outside providers within the I-STENTORE ecosystem. In the following, these needs are discussed along with possible requirements for data harmonization within each Demo's setup.

5.2.1 Demo 1

Overview of data sharing requirements within pilot

The internal data sharing needs of Demo 1 are mostly focused on the Flexibility Service and its need for data required for its calculations. This includes PV meter data and the Furnace

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Status from the FMS. Additionally, communication with the FMS is necessary to exchange flexibility requests, as well as evaluation results and activation notifications.

Required communication with I-STENTORE System

The flexibility service needs an interface to access external services, specifically one providing Weather Data. Additionally, a communication point with the central Asset Registration for I-STENTORE is necessary, communicating the relevant device details accordingly.

Data Harmonization

There is no explicit need for data harmonization within Demo 1. The flexibility service receives data from individual sources as needed.

5.2.2 Demo 2

Overview of data sharing requirements within pilot

Within the demonstrator itself, the system operator (EEM)'s SFTP Server is responsible for receiving SCADA data and forwarding it to the INESC TEC Virtual Machine. This includes information on load, reservoir's inflows, PV & Wind generation forecasts, Thermal and Hydro units' dispatch, VRFB bands for PV ramps and Li-ion bands for SR. This means that both the server and the VM need secure interfaces equipped for all the relevant SCADA information. Subsequently, the INESC VM needs to be able to provide setpoints (both battery systems), condenser status and operating points for the renewables to the DSO.

Required communication with I-STENTORE System

The INESC VM should be able to communicate aggregated result data to the I-STENTORE system regularly, and in a usable format. Additionally, a communication point with the central Asset Registration for I-STENTORE is necessary, communicating the relevant device details accordingly.

Data Harmonization

Within Demo 2, data from multiple separate hydro units needs to be considered in the optimisation algorithm. If this data isn't already harmonized when provided by the SCADA system, it will have to be brought together either on the SFTP server or the INESC VM.

5.2.3 Demo 4

Overview of data sharing requirements within pilot

The Flexibility Service of Demo 4 requires PV and Chargers Status, as well as PV power and Hub consumption forecasting from EMS. The EMS in turn requests and receives meter data from the SCADA unit. The DSO accesses the Flexibility Service through a Service Provider, which serves as an interface between the two. As the Flexibility Service receives all its

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required data from the EMS, only it needs an open communication line with the SCADA system itself.

Required communication with I-STENTORE System

As mentioned, the EMS provides forecasting values to the Flexibility Service. Unless the EMS has internal forecasting functionalities, it would make sense for it to have an interface to access external forecasting services, at minimum to acquire external weather data for this purpose. Additionally, a communication point with the central Asset Registration for I-STENTORE is necessary, communicating the relevant device details accordingly.

Data Harmonization

The EMS collects meter and charger status data to be used in common optimization. This data needs to be brought together to be usable within the EMS itself.

5.2.4 Conclusion

The bulk of Data Sharing happens within each Demo itself. Interfaces towards the i-STENTORE platform will be useful for three distinct purposes:

Asset Registration – a central i-STENTORE service, which requires device-specific information to be securely communicated from each Demo site to the central system.

Service Provision – definition of specific central services within i-STENTORE is an ongoing task. The most popular need is the necessity of weather and weather forecasting data. Depending on the specific needs of each Demo, access to other (forecasting) services may be necessary.

Reporting – Reporting of flexibility use and aggregated data to the i-STENTORE system for project-wide assessment purposes. The types of data shared in this category may vary greatly by Demo.

The individual types of data communicated for each will vary by Use Case. For the three demonstrators discussed here, the specifics can be inferred from the data set examples provided. More details and specifics as well as information on Demos 3 and 5 will follow in D2.4.

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6. I-STENTORE REFERENCE ARCHITECTURE

6.1 VOCABULARY

The table below presents all the concepts and terms that the i-STENTORE system refers to, in order to create a common vocabulary for all the stakeholders and avoid any misunderstanding and lack of clarity.

TABLE 5: I-STENTORE COMMON VOCABULARY

Term	Description
Generic Terminology	
Platform	A sophisticated array of integrated systems, interfaces, and processes working together to offer a range of functions and services.
Reference Architecture	A reference architecture acts as a template design for a system architecture of a particular domain. It can provide a methodology for implementation for all actors involved.
Use Case	A Use Case describes the high-level functions and a scope of a developed system.
Business Use Case	It showcases the business processes performed by its business actors for achieving a business goal.
System Use Case	It describes the process for implementing a business use case at the system functionality level, denoting the function or the service provided by the same system.
Requirement	A requirement refers to an individual documented physical or functional necessity that a specific design, product, or process seeks to fulfil.
Functional Requirement	Functionality, behaviour, and input/output information that the system requires to have.
Non-Functional Requirement	As the "Quality Attributes" of a system they are the conditions under which the solution must remain functional, qualities that the solution must have, or constraints within which it must almost always operate (e.g. reliability, testability, maintainability, availability, performance).
Actor	An actor represents a role carried out by an external entity that engages with the subject (for instance, by exchanging signals and data), whether it is a human user of the system under design (Person), another system, or hardware that utilises the subject's services.
Component	A Component is a modular and replaceable unit that encapsulates specific functionality in alignment with the implementation structure. As a self-contained entity, it is independently deployable, reusable, and replaceable. Components execute one or more Application Functions and restrict access to its functionality through a defined set of Application Interfaces.
Device	A Device is a physical IT or OT resource designed for storing or executing system software and artefacts. As a specialised type of Node, a Device

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	includes processing capabilities and is typically used to model hardware systems like mainframes, PCs, or routers. Devices usually form part of a node in conjunction with system software.
Application Programming Interface (API)	Is a specialised software interface which allows the connections between components, tools, and platforms. A document or standard that describes how to implement this interface is called an API specification. The term API may refer either to the specification or to the implementation result.
Interoperability	Interoperability involves the standards, protocols, technologies, and mechanisms that enable seamless data exchange between different systems with minimal human intervention. It ensures that diverse systems can communicate and share information in real-time.
i-STENTORE Terminology	
Demo Use Case	Use Case derived directly from the pilots.
Cross-Pilot Use Case	A Use Case that applies to more than one demo usually to showcase the connectivity amongst demonstrators through the potential i-STENTORE Data Space.
i-STENTORE Use Case	Use Case derived by following two processes; first, we identify and classify data and used services between actors/platforms for all demos. Second, we include SUCs identified in other H2020 projects, based on the work conducted in the context of T2.5 & T2.6, that are relevant to i-STENTORE, in order to have a complete list of General SUCs that will be implemented through the i-STENTORE digital system.
i-STENTORE Framework	Is the core design of the Reference Architecture. It consists of five main layers: the GUI & Application layer, the i-STENTORE Core services layer, the Semantic interoperability layer, the Data Integration and Homogenization layer, and the Data Ingestion layer. Core Services, Semantic Interoperability and Integration & Homogenization constitute the i-STENTORE Governance Middleware.
i-STENTORE Governance Middleware	It is implemented using a modern approach based on the more innovative standard architecture models and interfaces, namely IDS and FIWARE. It allows the integration and collaboration of the i-STENTORE participants, facilitating the envisioned energy storage-based operations, ensuring scalability and interoperability, while maintaining the data ownership.
i-STENTORE Connector	Is a specific instance of the Data Space Connector, which will be deployed locally and will allow an easy integration and cooperation among the platforms/actors, maintaining the data ownership and preserving access to the data sources. Use of the Data Space connector will be dependent upon SUCs and expected to occur if needed in the final technology release.
i-STENTORE Application Component	One of the main applications of the i-STENTORE system. Mainly the Virtual Power Plant and the Investment Planning Tool.

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i-STENTORE Participant	Any kind of actor involved in the i-STENTORE ecosystem. Can be divided into: data source, data provider, data consumer and service operator.
Data Source	A more generic source of data that can be integrated into the i-STENTORE system which may include a Data Provider, a single database, an IoT device, a file system, or similar sources.
Data Provider	A specific participant which can provide data to the system. To submit metadata or exchange data with a Data Consumer, the Data Provider uses software components (connector) that are compliant with the Reference Architecture.
Data Consumer	A specific participant that receives data from a Data Provider. From a business process perspective, the Data Consumer is the mirror entity of the Data Provider.
i-STENTORE Services Operator	A specific participant that makes use of services or tools. The Service Operator registers in the i-STENTORE Framework in order to have access, deploy, use, integrate with and test the i-STENTORE digital tools.

6.2 CONCEPT ARCHITECTURE

Following the methodology outlined in D2.2 – Services Co-creation, Business Models, Functional Specifications, and Reference Architecture (1st version), three distinct versions of the architecture will be developed during Task T2.6. This step-by-step approach enables incremental evolution and enhancement of the intermediate versions by incorporating feedback, comments, and results from technical partners, demo partners, and other tasks and work packages within the i-STENTORE project.

6.2.1 Concept Modelling

The i-STENTORE Model, based on established architectural initiatives, as the basis of the Reference Architecture integrates various storage technologies, generation assets, loads, business models, and services in an interoperable manner. This approach enables the multipurpose use of storage, fosters the integration of renewable energy sources (RES), and optimises the use of available flexibility across different energy sectors. The proposed Reference Model aims to primarily extend the Smart Grid Architecture Model (SGAM) by aligning with key initiatives in Data Space architecture modelling (e.g., IDSA and FIWARE), while also leveraging ongoing architectures from the BRIDGE Data Management WG, H2020 INTERRFACE, BD4NRG, OneNet, and others. The i-STENTORE model aims to act as a mediator, ensuring seamless and technology-agnostic connections and integrations of various storage systems and interconnected assets (such as RES, loads, controllers, management systems, etc.), thereby establishing a data ecosystem across the energy value chain. The i-STENTORE approach relies primarily on soft infrastructure, promoting decentralisation and creating a level playing field for intelligent energy-storage-based applications involving multiple energy stakeholders and systems. The i-STENTORE concept proposes deploying a decentralised middleware that incorporates data sovereignty features, such as interoperability, portability, security, privacy, trustworthiness, and, most importantly, discoverability. This implies direct end-user participation in the 'storage-centric European Energy System,' yielding collective

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benefits for all participants. Figure 19 illustrates the design of the i-STENTORE reference model, focusing on the SGAM interoperability layers.

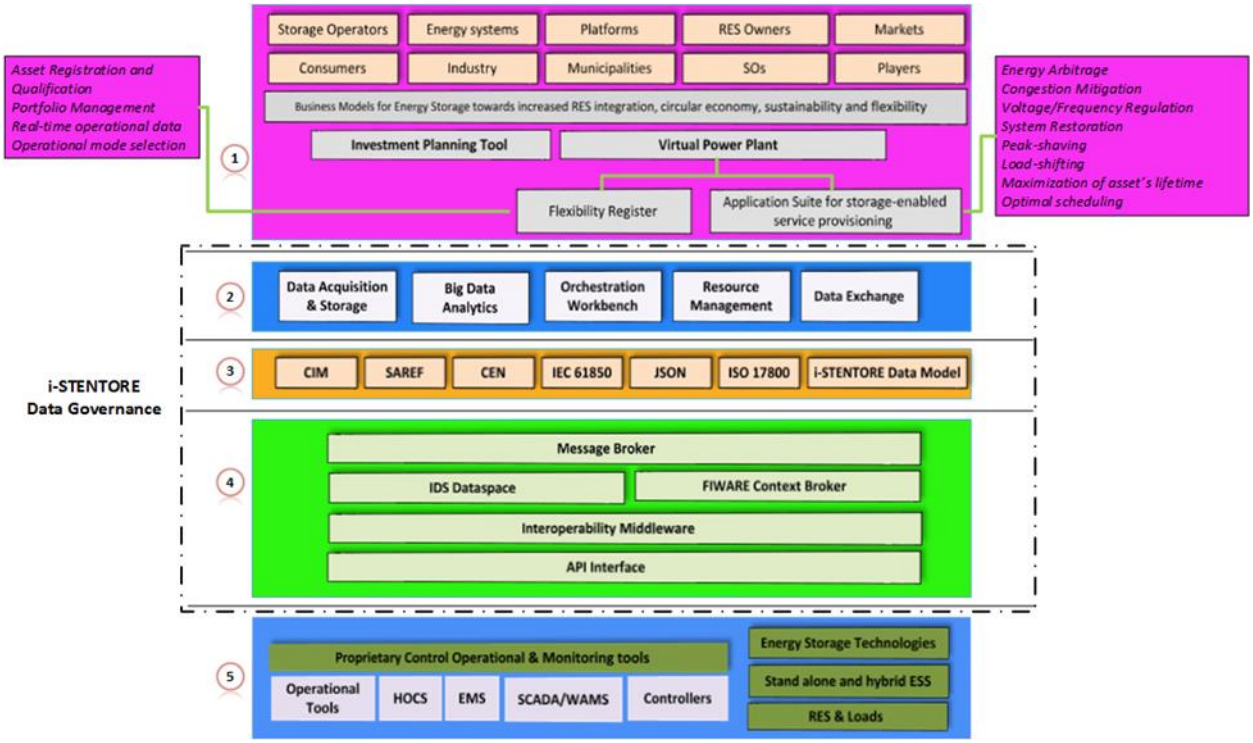

FIGURE 19: I-STENTORE SGAM REFERENCE MODEL

An evolved approach to the i-STENTORE reference model, takes into consideration the BRIDGE RA model based on the specific project needs and expectations (Figure 20). The end goal is to extend its structure with vertical pillars, containing aspects that are relevant across all the horizontal layers. The current deliverable details which other initiatives and architectures will be considered, and how their ideas will be included in the design of this RA, along with the specific needs of the project at the time.

The **Business Layer** encompasses associations, business roles (entities involved in the electricity domain such as municipalities, consumers, RES owners, industry players, etc.), and business processes (high-level activities like asset registration, operational data management, optimal scheduling, etc.). The Function Layer includes core functions or processes that support the business processes through the application of VPP and Investment Planning Tools. The **Information Layer** comprises Information Models (standards or frameworks for structuring and modelling data, such as ISO 17800, IEC 61850, etc.) and Profile Data Models (specific data models like the i-STENTORE data model or the i-STENTORE Semantic Ontologies that align with the mentioned standards). The **Communication Layer** involves Data Formats (actual formats for data representation like XML, JSON, and CSV) and Protocols (communication standards or protocols for data transfer, such as HTTP/HTTPS, REST, MQTT, etc.). The **Component Layer** includes Data Exchange Platforms (platforms designed to handle and exchange data, integrating the above layers), Applications (software

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or platforms for controlling, monitoring, and managing electricity domain processes and data), and Hardware (physical devices and tools used in the electricity domain, such as smart meters, batteries, SCADA systems, sensors, actuators, etc.). These initial versions reflect the project's status and knowledge at the time of the design of the RA 1st version. Current and future work detail how this architecture relates to technical developments and pilot needs within the project, and how their evolution will update the requirements for the final version of the Reference Architecture in the months following the deliverable submission.

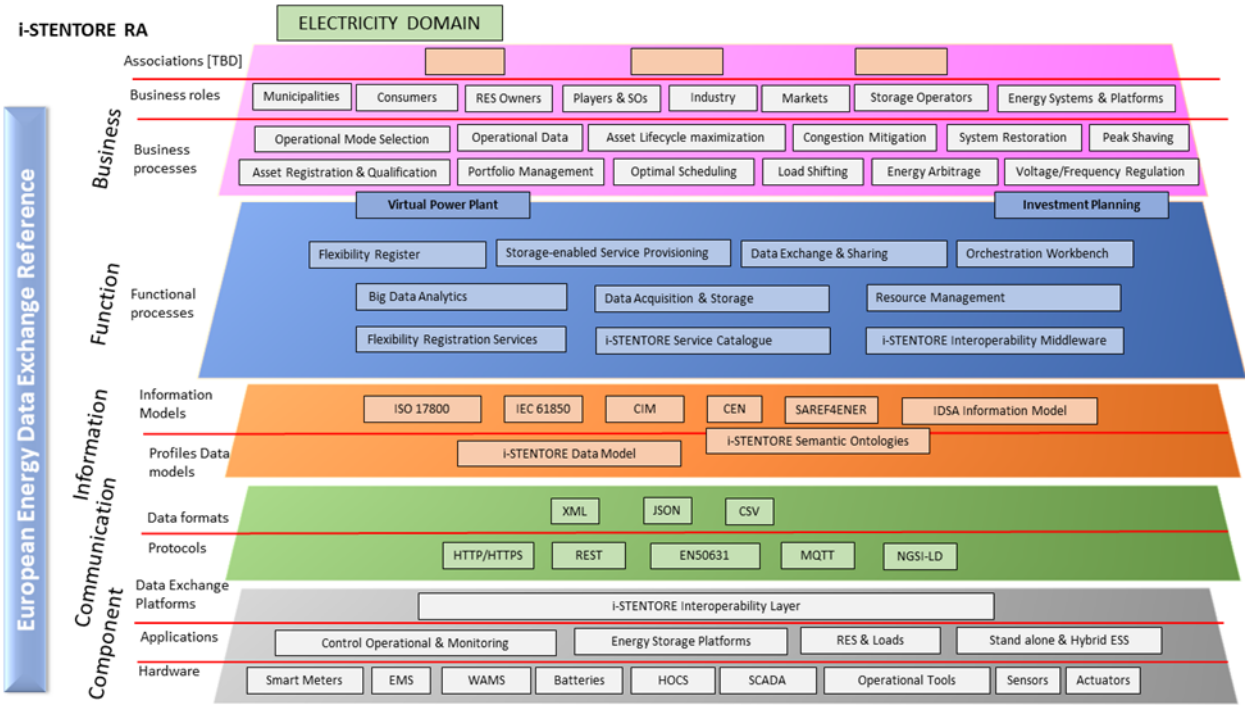

FIGURE 20: I-STENTORE BRIDGE REFERENCE MODEL

6.2.2 I-STENTORE RA 1st Version

The **i-STENTORE Reference Architecture v1** is the first initial draft of the architecture, starting from the i-STENTORE main objectives and solution as described on the DoA and D2.2. It includes: the i-STENTORE digital platform, named i-STENTORE first concept; different layers of data exchange for enabling cross-platform integration and cooperation; specific layer for cybersecurity and data privacy aspects, following GA guidelines. The below figure aims to visualise the high-level i-STENTORE 1st architecture concept based on the information regarding:

- Reference Architecture Models
- Business Use Cases as application scenarios
- Functional Requirements

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The idea was to create a concept consisting of building blocks (software components) hierarchically, presenting the information & data process flow, among the different building blocks (Figure 21). The concept also attempted to present the potential interfaces (interconnections between components) which upon finalisation would assist in the API design and implementation. This first conceptual version of the i-STENTORE software reference architecture was refined as the project progressed in the current version which we will zoom-in and examine in the following chapters. Special focus is given on how all interconnections and data exchanges will be implemented.

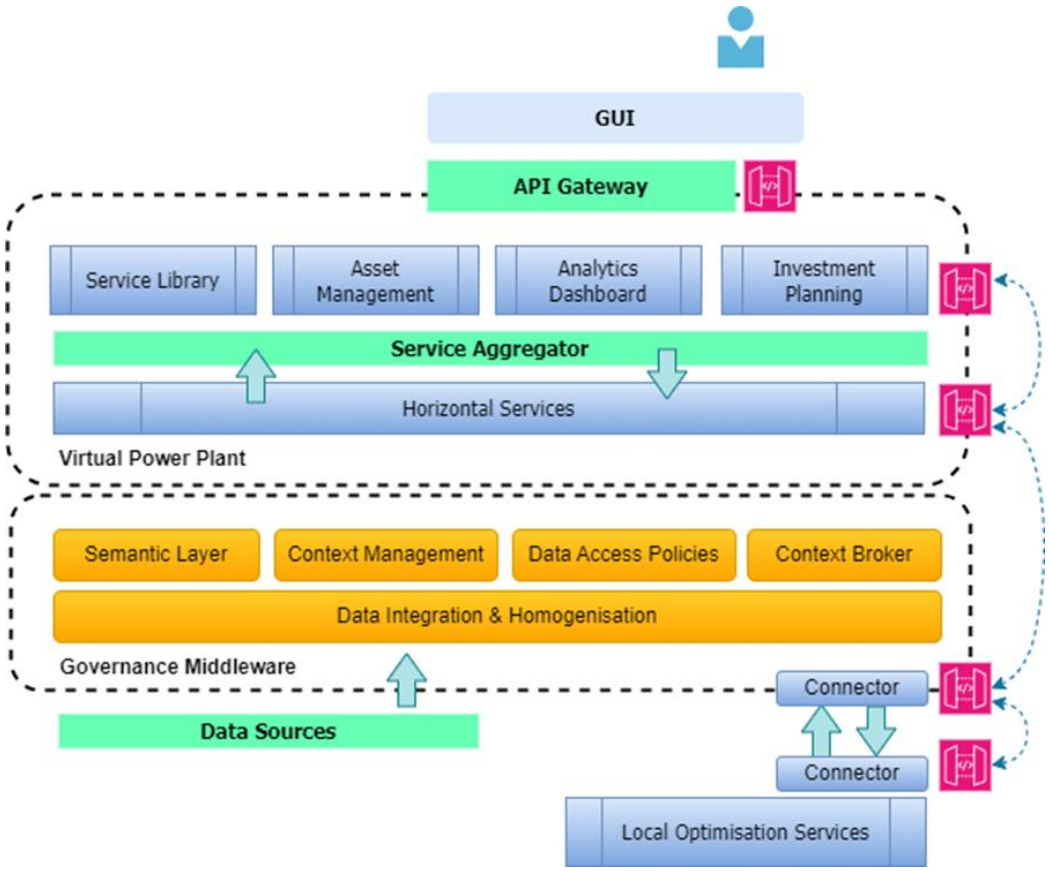

FIGURE 21: I-STENTORE REFERENCE ARCHITECTURE 1ST VERSION

6.3 COMPARISONS OF DEMOS

Using information from the Concept Modelling mapping, this section will attempt to identify commonalities and compare the various demos to uncover differentiations that could be interesting for i-STENTORE to address. The table below shows the common parameters found in most of the demos after analysing the mappings, or potential other different parameters for integration:

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TABLE 6: I-STENTORE CONCEPT AND DEMOS

Business Layer	• Regulations and Directives: GDPR, Energy Taxation Directive, Energy Performance of Buildings Directive, Renewable Energy Directive, Network Code on DSF, Alternative Fuel Infrastructure Regulation, Energy Efficiency Directive, Electricity Directive and Regulation (2019), Net-zero Industry Act • Associations: DSO/TSO • Entities: Municipalities, Consumers, RES Owners, Industry, Storage Operators, Market players • Processes: Asset Registration, Operational Data Management, Optimal scheduling Data exchange
Function Layer	• Virtual Power Plant Operations, Investment Planning, Authentication, Authorisation, Data Collection, Data sharing
Information Layer	• Info Models: ISO 17800, IEC 61850, CIM, SAREF4EN, FIWARE • Profile Data Models: i-STENTORE data model, i-STENTORE Semantic Ontologies
Communication Layer	• Data formats: CSV, XML, JSON • Protocols: ICCP, Web-services, REST, HTTPS, MQTT, XMPP, AMPQ
Components Layer	• Software: software or platforms for controlling, monitoring, and managing electricity domain processes and data exchange • Hardware: SCADA, Meters, Sensors, Actuators

6.4 I-STENTORE REFERENCE ARCHITECTURE V2

The **i-STENTORE Reference Architecture v2** is the first consolidated version of the architecture. Building on the draft previous version (D2.2 "Services Co-creation, Business Models, Functional Specifications, and Reference Architecture (1st version)"), it includes the definition of roles and actors, analysis of Demo and General System Use Cases, and an intermediate round of feedback from technical partners. The analysis of the IDS reference model, particularly the FIWARE interfaces, led to an IDS-compliant solution using standard models for implementing the i-STENTORE Governance middleware. Integrating the IDS Connector and the FIWARE Context Broker was identified as an efficient solution to ensure high levels of standardisation, interoperability, scalability, and reuse of the i-STENTORE framework. However, the current solution focuses on the integration of applications and services rather than IDS data exchange processes. Figure 22 illustrates the Logical View of the i-STENTORE Data Value Stack architecture using a data value stack logical diagram to describe the system's static behaviour.

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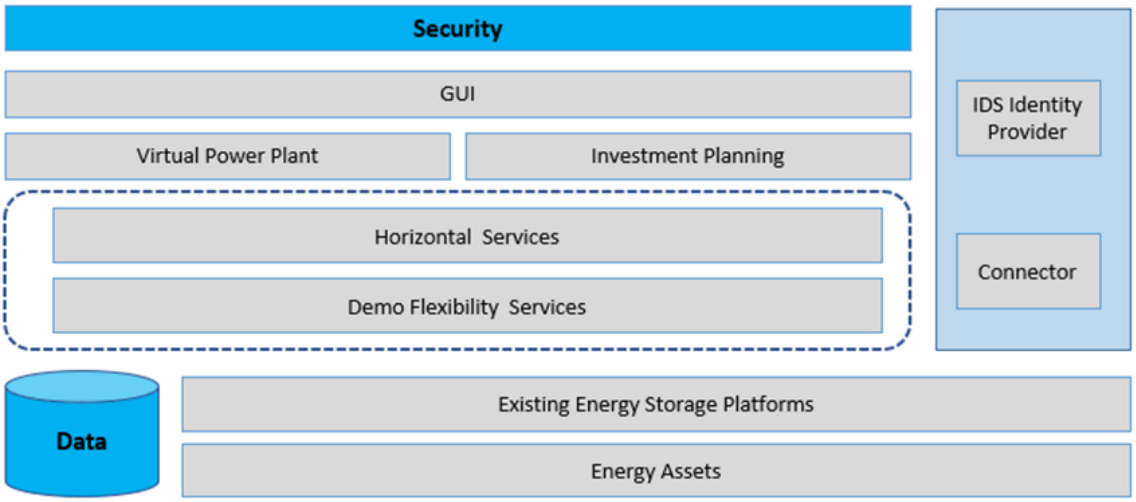

FIGURE 22: I-STENTORE LOGICAL DATA VALUE STACK ARCHITECTURE

The **i-STENTORE applications** are accessible through the **i-STENTORE User interface**. Through the **IDM Keycloak** integration it will be possible to register as a user to the Virtual Power Plant and Investment Planning modules. The VPP will be structured as a core service provider where a registered user will be able to take advantage of the developed functions such as:

- Asset registration and management
- Access to Horizontal Services
- Demo oriented registration to the VPP Service catalogue module
- Access to demo specific Analytics

The Service catalogue will provide by default the **VPP Horizontal services** but also allows the creation of **Local Demo flexibility services.**

The Reference Architecture v2 (Figure 23) consists of five logical layers which play a significant role in the entire i-STENTORE ecosystem:

- The Data Ingestion layer includes data sources and energy stakeholders, the i-STENTORE Participants (data and applications).
- The Data Integration and Homogenisation Layer as a key layer of the data management architecture attempts to ingest, homogenise and unify data from various sources, ensuring consistency, accuracy, and usability for downstream applications. Part of this layer will be the potential integration of the IDS Data Space connector allowing data sharing between actors but also the Energy Management and Operation control demo applications.
- The Semantic Interoperability layer bridges the gap between different data formats, structure and terminologies providing a common interpretation and understanding of data meaning (i-STENTORE Data Model). This layer is responsible for:
  - Semantic mapping, querying and ontology management,

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- Metadata management (FIWARE Context Broker),
- Reasoning and inference,
- Interoperability Standards Compliance through adherence to industry standards and protocols for semantic interoperability, such as RDF (Resource Description Framework), OWL (Web Ontology Language), and SPARQL (SPARQL Protocol and RDF Query Language),
- Compliance with standards for facilitation of a seamless data exchange.

- The Core Services layer is the one providing the collection of developed services and functionalities in a unified and standardised way. It considers BUCs and SUCs, functional specifications and requirements, authentication and authorisation, data exchange processes and the use of cross-demo (horizontal) and local demo (vertical) services. By offering these services i-STENTORE RA promotes efficiency, reduces redundancy and enhances the interoperability of the overall system.
- The top layer is the one defined as the i-STENTORE GUI and Application layer. This along with the Governance Middleware constitutes the core of the RA. It includes all the components to be implemented, and the necessary integration with the governance middleware leveraging specifications for data harmonisation, ontologies, data modelling, service orchestration, workflow monitoring, analytics, etc.

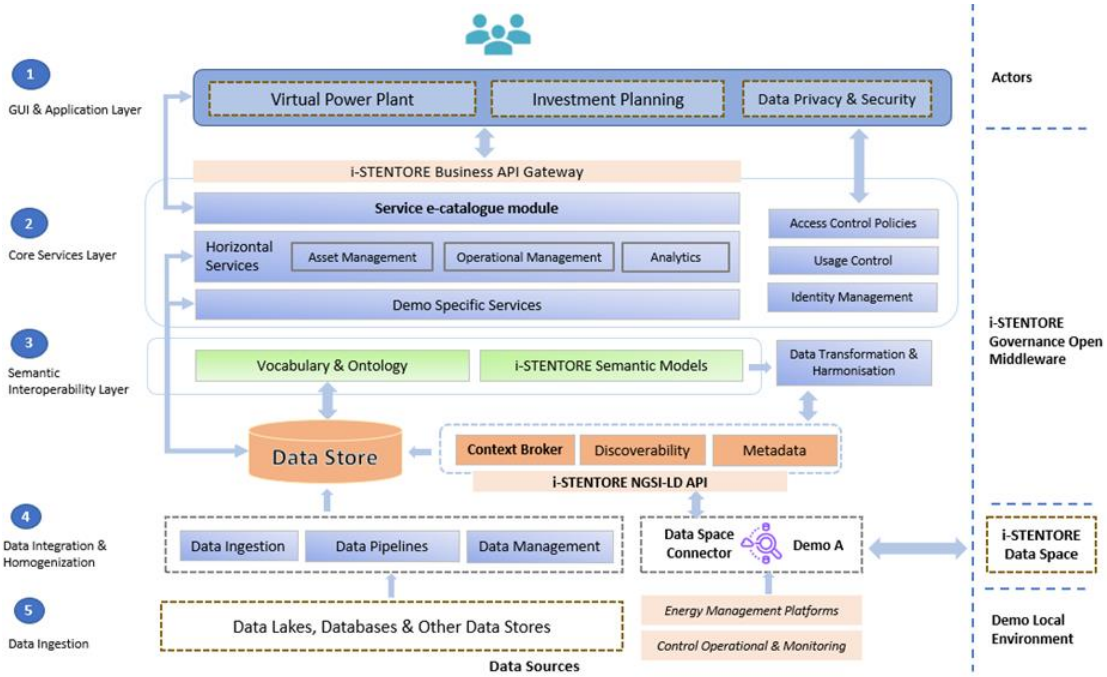

FIGURE 23: I-STENTORE REFERENCE ARCHITECTURE V2

6.5 I-STENTORE PARTICIPANTS (ACTORS ALIGNMENT)

The i-STENTORE Participants zone consists of all the actors and data sources involved in the system. The Business Actors are named according to their business role, and this can be ***DSO***, ***TSO***, ***Storage Operator***, ***Platform***, ***RES Owner***, ***Institute***, ***Industry***, ***Service Provider***, ***Consumer, Market Operator***, or others. Due to the focus of the architecture in the Data

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exchange and Storage Asset Management, these actors can be further classified as ***Data Owner***, ***Platform User***, ***Data Consumer***, ***Data Provider***, ***Service Operator*** and others. The list of Business Actors is clearly identified in D2.1 "SOTA Analysis, Barriers, Regulatory Framework and Use Cases' Descriptions" following the analysis conducted in WP2, as well as the result of the information collected from the Demos. The data sources refer to all the assets that produce or process data. These can be sensors, actuators, gateways, computing nodes, Storage Management Platforms and they can come from various energy sectors. Following the Actors and Roles identified in the i-STENTORE System Use Cases a Participant Role can be:

- **Data Source** refers to any generic origin of data that can be integrated into the digital system. This could include a Data Provider (as detailed below), a single database, a Data Lake, an IoT device, a file system, and more.
- **Data Provider** is a specific i-STENTORE participant that supplies data to the system. To submit metadata to a Broker or exchange data with a Data Consumer, the Data Provider uses software components (middleware/connector) that are compliant with the system overall. To facilitate data requests from a Data Consumer, the Data Provider must supply appropriate metadata about the data to the Broker Service Provider.
- **Data Consumer** receives data from a Data Provider. From a business process perspective, the Data Consumer mirrors the Data Provider, performing similar activities. Before establishing a connection with a Data Provider, the Data Consumer can search for existing datasets by making an inquiry with the Broker Service Provider. The Broker Service Provider then supplies the necessary metadata for the Data Consumer to connect with a Data Provider.
- **Service Operator** is the generic participant that has access/operates i-STENTORE services or tools. The Service Operator registers in the i-STENTORE Framework in order to be an authenticated and authorised user, able to use the software components.

Every business participant (role) should be connected indirectly with the Governance Middleware layer since it represents the source of data for all the business and data platforms, as well as any integratable services or applications. It could be also directly connected to the i-STENTORE ecosystem, since based on needs and requirements, there may be a need to integrate a data source directly, using the i-STENTORE Middleware and its interoperability mechanisms based on the FIWARE architecture and on the FIWARE Orion Context Broker.

6.6 I-STENTORE FRAMEWORK

This chapter discusses the i-STENTORE Framework (i.e., the business models, the data platforms and the application services. The i-STENTORE digital ecosystem aims to integrate external platforms, including Energy Storage platforms, market platforms, and other energy data platforms, into its system. This integration will be implemented irrespective of the technologies used by these platforms to ensure platform-agnostic compatibility. Technically, a platform refers to any software environment (such as applications, services, or tools) capable of connecting with the Governance Middleware using the Data Space Connector or

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the NGSI-API. The primary objective of this layer is to establish a fully decentralised P2P system for interoperability. In this infrastructure, two systems (Participants) can interact directly without the need for a third-party intermediary. This fully decentralised approach will result in the creation of the i-STENTORE digital ecosystem.

From a Data Management perspective, the most crucial component of the Reference Architecture is the Governance Middleware. The i-STENTORE Data Governance Middleware (iDGM) acts as an intermediary layer between the underlying ESS and other interconnected assets and the i-STENTORE intelligent business layer/services layer (such as VPP, Investment Planning Tool, Asset Register, etc.). The primary goal of the iDGM is to ensure semantic interoperability among data providers and consumers, not only within a single i-STENTORE installation but across the entire energy and smart grid domain. Figure 24 illustrates the decomposition of the i-STENTORE Data Governance Middleware (shown in green) alongside the related layers (shown in dark red) within the i-STENTORE architecture. This is an intermediate version of the iDGM and is subject to updates or changes before the final version of the i-STENTORE architecture is released.

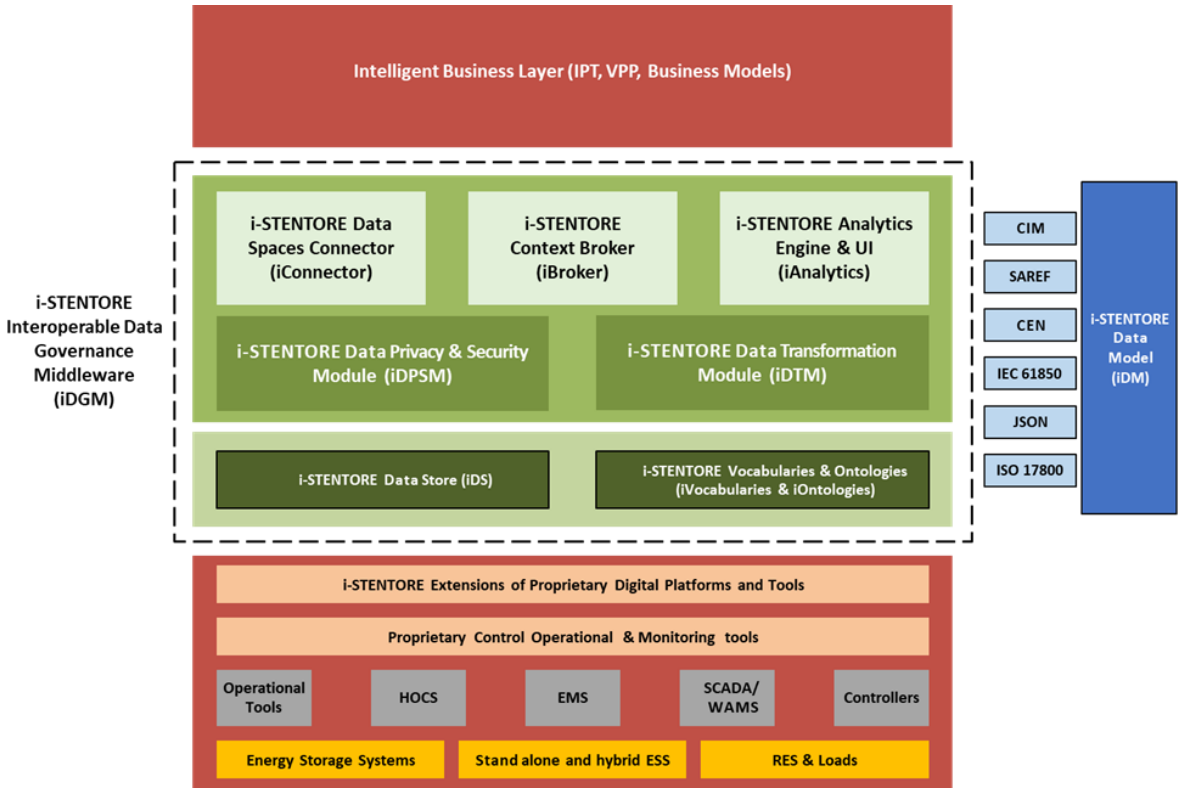

FIGURE 24: I-STENTORE DATA GOVERNANCE MIDDLEWARE DECOMPOSITION DIAGRAM

In the context of the smart grid domain, **semantic interoperability** refers to the capacity of different systems to exchange and interpret data meaningfully. This capability is crucial for the successful deployment and operation of the smart grid, which comprises a diverse array of heterogeneous devices and systems. These systems must communicate effectively with each other to ensure the smart grid operates efficiently. To reach the envisioned

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interoperability objectives and achieve the desired functionality the iDGM will include the following internal modules and building blocks:

- i-STENTORE Set of Vocabularies & Ontologies (iVocabularies, iOntologies)
- i-STENTORE Data Store (iDS)
- i-STENTORE Context Broker (iBroker)
- i-STENTORE Data Privacy & Security Module (iDPSM)
- i-STENTORE Data Transformation Module (iDTM)
- i-STENTORE Analytics Engine & UI (iAnalytics)
- i-STENTORE Data Spaces Connector (iConnector)

The i-STENTORE Data Spaces Connector (iConnector), a specific implementation of the IDSA Connector, can be integrated into each platform to facilitate easy cooperation and integration among platforms while preserving data ownership and access. Although the iConnector is an efficient solution for connecting and integrating a platform within the ecosystem, there are alternative architectural approaches to achieve this. Therefore, the i-STENTORE Reference Architecture (RA) prioritises IDSA compliance over the actual implementation of the Data Space Connector in this intermediate RA version. Based on the requirements, the iConnector (if implemented) will adhere to IDS connector specifications. Additionally, the Broker included in the iDGM will comply with the FIWARE Context Broker specifications. The FIWARE Context Broker will provide the FIWARE NGSI APIs and an associated information model (entity, attribute, metadata) as the primary interface for data sharing among i-STENTORE Participants. Data Providers will use these APIs to publish or expose their data, while Data Consumers will retrieve or subscribe to data notifications.

A significant part of the i-STENTORE Framework integrated to the IDGM and the local Demo Environments is a logical concept: The decentralised IoT-level middleware (Figure 25) which is usually active on top of the common IT infrastructure enabling the information exchange between assets and components integrated to i-STENTORE.

FIGURE 25: I-STENTORE IOT-LEVEL MIDDLEWARE

One of the most prevalent concepts of our time is the Internet of Things (IoT) paradigm, which connects edge devices via the Internet, enabling a wide range of applications. In recent years, the number of connected devices has increased significantly, leading to a substantial rise in the volume and variety of data generated at the network edge. An IoT-level middleware is a software application that acts as an interface or message bus between IT resources and IoT devices/sensors, facilitating communication between components. Therefore, an IoT-based (or edge-level) middleware is necessary to provide essential functional components for sensor registration, discovery, workflow composition, and data pre-processing. The growing

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importance of this paradigm, along with the necessity for these applications and new technical capabilities, has led to an exponential increase in edge middleware platforms, each with different requirements, architectures, and features. Methodologically our i-STENTORE framework implementation approach is step wise, based on the envisioned reference architecture, generic IoT-level middleware architectures and data management best practices:

- **Development of Semantic Models:** In this step, necessary semantic models (conceptual data models that include semantic information) are created to help stakeholders' IT systems interpret exchanged information and trigger actions if needed. Drawing from current demo SUCs, iDGM harmonises the actors, roles, business objects, etc., into a unified model that meets their needs and facilitates the exchange of information in a consistent form and content.
- **Categorization of Shareable Data:** Shareable data are classified into three categories: unstructured (text data), semi-structured (e.g., XML/JSON formatted data), and structured (e.g., data in operators' Data Hubs and Energy Data Management Systems).
- **Data Exchange:** Using the data-driven development of semantic models and the categorization of shareable data, we aim to implement an improved data exchange system.
- **Development of Added Value Services:** These services will support and are built upon the semantic models, including functionalities such as data quality checking, data consolidation, and aggregation.
- **Development of a Semantic Interoperability Framework:** A framework for orchestrating semantic interoperability, potentially based on the International Data Spaces for data sharing, will be developed. This framework will describe the data exchange interfaces for read/write access and the import/export of available data and output analytics.

Based on the above a common IoT-level middleware architecture approach comprising four separate layers (resource management, data processing, service, and security) can be considered as an additional architectural model for the i-STENTORE Reference Architecture design.

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7. INTEGRATION GUIDELINES

This chapter describes the integration plan for the past and next releases, providing an illustrative roadmap as this results from the internal proceedings discussed at the time of documentation. In case future circumstances direct so, this plan will be updated to reflect the new components and activities involved, to ensure accuracy, dissemination of information and mitigation of risks. The plan that is presented in the pages to follow has been founded on the deliverable baseline timeline, and includes relational offsets to maintain awareness of all deliverables schedule. The resulting complete illustration of the integration plan is presented in Appendix B.

7.1 INTEGRATION PLAN

This integration and development plan, which spans across M1 to M34 of the three-year project duration, is divided into four phases, detailed, one by one, on the subchapters of this Chapter 7.1 with corresponding explanations, per case. Each phase was defined by the nature and the volume of work expected per case, and as such, it is correlated by an MVP (Minimum Viable Product). So, as illustrated in Appendix B, this integration plan is created around three essential MVPs (MVP-1, MVP-2, MVP-3, also related with the three technical releases of the project) and one intermediate version.

7.1.1 MVP-1

The plan, beginning with MVP-1 (the first technical release - deliverable D3.4), is supported by the following components:

- Reference Datasets
- Virtual Power Plant - Asset Management
- Orion Context Broker Deployment
- Identity Management Deployment
- i-STENTORE Semantic Model 1st version
- Investment Planning 1st version

and the corresponding activities (all of which have been completed, except for the functional validation which is currently ongoing), as illustrated in Figure 26.

1. Finalisation of Functional Requirements v1
2. Definition of MVP Components
3. Implementation
4. Initial functional validation

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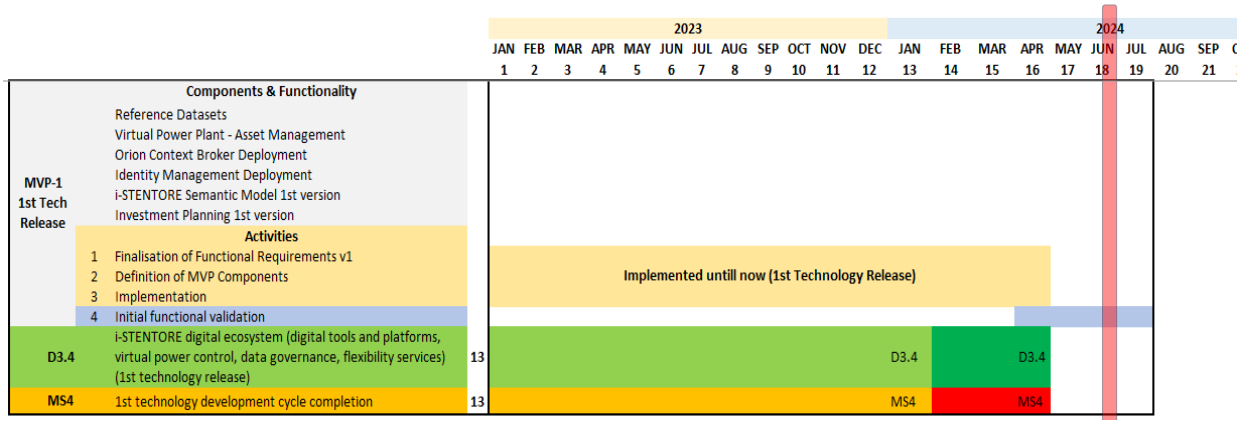

FIGURE 26: MVP-1 OF I-STENTORE INTEGRATION AND DEVELOPMENT PLAN

It is important to note that activities 1 to 3 of MVP-1 were completed with a three-month offset, meaning that their finalisation was achieved by the end of April 2024, subsequently affecting the official delivery of D3.4 and, in respect, milestone MS4. The ongoing "Initial functional validation" activity (highlighted in blue), which started in M16, is expected to finish on M19 (end of July 2024).

7.1.2 MVP-2

For the second phase, the MVP-2 is coinciding with the second technology release and deliverables D3.5 / Milestone MS6 which are scheduled for M20 (August 2024).

MVP-2 includes the following components:

- Integration of actual pilot datasets
- Pilot Services 1st version
- i-STENTORE Governance Middleware 1st version
- i-STENTORE Semantic Model final version
- Virtual Power Plant - Service Catalogue
- IDM - Integration (SSO)
- Investment Planning 2nd version

and the following activities:

1. Finalisation of Functional Requirements v2
2. Definition of MVP Components
3. Implementation
4. Pre-integration testing
5. Integration MVP-1 to MVP-2
6. Post-integration testing
7. Pilots' Functional verification - central
8. Pilots' MVP-2 test & validation - central

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As depicted by the yellow timeline bars, the activities supporting MVP-2 (Figure 27), also listed above, will be finalized by Month 20 (August 2024). The "Pilots' Functional verification" is expected to take place from M21 to M23 (September to November of 2024), and the Pilots MVP-2 test and validation will occur from M23 to M26 (November 2024 to February 2025) which coincides with Milestone MS7.

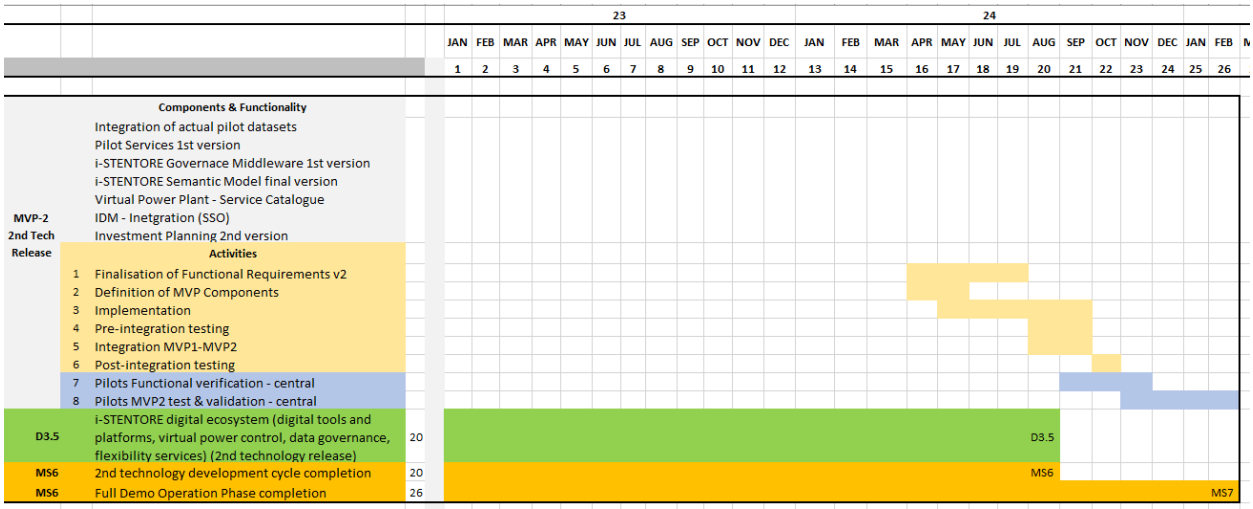

FIGURE 27: MVP-2 OF I-STENTORE INTEGRATION AND DEVELOPMENT PLAN

7.1.3 Final MVP (MVP-3)

The integration plan concludes with MVP-3, which is associated with deliverable D3.6 and milestones MS7 and MS8.

The components of MVP-3 include:

- Integration of actual pilot datasets
- Pilot Services 2nd version
- Horizontal service registration to VPP Catalogue
- i-STENTORE Governance Middleware 2nd version
- Data & Service Access Policies
- Integration of components – demo

The activities for this phase, starting in M26 (February 2025) and extending to M34 (October 2025), are as follows:

1. Fine tuning of Functional Requirements
2. Definition of MVP Components
3. Implementation
4. Pre-integration testing
5. Integration to MVP-2.5
6. Post-integration testing
7. Full Deployment (central - local)

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8. Pilot test & validation of final integrated release

More specifically, as depicted in Figure 28, the "Full Deployment" takes place in M31 and M32 (July and August of 2025), while the "Pilot testing and validation of the final integrated release" commence in M30 (June 2025) and conclude in M34 (October 2025).

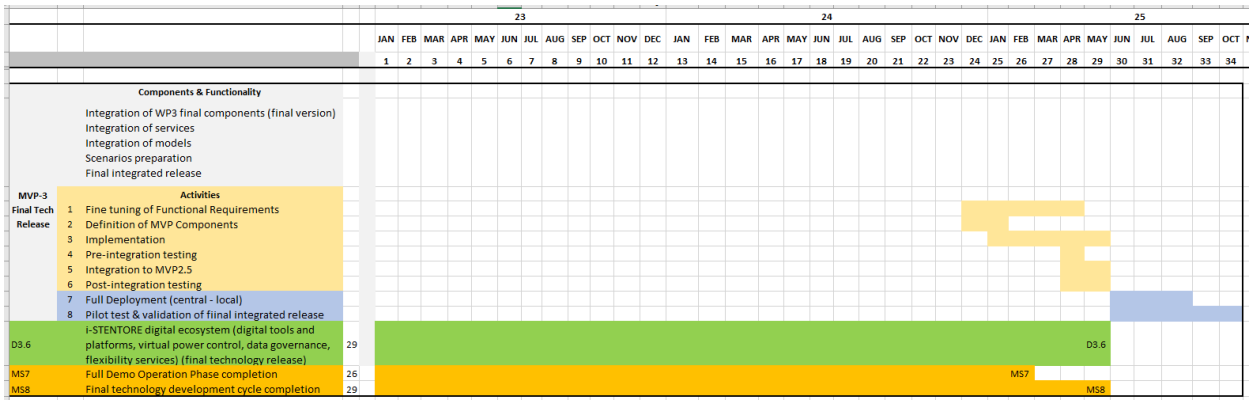

FIGURE 28: MVP-3 OF I-STENTORE INTEGRATION AND DEVELOPMENT PLAN

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8. CONCLUSIONS

The deliverable D2.3, titled "Services Co-Creation, Business Models, Functional Specifications, and Reference Architecture (2nd Version)", represents a critical enhancement, signifying a key step towards the integration of energy storage systems within Europe's energy infrastructure. This document provides an elaborate delineation of the progress on the pilot's architecture and their alignment under the common reference architecture, with models that are designed to augment the economic viability and environmental sustainability of energy storage technologies. The respective business and system use cases have been refined and their realizations have undergone testing, where applicable, in order to validate their full expressions and thus their applicability in real-world settings.

Standardized technical specifications that facilitate standardized data access and integration have been established, promoting interoperability across various systems and components within the energy sector. This standardization is essential for the efficient exchange and management of data, forming the backbone of operational success for energy storage systems.

Moreover, the detailed and refined i-STENTORE Reference Architecture offers a comprehensive framework that supports scalable and flexible integration of energy storage solutions. This architecture is aligned not only with current technological and regulatory standards but is also adaptable to future advancements and requirements, ensuring the project's enduring relevance and impact.

Guidelines for integration, meticulously outlined in the document, provide clear activities for the phased implementation of components, ensuring precise alignment with the overall project objectives. This methodical approach ensures that all stakeholders are well-prepared with the necessary knowledge and tools for the effective deployment of the project's outcomes, including provisioning for mitigation, if required.

The interoperability specifications, grounded in the work of WP2, enrich the data interoperability layer and the Sovereignty and Trust layer within the Reference Architecture (RA). They clarify the process of aligning with current initiatives and concepts in these domains by integrating methodologies (of IDSA, GAIA-X, and FIWARE) to advance the objectives of i-STENTORE. This ongoing development within the RA will continuously provide a 'development view' that offers a precise perspective on the functional specifications of i-STENTORE, mapping these to distinct components that will be developed in accordance with these specifications, as described by the integration plan in Chapter 7. This narrative extends the foundational outcomes of initial WP2 tasks, aiming to solidify the concepts discussed in this document and connect them with the ongoing progress of the project.

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1. C. Steinbrink *et al.,* "CPES Testing with mosaik: Co-Simulation Planning, Execution and Analysis," *Applied Sciences*, vol. 9, no. 5, p. 923, 2019, doi: 10.3390/app9050923.
2. Horizon Europe i-STENTORE project, Deliverable 2.2 – Services Co-creation, Business Models, Functional Specifications and Reference Architecture (1st Version)

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A. APPENDIX: USE CASES

A.1 DEMO 1: MOLTEN GLASS THERMAL STORAGE FOR AN INCREASED UPTAKE OF RENEWABLE ELECTRIC ENERGY

A.1.1 Description of the use case

Use case describes functions of a system in a technology-neutral way. It identifies participating actors which can for instance be other systems or human actors which are playing a role within a use case. Use cases can be specified on different levels of granularity and are according to their level of technological abstraction and granularity either described as Business Use Case (BUC) or System Use Case (SUC).

A.1.2 Name of the use case

ID	Area / Domain(s)	Name of Use Case
Demo 1	(1) Local energy sharing and (4) Cross-sector	Molten glass thermal storage for an increased uptake of renewable electric energy

A.1.3 Version management

Version Management			
Version No.	**Date**	**Name of Author(s)**	**Changes**
V0.5	10.06.2024	Andrej Čampa	Initial version
V1.0	13.06.2024	Gorazd Krese	

A.1.4 Scope and objectives of use case

Scope and Objectives of Use Case	
Scope	Aligning the glass melting process, i.e. coordinated manipulation of electric boosting at uncompromised glass quality, with the availability of RES and opening-up glass manufacturing to provide ancillary services
Objective(s)	• Decreased carbon footprint of glass melting process by higher uptake of RES; • Higher utilization of PV power plant and lower energy costs; • Higher overall share of RES in fed-in energy mix for glass melting; • Resilience to energy supply disruptions of glass manufacturing process (higher energy autarky); • Increasing the resilience and security of energy systems by opening -up the glass manufacturing process to provide auxiliary services.
Related business case(s)	The business case focuses on reducing the carbon footprint of the glass melting process by increasing the uptake of RES, improving the utilization of photovoltaic (PV) power plants to lower energy costs, and enhancing the energy autarky and resilience of the glass manufacturing process. Furthermore, the resulting end products, i.e. glass containers, with lower carbon footprint can be sold with a premium over market price (example: https://www.businesswire.com/news/home/20231207942037/en/). Additionally, by opening-up the glass manufacturing process to provide auxiliary services, such as congestion management and peak shaving, additional revenue streams for glass manufactures will be created. This will improve the competitiveness and, hence, the economic resilience of manufacturing.

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A.1.5 Narrative of use case

Narrative of Use Case
Short description
This use case describes the process of using a molten glass thermal storage system to increase the uptake of renewable electric energy in the glass manufacturing industry. The system involves the use of a hybrid regenerative furnace with an installed electric boosting system of 3.6 MW, a 521 kWp PV rooftop power plant, and a furnace control system. The aim is to use the molten glass within the furnace as an energy storage unit when surplus energy is available from the PV plant, and to achieve a higher carbon neutrality of glass manufacturing and enhanced grid stability.
Complete description
The glass melting process in the furnaces is a continuous process that runs around the clock and requires a well-controlled environment to ensure the quality of the end product. Therefore, the production process is also spread throughout the day to maximize the utilization of the melting furnaces. However, energy prices and the availability of electricity and gas sources can fluctuate significantly on a daily and seasonal basis, which can pose a significant challenge to the profitability and resilience of glass production. The aim is to use the molten glass and the furnace envelope as storage when excess energy is available or to use the stored energy during peak demand periods, for example. To overcome this challenge, the use case aims to combine the glass melting process with a variety of energy sources, including local and geo-independent renewable energy sources (RES), to create a more independent and resilient production process. By using a hybrid regenerative furnace that can adjust the ratio of different energy sources, glass manufacturing can mitigate the geopolitical risks associated with energy prices and ensure a stable and reliable energy supply. The integration of renewable energy sources (RES) into the glass melting process can help achieve a higher degree of carbon neutrality and improve the stability of the power grid. The use case aims to optimize the energy use of the hybrid regenerative furnace by balancing the energy demand of the furnace with the availability of renewable energy. This is done in the following steps: 1. **Furnace profiling:** The first step is to create a digital twin (DT) of the furnace and take into account the production schedule. The DT will simulate the behavior of the furnace and the energy demand under different conditions. 2. **RES generation profiling:** The second step is to calculate the generation profiles of available RES using forecasting tools and weather data.

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3. **Optimization and compilation of criteria functions:** The third step is to perform the optimization and create the criteria function. The criteria function is based on the objectives of the use case, such as maximizing the use of RES, minimizing the carbon footprint or reducing energy costs. In the case of an external request, e.g. from the distribution system operator (DSO), the criteria function will also include the demand of the external actor.

In all optimization cases, the algorithm provides the energy usage profiles for the next day with a resolution of 15 minutes. This profile is converted into a flexibility request to the furnace monitoring system (FMS). The FMS accepts or rejects the request based on the quality requirements for the glass batch. If the request is rejected, the optimization is performed again, taking into account the maximum flexibility provided by the FMS.

A.1.6 Use case conditions

Use case conditions
Assumptions
1. The hybrid regenerative furnace is able to operate with electric energy rate up to 41%. 2. The weather forecast is available for location. 3. The furnace control system is able to properly coordinate the electric boosting manipulation to not negatively affect the glass batch quality or furnace refractory materials. 4. Historical operation data is available for all assets.
Prerequisites
1. Flexibility tags in the OPC UA server are defined and integrated in the FMS. 2. Production schedule is available for a day ahead.

A.1.7 Further Information to the use case for classification / mapping

Classification Information
Relation to other use cases

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According to repository: https://smart-grid-use-cases.github.io/docs/usecases/bridge/) we have identified the following relations with some similarities or enabling additional functionalities of aforementioned SUC: **BRIDGE** • edf-1 (BUC) • elering-10 (SUC) • elering-12 (SUC) • UC2-1 • UC2-4
Level of depth
System use case (SUC)
Prioritisation
Mandatory
Generic, regional or national relation
Generic
Nature of the use case
Technical/system use case
Further keywords for classification
Molten glass, thermal storage, renewable energy, hybrid regenerative furnace, PV system, furnace control system

A.1.8 Diagrams of use case

For clarification, in general it is recommended to provide drawing(s) by hand, by a graphic or as UML graphics. The drawing should show interactions which identify the steps where possible.

Diagram(s) of use case

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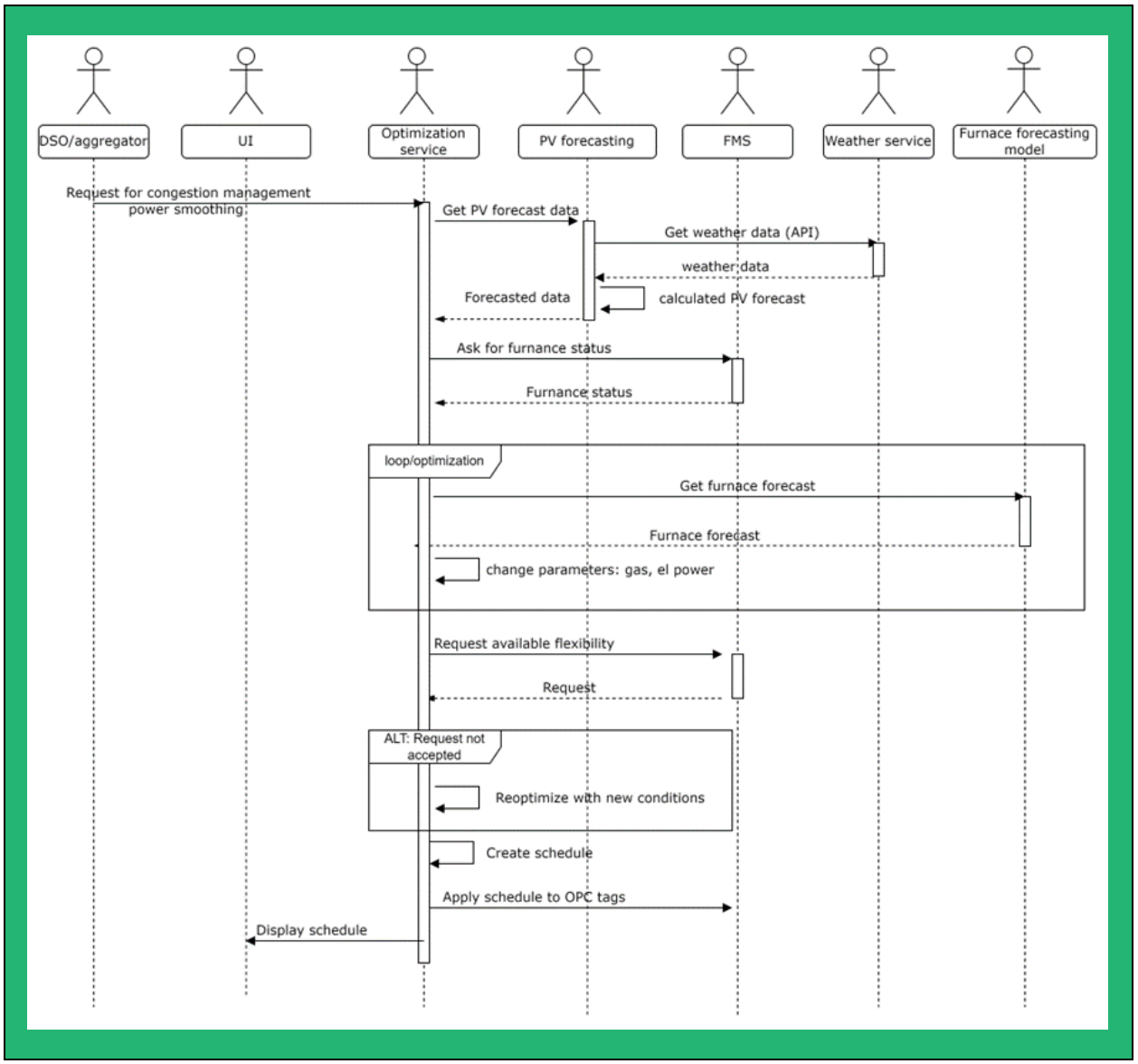

A.1.9 Actors

In this section 3.1, actors which are involved in the use case are listed and described. These can for instance include people, systems, applications, databases, devices, etc. With the aim of improving consistency among Use Case descriptions, we shall use the BRIDGE "Harmonized Electricity Market Role Model" (HEMRM) - https://energy.ec.europa.eu/system/files/2021-06/bridge_wg_regulation_eu_bridge_hemrm_report_2020-2021_0.pdf - for actor names and description. Thus, the information included in the fields of the following table should be obtained from the Actors List defined in BRIDGE HEMRM. Nevertheless, it is possible to add new Actions.

Actors

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Actor Name	Actor Type	Actor Description
DSO	Role	A party operating and monitoring the distribution grid. Initiate the request for flexibility in case of the congestion management.
Aggregator	Role	Aggregates and manages flexibility assets in the network and is responsible for setting the request for flexibility.
FMS	System	Furnace monitoring system is a monitoring and control system comprising a control system for high-level supervisory management of the furnace.
Optimization service	Application	Central service of the flexibility platform, responsible for optimization and creating schedules.
PV forecasting	Application	Application that provides PV power forecasting according to input data.
Furnace forecasting models	Application	Digital twin of the furnace used in the optimization process.
Weather service	Service	Third-party service that provides weather data prediction for the forecast period for the area.
UI	Application	User interface for monitoring and modifying the input parameters for optimization service.

A.1.10 Step by step analysis of use case

Template section 4 focuses on describing scenarios of the use case with a step-step analysis (sequence description). There should be a clear correlation between the narrative and these scenarios and steps.

A.1.11 Overview of scenarios

The table provides an overview of the different scenarios of the use case like normal and alternative scenarios which are described in section 4.2 of the template.

In general, the writer of the use case starts with the normal sequence (success). In case precondition or post-condition does not provide the expected output (e.g. no success = failure), alternative scenarios have to be defined.

Scenario conditions						
No.	**Scenario name**	**Scenario description**	**Primary actor**	**Triggering event**	**Pre-condition**	**Post-condition**

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1	**Request for flexibility**	External actor requests flexibility for congestion management or power smoothing	DSO/Aggregator	Request for flexibility	There is flexibility available in the hybrid storage and is not utilized by internal process	Flexibility request is either accepted or rejected; Optimization is performed with new conditions if needed.

A.1.12 Steps – Scenarios

For this scenario, all the steps performed shall be described going from start to end using simple verbs like – get, put, cancel, subscribe etc. Steps shall be numbered sequentially – 1, 2, 3 and so on. Further steps can be added to the table, if needed (number of steps are not limited). Should the scenario require detailed descriptions of steps that are also used by other use cases, it should be considered creating a new "sub" use case, then referring to that "subroutine" in this scenario.

Scenario								
Scenario name:		**No. 1 - Reference scenario**						
Step No.	**Event**	**Name of process/ activity**	**Description of process/ activity**	**Service (*)**	**Information producer (actor)**	**Information receiver (actor)**	**Information Exchanged (IDs)**	**Req, R-IDs**
1	**DSO/aggregator request for flexibility**	Flexibility request	DSO or Aggregator asks optimization service for flexibility activation	**GET**	DSO/Aggregator	Optimization service	Request	
2	**PV forecast**	PV forecast	Optimization service ask PV forecast service for a forecast of PV system at the location	**GET**	Optimization service	PV forecasting	PV service request	
3	**Weather**	Get weather data	Request for weather prediction for the target period	**GET**	PV forecasting	Weather service	Weather request	R-1
4	**Receive weather**	Receive weather data	Obtain weather prediction for the target period	**EXECUTE**	Weather service	PV forecasting	Weather data	

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5	**Calculate PV forecast**	Calculate PV forecast	Calculate PV forecast using the weather data	**CREATE**	PV forecasting	PV forecasting	-	
6	**Return PV forecast**	Return PV forecasted data	PV forecasting returns the forecast of PV system	**REPORT**	PV forecasting	Optimization service	PV forecast	
7	**Ask for furnace status**	Ask for furnace status	Optimization service ask for current operational data	**GET**	Optimization service	FMS	Operational data request	
8	**Return Furnace status**	Return furnace status	Return operational data of furnace	**REPORT**	FMS	Optimization service	Operational data	
9	**Furnace forecast**	Get furnace forecast	Request for next day furnace forecast	**GET**	Optimization service	FMS	Furnace forecast request	
10	**Return furnace forecast**	Return furnace forecast	Return furnace forecasted data	**REPORT**	FMS	Optimization service	Furnace forecast	
11	**optimization forecast**	Optimization loop	Optimization process	**CREATE**	Optimization service	Optimization service	-	
12	**Request flexibility**	Request to activate the flexibility	Request to activate the calculated flexibility	**GET**	Optimization service	FMS	Activation related data	
13	**Return acceptance of flexibility**	Return acceptance of flexibility	Response to request on activation	**report**	FMS	Optimization service		
14	**ALT: Optimization**	Optimization	Optimization process	**CREATE**	Optimization service	Optimization service	-	
15	**Schedule**	Create Schedule	Create schedule for furnace	**CREATE**	Optimization service	Optimization service	-	
16	**Apply schedule**	Apply schedule	Optimization service send the schedule to FMS	**EXECUTE**	Optimization service	FMS	Optimized schedule	
17	**Display**	D	Display the final optimized schedule for monitoring	**REPORT**	Optimization service	UI	-	

(*) Available options are:

- ***CREATE*** *means that an information object is to be created at the Producer.*
- ***GET*** *(this is the default value if none is populated) means that the Receiver requests information from the Producer (default).*

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- ***CHANGE*** *means that information is to be updated. Producer updates the Receiver's information.*
- ***DELETE*** *means that information is to be deleted. Producer deletes information from the Receiver.*
- ***CANCEL, CLOSE*** *imply actions related to processes, such as the closure of a work order or the cancellation of a control request.*
- ***EXECUTE*** *is used when a complex transaction is being conveyed using a service, which potentially contains more than one verb.*
- ***REPORT*** *is used to represent transferral of unsolicited information or asynchronous information flows. Producer provides information to the Receiver.*
- ***TIMER*** *is used to represent a waiting period. When using the TIMER service, the Information Producer and Information Receiver fields shall refer to the same actor.*
- ***REPEAT*** *is used to indicate that a series of steps is repeated until a condition or trigger event. The condition is specified as the text in the "Event" column for this row or step. Following the word REPEAT, shall appear, in parenthesis, the first and last step numbers of the series to be repeated in the following form REPEAT(X-Y) where X is the first step and Y is the last step.*

A.1.13 Information exchanged

These information objects are corresponding to the "Name of Information" of the "Information Exchanged" column referenced in the scenario steps in template section 4 "Step by Step Analysis". If appropriate, further requirements to the information objects can be added.

Information exchanged			
Information exchanged (ID)	**Name of information**	**Description of information exchanged**	**Requirement, R-IDs**
1	Request	Initial request for flexibility from the DSO or Aggregator	RS_1
2	PV Service request	Request for PV forecast data from the PV forecasting service (location, orientation provided)	RQ_1
3	Weather request	Request for weather data for the target period using the API, (location provided)	RQ_1
4	Weather data	Weather prediction data for the target period (API) Data: temperature and insolation for targeted period	RQ_1
5	PV forecast	Forecasted PV power profile for the area of interest for next day with 15min resolution	RQ_1
6	Operational data request	Request data from OPC UA tags (current, gas consumption, electric power, air flow, air gas ratio, …)	RQ_1, RS_1
7	Operational data	Obtain data from OPC UA tags (current, gas consumption, electric power, air flow, air gas ratio, …)	RQ_1, RS_1
8	Furnace forecast request	Request	RQ_1

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9	Furnace forecast	Forecast furnace power profile for the next day with 15min resolution (gas flow, air flow, electricity consumption, air gas ratio, melt temperature…)	RQ_1
10	Activation related data	OPC UA tags data (flexibility request and datetime data, for different periods)	RS_1
11	Optimized schedule	OPC UA tags data (flexibility request and datetime data, for different periods)	RS_1

A.1.14 Requirements

A list of non-functional requirements was defined in BeFlexible (here) to provide guidelines on possible values that could be given to each type of requirement. However, other values not included in the list could be used if necessary.

Requirements		
Categories ID	**Category name for requirements**	**Category description**
Q	Quality of service	Address availability of the system, such as acceptable downtime, recovery, backup, rollback, etc. Quality of Services issues also address accuracy and precision of data, the frequency of data exchanges, and the necessary flexibility for future changes.
S	Security	The category covers security aspects of the system, relates to the security properties that needs to be provided, namely integrity, authenticity, confidentiality, non-repudiation and availability.
Requirement R-ID	**Requirement name**	**Requirement description**
RS-1	Data security	The system must ensure data integrity and security during information exchange between all actors.
RQ-1	Data availability	Continuous availability of data at specific times or under specific conditions.

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A.2 DEMO 2: HYBRID ENERGY STORAGE INTEGRATION: SYNCHRONOUS CONDENSERS, PUMPED HYDRO, LI-ION BATTERY AND VRFB FOR MULTIPLE SERVICES PROVISION AND INCREASED RES INTEGRATION IN ISOLATED POWER GRIDS

A.2.1 Description of the use case

Use case describes functions of a system in a technology-neutral way. It identifies participating actors which can for instance be other systems or human actors which are playing a role within a use case. Use cases can be specified on different levels of granularity and are according to their level of technological abstraction and granularity either described as Business Use Case (BUC) or System Use Case (SUC).

A.2.2 Name of the use case

ID	Area / Domain(s)	Name of Use Case
	(2) Grid-centric flexibility	Hybrid energy storage integration: synchronous condensers, pumped hydro, Li-Ion battery and VRFB for multiple services provision and increased RES integration in isolated power grids

A.2.3 Version management

Version Management			
Version No.	Date	Name of Author(s)	**Changes**
1.0	20.05.2023	INESC TEC	**Initial draft**
2.0	**19.06.2024**	**INESC TEC**	**Final version**

A.2.4 Scope and objectives of use case

Scope and Objectives of Use Case	
Scope	Use a hybrid ESS (Li-ion battery, VRFB, pumped hydro and synchronous condensers) to increase the robustness of the Madeira island power system and facilitate the safe integration of more

	renewable generation, while maximising the lifetime of the hybrid storage system components. Adapt the dispatch rules of the generation system to eliminate the requirement of always having in operation a minimum number of thermal groups for security reasons.
Objective(s)	Perform the economic dispatch of the Madeira Island generation system (having an hybrid ESS for the provision of multiple regulation services) using a security constrained multi-temporal OPF. The goals are: Minimise renewables curtailment; Minimise the thermal groups that need to be dispatched; Maximise the lifetime of the hybrid ESS components. Maintain frequency Nadir and RoCoF within the defined limits.
Related business case(s)	N/A

A.2.5 Narrative of use case

Narrative of Use Case
Short description
This use case focuses on optimising the Madeira island grid using a HESS using an optimisation algorithm. The algorithm will provide the optimal operation point for the grid using economic dispatch approach. The results from the optimisation algorithm will then be check by a dynamic security and contingencies assessment. Thereafter the results are sent to EEM which will use the set points in the dispatch centres. By using this solution is expected to reduce overall CO_2 emissions from electricity generation, reduce renewables curtailment, increase overall efficiency of the grid, reduce cost of operation of the grid and increase lifetime of the storage systems.

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Complete description
This use case describes how the Madeira Island system operator optimises the operation of an hybrid storage system composed of Li-ion and VRF batteries, pumped hydro and synchronous condensers to: i) Minimise renewables curtailment; ii) Minimise the thermal groups that need to be dispatched; iii) Maximise the lifetime of the hybrid ESS components; iv) Maintain frequency Nadir and RoCoF within the defined limits. To accomplish this objective, a mix of existing and newly developed algorithms (hereafter referred to as "the procedure") will be used, as described in the following steps: The system operator wishes to define the optimal Li-ion battery SOC, VRF battery SoC, synchronous condensers operating point and renewables operating point for a given time interval between 'ti-tf'. For that, he triggers the procedure providing the inputs 'ti-tf' '. The first step of the procedure is running the load/renewable generation forecasting algorithms for 'ti-tf'. Load and renewable generation forecasts are saved in the local SCADA. '.. The second step of the procedure is running the dispatch algorithm for 'ti-tf'. Thermal and hydro units dispatch status is saved in the local SCADA. The third step consists of running the multi-temporal optimization algorithm for 'ti-tf', which performs the following sequential tasks: ', Accesses the local SCADA through a REST API to retrieve load/renewable generation forecasts and thermal/hydro units dispatch status for 'ti-tf'. Runs the optimisation problem with the following characteristics: Objective function: Min Cost (Ren_Curt, HESS_Degrad, Sync_Cond) Subject to security constraints: key frequency indicators within predefined limits (RoCoF and Nadir); Generation units capacity limits$Generation\ units$ capacity limits; ESS limits and power ramps$ESS\ limits\ and\ power$ ramps; Thermal units power ramps$Thermal\ units\ power$ ramps;

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Minimum up and down times of thermal units and synchronous condensers;

Hydro reservoirs water storage capabilities;

Decision variables:
Li-ion SoC;VRF battery SoC;Synchronous condensers operatings point;Renewables operating point;
.
If the RoCoF and Nadir are far from their limits (specific criteria to be defined), go back to point 3 (second step) and re-run the dispatch algorithm for 'ti-tf' with the removal of one thermal unit. Otherwise, store the decision variables in the local SCADA.

In the fourth step, the system operator retrieves from the SCADA the optimised decision variables and implements them during 'ti-tf'.

A.2.6 Use case conditions

Use case conditions
Assumptions
The local regulatory framework allows the system operator to install and operate storage devices. Load and renewable generation forecasting algorithms are implemented and running locally. Outputs from these algorithms can be obtained from local SCADA. Generation dispatch algorithm is implemented and running locally. Outputs from this algorithm can be obtained from local SCADA. The multi-temporal optimisation algorithm is implemented and running in a virtual machine at INESC TEC and has access to the island's SCADA (only selected information) through EEM SFTP server that will communicate with INESC TEC virtual machine. The multi-temporal optimisation algorithm results will then be checked, considering Nadir and RoCoF-related restriction defined through a previously trained ANN. The ANN used to define Nadir and RoCoF-related restrictions was trained using: The most relevant contingencies for the island system, which are defined and characterized in a local database that can be accessed remotely. Trustworthy network/assets data for dynamic simulations provided by the system operator.
Prerequisites
Real time data from EEM including: Load Load forecasts

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Generation Generation forecasts Weather forecasts Water reservoirs levels To all of this data be shared a connection between EEM and INESC TEC is necessary. It is also needed to have the VRFB installed and operating in the Madeira island grid.

A.2.7 Further Information to the use case for classification / mapping

Classification Information
Relation to other use cases
edf-1 | Smart Grid Use Cases (smart-grid-use-cases.github.io)
Level of depth
System use case (SUC) use case which describes in detail the functionality/technological solutions of (a part of) a business process.
Prioritisation
This is a core use case of Demo 2.
Generic, regional or national relation
This use case is regional since is being applied to Madeira Island but it is also generic since this can be applied to other isolated electrical systems.
Nature of the use case
Technical/System use case.
Further keywords for classification
Hybrid storage, Optimisation, Renewable energies.

A.2.8 General Remarks

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General Remarks
N/A

A.2.9 Diagrams of use case

For clarification, in general it is recommended to provide drawing(s) by hand, by a graphic or as UML graphics. The drawing should show interactions which identify the steps where possible.

Diagram(s) of use case
The ancillary services will be provided simultaneously by the optimisation process, represented in the sequence diagram bellow. The process consists in defining a general technology dispatch, optimal from an economic dispatch perspective and viable from a dynamic viewpoint. This optimisation process starts with a request from EEM through the API. The virtual machine will fetch updated data from the EEM server, which will then be used by the optimisation algorithm. Afterwards, the results from the optimisation algorithm will be assessed by a dynamic-based procedure featuring the N-1 criterion. If the algorithm outputs result in a safe and stable system, the data will be stored in EEM SFTP server and INESC TEC virtual machine. If the output does not result in a safe point of operation, then the algorithm will dispatch synchronous condensers and run again. This process is repeated until a safe point of operation is achieved. When a stable point of operation is calculated EEM will set their power generation technologies to the defined point of operation.

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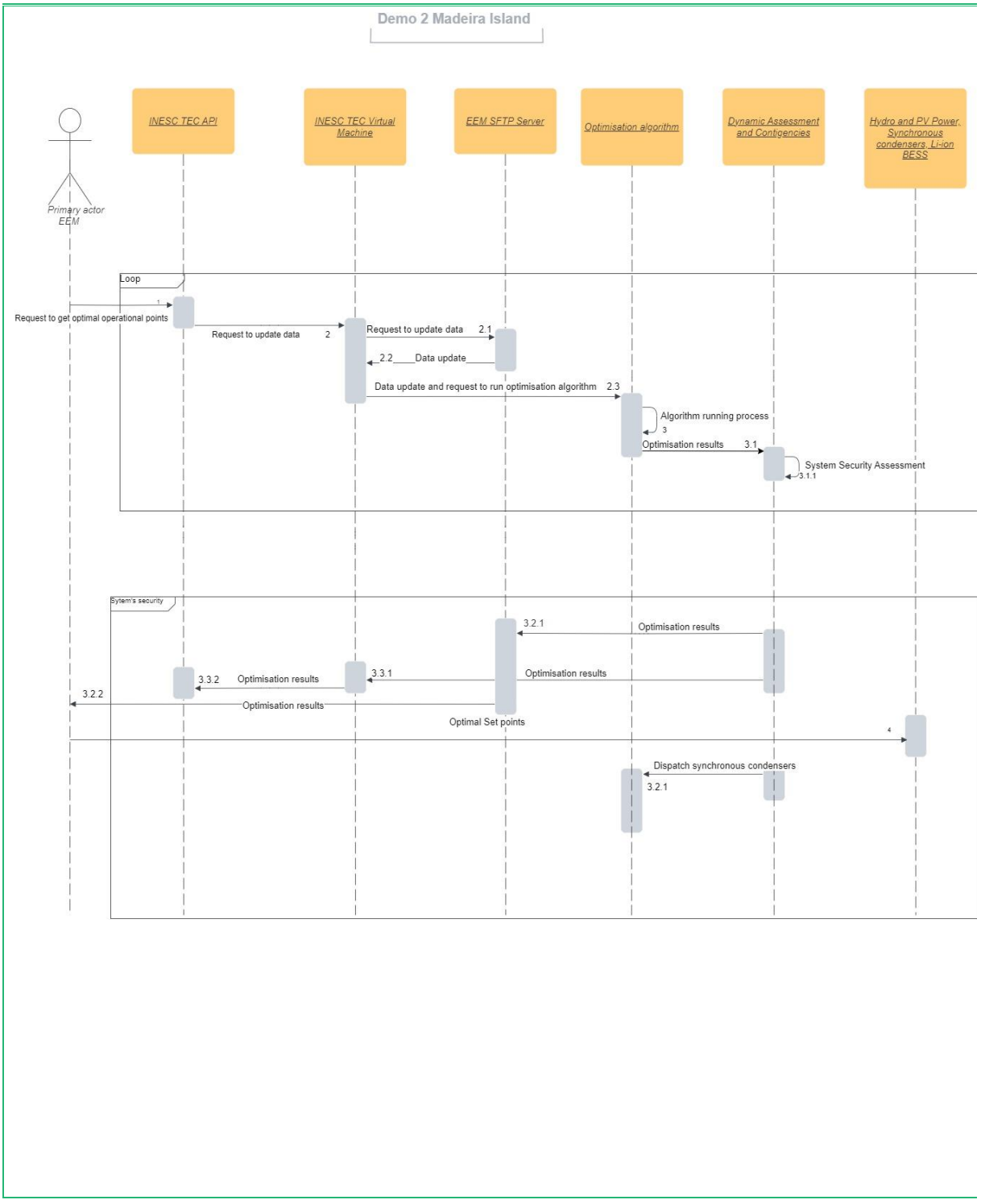

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A.2.10 Actors

In this section 3.1, actors which are involved in the use case are listed and described. These can for instance include people, systems, applications, databases, devices, etc.

With the aim of improving consistency among Use Case descriptions, we shall use the BRIDGE "Harmonized Electricity Market Role Model" (HEMRM) - https://energy.ec.europa.eu/system/files/2021-06/bridge_wg_regulation_eu_bridge_hemrm_report_2020-2021_0.pdf - for actor names and description. Thus, the information included in the fields of the following table should be obtained from the Actors List defined in BRIDGE HEMRM. Nevertheless, it is possible to add new Actions.

Actors		
Actor Name	Actor Type	**Actor Description**
EEM	Primary actor	**EEM is the primary actor in this use case. As system operator, it is EEM that requests a service from the system under discussion and that aims at achieving the use case main objective.**
Renewable energy companies	Secondary actors	**Companies investing in renewable generation facilities are external actors as they are who provide the renewable curtailment service. They may also be regarded as external actors since they a stakeholder with a clear goal: minimise renewables curtailment.**
Madeira regional government	External actor	**The Madeira regional government is considered a stakeholder in this use case, as they have a significant interest in maximising local renewable generation to progressively decarbonise the island.**
Electricity network clients	**External actor**	**The customers of Madeira Island's electricity networks are considered stakeholders in this use case, as they have a significant interest in ensuring the resilience of the power grid.**

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A.2.11 References

References (which are standards, reports, mandates and regulatory constraints) associated with the Use Case. The writers must identify the standards that should be used to realize the Use Case and improve the replicability of the solution.

Identify any legal issues that might affect the design and requirements of the function, including contracts, regulations, policies, financial considerations, engineering constraints, pollution constraints, and other environmental quality issues.

References						
No.	References Type	Reference	Status	Impact on use case	Originator / organisation	**Link**
1.	**Grid Code**	**Madeira Island Grid Code**	**Developed**		**EEM**	**ISerie-175-2019-11-06.pdf (madeira.gov.pt)**

A.2.12 Step by step analysis of use case

Template section 4 focuses on describing scenarios of the use case with a step-step analysis (sequence description). There should be a clear correlation between the narrative and these scenarios and steps.

A.2.13 Overview of scenarios

The table provides an overview of the different scenarios of the use case like normal and alternative scenarios which are described in section 4.2 of the template.
In general, the writer of the use case starts with the normal sequence (success). In case precondition or post-condition does not provide the expected output (e.g. no success = failure), alternative scenarios have to be defined.

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	**Post-condition**
1.0	System Safe	The optimisations results will be checked by a dynamic	EEM	EEM request for new	System is operating normally and stable with EEM	**A more efficient grid point of operation**

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		security assessment. In case the results are safe INESC TEC will send those results to EEM through an API		optimisation results	dispatch rules	**is achieved**
2.0	System unsafe	The optimisation results will be checked by a dynamic security assessment. In case the results are unsafe INESC TEC will need to re-run the algorithms with more synchronous condensers dispatched and check the dynamic security assessment again. The whole process is repeated until a stable result is achieved	EEM	EEM request for new optimisation results	System is operating normally and stable with EEM dispatch rules	**A more efficient grid point of operation is achieved.**
3.0	**No optimisation is possible**	**The optimisation results will be checked**	**EEM**	**EEM request for new**	**System is operating normally and stable**	**System will continue operate**

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		by a dynamic security assessment. In case the results are unsafe INESC TEC will need to re-run the algorithms with more synchronous condensers dispatched and check the dynamic security assessment again. The whole process is repeated increasing the dispatched synchronous condensers until all the synchronous condensers are dispatch and the optimisation results aren't safe yet		**optimisation results**	**with EEM dispatch rules**	**without any changes, EEM will receive the optimisation results and that no optimisation is possible.**

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A.2.14 Steps – Scenarios

For this scenario, all the steps performed shall be described going from start to end using simple verbs like – get, put, cancel, subscribe etc. Steps shall be numbered sequentially – 1, 2, 3 and so on. Further steps can be added to the table, if needed (number of steps are not limited).
Should the scenario require detailed descriptions of steps that are also used by other use cases, it should be considered creating a new "sub" use case, then referring to that "subroutine" in this scenario.

Scenario								
Scenario name :	**No. 1 -**	**Reference scenario**						
Step No.	Event	Name of process/ activity	Description of process/ activity	Service	Information producer (actor)	Information receiver (actor)	Information Exchanged (IDs)	**Requirement, R-IDs**
1.0	EEM request to get optimal operational points	Request to get optimal operational points	EEM will do this request on the INESC TEC API that will respond accordingly		EEM	INESC TEC API	Request to get optimal operational points – 1.0	
2.0	INESC TEC API makes a request to update data	Request to read updated data	INESC TEC API will make a request to update data to INESC TEC virtual machine		INESCTEC API	INESC TEC Virtual Machine	Request to read updated data – 2.0	

2.1	INESC TEC virtual machine makes a request to update data	Request to read updated data	INESC TEC Virtual machine will make a request to update data to EEM SFTP server		INESC TEC Virtual Machine	EEM SFTP Server	Request to read updated data – 2.1	
2.2	EEM SFTP Server send data update	Data update	EEM SFTP Server responds the request sending updated data to INESC TEC Virtual Machine		EEM SFTP Server	INESC TEC Virtual Machine	Data update – 2.2	
2.3	INESC TEC Virtual Machine sends Data update and request to run optimisation algorithm	Data update and request to run optimisation algorithm	INESC TEC Virtual Machine will send data update and a request to run the optimisation algorithm after receiving the data update from EEM SFTP server		INESC TEC Virtual Machine	Optimisation Algorithm	Data update and request to run optimisation algorithm – 2.3	
3.0	The algorithm will run	Algorithm Runing process	After receiving data update from INESC TEC Virtual Machine the		Optimisation Algorithm	Optimisation Algorithm	Updated data from INESC TEC	

	considering the latest data		Optimisation Algorithm will run using the data it has received				Virtual Machine – 3.0	
3.1	The algorithm will send the optimisation results	Optimisation Results	After the algorithm's running process the algorithm will send its results to the Dynamic Assessment and Contingencies		Optimisation Algorithm	Dynamic Assessment and Contingencies	Optimisation results – 3.1	
3.1.1	A System Security Assessment is preformed considering the optimisation results	System Security Assessment	A dynamic assessment and contingencies is preformed considering the data from the optimisation algorithm.		Dynamic Assessment and Contingencies	Dynamic Assessment and Contingencies	Dynamic Security Results – 3.1.1	
3.2.1	The Dynamic Assessment and contingencies sends the results to the EEM	Optimisation Results	In case the dynamic assessment an contingencies verify that the results represent indeed a safe and stable system then the results are sent to EEM SFTP Server		Dynamic Assessment and Contingencies	EEM SFTP Server	Dynamic Security Results – 3.2.1	

	SFTP Server							
3.2.2	The EEM SFTP Server sends optimisation results to EEM	Optimisation Results	The EEM SFTP Server sends the results dynamic security results to the EEM		EEM SFTP Server	EEM	Dynamic Security Results – 3.2.1	
3.3.1	The EEM SFTP Server sends the results to the INESC TEC Virtual Machine	Optimisation Results	In case the dynamic assessment an contingencies verify that the results represent indeed a safe and stable system then the results are sent to INESC TEC Virtual Machine		EEM SFTP Server	INESC TEC Virtual Machine	Dynamic Security Results – 3.3.1	
3.3.2	The INESC TEC Virtual Machine sends the results to the INESC TEC API	Optimisation Results	In case the dynamic assessment an contingencies verify that the results represent indeed a safe and stable system then the results are sent to INESC TEC API through		INESC TEC Virtual Machine	INESC TEC API	Dynamic Security Results – 3.3.2	

			the INESC TEC Virtual Machine					
3.2.1	Dynamic Assessment and Contingencies	Dispatch Synchronous condensers	In case the dynamic assessment and contingencies verifies that the system is not safe it will send a new request to run the optimisation algorithm with more synchronous condensers, this will repeat until a safe system's point of operation is achieved		Dynamic Assessment and Contingencies	Optimisation Algorithm	Dynamic Security Results – 3.2.1	
4	**EEM sets the optimal set points**	**Optimal set point**	**After receiving the optimal point of operation from INESC TEC tools EEM will define their assets point of operation.**		**EEM**	**Hydro Power with reservoir,** **PV power,** **Synchronous Condensers,**	**Set points - 4**	

						Wind Power, **VRFB and Li-ion BESS**		

A.2.15 Information exchanged

These information objects are corresponding to the "Name of Information" of the "Information Exchanged" column referenced in the scenario steps in template section 4 "Step by Step Analysis". If appropriate, further requirements to the information objects can be added.

Information exchanged (ID)	Name of information	Description of information exchanged
1.0	Aggregated load forecasts	**The prediction of the total electrical load for a specific time period, compiled from multiple individual load forecasts across various segments of the grid**
2.0	Aggregated PV Power forecasts	**The prediction of the total power output from multiple photovoltaic (PV) systems over a specific period.**
3	Aggregated Wind Power forecasts	**The prediction of the total power output from multiple Wind Power systems over a specific period.**
4	Aggregated Hydro Power forecasts	**The prediction of the total power output from multiple Hydro power systems over a specific period.**
5	Water reservoir levels	**The current and forecasted water storage levels in hydroelectric power plant reservoirs.**
6	Aggregated PV Power generation	**The combined electrical power output from multiple photovoltaic (PV) systems, summed together to provide a total power generation value**
7	Aggregated Wind Power generation	**the combined electrical power output from multiple wind power systems, summed together to provide a total power generation value**
8	Aggregated Hydro Power generation	**The combined electrical power output from multiple hydro power systems, summed together to provide a total power generation value**
9	Aggregated thermal power forecasts	**The prediction of the total power output from multiple thermal units summed together over a specific period.**
10	Aggregated thermal power generation	**The combined electrical power output from multiple thermal units, summed together to provide a total power generation value**

A.2.16 Requirements

A list of non-functional requirements was defined in BeFlexible (here) to provide guidelines on possible values that could be given to each type of requirement. However, other values not included in the list could be used if necessary.

Requirements		
Categories ID	Category name for requirements	**Category description**
Requirement R-ID	**Requirement name**	**Requirement description**

A.2.17 Common Terms and Definitions

Should be defined in a common glossary for all use cases. Here relevant terms belonging to this use case are listed. Using a database repository for the glossary, the definitions might be filled automatically based on existing information.

Common Terms and Definitions	
Term	**Definition**
HESS	**Hybrid Energy Storage System**
VRFB	**Vanadium Redox Flow Battery**

A.3 DEMO 2: ENHANCED VRFB PERFORMANCE FOR POWER SMOOTHING

A.3.1 Description of the use case

Use case describes functions of a system in a technology-neutral way. It identifies participating actors which can for instance be other systems or human actors which are playing a role within a use case. Use cases can be specified on different levels of granularity and are according to their level of technological abstraction and granularity either described as Business Use Case (BUC) or System Use Case (SUC).

A.3.2 Name of the use case

ID	Area / Domain(s)	Name of Use Case
	(2) Grid-centric flexibility	Enhanced VRFB performance for power smoothing

A.3.3 1.2 Version management

Version Management			
Version No.	**Date**	**Name of Author(s)**	**Changes**
1.0	20.05.2023	INESC TEC	**Initial draft**
2.0	**19.06.2024**	**INESC TEC**	**Final Version**

A.3.4 Scope and objectives of use case

Scope and Objectives of Use Case	
Scope	This use case explores the integration of a Vanadium Redox Flow Battery (VRFB) into the Madeira Island electrical grid. The primary objective is to utilize the VRFB to provide power smoothing services, particularly in response to photovoltaic (PV) power fluctuations. The set points for the VRFB will be determined by an optimization algorithm designed to enhance grid stability and efficiency.

Objective(s)	Enhance VRFB performance focused on: Power Smoothing: To mitigate the impact of PV power ramps on the grid by leveraging the VRFB's capabilities. Optimization: To determine the optimal VRFB set points through an advanced optimization algorithm, ensuring effective and efficient operation. Grid Stability: To maintain and enhance the stability of the Madeira Island grid by reducing power fluctuations from PV generation.
Related business case(s)	N/A.

A.3.5 Narrative of use case

Narrative of Use Case
Short description
The VRFB will be developed, tested and lately installed in Madeira Island. The use case consists in developing the battery's optimisation algorithm mitigate PV ramps, providing power smoothing capabilities to the grid.
Complete description
This use case describes the three planned action lines to enhance the performance of a Vanadium Redox Flow Battery (VRFB) connected to the Madeira Island grid, with the goal of providing power smoothing services, particularly for photovoltaic (PV) power ramps. To accomplish this objective, three different action lines will be applied: Day-Ahead Optimal Operational Setpoints:The VRFB operator will define the optimal operational setpoints for the VRFB on a day-ahead basis using available PV predictions. This ensures that the VRFB is used effectively to smooth out PV power fluctuations. Data Integration and Algorithm Deployment: Load and Generation Data: The service will include the collection and integration of load and generation data from the grid. Data Pipeline: Establishment of a robust data pipeline between EEM (the system operator) and INESC TEC for seamless data exchange.

Optimisation Algorithm: Development and deployment of an advanced optimisation algorithm tailored to enhance the VRFB's performance in power smoothing applications.

Validation: Continuous validation of the optimisation algorithm's outputs to ensure accuracy and reliability in real-world scenarios.

Optimisation Algorithm Execution: The service will involve executing the optimisation algorithm to determine the optimal VRFB setpoints, taking into account the following factors:

Cost of Renewable Curtailment (Ren_Curt): Minimizing the curtailment of renewable energy sources like PV.

Cost of VRFB Degradation (HESS_Degrad): Minimizing the degradation costs associated with VRFB charging and discharging cycles.

Cost of Grid Instability (Sync_Cond): Ensuring grid stability by optimizing the operating points of synchronous condensers and other grid stability measures.

The algorithm should be taking into account the following constraints:

SoC Limits: $SoC_{min} \leq SoC_{VRFB}(t) \leq SoC_{max}$SoC

Power Limits: $P_{VRFB,min} \leq P_{VRFB}(t) \leq P_{VRFB,max}$

Grid Stability: $RoCoF_{min} \leq RoCoF(t) \leq RoCoF_{max}$

The system operator will retrieve from the SCADA the optimised level of SoC of the VRFB

A.3.6 Use case conditions

Use case conditions
Assumptions
VRFB communication protocol is provided by the manufacturer (enabling the interoperability with the additional subsystems). VRFB BMS provides accurate state estimation of the SoC, temperature, and leaks. The weather and load forecast data is reliable
Prerequisites

VRFB should be installed and fully operational in the Madeira Island electrical grid

A.3.7 Further Information to the use case for classification / mapping

Classification Information
Relation to other use cases
Level of depth
System use case (SUC) use case which describes in detail the functionality/technological solutions of (a part of) a business process.
Prioritisation
This is a core use case of Demo 2.
Generic, regional or national relation
This use case is regional since is being applied to Madeira Island but it is also generic since this can be applied to other isolated electrical systems.
Nature of the use case
Technical/system use case.
Further keywords for classification
Optimisation, Power Smoothing, Storage, VRFB.

A.3.8 General Remarks

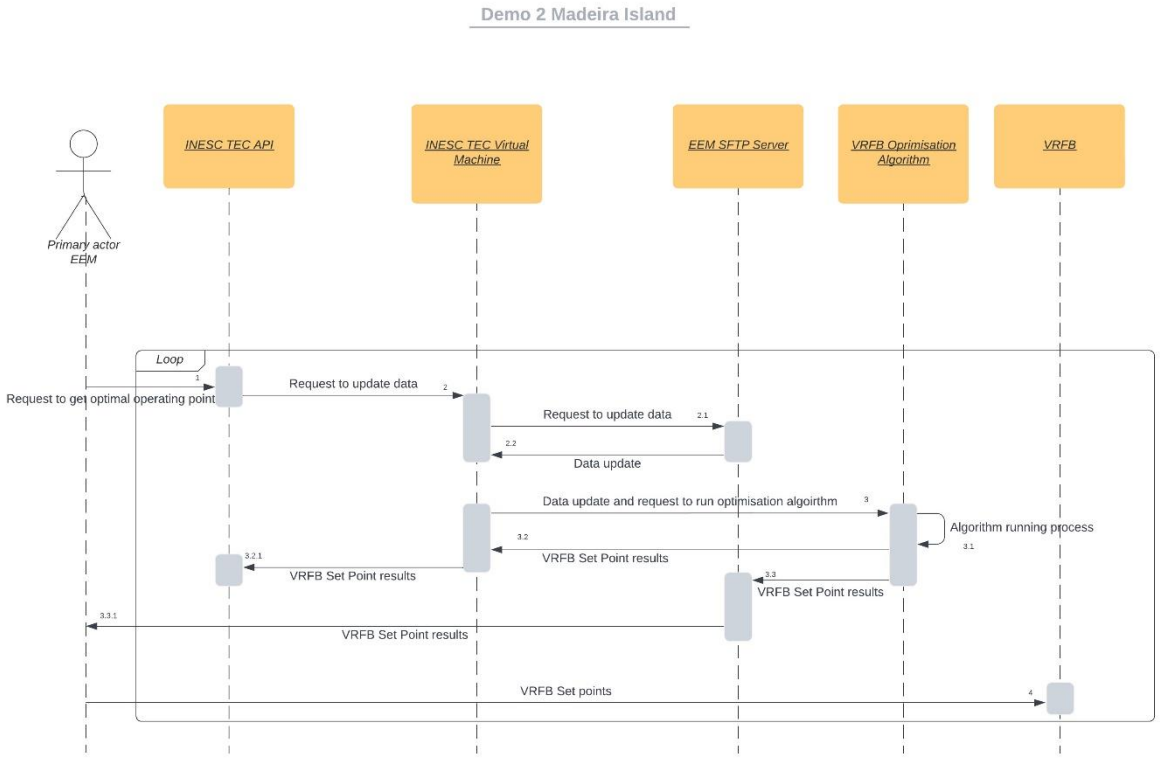
General Remarks
N/A

A.3.9 Diagrams of use case

For clarification, in general it is recommended to provide drawing(s) by hand, by a graphic or as UML graphics. The drawing should show interactions which identify the steps where possible.

Diagram(s) of use case

The VRFB will be used for power smoothing, the process is initiated by EEM through a request via the API previously mentioned, as shown in the figure above. INESC TEC virtual machine will then fetch updated data from the EEM server and run the VRFB optimisation algorithm. The results will be stored in INESC TEC virtual machine and EEM server when the process is completed. EEM will control the VRFB accordingly.



A.3.10 Actors

In this section 3.1, actors which are involved in the use case are listed and described. These can for instance include people, systems, applications, databases, devices, etc.

With the aim of improving consistency among Use Case descriptions, we shall use the BRIDGE "Harmonized Electricity Market Role Model" (HEMRM) - https://energy.ec.europa.eu/system/files/2021-06/bridge_wg_regulation_eu_bridge_hemrm_report_2020-2021_0.pdf - for actor names and description. Thus, the information included in the fields of the following table should be obtained from the Actors List defined in BRIDGE HEMRM. Nevertheless, it is possible to add new Actions.

Actors		
Actor Name	Actor Type	Actor Description
VRFB manufacturers	External Actor	VRFB manufacturers are primary actors in this use case. Manufacturers as VRFB providers will benefit directly from the project outcomes allowing to increase their system performance in terms of efficiency and lifespan.
Storage System Integrator	External Actor	Storage system integrators are primary actors in this use case as they will benefit from the hybridization system strategy and respective and project outcomes.
EEM	Primary Actor	EEM is the primary actor in this use case. As system operator, it is EEM that requests a service from the system under discussion and benefit directly from the characteristics of the demo unit.
Renewable Energy Companies	Secondary Actor	Companies investing in renewable generation facilities are external actors as they are who provide the renewable curtailment service. They may also be regarded as external actors since they are stakeholders with a clear goal: minimise renewables curtailment.
Madeira Island Regional Government	Secondary Actor	The Madeira regional government is considered a stakeholder in this use case, as they have a significant interest in maximising local renewable generation to progressively decarbonise the island.

Electricity Network Clients	Secondary Actor	The customers of Madeira Island's electricity networks are considered stakeholders in this use case, as they have a significant interest in ensuring the resilience of the power grid.

A.3.11 References

References (which are standards, reports, mandates and regulatory constraints) associated with the Use Case. The writers must identify the standards that should be used to realize the Use Case and improve the replicability of the solution.

Identify any legal issues that might affect the design and requirements of the function, including contracts, regulations, policies, financial considerations, engineering constraints, pollution constraints, and other environmental quality issues.

References						
No.	References Type	Reference	Status	Impact on use case	Originator / organisation	Link
1.0	**Grid Code**	**Madeira Island Grid Code**	**Developed**		**EEM**	**ISerie-175-2019-11-06.pdf (madeira.gov.pt)**

A.3.12 Step by step analysis of use case

Template section 4 focuses on describing scenarios of the use case with a step-step analysis (sequence description). There should be a clear correlation between the narrative and these scenarios and steps.

A.3.13 Overview of scenarios

The table provides an overview of the different scenarios of the use case like normal and alternative scenarios which are described in section 4.2 of the template.

In general, the writer of the use case starts with the normal sequence (success). In case precondition or post-condition does not provide the expected output (e.g. no success = failure), alternative scenarios have to be defined.

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
1.0	VRFB SoC is optimised	The VRFB Optimisation Algorithm runs and defines the VRFB optimal SoC	EEM	VRFB Optimisation Algorithm sending its results to EEM	System working in a stable point of operation	**System working stable with more capability to respond to power smoothing**

For this scenario, all the steps performed shall be described going from start to end using simple verbs like – get, put, cancel, subscribe etc. Steps shall be numbered sequentially – 1, 2, 3 and so on. Further steps can be added to the table, if needed (number of steps are not limited).

Should the scenario require detailed descriptions of steps that are also used by other use cases, it should be considered creating a new "sub" use case, then referring to that "subroutine" in this scenario.

Scenario								
Scenario name :		No. 1 - Reference scenario						
Step No.	Event	Name of process/ activity	Description of process/ activity	Service	Information producer (actor)	Information receiver (actor)	Information Exchanged (IDs)	Requirement, R-IDs
1.0	EEM makes the request	Request to get optimal operational point	EEM makes a request to INESC TEC API to get operational point		EEM	INESC TEC API	Request to et optimal operational point – 1.0	
2.0	INESC TEC API makes the request to update data	Request to update data	INESC TEC API makes a request to get data updated from INESC TEC Virtual Machine		INESC TEC API	INESC TEC Virtual Machine	Request to update data – 2.0	

2.1	INESC TEC Virtual Machine makes the request to update data	Request to update data	INESC TEC Virtual Machine makes a request to get data updated from EEM SFTP Server		INESC TEC Virtual Machine	EEM SFTP Server	Request to update data – 2.1	
2.2	EEM SFT SERVER responds to the request sending the data	Data update	EEM SFTP server sends updated data to the INESC TEC Virtual Machine		EEM SFTP Server	INESC TEC Virtual Machine	Data update – 2.2	
3	INESC TEC Virtual Machine sends the data received to the optimisation algorithm alongside with a request to	Data update and request to run optimisation algorithm	INESC TEC Virtual Machine sends the data to the optimisation algorithm. At the same time sends a running request with the data sent.		INESC TEC Virtual Machine	Optimisation Algorithm	Data update and request to run optimisation algorithm - 3	

	run the algorithm							
3.1	The optimisation algorithm responds to the request running	Algorithm running process	The optimisation algorithm will run with the data it has received and output the optimal set point for the VRFB		VRFB Optimisation Algorithm	VRFB Optimisation Algorithm		
3.2	The algorithm sends the output	VRFB Set Point results	The optimisation algorithm sends the results from the running process to the INESC TEC Virtual Machine		VRFB Optimisation Algorithm	INESC TEC Virtual Machine	VRFB Set Point results – 3.2	
3.2.1	INESC TEC Virtual Machine sends the VRFB set point results	VRFB Set Point results	After the INESC TEC Virtual Machine received the VRFB Set Point Results, sends it to the INESC TEC API		INESC TEC Virtual Machine	INESC TEC API	VRFB Set Point results – 3.2.1	
3.3	The optimisation algorithm	VRFB Set Point results	The optimisation algorithm sends the results from the		VRFB Optimisation Algorithm	EEM SFTP Server	VRFB Set Point results – 3.3	

	sends the results		running process to the EEM SFTP Server					
3.3.1	The optimisation algorithm sends the results	VRFB Set Point results	EEM SFTP Server sends the VRFB Set point results to EEM		EEM SFTP Server	EEM	VRFB Set Point results – 3.3.1	
4	**EEM sets the point of operation of the VRFB**	**VRFB Set Points**	**EEM sets the VRFB considering the results received from the VRFB optimisation algorithm**		**EEM**	**VRFB**	**VRFB Set Points – 4**	

A.3.15 Information exchanged

These information objects are corresponding to the "Name of Information" of the "Information Exchanged" column referenced in the scenario steps in template section 4 "Step by Step Analysis". If appropriate, further requirements to the information objects can be added.

Information exchanged			
Information exchanged (ID)	Name of information	Description of information exchanged	Requirement, R-IDs
1.0	Aggregated load forecasts	the prediction of the total electrical load for a specific time period, compiled from multiple individual load forecasts across various segments of the grid	Can be used to define requirements referring to the information and not to the step as in the step by step analysis (see template section 6 below): EXAMPLE: Data protection class corresponding to this information object.
2.0	Aggregated PV Power forecasts	The prediction of the total power output from multiple photovoltaic (PV) systems over a specific period.	
3.0	Aggregated PV Power generation	The combined electrical power output from multiple photovoltaic (PV) systems, summed together to provide a total power generation value	

A.3.16 Requirements

A list of non-functional requirements was defined in BeFlexible (here) to provide guidelines on possible values that could be given to each type of requirement. However, other values not included in the list could be used if necessary.

Requirements		
Categories ID	Category name for requirements	Category description
Unique identifier for the category.	Name for the category of requirements.	Description of the requirement category.
Requirement R-ID	Requirement name	Requirement description
Unique identifier which identifies the requirement within its category and which can link the requirement to an external requirement document.	A name of the requirement.	Description of the requirement (this might be populated automatically from the repository, if the requirement has already been described in the external document before).

A.3.17 Common Terms and Definitions

Should be defined in a common glossary for all use cases. Here relevant terms belonging to this use case are listed. Using a database repository for the glossary, the definitions might be filled automatically based on existing information.

Common Terms and Definitions	
Term	Definition
BESS	**Battery Energy Storage System**
HESS	**Hybrid Energy Storage System**
VRFB	**Vanadium Redox Flow Battery**

B. APPENDIX: INTEGRATION PLAN