The DELTA project has received funding from the EU's Horizon 2020 research and innovation programme under grant agreement No 773960

D E L T A

Project Acronym:	**DELTA**
Project Full Title:	**Future tamper-proof Demand rEsponse framework through seLf-configured, self-opTimized and collAborative virtual distributed energy nodes**
Grant Agreement:	**773960**
Project Duration:	**36 months (01/05/2018 – 30/04/2021)**

DELIVERABLE D4.1

DELTA Aggregator Infrastructure and Reference Implementation

Work Package	**WP4 – Adaptive Aggregator DELTA Supervisory Engine**
Task	**T4.1 – Delta Aggregator Infrastructure, Design and Implementation**
Document Status:	**Final**
File Name:	**DELTA_D4.1_Final**
Due Date:	**31 October 2019**
Submission Date:	**01 November 2019**
Lead Beneficiary:	**UCY**

Dissemination Level	
Public	X
Confidential, only for members of the Consortium (including the Commission Services)	

Authors List

Leading Author				
First Name		Last Name	Beneficiary	Contact e-mail
Ian		Cole	UCY	cole.ian@ucy.ac.cy
Co-Author(s)				
#	First Name	Last Name	Beneficiary	Contact e-mail
1	Venizelos	Venizelou	UCY	venizelou.venizelos@ucy.ac.cy
2	Kyriaki	Psara	UCY	kyriaki-ps@hotmail.co.uk
3	Alba	Fernández-Izquierdo	UPM	albafernandez@fi.upm.es
4	Andrea	Cimmino	UPM	cimmino@fi.upm.es
5	Phivos	Therapontos	EAC	PTherapo@Eac.com.cy
6	Ioannis	Aristidou	UCY	aristidou.ioannis@ucy.ac.cy
7	Venizelos	Efthymiou	UCY	efthymiou.venizelos@ucy.ac.cy
8	Apostolos	Tsolakis	CERTH	tsolakis@iti.gr
9	Stelios	Krinidis	CERTH	krinidis@iti.gr
10	Ioannis	Moschos	CERTH	imoschos@iti.gr

Reviewers List

Reviewers			
First Name	Last Name	Beneficiary	Contact e-mail
Dimosthenis	Ioannidis	CERTH	djoannid@iti.gr
Phivos	Therapontos	EAC	PTherapo@Eac.com.cy
Ioannis	Papageogriou	EAC	IPapageo@Eac.com.cy

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Executive Summary

The general objective of this work is to devise and document a common platform that will act as a reference for the development and deployment of components within the DELTA aggregator layer. This document is used to ensure that the specification and documentation of the aggregator layer has arrived at herein meets the objectives specified above, a review of the DELTA specifications for Business Models, Use Cases and Requirements pertaining to the aggregator layer was first performed. To further specify the operation of the aggregator layer components, namely: Grid Stability Simulation Engine (GSSE), Self-Portfolio Energy Balancing (SPEB), Asset Handling Optimisation (AHO), Node Flexibility Data Monitoring and Profiling (NFDM&P), Energy Market Price Forecast (EMPF), DR & Flexibility Forecasting (DR&FF), and Energy Portfolio Segmentation & Classification (EPS&C), architectural and operational requirements are derived from the DELTA specification and documentation used to improve implementation of user requirements and relationships. The fundamental components of the domain and the relations between them are defined in a Reference architecture in order to identify any missing architectural information and to enable consistent architectural practices. A product's functionality is used to identify product features and to enable users to have a set of system capabilities. Consequently, we define the provisional specifications for the DELTA platform in order to understand the configuration and guide production of the system. The Final chapter provides an example case study of how the two DELTA components communicate and produce the required outputs.

As stated within the main body, for some of the Aggregator's components a high level overview is presented, whereas more detailed technical implementation is to be expected in other WP4 deliverables (i.e. D4.2, D4.3, D4.4).

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List of Acronyms and Abbreviations

Term	Description
FEID	Fog Enabled Intelligent Device
DR	Demand Response
DSS	Decision Support System
DVN	DELTA Virtual Node
DVNP	DELTA Virtual Node Platform
F	Functional requirement
NF	Non-functional requirements
IEEE	Institute of Electrical and Electronics Engineers
SPEB	Self-Portfolio Energy Balancing
GSSE	Grid Stability Simulation Engine
C/PC	Consumer/Prosumer Clustering
C/PFDMP	Consumer/Prosumer Flexibility Data Monitoring and Profiling
G/COD	Generation/Consumption Optimal Dispatched
DRFF	Demand /Response Flexibility Forecasting
NFDMP	Node Flexibility Data Monitoring and Profiling
EMPF	Energy Market Price Forecasting
RDBMS	Relational DataBase Management System

1. Introduction

1.1 Scope and objectives of the deliverable

A technical specification (or documentation) is a document that has a set of requirements for the product that has to be met before the product development is complete. It specifies how the functional and non-functional requirements are to be implemented using technology. This is a critical stage before the development progress that gives a clear picture and determines the single definition of what the project should look like from the perspective of programming. This Deliverable will deliver the DELTA Aggregator architecture in detail, as an individual component and as part of the overall DELTA architecture. The DELTA Aggregator will be designed and implemented on existing energy assets while also allowing communication and interaction with the DVNP. Thus, the Aggregator backbone infrastructure, the communication channels and the overall functionalities will be identified and fully researched for creating a robust and functional (in terms of existing services provided) Aggregator, which will be later enriched with the DELTA ingenious modules.

The report presents the description of the aggregator and the process followed to construct the prototype, which is a specific instantiation of the Reference Architecture for a data flow. The main objective is to demonstrate the capability of the components according to a Reference Architecture. The aggregator or prototype presented in this task has been deployed using standard technologies and tools that can be accessed through Internet and used in the context of the DELTA project. At this early stage of the DELTA project, the focus of this document lies in an initial component design with a basic specification of technical details. The DELTA project aims at a collaborative design which is a methodology that involves people who will be affected by new technologies throughout all design phases.

Besides standard attributes of energy market Aggregators, this task will present core functionalities of the DELTA Aggregator, which briefly are:

a) Grid Stability Simulation Engine (GSSE): This module will be responsible for monitoring the stability (e.g. voltage fluctuations) within the available portfolio and run background scenarios simulating issues that could occur based on current status. The main purpose of the GSSE would be the quantification of DR-related grid constraints, in order to have a clear knowledge of such limits and how to not surpass them; as inputs, the Engine will entail the topological information of the DR customers and the DR amount that is about to be validated (requested from the grid). Also, the grid structure and components (RES/ critical non-curtailed load/voltage regulators such as tap changers etc.) at the distribution level and at the substations which will be affected from the DR deployment would be made known, for the most accurate grid representation. The integrated Engine algorithms will aggregate the Low Voltage DR sources below each MV substation and evaluate their impact on voltage and load constraints in respect with current grid code requirements (overvoltage/overload), based on an enhanced optimal power flow algorithm.,

b) Self-Portfolio Energy Balancing (SPEB): This tool will also provide the DSS with assessments (error and reliability) of the available energy (excess or shortage) within the Aggregator portfolio, targeting a balanced state where the use of available flexibility is maximised.

c) **Asset Handling Optimisation (AHO)**: The AHO is the core component of the Aggregator Decision Support System (DSS). Based on information provided from all other Aggregator components as well as information received from lower DELTA layers, the AHO will allow the aggregator to optimise the mechanisms that will define how each and every element of the portfolio (virtual or real) will be handled and which DR strategy should be used in each case towards gaining the most in terms of energy distribution and financial merits.

d) **Node Flexibility Data Monitoring and Profiling (NFDM&P)**: This component, the second part of the DSS, will be responsible for the entire communication of the Aggregator Layer with other DELTA layers through the DELTA CIM. In addition, the NFDM&P will allow the Aggregator to supervise each Nodes' flexibility and contextual data, for activating profiling mechanisms for each Node and provide that information to the AHO tool towards facilitating decision making processes. All dynamic information required from the portfolio for the other Aggregator tools, will be provided by the NFDM&P.

e) **Energy Market Price Forecast (EMPF)**: Linking the Aggregator with the energy markets, the EMPF component will be responsible for anticipating or retrieving the price schemes of the various markets. Typical factors that influence electricity prices will be reviewed (such as season/day, weather, fuel prices, demand elasticity etc.) and price forecasting techniques will be employed (regression techniques/SVM/neural networks etc.).

f) **DR & Flexibility Forecasting (DR&FF)**: The DR&FF will undertake the role of predicting the energy behaviour of the portfolio Nodes, towards delivering a flexibility estimation which will depict the DR capacity of the overall portfolio. Similar methods as the ones used for price forecasting can be applied in this case. In order to provide accurate and state of the art forecasting results, a simulation suite will be running all possible scenarios utilising the developed testbed for more effective and robust computational efficiency. This activity is achieved with the inputs from the load forecast component and the respective training data of the DELTA Fog-Enabled Intelligent Devices (FEIDs) and DELTA Virtual Nodes (DVNs).

Finally **g) Energy Portfolio Segmentation & Classification (EPS&C):** This component is one of core innovation tools of the DELTA framework, since it will be responsible to create the DVNs, by assessing various factors (e.g. geolocation, topology, capacity, customer type, etc.) and exploiting cutting edge technologies. This component will only be used when there is a change in the Aggregator's portfolio or when the business objectives aren't achieved due to certain circumstances. Exploiting also information from the GSSE, SPEB, and NFDM&P components, the EPS&C will ensure also system stability and reliability.

Most of the Aggregator modules will be able to perform with or without the integration of the DVNP, given sufficient information is available.

1.2 Structure of the deliverable

This report presents the results of Task 4.1 – DELTA Aggregator Infrastructure, Design and Implementation. The document is divided into ten (10) chapters the first one being the methodology that has been used in order to accomplish this task, the second chapter is the description of the overall architecture of the Aggregator layer, the third to ninth chapters are the specification of the development and deployment of the main components of the

Aggregator, and the final chapter is a verification of the implementation of the components with a key use case.

1.3 Relation to Other Tasks and Deliverables

Accordingly to T3.1, this task will build upon the functional and technical requirements derived in WP1, and the Business Models extracted in WP2, in order to deliver the DELTA Aggregator architecture in detail, as an individual component and as part of the overall DELTA architecture. The DELTA Aggregator will be designed and implemented on existing energy assets while also allowing communication and interaction with the DVNP. The initial development of the Aggregator component will be delivered within T4.1 awaiting the completion of sub-components presented in T4.2, T4.3 and T4.4. Thus, the Aggregator backbone infrastructure, the communication channels and the overall functionalities will be identified and fully researched for creating a robust and functional (in terms of existing services provided) Aggregator, which will be later enriched with the DELTA ingenious modules.

2. Methodology

The general objective of this work is to devise and document a common platform that will act as a reference for the development and deployment of components within the DELTA aggregator layer. Specific objectives of this deliverable are:

- To provide a specific architectural overview of the DELTA aggregator layer dealing with
  - Infrastructure
  - Communication
  - Functionalities
- To describe in detail the design and operation of all aggregator layer subcomponents
  - Grid Stability Simulation Engine (GSSE)
  - Self-portfolio Energy Balancing (SPEB)
  - Aggregator DSS:
    - Asset Handling Optimisation (AHO),
    - Node Flexibility Data Monitoring and Profiling (NFDM&P),
  - Energy Market Price Forecast (EMPF),
  - DR & Flexibility Forecasting (DR&FF), and
  - Energy Portfolio Segmentation & Classification (EPS&C)

The methodology employed to achieve these objects is described below.

2.1 Overview of the Aggregator Layer

To ensure that the specification and documentation of the aggregator layer arrived at herein meets the objectives specified above, a review of the DELTA specifications for Business Models, Use Cases and Requirements pertaining to the aggregator layer was first performed. Key Use Cases have been identified for elaboration of the aggregator layer specification. This chapter is used in order to identify key scenarios in which the aggregator layer will be active and to demonstrate the roles of subcomponents. It also documents the backbone infrastructure of the DELTA aggregator layer and specifies the communication channels and overall functionalities.

2.2 Development of Components

To further specify the operation of the aggregator layer components, architectural and operational requirements are be derived from the DELTA specification and documentation (D1.1 [1] and D1.2 [1]) to date and used to better define implementation requirements and relationships. Four key subsections are dedicated to this process of analysis and description:

- Architectural Requirements
- Reference Architecture
- Functionality
- Technical Specification

2.2.1 Architectural Requirements

An Architectural Requirements specification is performed in order to provide a set of quantitative statements that outline what an implementation project must do in order to comply with the architecture. It provides a quantitative view of the solution, stating measurable criteria that must be met during the implementation of the architecture. This is a design and product development process common to many fields. A set of requirements is documented and used as a specification to be satisfied by a given material, design, product, service, etc.

An architectural requirement is any requirement that is architecturally significant, whether this significance be implicit or explicit. Implicit architectural requirements are those requirements that have particular attributes. For example, any high-risk, high-priority, or low-stability requirement could be considered to be architecturally significant. Explicit requirements are typically technical in nature. Any architectural requirement must be:

- Maintainable
  Whatever choices made in organizing requirements should create a structure that can adapt to changes in requirements.
- Traceable
  Any given process flow step can be traced to associated requirements.
- Usable
  Defined in such a way that requirements and associated objects are easily identified.
- Scalable
  Able to support the addition of new requirements with minimal overhead.
- Elegant
  Simply hierarchically defined.
- Generalizable
  Defined using a repeatable approach that can be applied to other projects.

Architectural requirements are gathered by documenting the data and application requirements identified in this phase, and the constraints, assumptions and success measures associated with the requirements. Those requirements defined elsewhere in the DELTA documentation to date that pertain to the aggregator layer are used as a starting point here. However, in the case where requirements are unspecified or unclear these are reviewed and updated accordingly. Decomposition methods are applied to some such requirements to segment them in order to better defined their meanings and rationales. Moreover, a requirements analysis is performed to prioritise them, identify implementation possibilities and document relationships. The purpose of goals is to clarify requirements.

2.2.2 Reference Architecture

In this section, the fundamental components of the domain and the relations between them are defined in order to identify any missing architectural information and to enable consistent architectural practices. According to ISO/IEC/IEEE 42010 [3], the reference architecture provides a template solution for the architecture of a particular domain. The reference architecture also provides a common vocabulary to discuss implementations and stress commonality. In this way, it serves as a "reference" for a higher level of abstraction which extracts a set of practices and patterns to develop a specific architecture based on best practices or authoritative sets of potential artefacts. In this document we use a lower level reference architecture which demonstrates the interactions of procedures within a software program defined to perform a very specific task. A reference architecture often consists of a list of layers, modules and functions and some indication of their interfaces and interactions with each other and with elements located outside of the scope of the reference architecture. The goals and objectives of Reference Architecture are to establish a standard solution and common mechanisms information exchange and thus improves interoperability of the software system, reduces the development costs, increases reuse, reduces redundancy, and increases visibility and governance.

2.2.3 Functionality

Functionality is the needs and preferences of what a product, such as a software application or computing device, can do for a user. A product's functionality is used to identify product features and enables a user to have a set of system capabilities. Features are the "tools" you use within a system to complete a set of tasks or actions. Documented functionality explains how those features actually work to provide users with a desired outcome. Previous project documentation describes the role and functions of the data infrastructure and its constituent environment and components in general terms. This section will translate these roles and functions to more detailed functionalities that the infrastructure is expected to provide. DELTA D1.2 [2] offers some detailed functionality described from the perspective of the various DELTA subtasks that are interdependent on the data infrastructure. A more contextual and component specific consideration of the functionality is documented herein.

2.2.4 Technical Specification

This section defines the provisional specifications for the DELTA platform. Technical specifications are used to understand the configuration and guide production of the system. Technical specifications help to understand the feasibility of scaling up and integrating with other components or devices. The specifications presented in this section should meet most architectural requirements and prepare for meeting the remainder of the requirements during the project.

The requirements on which these specifications are based are provisional and are in turn based on a consortium-wide best effort to think through and define the various subtasks of the DELTA project and their dependencies. It is not possible to entirely foresee how these interdependencies and requirements will evolve as the DELTA platform is developed and interdependent tasks are built. In this regard, as per the architectural requirements, a sensible amount of flexibility will be included within these specifications. Flexibility here provides the capacity to handle additional requirements without the need to rebuild parts of the DELTA platform at a fundamental level.

2.3 Component Verification

In this chapter the DELTA components are tested in order to verify and validate their design. Verification and validation are independent procedures that are used together for checking that a software product, a service, or a system meets requirements and specifications and that it fulfils its intended purpose. Their functional correctness is tested as specified in the requirement specification. The design features are extracted from the requirement specification. This includes tests at the top-level of the design as well as the sub-blocks. An example of a key use case is provided where on a higher level we can observe the interactions between various interconnected components where on a lower level we can observe the implementation of their functionalities.

3. Overview of the Aggregator Layer

3.1 Context of the Aggregator Layer within the DELTA Architecture

3.1.1 Overall Architecture

This chapter provides an overview of DELTA's conceptual architecture introducing the major layers and sub-layers of the DELTA platform along with the included architectural components. Distinctions between the different layers and sub-layers are highlighted. This section describes the aggregator module including the Grid Stability Simulation Engine module and the Self-Portfolio Energy Balancing module in the context of the overall DELTA architecture. The different inputs and outputs expected from each module are listed. Finally, the section describes the interfaces needed to allow the modules to communicate with the other modules. Figure 1 illustrates the Aggregator reference architecture for the modules of the Grid Stability Simulation Engine and the Self-Portfolio Energy Balancing belonging to the DELTA aggregator. The DELTA Aggregator as well as its sub-modules is treated as a "black box" within the overall architecture.

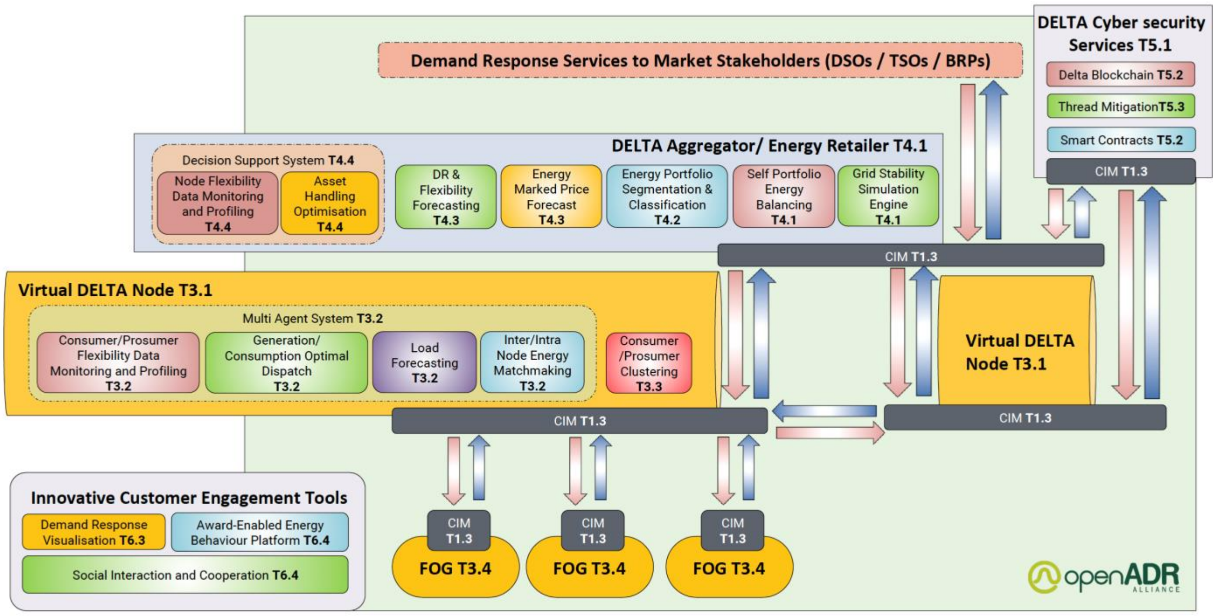

Figure 1. Overall Architecture.

This document will describe the DELTA Aggregator architecture in detail, as an individual layer and as part of the overall DELTA architecture. Even though the concept of the DELTA solution can be applied to existing Aggregator schemas (where each Node will be perceived as a large-scale prosumer), an extended version termed the DELTA Aggregator is also defined towards further exploiting the envisioned ICT framework.

At the Aggregator level, the proposed framework must work as an energy management system, featuring flexibility aggregation while maintaining the stability of the grid at all times. To attain this functionality, the DELTA Aggregator will be equipped with the various components including:

- Energy Market Price Forecast
- DR & Flexibility Forecasting
- Node Flexibility Data Monitoring and Profiling

- Asset Handling Optimization
- Energy Portfolio Segmentation & Classification
- Self-Portfolio Energy Balancing
- Grid Stability Simulation Engine

Energy Market Price Forecast (EMPF)
The EMPF component is activated when the Aggregator needs to exploit their participation in the wholesale markets (if such scheme is supported by the market regulatory frameworks). Typical factors that influence electricity prices will be reviewed (such as season/day, weather, fuel prices, demand elasticity etc.) and price forecasting techniques will be employed (regression techniques/SVM/neural networks etc.). However, for use cases involving bilateral agreements and participation in e.g. capacity markets, the market price will be perceived as a known-constant value.

DR & Flexibility Forecasting (DR&FF)
The DR&FF component is of crucial importance in the DELTA architecture, for the Aggregator to conform to their balance responsibility. The Aggregator needs to forecast the energy consumption profiles of the prosumer Nodes lying in their portfolio, before and after a DR request is activated. Similar methods as the ones used for price forecasting can be applied in this case. In order to provide accurate and state of the art forecasting results, a simulation suite will be running all possible scenarios utilising the developed testbed for more effective and robust computational efficiency. This activity is achieved with the inputs from the load forecast component and the respective training data of the DELTA Fog Enabled Intelligent Devices.

Node Flexibility Data Monitoring and Profiling (NFDM&P)
The NFDM&P will allow the Aggregator to supervise each Nodes' flexibility and contextual data, for activating profiling mechanisms for each Node and decide upon their DR request strategies.

Asset Handling Optimization (AHO)
The AHO will allow the aggregator to integrate with existing large customers and generation facilities. For that reason a supervisory asset system will be responsible in optimising the mechanisms that will define how each and every element of the portfolio will be handled and which DR strategy should be used in each case towards gaining the most in terms of energy distribution.

Energy Portfolio Segmentation & Classification (EPS&C)
The EPS&C component analyses all the information provided by the overall energy portfolio, the existing infrastructure and creates the DELTA DVNs. By doing so, it also creates guidelines/strategies for the DVNs to further perform clustering in within. Moreover, these strategies deployed to each available Node will also include information about reporting intervals, pricing ranges, DR potential strategies, as well as other related and essential restrictions/suggestions that will facilitate the DR communication and maximise the accessibility to Distributed Energy Resources.

Grid Stability Simulation Engine (GSSE)
The GSSE module will be responsible for monitoring the stability (e.g. voltage fluctuations) within the available portfolio and run background scenarios simulating issues that could occur based on current or future status. The main purpose of the GSSE would be the quantification

of DR-related grid constraints, in order to have a clear knowledge of such limits and how to not surpass them; as inputs, the Engine will entail the topological information of the DR customers and the DR amount that is about to be validated (requested from the grid). Also, the grid structure and components (RES/ critical non-curtailed load/voltage regulators such as tap changers etc.) at the distribution level and at the substations which will be affected from the DR deployment would be made known, for the most accurate grid representation. The integrated Engine algorithms will aggregate the Low Voltage DR sources below each MV substation and evaluate their impact on voltage and load constraints in respect with current grid code requirements (overvoltage/undervoltage, overload and frequency violations), based on an enhanced optimal power flow algorithm. Essentially, the GSSE considers the balanced aggregated profile for real-time as well as DA markets to identify potential physical constraints.

Self-portfolio Energy Balancing (SPEB)

This module will provide the DSS with assessments of the available energy (excess or shortage) within the Aggregator portfolio, targeting a balanced state where the use of available flexibility is maximised. This component will be employed in real-time operation regardless of incoming DR signals (either from the DSO/TSO or the DVNP) as to ensure stability and optimal distribution of electrical energy within the DELTA energy network. An autonomous tool will constantly monitor the portfolio in terms of flexibility and stability and will provide feedback to the DSS for creating DR signals for scenarios that the self-balancing at Node level is not enough or large customer not included in the DVNP present challenges that need to be addressed.

Aggregator Common Information Model (CIM)

The CIM is the DELTA sub-component present in all the DELTA components that is responsible of inter-connecting them; allowing to exchange data using a P2P network and receiving such data. The CIM adapts the interfaces of the DELTA components to the ones required by the OpenADR standard. In addition, the CIM is in charge of implementing the semantic interoperability in the DELTA platform, ensure that the data been exchanged is compliant with the DELTA ontology, and also it ensures that the security mechanisms established in the platform are preserved. To ensure its functionality the CIM is divided into four sub-services: the bridging service, the validation service, the knowledge graph publisher, and the knowledge graph services. To facilitate the functionality of the DELTA Aggregator, the communication through the CIM will be handled by a single component (NFDM&P), however if needed or deemed essential this can easily be expanded to other components as well.

3.1.2 DELTA Aggregator Deployment View

In this section, we present the topology of software components on the physical layer, as well as, specifications regarding the connections between them. The following figure presents the deployment view diagram of the DELTA Aggregator. The software components that comprise the DELTA Aggregator are deployed on a physical device, i.e., a server machine, to which we refer to as Aggregator Server. As is illustrated in the figure, there are several distinct processes that run on the hosting machine. At the topmost layer lies the CIM that is the gateway of DELTA Aggregator to the P2P network. The CIM interfaces with the Knowledge Graph Service, the Knowledge Graph Publisher and the Validation Service, all of which are separate processes, via RESTful APIs. The DELTA Aggregator is modelled as a monolithic, multi-threaded process that receives JSON-LD payloads from the Knowledge Graph Service and the Knowledge Graph Publisher via its Web Server component.

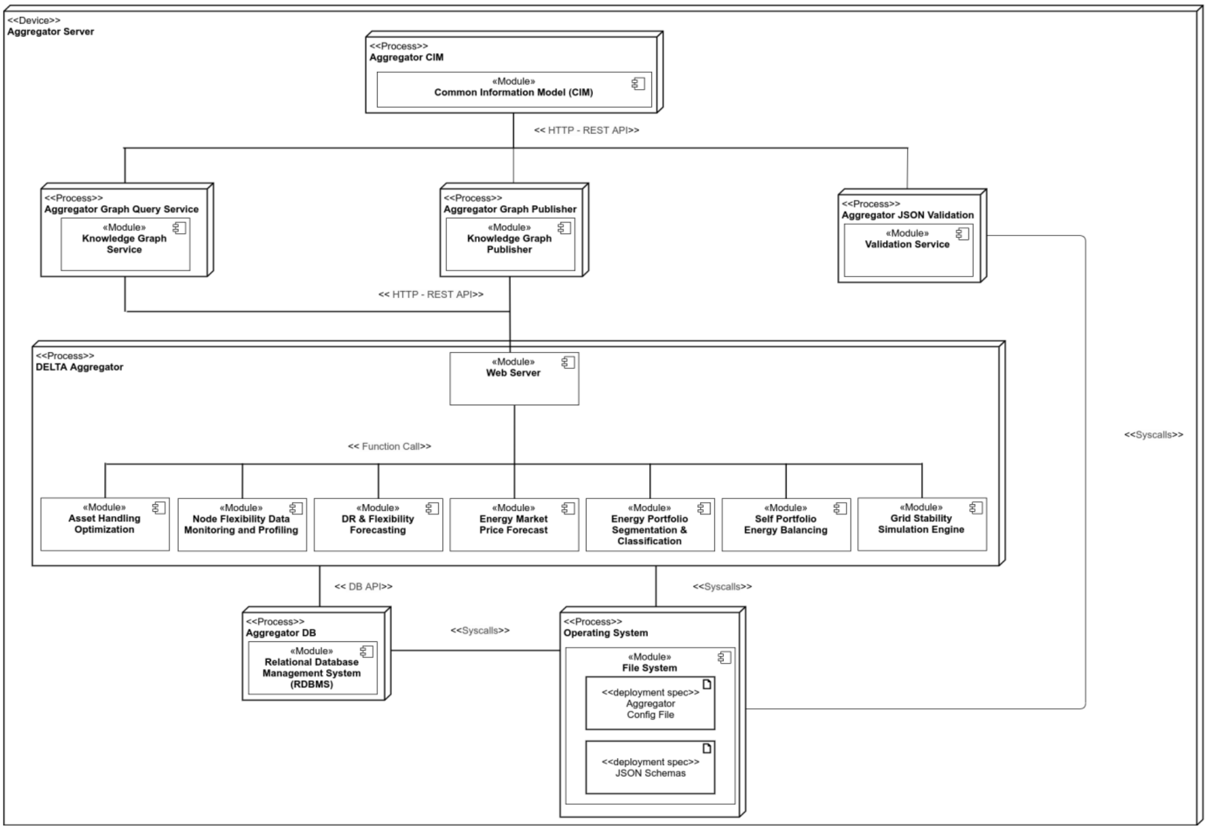

Figure 2. Deployment diagram of the DELTA Aggregator.

This component maintains a thread pool that is multiplexed to service, in parallel, input payloads by calling appropriate functions of the components that comprise the DELTA Aggregator. The Aggregator's components interface with its RDBMS, which is a separate process, via well-established and standard APIs. Furthermore, we model the Operating System of the host machine as a monolithic process and illustrate how the DELTA Aggregator can access the deployment specification files, such as its configuration file, via appropriate system calls. The same holds for the Validation Service as well in regards to accessing JSON schemas.

3.2 DELTA Use Cases Involving the Aggregator Layer

Established Use Cases where WP4 components are mutually active are key to the directed development of the Aggregator Layer. An overview of established DELTA Use Cases can be found in the DELTA deliverable D1.1 [1]. A review of those Use Cases most relevant to the aggregator layer is given here for consistency.

Table 1: Overview of the Use Case entitled 'Flexibility forecast to improve assets availability declaration and maximize Demand Response revenues'

Use Case Name	More accurate flexibility forecast to improve assets availability declaration and maximise Demand Response

	revenues
Brief Description	Accurate flexibility forecasts are produced for 2 hours / daily / weekly profiles to allow aggregators dynamic availability declaration and maximise DR revenues.
Assumptions & Preconditions	Sites / assets in the aggregator's portfolio are managed via DVN
Objective	Maximise availability and utilisation revenues from a given portfolio of turndown assets or from an existing portfolio of prosumers.
Effects/Post Conditions	Increased availability and utilisation revenues from existing portfolios
Involved Actors	Aggregator, SO, Prosumer, DVN
Use Case Initiation	Reserve services dispatch from the SO.
Main course	1. The aggregator, via the node flexibility data monitoring and profiling component of the DVNP, receives data of short (one hour ahead), medium (day ahead) and long term (week ahead) flexibility forecasting, and power demand and supply in each DVN. 2. The aforementioned data is used by the same component to readjust each asset's availability declaration as permitted by each market programme. 3. The newly computed asset availability declarations are input to the AHO component of the DVNP to maximise revenues and improve overall reliability. 4. When an asset is dispatched, which is handled by the AHO component of the DVNP, a performance report is fed back into the DR&FF tool to allow for future improvements of the algorithm. 5. Monthly performance reports will reflect the availability and utilisation based on the values forecasted by the DVNP via the DR&FF tool and based on the metered value for the assets that have been dispatched. 6. Settlements with the SO will be based on the new availability data provided by the FEID generation, consumption, flexibility and forecasting tool.

Alternate Courses	• Assets / sites with baselines under declared values (assessed via spot tests every 6 months) are undeclared from contracts. • Assets / sites with baselines over the declared values will perform based on the declared values.
Architectural Elements/Services Involved	• NFDM&P • Consumer/Prosumer Flexibility Data Monitoring and Profiling • FEID OpenADR • FEID Generation, Consumption, Flexibility Forecasting Tool • DR&FF • AHO • Generation/Consumption Optimal Dispatch

UML Sequence Diagram

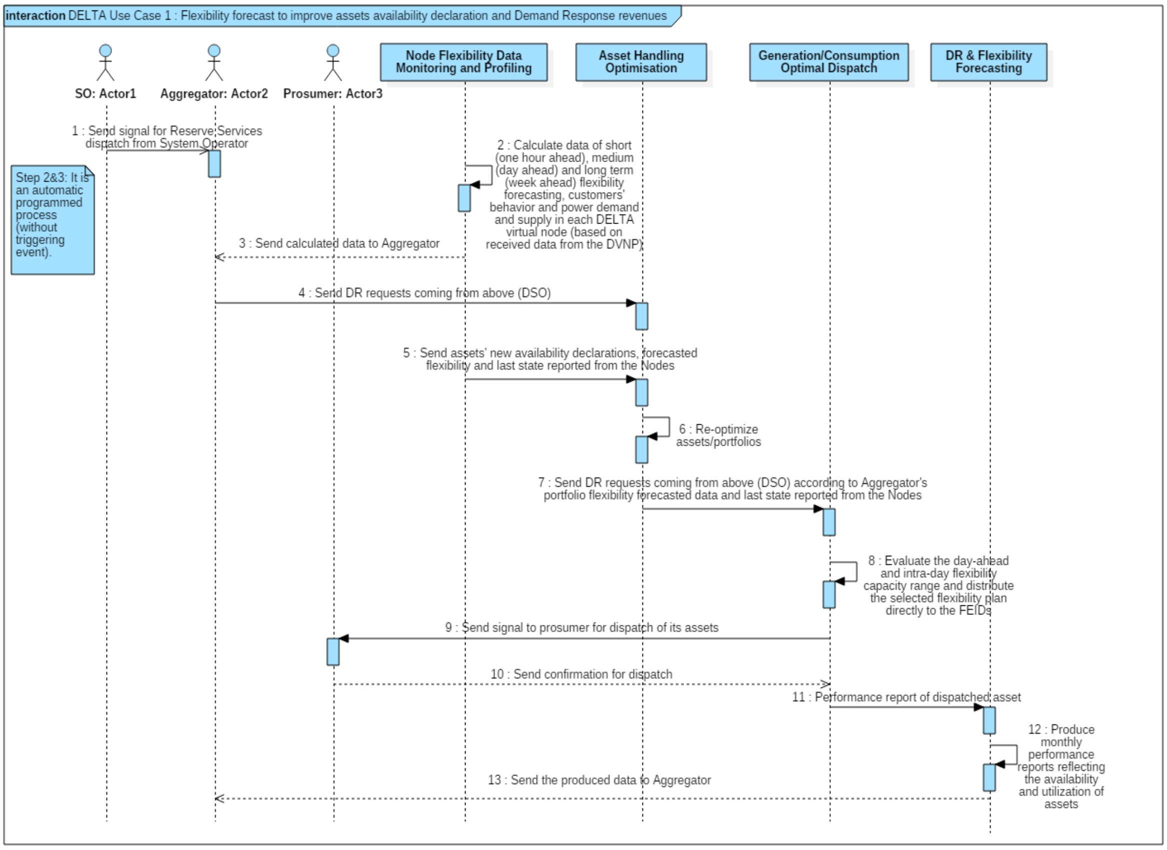

Figure 3: UML Sequence Diagram for the Use Case entitled '3.2.1 Flexibility forecast to improve assets availability declaration and maximise Demand Response revenues'

Table 2: Overview of the Use Case entitled 'Improving Demand Response revenues by trading flexibility in the market based on Energy Market Price Forecasts'

Use Case Name	Improving DSR revenues by trading flexibility in the Market based on Energy Market Price Forecasts
Brief Description	The EMPF module allows the aggregator to spot opportunities in the Market and shift flexibility towards that market when prices are likely to go above certain values.
Assumptions & Preconditions	Each site/asset in the aggregator's portfolio is managed via DVN; price forecasts for the market are made on 1- and 2-hours base to allow the aggregator to un-declare capacity in other operational programmes; bilateral agreements are in place with participants in the Market or the aggregator is qualified to bid directly in the Market.
Objective	Maximise MWh revenues from flexibility services.
Effects/Post Conditions	Increase DSR revenues for customers and the aggregator.
Involved Actors	Aggregator, Suppliers, Prosumer
Use Case Initiation	Forecasted clearing price in the market exceeds a certain threshold (i.e., 20% over the price paid in a STOR contract).
Main course	1. The aggregator receives market price forecast signals from the EMPF tool for the next trading period and the energy volumes likely to clear at that price. 2. The aggregator, via the DR&FF component of the DVNP, forecasts future availability and decides how much capacity can be made available to the Market. 3. Assets/portfolios are undeclared from less efficient programmes. 4. Suppliers with bilateral agreements active in the market are made aware of the capacity being available for the following settlement period at a price lower than the forecasted clearing price. 5. One or more suppliers will issue counter offers for the available capacity until the entire capacity is contracted and prices locked down. 6. At the beginning of the settlement period, the aggregator will dispatch contracted capacity via the generation/consumption optimal dispatch component of the DVNP.

Alternate Courses	● Capacity is fixed to a contract/programme without the ability to move in/out of high paying markets unless undeclared the day ahead. If capacity is still traded in the higher paying market but not undeclared in other programmes there is a high operational risk of asset being dispatch in multiple programmes and trigger heavy penalties.
Architectural Elements/Services Involved	● NFDM&P ● DR & FF ● EMPF ● Generation/Consumption Optimal Dispatch ● FEID OpenADR ● FEID Generation, Consumption, Flexibility Forecasting Tool ● AHO

UML Sequence Diagram

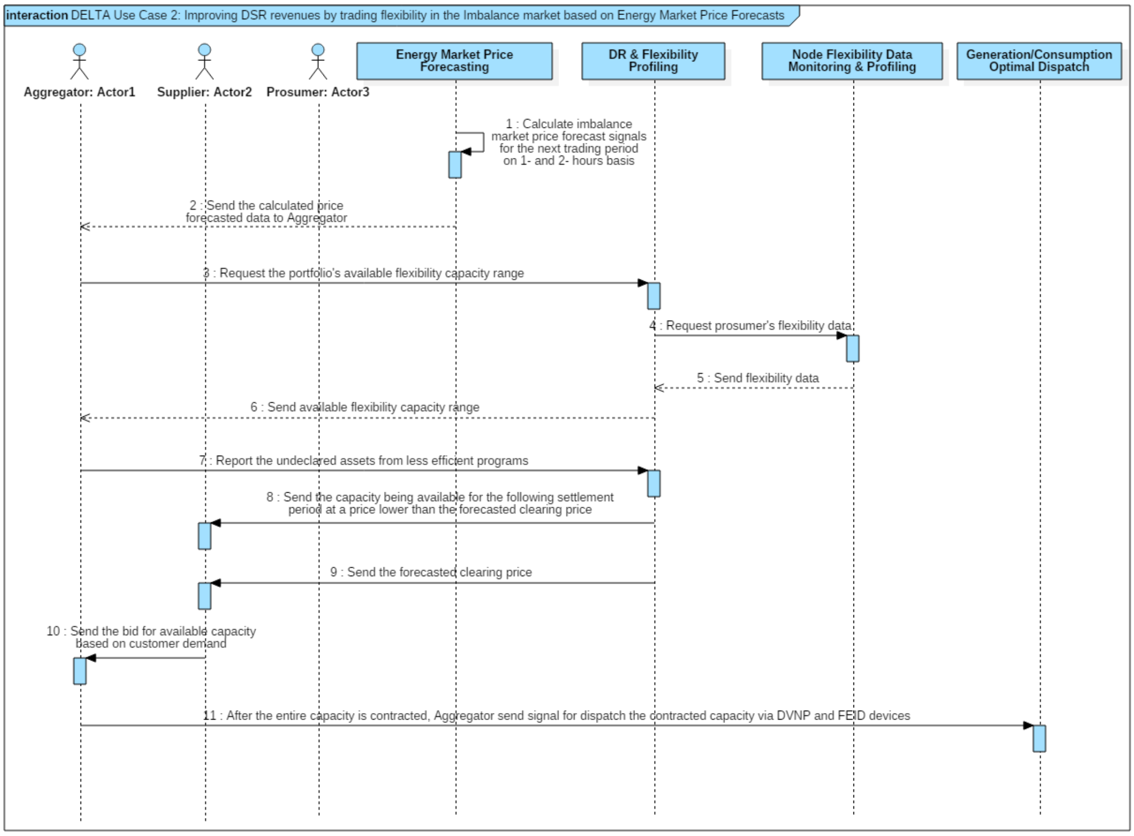

Figure 4: UML Sequence Diagram for the Use Case entitled 'Improving Demand Response revenues by trading flexibility in the market based on Energy Market Price Forecasts'

Table 3: Overview of the Use Case entitled ‘Optimize prosumer Renewable Energy Systems self-consumption and increase flexibility’

Use Case Name	Optimise prosumer Renewable Energy Systems (RES) self-consumption and increase flexibility
Brief Description	Integrate existing RES and consumption points via DVN to maximise self-consumption and reduce energy cost while maximising flexibility services.
Assumptions & Preconditions	Existing RES control systems are connected to DVNP Existing consumption devices are connected to DVNP
Objective	To maximise self-utilisation of RES generation while increasing flexibility
Effects/Post Conditions	Prosumer is able to reduce energy cost / increase flexibility revenue
Involved Actors	Prosumer, Aggregator, DVNP
Use Case Initiation	Auto-triggered process.
Main course	1. Prosumer allocates RES generation capacity towards self-consumption as the main business rule on the DVNP. 2. Any RES generation capacity that exceeds Prosumer consumption need is made available to an Aggregator via the DVNP. 3. Load/Generation Forecasting tool generates forecasts for the Prosumer load curves and generation capacity on half hourly basis. 4. DELTA Aggregator allocates any extra capacity to the best paying services in the market. 5. If prices in specific market exceed a certain threshold, DELTA Aggregator can redirect the entire RES generation capacity to export towards the grid. 6. When prices drop below certain threshold, the RES capacity is redirected towards self-consumption.
Alternate Courses	RES generation capacity is entirely used either for self-consumption, or entirely for export. The only flexibility that is being monetized is fixed capacity turndown services based on

	equipment specification and turndown tests.
Architectural Elements/Services Involved	● Building Management System (BMS – connected to prosumer's FEID) ● Inter/Intra Node Energy Matchmaking ● SPEB ● Load/Generation Forecasting ● GSSE ● DELTA Repository
UML Sequence Diagram	

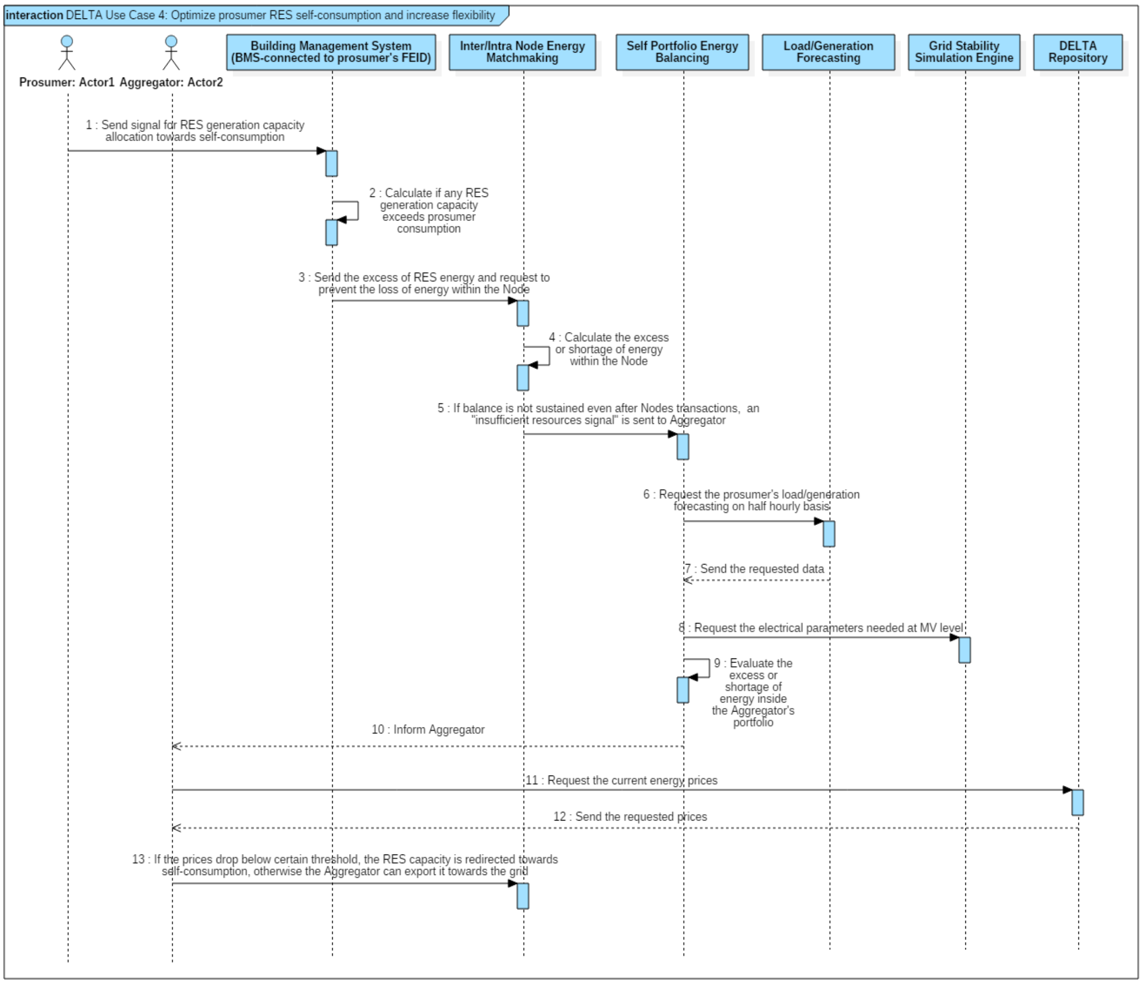

Figure 5: UML Sequence Diagram for the Use Case entitled 'Optimise prosumer Renewable Energy Systems self-consumption and increase flexibility'

3.2.1 Key Use Case Demonstrating the Full Functionality of Aggregator Components

Given that there are several programs inside the Balance market (SFFR, Constraint management, capacity, STOR) to which an aggregator could sell its available flexibility, how can an aggregator maximise its profit and allocate its assets? Let's assume two programs:

STOR and constraint management (CM). Short Term Operating Reserve (STOR) is a service which customers (service providers) can provide to National Grid to deliver either a specific level of power from their generators or a reduction of demand. The service is limited to the timings that are agreed in the contract. Such timings are known as the "Availability Windows" which are the periods where the provider is obliged to deliver the specified power. This is generally carried out via electronic instructions from DSO to the provider. Constraint management services (CM) are employed when bottlenecks occur when there can be limited capacity to transmit the electricity across the different locations. Where the energy is restricted in its ability to flow between two points this is known as a constraint and DSO needs to take action to both circumvent and reduce these constraints. To help the DSO manage constraints, potential service providers will be requested to limit or profile their generation or demand during a specific period.

An aggregator is paid in two ways: First by the power made available to the program such (e.g. 1.5£/MW per hour) and also is paid when it actually delivers energy (e.g. 60£/MWh). The aggregator can make a decision to make its assets available for both programs (STOR and constraint management) and the rewarded for it. However, if an event occurs in one of them he will get a penalty for withdrawing his committed availability. We have hence to analyse the probability of occurrence of both events happening simultaneously and decide if and when to commit the assets to both programs or just to one program. The initial model will consider only CM and the STOR program for asset allocation. Once is running and the methodology is well defined frequency response and capacity markets could be added as well.

Variables and required data:

- Input is a given amount of assets
- Historical data of both programs
- Prices for availability of both programs
- Prices for actually delivering on the event
- Penalties for failing to deliver of both events.

Table 4: Overview of Key Use Case entitled 'Targeting a balanced state where the use of available flexibility is maximized'

Use Case Name	Risk reduced optimised asset program commitment
Brief Description	Assets declared in two programs with availability payments for both, activation payments for both and potential penalties if not able to act in one or both.
Assumptions & Preconditions	Given amount of assets Historical data of both programs Prices for availability of both programs Prices for actually delivering on the event Penalties for failing to deliver of both events.

Objective	To maximize aggregator's profit and allocate its assets
Effects/Post Conditions	Prosumer is able to reduce energy cost / increase flexibility revenue
Involved Actors	Prosumer, Aggregator
Use Case Initiation	Auto-triggered process.
Main course	1. The GSSE can help identify the likelihood of required flexibility based on the violations of the Voltage, Line Loading and Frequency. 2. The aggregator, via the DR&FF component, forecasts future availability and decides how much capacity can be made available to the Market and from which component. 3. The aggregator retrieves from OpenADR DELTA Repository CIM the contracted prices for the next trading period and the energy volumes likely to clear at that price. 4. SPEB will hence analyse the most profitable combinations of contracted prices along with the associated assets in order to identify the identified most profitable strategies. 5. The aggregator can make a decision to make its Assets/portfolios available for multiple programs and get rewarded for it. Therefore, AHO will analyze the probability of multiple events happening simultaneously and decide which of the combinations from SPEB is the most suitable and commit its assets to multiple programs or just to one program by allocating any extra capacity to the best paying services in the market. 6. At the beginning of the settlement period, the aggregator will dispatch contracted capacity. 7. If an event occurs in more than one programs the Aggregator will get a penalty for withdrawing his committed availability.
Alternate Courses	Capacity is fixed to a contract/programme without the ability to move in/out of high paying markets unless undeclared the day ahead. If capacity is still traded in the higher paying market but not undeclared in other programmes there is a high operational risk of asset being dispatch in multiple

	programmes and trigger heavy penalties.
Architectural Elements/Services Involved	• GSSE • SPEB • DR & FF • EMPF

UML Sequence Diagram

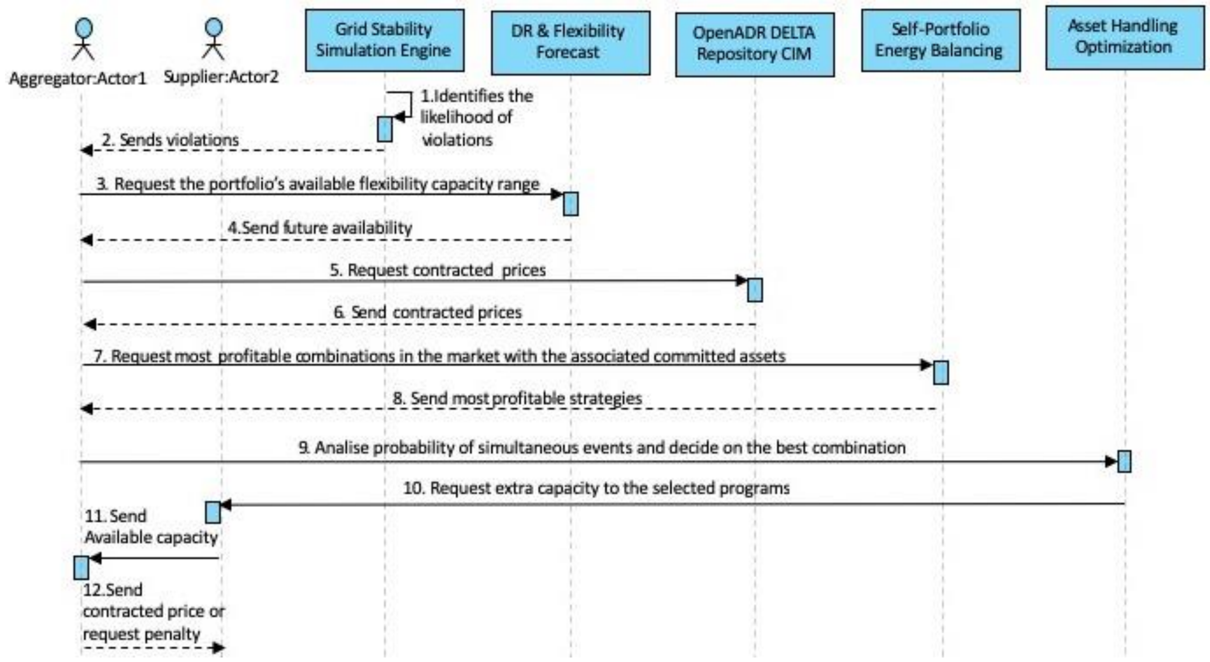

Figure 6: UML Sequence Diagram of Key Use Case entitled 'Targeting a balanced state where the use of available flexibility is maximized'

3.3 Semantic Interoperability of the Aggregator Layer

The Semantic Interoperability allows any component to exchange data with others transparently, it ensures that the data been exchange will be understandable and processable. This feature is paramount for the Aggregator since this component needs to manage and orchestrate all the rest of components within the DELTA platform.

3.3.1 Transparent control of the platform

The Aggregator relies on the semantic interoperability to manage DELTA components transparently. For instance, it needs to distribute ACL policies among all DELTA components which are a set of security rules (permissions) that specifies the conditions necessary to perform certain operations on the secure domain of the DELTA platform. Another example to showcase the importance of the interoperability for the Aggregator is the fact that it needs to control the FEIDs transparently even if they have underneath non-DELTA original components (this showcase is explained in the next sub-section).

In order the Aggregator to control the rest of the components transparently it relies on two CIM sub-components. The former is the Knowledge Graph Publisher, which enables a SPARQL query interface that allows to not only answer SPARQL queries that gather and aggregate data from the different sub-components of a given DELTA component, but it also allows to perform the opposite operation which is writing something in the SPARQL query and translate it into a writing request for a specific sub-component.

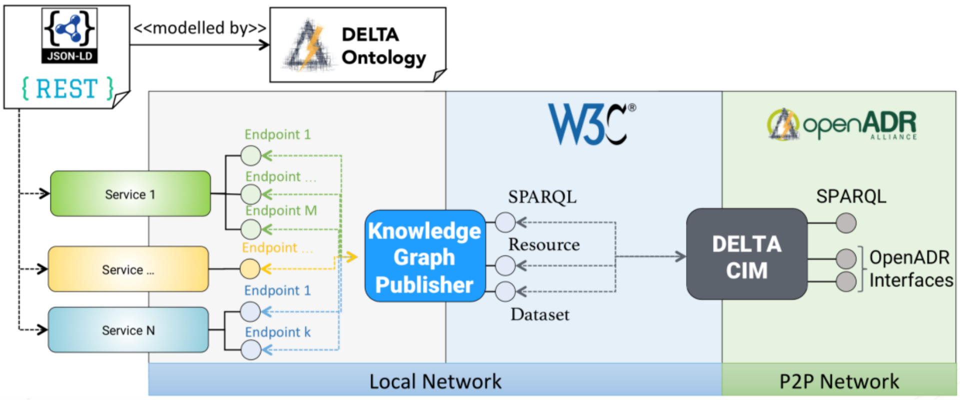

Figure 7. Deployment diagram of the DELTA aggregator.

As Figure 7 displays the Knowledge Graph Publisher acts as a wrapper of the different Services that conform a DELTA component, for instance in the aggregator it would be all those sub-component interfaces that interact with the rest of the platform. Once the SPARQL endpoint is enable, this endpoint is accessible through the P2P network allowing other components to send queries and produce a response. Consider that the SPARQL queries will be solved depending on the component that issued such query and applying the security mechanisms established in DELTA.

The second relevant component involved in the interoperability is the Knowledge Graph Services. This sub-component register SPARQL endpoints in the P2P network that belong to the Knowledge Graph Publishers of others DELTA components. When a query is issued to the Knowledge Graph Services, a discovery of relevant registered endpoints is performed and then the query is federated to all those endpoints. As a result, for every endpoint a query result, i.e., the query answer, is received. Considering all the answers this sub-component aggregates them and provides a unified answer. Using the Knowledge Graph Services the aggregator can send queries to read or to write to all the components in DELTA.

Figure 8 displays how a SPARQL query can be issued to the Knowledge Graph Services, this CIM sub-component federate the query to the relevant SPARQL endpoints in the P2P network. These SPARQL queries are received by the Knowledge Graph Publishers of other CIMs in the DELTA cloud. The Knowledge Graph Publishers provide a query answer in each of the different components.

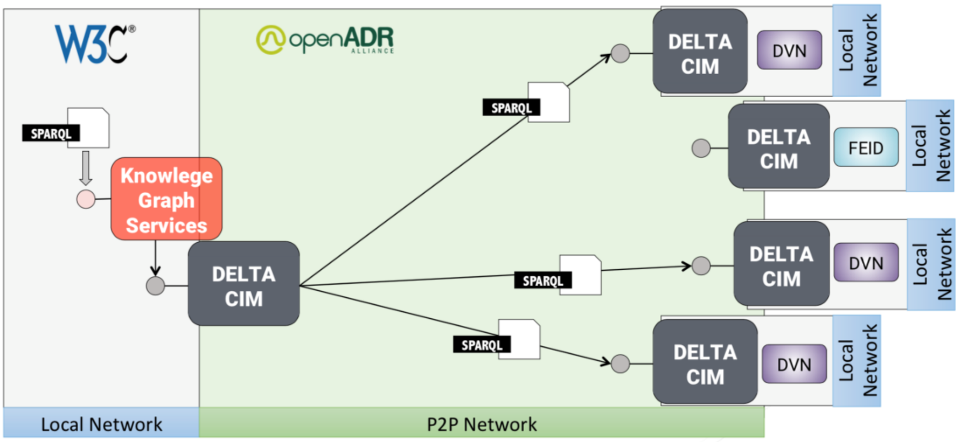

Figure 8. Query federation through the DELTA platform.

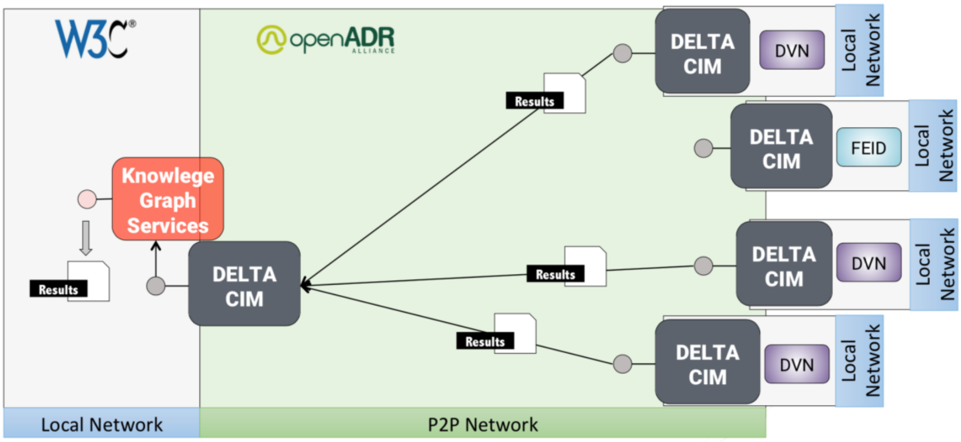

Figure 9. Combination of the different query results.

Figure 9 shows how the different answers are sent back to the former CIM, where the Knowledge Graph Services aggregates them and produces a unique answer for the query combining all the received answers.

3.3.2 Seamless integration and control of external components

In DELA we aim at developing a platform that is universal in order to be able to incorporate new infrastructures that are not DELTA native. The platform is based on the openADR standard, nevertheless such standard is extended and semantized in DELTA. Nevertheless, the DELTA platform should, and it is, compatible with pure OpenADR devices. In addition, we aim at been compatible with other devices that follow different standards like USEF. To achieve this goal the DELTA platform relies on the Knowledge Graph Publisher, which provides a unified and transparent mechanism to interact with a set of endpoints. Figure Z shows how this sub-component of the CIM can be configured to include new infrastructures.

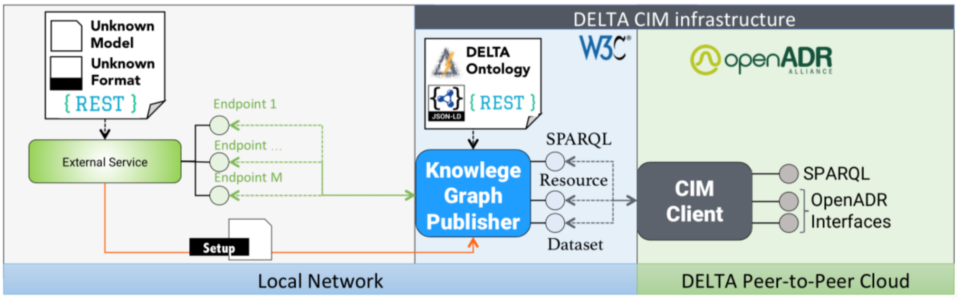

Figure 10. Seamless integration of external components.

The external service that is been integrated has an unknown model that the DELTA platform is not aware, and relies on an unknown format. The only restriction in order to integrate external components is that they must enable a REST API to interact with them. As it can be seen in Figure 10 the Knowledge Graph Publisher receives a configuration file that contains a set of translation rules that encode the external service endpoints, its model, and how retrieve data from the endpoint (or endpoints), and align their data with the Ontology model (thanks to a set of equivalences between their model and the DELTA ontology). Using this configuration file, the Knowledge Graph Publisher, is able to process SPARQL queries expressed in the DELTA ontology; either to read data or to send data back to the original endpoints using their data and format.

Following this approach DELTA is able to offer to the Aggregator the same interface to control the FEIDs, although underneath such components there could be an OpenADR device or a device compliant with other standards. The drawback of this approach is that a user has to align the models in order to provide the translation rules. Integrating new infrastructures and make them DELTA compatible is just a matter of submitting configuration files, and therefore, no coding software is required. This benefit enables a seamless integration of components.

4. Grid Stability Simulation Engine Component

One of the core functionalities of the DELTA Aggregator is that of the GSSE. The aim of the GSSE component is to optimally avoid congestion and operate within prescribed voltage, frequency and line loading margins. This module is able to perform with or without the integration of the DVNP.

Essentially, the GSSE considers the balanced aggregated profile for real-time as well as DA markets to identify potential physical constraints by performing Load flow calculations. These calculations are used to analyse power systems under steady-state non-faulted (short-circuit-free) conditions. The load flow simulator used here is the DIgSILENT Powerfactory, which is a leading power system analysis software application for analysing generation, transmission and distribution systems.

4.1 Architectural Requirements

4.1.1 Interface Requirements

A system requirement is classified as an interface requirement when it involves an interaction with another system through an associated interface. An interface requirement indicates or implies the conditions that need to be satisfied concerning the interfaces of the DELTA platform.

Table 5: Grid Stability Simulation Engine Interface Requirements

ID	Description	Type	Rationale	Fit Criterion	Priority	Associated Use Cases
1	Pre-specified Constraints and time steps	F	The platform should allow the aggregator to pre-specify the time steps in which the data will be taken as well as the constrains on line loading, frequency and voltage	The platform is able to run simulations on different values of the main parameters	Must Have	5.1.1
2	Request feedback from occupant regarding its comfort	NF	To ensure that occupants are not negatively affected	Feedback on occupant's comfort	Could have	5.2.2

4.1.2 Hardware Requirements

Hardware requirements describe the compatible hardware devices for a particular software system. These requirements describe the conditions that do not need to be exceeded including the minimum processor speed, memory, and disk space required to install the system.

Table 6: Grid Stability Simulation Engine Hardware Requirements

ID	Description	Type	Rationale	Fit Criterion	Priority	Associated Use Cases
1	4 Processor Cores, 16 GB RAM, GPU required for fast processing of state simulations. Likely will coded using CUDA libraries thus GPU must be NVIDIA, to reduce time for simulations a GTX1080 minimum. 1TB RAID Array Storage	F	The platform will be implemented in Windows VM deployed on Windows server 2012 on UCY server at the UCY campus in Nicosia	DIgSILENT and Python can be installed	Must have	5.1.1

4.1.3 Software requirements

Software requirements convey the expectations and needs of the stakeholders into a viable set of conditions that validate the success of a software product. Specifically, they describe the functionalities and features of a software product that solves the needs of the end user.

Table 7: Grid Stability Simulation Engine Software Interfaces

ID	Description	Type	Rationale	Fit Criterion	Priority	Associated Use Cases
1	Run DR scenarios based on potential DSO needs for grid balancing/stabilisation simulating	F	To increase revenue and support grid stability	quantification of DR-related grid constraints	Must have	5.3.1

	issues that could occur based on current status.					
2	Provide feedback of potential risks and physical constrains that may affect the marketplace.	F	To demonstrate operation and allow adaptation	Provision of real-time data and future operation	Must have	5.3.1

4.1.4 Communication Interfaces

Communication requirements convey the conditions under which the various components consisting software communicate. Specifically, it describes the communication in either direction between two or more connected parties or devices. As the Grid Stability Simulation Engine may be quite heavy in terms of processing power and time, to meet the below requirement, different operational schemes will be tested towards ensuring that the expected results can be used if needed in real-time operation.

Table 8: Grid Stability Simulation Engine Communication Interfaces

ID	Description	Type	Rationale	Fit Criterion	Priority	Associated Use Cases
1	Respond in real-time operation regardless of the incoming DR signals	NF	To reduce investment of time and expertise	Setting of bounds for automated operation and demonstration of automated functioning	Could have	5.3.1

4.2 Reference Architecture

4.2.1 Interfaces with other DELTA components

One of the core functionalities of the DELTA Aggregator is that of the GSSE. Since not all assets are expected to be included in the DVNP, the aggregator should be able to monitor the entire distribution network under its supervision. In particular, the NFDM&P will supervise each Nodes' flexibility and contextual data, for activating profiling mechanisms for each Node and decide upon their DR request strategies. The NFDM&P will therefore feed the GSSE with profiling data in order to be able to monitor the stability (e.g. voltage fluctuations) within the available portfolio.

The Engine will quantify DR-related grid constraints and will feed the DSS, in particular the DR&FF, with potential risks, including assets that are in the DVNP or not. The DR&FF component is of crucial importance in the DELTA architecture, for the Aggregator to conform to their balance responsibility. The Aggregator needs to forecast the energy consumption profiles of the prosumer Nodes lying in their portfolio, before and after a DR request is activated. Similar methods as the ones used for price forecasting can be applied in this case. In order to provide accurate and state of the art forecasting results, a simulation suite will be running all possible scenarios utilising the developed testbed for more effective and robust computational efficiency.

Another component known as the EMPF will receive the violations in order to review the typical factors that influence electricity prices and employ the appropriate price forecasting techniques. In the unbundled national electricity markets in Europe, the balancing market is the institutional arrangement that deals with the balancing of electricity demand and supply. Short-term power trading generally refers to trading power in quarter-hour or one-hour intervals, although trading larger intervals is also possible. In the balancing energy market, production and load owners can give balancing energy bids for their adjustable capacity. A reserve provider whose capacity bid is accepted on the balancing capacity market is obliged to give upper balancing energy bids to the balancing energy market in exchange for a financial compensation. The prices of balancing energy are set based on the balancing carried out in the Nordic balancing energy markets. Both an upper- and lower balancing energy price are set for each hour of use.

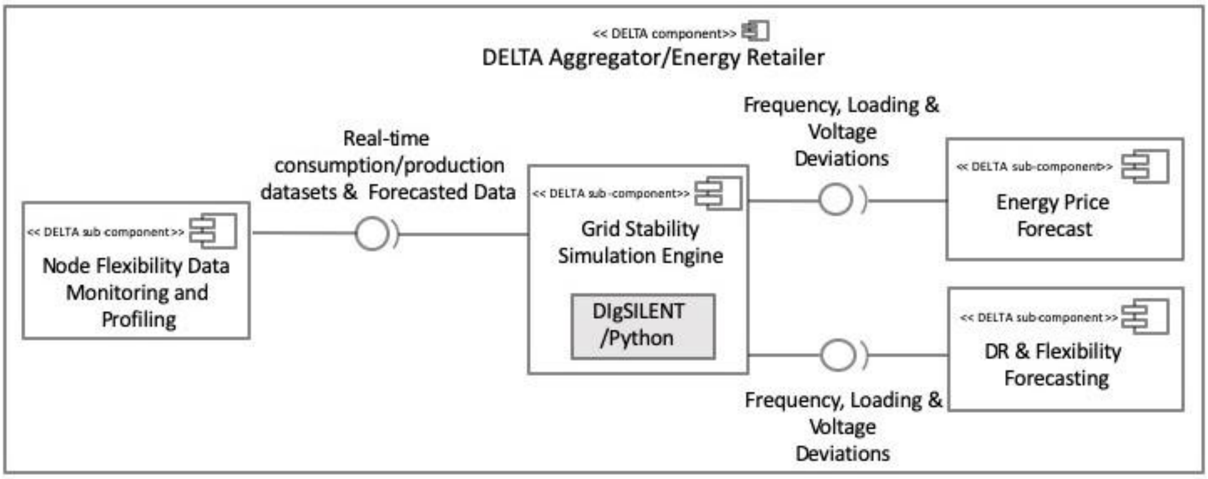

Figure 11: Grid Stability Simulation Engine Interfaces

The following table describes the read and write interfaces between the GSSE Component and other DELTA components.

Table 9: Grid Stability Simulation Engine Interfaces

Interface	R/W	Description
Real-time consumption/production datasets & forecasted data	W	This interface allows the GSSE to receive Real-time and forecasted consumption and production datasets from the NFDM&P. This data follows the DELTA data model specification.
Voltage, Loading &	R	This interface exposes the voltage, loading and frequency constraints computed by GSSE. The voltage

Frequency Constraints		loading and frequency constraints follow the DELTA data model. The violations along with the associated assets (based on the grid topology) are forwarded to the DR&FF in order to decide which of the assets should be considered as priority to offer flexibility and in order to assign flexibility to them. The constraints are also forwarded to the EMPF component in order to review typical factors that influence electricity prices and to exploit their participation in the wholesale markets.

4.2.2 Grid stability simulation engine Architecture

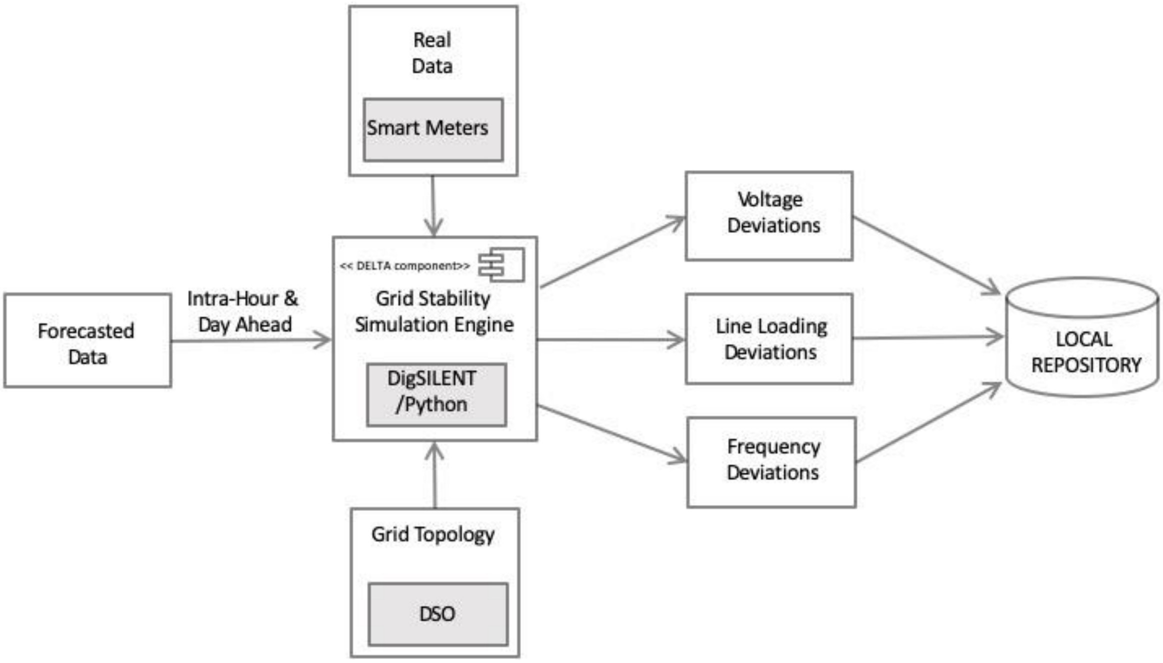

Figure 12: Grid Stability Simulation Engine Architecture

The DELTA Aggregator will be designed and implemented on existing energy assets while also allowing communication and interaction with the DVNP. The GSSE has two functionalities: i) running on forecasted data and ii) running on real data with real time monitoring. The energy profile data acquired by the Smart Meters (SMs) will be imported through the DSS to DIgSILENT via python scripting. The Local Repository represents the database containing voltage, line loading and frequency deviations.

As inputs, the Engine will entail the topological information of the customers and the flexibility amount that is about to be validated (requested from the grid). The NFDM&P will supervise each Nodes' flexibility and contextual data using smart meters for gathering and analysing real time data. The grid structure and components (RES/ critical non-curtailed load/voltage regulators such as tap changers etc.) at the distribution level and at the substations which will be affected from the DR deployment would be made known by the DSO, for the most accurate grid representation.

The NFDM&P will also provide the Engine with Day-Ahead forecasted data that correspond to the predicted amount of consumption/production for the duration of the next 24 hours. These Forecasted data will be updated during the day with new predictions provided by the NFDM&P based in order to improve the forecasting with new close to real time data. The continuously updated Forecasted data or real data along with the Grid Models will be used in order to quantify DR-related grid constraints with potential risks, including assets that are in the DVNP or not. In particular the Engine will produce Voltage, Loading and Frequency Constraints.

4.2.3 Inputs and Outputs

The table below gives an overview of the inputs and outputs of each module along with a short description.

Table 10: Grid Stability Simulation Engine Inputs/Outputs

Output	Output Description	Inputs needed	Input Description	Format
Voltage Constraints	Voltage violations and potential risks that are predicted for the forecasted data	Forecasted Data	Predicted day-ahead data for every pre-specified time step in a 24-hour time span provided by DSS	SQL
		Real Data	Real consumption/production data provided by the DSS and generated from smart meters	SQL
		Grid Models	Predicted interconnected network for delivering electricity from producers to consumers	PFD
Line loading Constraints	The violations of consumed/produced active electric power that are predicted for the forecasted data	Forecasted Data	Predicted day-ahead data for every pre-specified time step in a 24-hour time span provided by DSS	SQL
		Real Data	Real consumption/production data provided by the DSS and generated from smart meters	SQL
		Grid Models	Predicted interconnected network for delivering electricity from producers to consumers	PFD
Frequency	Violations on the	Forecasted	Predicted day-ahead data	SQL

Constraints	nominal frequency of the oscillations of alternating current that are predicted for the forecasted data	Data	for every pre-specified time step in a 24-hour time span provided by DSS	
		Real Data	Real consumption/production data provided by the DSS and generated from smart meters	SQL
		Grid Models	Predicted interconnected network for delivering electricity from producers to consumers	PFD

The following sections describe the three key inputs required for the GSSE to perform its function within the DELTA aggregator layer, namely: Grid Models, Forecasted and Real Data.

Grid Models

A distribution grid is consisted by the medium and low voltage part of a large power system. This operation develops the structure of the distribution grid from synchronized voltage measurements in the grid subject to the exogenous fluctuations in nodal power consumption. The operation of a large power grid is separated into different tiers/levels: transmission grid that consists of high voltage lines connecting the generators to the distribution substations, and distribution grid consisting of the medium and low voltage lines that connect distribution substations to loads. Topology estimation in the distribution grid thus refers to the problem of determining the current set of operational lines which are energized. Accurate topology estimation in the distribution grid is necessary for checking system status/integrity, e.g. failure detection, and also for taking consecutive optimization and control decisions. The smart meters are capable of providing real time measurements of consumption/production limited to the grid nodes. The goal of this operation is to utilize measurements given by DSS acquired by SMs, to efficiently estimate the topology of the distribution grids.

Forecasted Data

The Node profiling Energy Balancing component will provide once a day forecasted data for the next 24 hours for every pre-specified time step. The GSSE will examine whether the provided data correspond to the pre-specified time step. The forecasted data will be updated during the hour with new predictions based on data over the day. Short-term load forecasting is crucial for the operations planning of an electrical grid. Forecasting the next 24 h of electrical load in a grid allows operators to plan and optimize their resources. Short-term electrical load forecasting is vital for the efficient operation of electric power systems. A power grid integrates many stakeholders who can be affected by an inaccurate load forecast: power generation utilizes 24-hour ahead forecasts for operations planning, i.e., to determine which power sources should be allocated for the next 24 h; transmission grids need to know in advance the power transmission requirements in order to assign resources; end users utilize the forecast to calculate energy prices based on estimated demand. Contingency planning, load shedding, management strategies and commercialization strategies are all influenced by load forecasts. Forecast errors result in increased operating costs: predicting a lower load than the actual load results in utilities not committing the necessary generation units and therefore incurring higher costs due to the use of peak power plants; on the other hand, predicting a higher load than actual will result in higher costs because unnecessary baseline units are started and not used. When the 24 hour ahead data expire the forecasted data will be updated by replacing the inaccurate entries with the corresponding real data and then then be added to the repository of historical data.

Real Data

The GSSE component manages and gives access to the following data resources: historical data, real data, forecasted data, grid models, voltage constraints, loading constraints, and frequency constraints. Accordingly, an instance of voltage constraints, loading constrain, and frequency constraints is depended on multiple Forecasted data of a particular grid model. The NFDM&P will provide the engine with historical data as observed by smart meters in order to accurately predict the grid model. Each grid model has an association with its corresponding historical data that are used to predict the grid topology. The DSS will provide the initial historical data and the day-ahead forecasted data for every pre-specified time step in the next 24 hours generated in CSV format. The GSSE will use these forecasted data in order to produce voltage constraints, loading constraints, and frequency constraints in CSV as the primary data-interchange format. The forecasted data will be updated with the real data provided by the DSS and after the duration of 24hours has passed the forecasted data will become historical.

4.3 Functionality

4.3.1 Workflows

This section describes a first set of workflows in order to foster a deeper understanding of how the GSSE component works. A workflow consists of an orchestrated and repeatable patter of activity, enabled by the systematic organization of resources into processes that transform materials, provide services, or process information. From a more abstract or higher-level perspective, workflow may be considered a view or representation of real work. The flow being described may refer the document, service, or a product that is being transferred from one step to another.

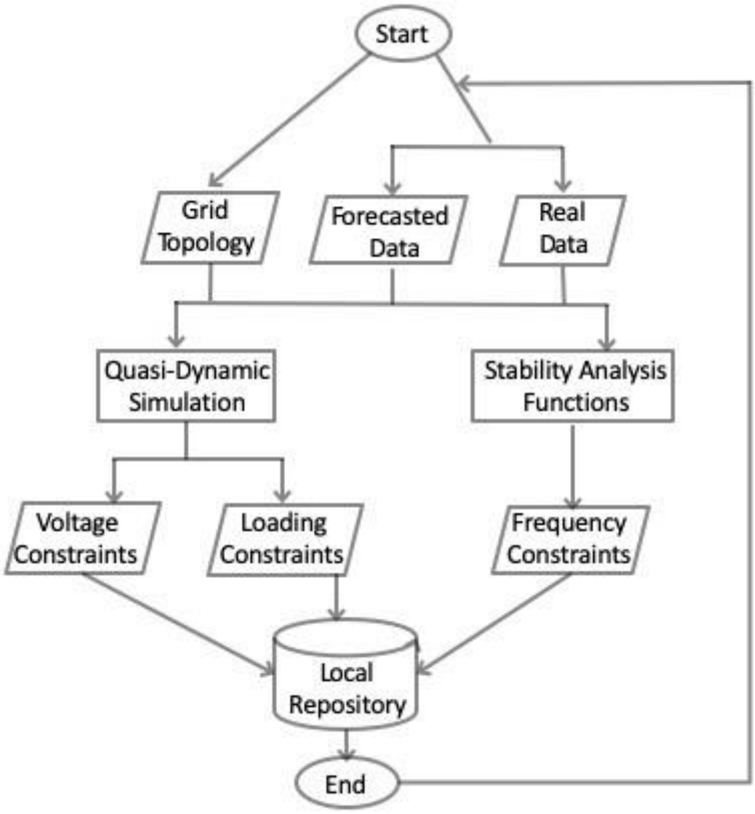

Figure 13: Grid Stability Simulation Engine Flowchart

Quasi-Dynamic Simulation

Power Factory [5] offers Quasi-Dynamic Simulation for the execution of medium to long term simulations. Multiple load flow calculations are carried out with user-defined time step sizes. The tool is particularly suitable for planning studies in which long term load and generation profiles are defined, and network development is modelled using variations and expansion stages. The integrated Engine algorithms will aggregate the Low Voltage DR sources below each MV substation and evaluate their impact on voltage and load constraints in respect with current grid code requirements (overvoltage/overload), based on an enhanced optimal power flow algorithm. When the engine predicts forecasted congestion in a line during the quantification of DR-related gird constraints, it will calculate and request flexibility from a neighbouring line. The forecasted load will be calculated individually for each substation and flexibility will be requested in both directions within the grid. DIgSILENT offers medium- to long-term simulations based on steady-state analysis.

Stability Analysis Functions (RMS)

The RMS simulation tool in PowerFactory [4] can be used to analyse mid-term and long-term transients under both balanced and unbalanced conditions, incorporating a simulation scan feature. DIgSILENT Simulation Language (DSL) is used for model definition, and a large library of IEEE standard models is available. Flexible co-simulation options are also available. The objective of a time domain stability analysis is a concise, yet complete, quantitative and standardized description of the phase and frequency of the source, including their nominal values, the fluctuations of those values, and their dependence on time and environmental conditions. RMS provides A-stable numerical integration algorithms supporting long-term stability simulations with integration step sizes ranging from milliseconds to minutes, individually selectable for each model.

Updated Forecasted/Real Data
The DSS component known as Node profiling Energy Balancing will provide once a day forecasted data for the next 24 hours for every pre-specified time step. The forecasted data will be updated during the hour with new predictions based on data over the day.

4.4 Technical Specification

The implementation of the GSSE component involves integration between python and DIgSILENT PowerFactory. As an input the engine will receive the forecasted and real time power data in csv format which will be fed to DIgSILENT via python script which will assign the data to the respective grid components. DIgSILENT will then run Power Flow Analysis based on predefined constraints which will result in graphical representations and reports with numerical values of voltage, frequency and line loading.

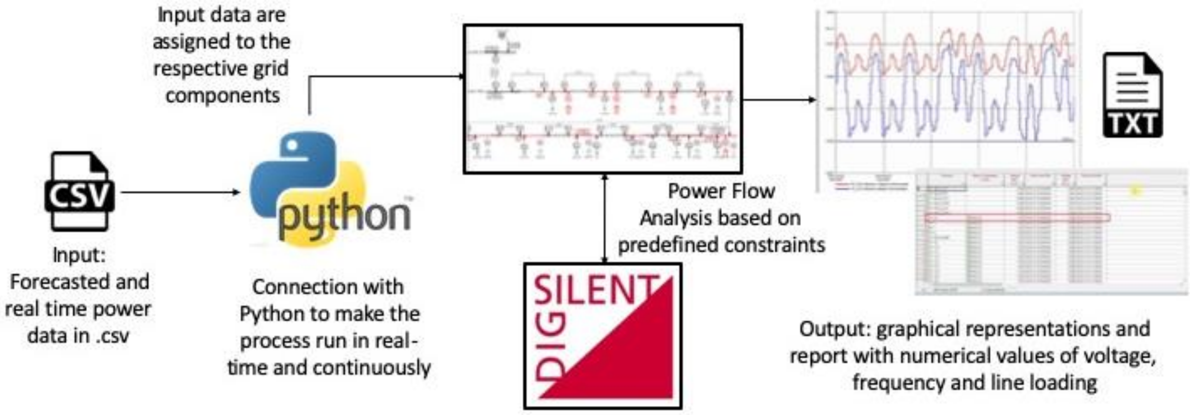

Figure 14: Grid Stability Simulation Engine Technical Overview

4.4.1 DIgSILENT

PowerFactory is a leading power system analysis software application for use in analysing generation, transmission, distribution and industrial systems. It covers the full range of functionality from standard features to highly sophisticated and advanced applications including windpower, distributed generation, real-time simulation and performance monitoring for system testing and supervision. The calculation program PowerFactory, is a computer aided engineering tool for the analysis of transmission, distribution, and industrial electrical power systems. It has been designed as an advanced integrated and interactive software package dedicated to electrical power system and control analysis in order to achieve the main objectives of planning and operation optimization.

The proven advantages of PowerFactory software are its overall functional integration, its applicability to the modelling of generation, transmission, distribution and industrial grids and the analysis of their interactions. With its rich modelling capabilities, PowerFactory is perfectly suited for network planning and operation studies of increasingly smart grids. PowerFactory is easy to use, fully Windows compatible and combines reliable and flexible system modelling capabilities with state-of-the-art algorithms and a unique database concept.

Also, with its flexibility for scripting and inter- facing, PowerFactory is perfectly suited to highly automated and integrated solutions in your business applications.

DIgSILENT will run simulation forecast in order to predict congestion and then it will request from aggregator a new prediction based on historical data which will respond with flexibility. The python algorithm will calculate forecasted flexibility by comparing the preferable load vs the historical data based on an objective baseline curve. The component will identify whether we need flexibility the python script will import the forecasted flexibility to the CIM component that will use openADR interfaces that will connect /share input and output through the aggregator. As described before, for complexity reasons the communication can be performed internally with the monitoring component which will use the DELTA CIM for retrieving data.

4.4.2 Grid stability simulation engine specification

The method of simulation has been split into several steps, this has been done to ensure the procedure reflects the grid under evaluation as close to the actual grid as possible. The steps for setting up the simulations are as follows:

- Gathering information of real grid examples
- Establishing the grids in a proper simulation tool
- Generating load and charging profiles

The grids have been established in the DIgSILENT PowerFactory. The grid topology is based on data and information provided by the local DSO as it is anticipated in their new role as neutral market facilitators, DSOs will make available pertinent information to the competent players. Therefore, the grid topology is created as following:

Feeder
Feeders are used for the transmission of electricity it is the power line in which electricity is transmitted in power systems. It does the transmission of power from the generating station or substation to the distribution points. There is no intermediate tapping and by that, the flow of current will be the same for the sending and the receiving section. Feeders are the conducting device which is used for the transmission of power to the main load centre we could get constant voltage from the feeder.

Transmission line
A transmission line is used for the transmission of electrical power from generating substation to the various distribution units. It transmits the wave of voltage and current from one end to another. The transmission line is made up of a conductor having a uniform cross-section along the line.

Substations
A substation is a part of an electrical generation, transmission and distribution system. Substations transform voltage from high to low, or the reverse, or perform any of several other important functions. Between the generating station and consumer, electric power may flow through several substations at different voltage levels. A substation may include transformers to change voltage levels between high transmission voltages and lower

distribution voltages, or at the interconnection of two different transmission voltages. Substations may be owned and operated by an electrical utility or may be owned by a large industrial or commercial customer.

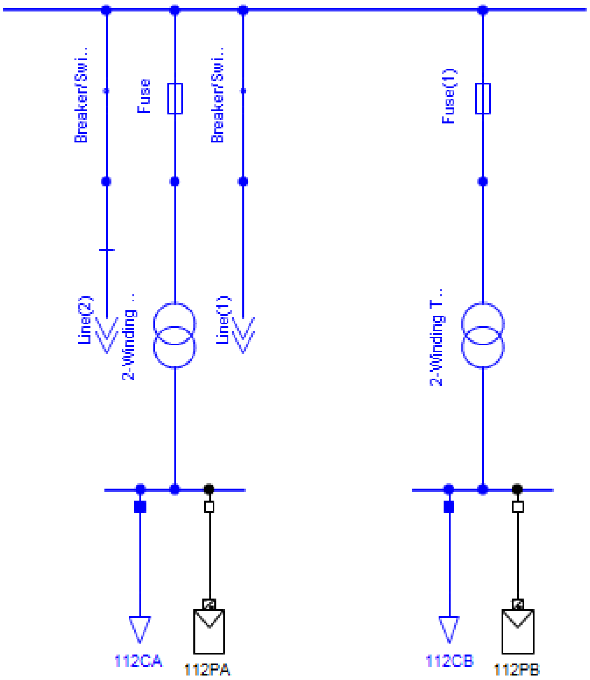

Figure 15: Substation specification

Our pilot study is on the campus of the University of Cyprus where the various substations represent the different buildings of the university. Generally, substations are unattended, relying on smart meters for remote supervision and control. The substation layout is the preparation of a one-line diagram, which shows in simplified form the switching and protection arrangement required, as well as the incoming supply lines and outgoing feeders or transmission lines. We have used universal labels such as 111CA where the first element represents the transmission line and each time a line is divided a second digit is added, the third digit represents the feeder where the first letter represents consumption/production with C and P respectively and finally A represents that it is the sequential number of loads.

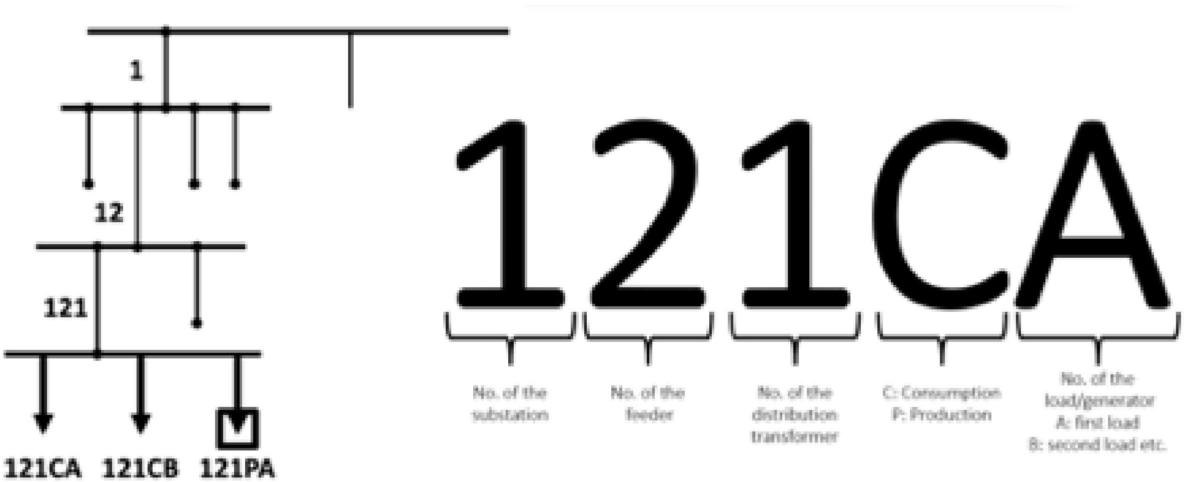

Figure 16: Universal component labeling.

Transmission substation
The purpose of this substation is connecting two or more grid transmission lines. The simplest case is when the voltages are the same (in such case high-voltage switches allow lines to be connected or isolated). In the case the voltages are different some transformers have to be used to convert them. Other devices to control voltage and power factor like reactors (shunt, variable shunt) and phase shifting transformers to control power flow between two adjacent power systems have to be used.

Primary distribution substation
This substation is used to transfer power from the network transmission lines to the distribution line of an area. It is uneconomical to directly connect electricity consumers to the main transmission network, unless they use large amounts of power, so the distribution station reduces voltage to a level suitable for local distribution.

Generating Load profiles
To be able to make a precise simulation of the chosen grids, different profiles of loads have to be taken into account. This covers load profiles for every household and additional network feeders connected to the same low-voltage transformer. In order to achieve a precise result of the simulations of the grids, a range of load profiles depending on the number of customers have been included in the simulation tool, PowerFactory. We use python scripting in order to feed DIgSILENT the forecasted data given by the DSS and associate with their corresponding substation.

Quasi-Dynamic Analysis and Stability Analysis Functions
Therefore, we perform a simulation run which is focused on time domain simulations with duration from several minutes to several weeks. This type of simulations are useful for analysis of power system behaviour due to slow variations, studies on power and energy management, active and reactive power balancing, demand side management, voltage control strategies, determination of the proximity to operating limits, power system stability etc. Depending on the state variables defined by the user, on the grid topological data and on the available sensor data, the model can capture both single- and three-phase electrical quantities.

Voltage and loading limits must be maintained to ensure proper functioning of the power system. Some systems might require special considerations and might have more or less restrictive specifications. Therefore, we allow the aggregator to customize constrains based on individual system specifications for actual requirements. Mains electricity is nominally 230 V in the European Union but is allowed to vary ±10%. The phase-to-phase steady-state voltage must be maintained between plus 10 percent or minus 10 percent of the nominal voltage and must return to a steady-state tolerance of normal rated voltage within 0.5 second. Therefore, the simulation results demonstrate how voltage and loading are effectively captured across the whole network via the utilized formulation and the power flow through the interlinking converter is associated with voltage variation (i.e. 0.95-1.05 p.u.) and loading variation which must not exceed 100% SPEB.

One of the core functionalities of the DELTA Aggregator is that of the self-portfolio energy balancing. The aim of the SPEB components is to optimally access the energy flexibility market services and exploit DR without affecting the stability and adaptation capacity of the network. This module will be able to perform with or without the integration of the DVNP. It will be employed in real-time operation regardless of incoming DR signals (either from the DSO/TSO or the DVNP) as to ensure stability and optimal distribution of electrical energy within the DELTA energy network. The DELTA Aggregator modules perform all communication and interactions with the other components of The DELTA architecture through the Common Information Model (CIM). The OpenADR interface serves as the general interface.

4.5 Architectural Requirements

4.5.1 Interface Requirements

A system requirement is classified as an interface requirement when it involves an interaction with another system through an associated interface. An interface requirement indicates or implies the conditions that need to be satisfied concerning the interfaces of the DELTA platform.

Table 11: Self- Portfolio Energy Balancing interface requirements

ID	Description	Type	Rationale	Fit Criterion	Priority	Associated Use Cases
2	Request feedback from occupant regarding its comfort	NF	To ensure that occupants are not negatively affected	Feedback on occupant's comfort	Could have	5.2.2

4.5.2 Hardware Requirements

Hardware requirements describe the compatible hardware devices for a particular software system. These requirements describe the conditions that do not need to be exceeded including the minimum processor speed, memory, and disk space required to install the system.

Table 12. Self-Portfolio Energy Balancing hardware requirements

ID	Description	Type	Rationale	Fit Criterion	Priority	Associated Use Cases
1	2 Processor Cores, 8 GB RAM. 0.5TB RAID Array Storage	F	Windows VM deployed on Windows server 2012 on UCY server at the UCY campus in Nicosia	Python can be installed	Must have	5.1.1

4.5.3 Software requirements

Software requirements convey the expectations and needs of the stakeholders into a viable set of conditions that validate the success of a software product. Specifically, they describe the functionalities and features of a software product that solves the needs of the end user.

Table 13. Self- Portfolio Energy Balancing software requirements

ID	Description	Type	Rationale	Fit Criterion	Priority	Associated Use Cases
1	Generate Bids that are sent to the external oracle Demand Response Services to Market Stakeholders as answer of a previous submitted demand response signal.	F	To increase revenue and support grid stability targeting a balanced state where the use available flexibility is maximized.	Calculation and offering of flexibility	Must have	5.3.1
2	Produce a market settlement that specifies a certain behaviour that the DELTA Aggregator / Energy Retailer should consider behaving	F	To decrease expenditure	Provable demonstration that strategies employed avoided cost and/or generated	Must have	5.3.1
3	Constantly monitor the portfolio's composition and capabilities in terms of stability and flexibility	F	To ensure that flexibility of distributed assets can be aggregated as a single unit to sell services	Single control requests communicate appropriately	Must Have	5.1.1

4.5.4 *Communication requirements*

Communication requirements convey the conditions under which the various components consisting a software communicate. Specifically, it describes the communication in either direction between two or more connected parties or devices.

Table 14. Self- Portfolio Energy Balancing communication requirements

ID	Description	Type	Rationale	Fit Criterion	Priority	Associated Use Cases
1	Respond in real time operation regardless of the incoming DR signals	NF	To reduce investment of time and expertise	Setting of bounds for automated operation and demonstration of automated functioning	Could have	5.3.1

4.6 Reference Architecture

4.6.1 Interfaces with other DELTA components

One of the major functionalities of the DELTA Aggregator is that of the SPEB. This module will also provide the DSS with assessments of the available energy (excess or shortage) within the Aggregator portfolio, targeting a balanced state where the use of available flexibility is maximised. This component will be employed in real-time operation regardless of incoming DR signals (either from the DSO/TSO or the DVNP) as to ensure stability and optimal distribution of electrical energy within the DELTA energy network. An autonomous tool will constantly monitor the portfolio in terms of flexibility and stability and will provide feedback to the DSS for creating DR signals for scenarios that the self-balancing at Node level is not enough or large customer not included in the DVNP present challenges that need to be addressed.

To achieve its goal the SPEB relies in the output of the DR&FF through the interface Total Requested Flexibility and Associated Assets, the output of the OpenADR Security Services CIM throughout the interface OpenADR: Contracted Prices, the Historical node flexibility and contextual data provided by the OpenADR DELTA Repository CIM. Figure below depicts these interactions.

The OpenADR DELTA Repository CIM should have access to each Nodes' flexibility and contextual data, for activating profiling mechanisms for each Node's flexibility and decide upon their DR request strategies. The SPEB will therefore be able to collect profiling data of the historical flexibility offered so far in order to be able to monitor the stability (e.g. voltage fluctuations) within the available portfolio.

The SPEB aims at considering the contracted energy market behaviour into account to produce assessments in the DELTA Aggregator / Energy Retailer portfolio. Therefore, another component known as the OpenADR Security Services CIM will store the smart contracts that will later be given to the SPEB. The main indicators included in each smart contract would be the points earned/kW of DR-enabled capacity, which will be translated in a realistic respective rewards to the customer (monetary or behavioural based) through social collaboration and awards-based gamification schemes. Smart Contracts designed over a (DELTA) blockchain-based distributed ledger will be used to ensure the security of the energy information exchange within the DELTA energy network, enabling both energy data traceability and secure access for stakeholders through the use of certificates, relevant security standards and state of the art security and privacy algorithms.

The DR&FF component will forecast the energy consumption profiles of the prosumer Nodes lying in their portfolio, before and after a DR request is activated. In order to provide accurate and state of the art forecasting results, a simulation suite will be running all possible scenarios that will forecast future availability. The total requested flexibility along with the associated assets will be fed to the SPEB which will decide how much capacity can be made available to the Market. The Asset association will indicate whether flexibility should be requested from particular assets or the selection could be made based on the most profitable strategy.

The SPEB will generate Flexibility Combinations that are sent to AHO as answer of a previous submitted demand response signal. On the other hand, this sub-component aims at producing a market settlement that specifies a certain behaviour that the DELTA Aggregator / Energy Retailer should consider to take, i.e., adapting its assets to the market status. After the settlement the profiles of every asset that is requested to offer flexibility will be revised. These profiles will be fed to the NFDM&P to update the forecasted data that correspond to the predicted amount of consumption/production for the duration of the next 24 hours. These data will be updated based on the assigned flexibility in order to estimate new predictions that improve the forecasting.

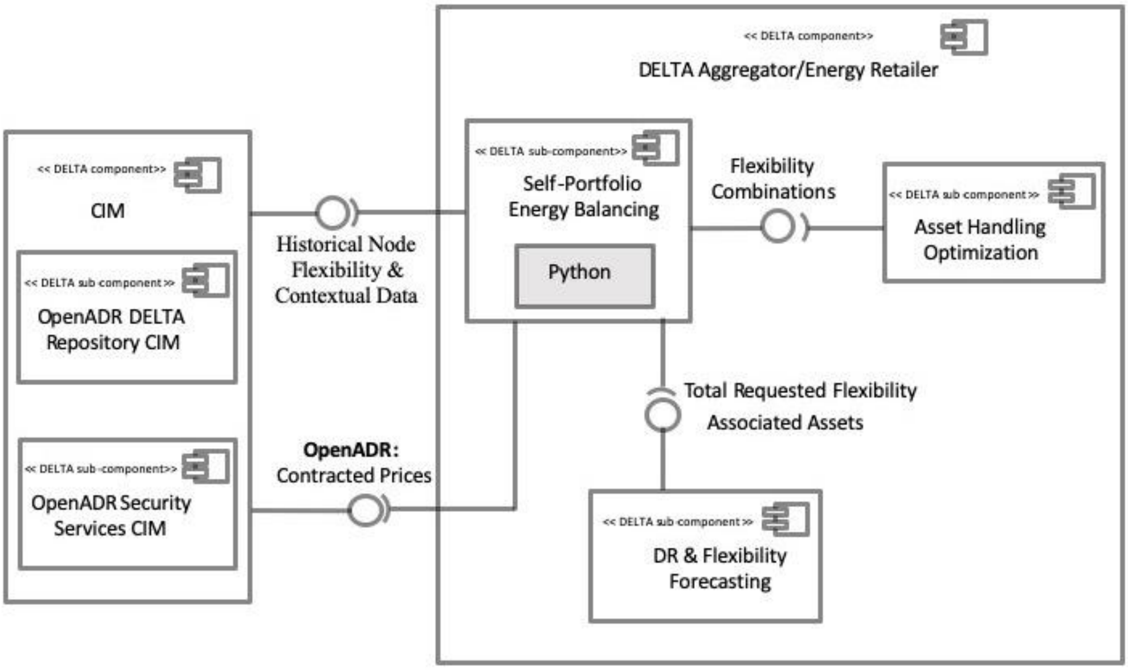

Figure 17. Self-Portfolio Energy Balancing interfaces

The following table describes the read and write interfaces between the SPEB and other DELTA components.

Interface	R/W	Description
Total Requested Flexibility	W	This interface receives the forecasted flexibility

& Associated Assets		provided locally by the DR&FF, based on the flexibility monitoring and load forecast activities. The forecasted flexibility follows the DELTA data model specification. The DR&FF component will forecast the total requested flexibility along with the associated assets in order to indicate whether flexibility should be requested from particular assets or the selection could be made based on the most profitable strategy.
Historical Node Flexibility & Contextual Data	W	This interface receives each Nodes' flexibility and contextual data from OpenADR DELTA Repository CIM. The SPEB will receive the historical flexibility offered so far from each asset in order to be able to monitor the stability (e.g. voltage fluctuations) within the available portfolio.
Contracted Prices	W	This interface receives the energy price profile stored in the OpenADR DELTA Repository CIM. The contracted price profile follows the DELTA data model. Therefore, OpenADR Security Services CIM will store the smart contracts that will later be given to the SPEB. The main indicators included in each smart contract would be the points earned/kW of DR-enabled capacity, which will be translated in a realistic respective rewards to the customer (monetary or behavioural based) through social collaboration and awards-based gamification schemes.
Flexibility Combinations	R	This interface exposes the computed flexibility combinations; which follows the DELTA data model. SPEB will prioritise the possible combinations of market settlements that specify a certain behaviour that the DELTA Aggregator / Energy Retailer should consider behaving. This output entails every asset that is requested to offer flexibility along with the associated market.

Table 15. Self-Portfolio Energy Balancing interfaces

4.6.2 Self-Portfolio Energy Balancing Architecture

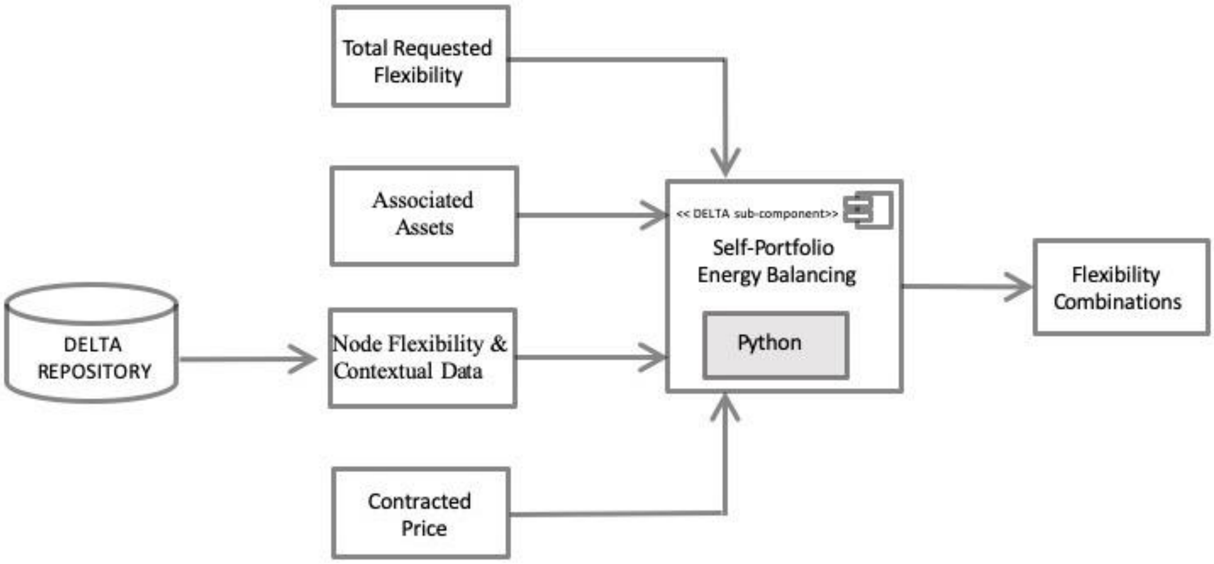

Figure 18. Self-Portfolio Energy Balancing architecture

The DELTA Aggregator will be designed and implemented on existing energy assets while also allowing communication and interaction with the DVNP. The implementation of the SPEB will be universal in order to support various kinds of networks and will be an integrated platform with user friendly interfaces that will convert absolute data to relative. The data will be provided by other components inside and outside the Aggregator layer and will by imported and manipulated via python scripting.

As inputs SPEB will receive contracted prices for the next trading period and the energy volumes likely to clear at that price will be taken into account in order to decide if and when to commit the assets to the most profitable markets. The OpenADR DELTA Repository CIM will include each Nodes' historical flexibility and contextual data. The total requested future availability along with the associated assets will also be made known in order to identify how much capacity can be made available to the Market.

The DR&FF component will generate forecasted flexibility along with a list of the entire possible corresponding component which should offer flexibility. This will allow the SPEB component to use the total requested flexibility associated with the possible assets along with the average flexibility and calculate the profitability of the best paying market. In particular, the SPEB component should be able to compare the forecasted flexibility with the historical data of the flexibility offered so far from that particular component and it will identify whether the component can respond to the request. At the same time SPEB should look for potential markets and will prioritize the markets based on how fast we should act and how profitable they are. SPEB will get availability payments for all markets and the one that has the highest paying price will be the one recommended the most. SPEB will identified most profitable strategies to employ and therefore the DELTA Aggregator via AHO will analyse the probability of multiple events happening simultaneously and decide which of the strategies from SPEB is the most profitable and hence commit the assets to multiple programs or just to one program allocates any extra capacity to the best paying services in the market.

At the beginning of the settlement period, the aggregator will dispatch contracted capacity. If an event occurs in more than one program the Aggregator will get a penalty for withdrawing his committed availability.

4.6.3 Inputs and Outputs

The table below gives an overview of the inputs and outputs of each module with a short description respectively.

Table 16. Self-Portfolio Energy Balancing inputs/outputs

Output	Output Description	Inputs needed	Input Description	Format
Flexibility Combinations	SPEB will prioritise the possible combinations of market settlements that specify a certain behaviour that the DELTA Aggregator / Energy Retailer should consider behaving. This output entails every asset that is requested to offer flexibility along with the associated market in order to deliver either a specific level of power from generators or a reduction of demand.	Total Requested Flexibility & Associated Assets	Forecasted future availability along with a list of all possible assets that could offer this flexibility which will be fed to the SPEB in order to decide how much capacity can be made available to the Market	SQL
		Historical Node Flexibility & Contextual Data	The aggregated assets in the entire distribution network, along with each Nodes' flexibility and contextual data in order to allow SPEB to monitor the stability (e.g. voltage fluctuations) within the available portfolio	SQL
		Contracted Prices	Smart contracts that will be given to the SPEB including the points earned/kW of DR-enabled capacity, which will be translated in a realistic respective rewards to the customer (monetary or behavioural based) through social collaboration and awards-based gamification schemes.	SQL

Total Requested Flexibility & Associated Assets

The DR&FF component will forecast the extent to which a node can modify electricity production or consumption in response to variability, expected or otherwise. This component will run a simulation suite that will forecast which of the nodes is able to modify its generation and/or consumption in reaction to an external signal in order to provide a service within the energy system. The Asset association will indicate whether flexibility should be requested from particular assets or the selection could be made based on the most profitable strategy. This input will be given to the SPEB component which will compare the requested flexibility to the historical data of the offered flexibility of the particular node. SPEB will decide whether and how much capacity can be made available to the Market.

Historical Node Flexibility & Contextual Data

The historical data of the each node's flexibility and contextual data will be provided by the OpenADR DELTA Repository CIM, which will contain all assets that are under the supervision of the aggregator. The SPEB will therefore receive profiling data of the flexibility offered so far from each component in order to be able to compare the historical data to the requested flexibility and identify whether the node can respond to the requested flexibility. This will allow the aggregator to monitor the stability (e.g. voltage fluctuations) within the available portfolio.

Contracted Prices

The SPEB aims at considering the contracted energy market behaviour into account to produce assessments in the DELTA Aggregator / Energy Retailer portfolio. Therefore, another component known as the OpenADR Security Services CIM will store the smart contracts that will later be given to the SPEB. The main indicators included in each smart contract would be the points earned/kW of DR-enabled capacity, which will be translated in a realistic respective rewards to the customer (monetary or behavioural based) through social collaboration and awards-based gamification schemes. Smart Contracts designed over a (DELTA) blockchain-based distributed ledger will be used to ensure the security of the energy information exchange within the DELTA energy network, enabling both energy data traceability and secure access for stakeholders through the use of certificates, relevant security standards and state of the art security and privacy algorithms. These contracted prices will be fed to the SPEB component which will look for potential markets and will prioritize the markets based their profitability.

4.7 Functionality

4.7.1 Workflows

This section describes a first set of workflows in order to foster a deeper understanding of how the GSSE component works. A workflow consists of an orchestrated and repeatable patter of activity, enabled by the systematic organization of resources into processes that transform materials, provide services, or process information. From a more abstract or higher-level perspective, workflow may be considered a view or representation of real work. The flow being described may refer the document, service, or a product that is being transferred from one step to another.

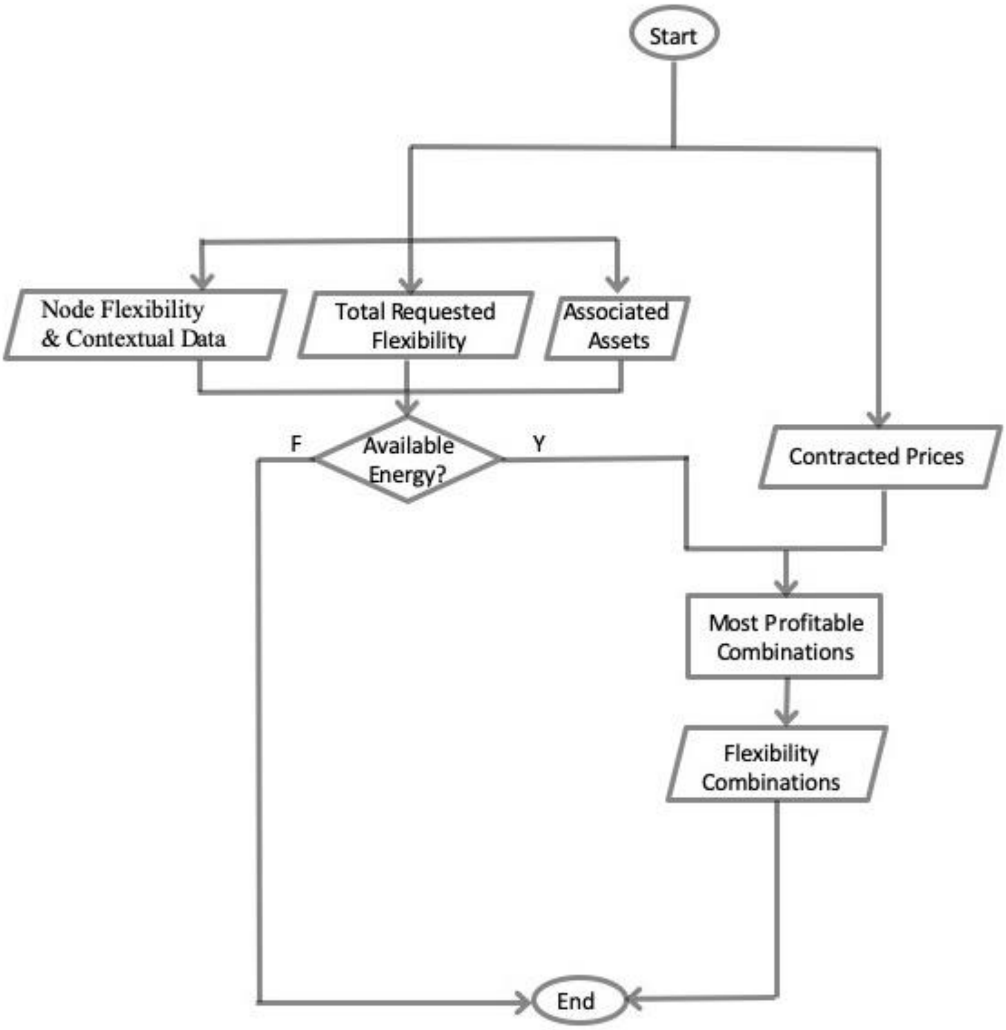

Figure 19: Self-Portfolio Energy Balancing flowchart

Available Energy

The aggregator, via the DR&FF component, forecasts future availability and decides how much capacity can be made available to a DR procurement. The DR&FF component will generate total requested flexibility along with a list of assets that could possibly offer flexibility. SPEB must prioritise the available assets n order to meet the total requested flexibility based on the selected specific assets that correspond to voltage, line loading and frequency violations as given by the DR&FF. Thereafter the SPEB component will be able to compare the forecasted flexibility with the historical data of the flexibility offered so far from that particular component and it will identify whether the component can respond to the request.

Most profitable strategy

The SPEB components receives contracted prices from the OpenADR Security Services CIM for the next trading period and the energy volumes likely to clear at that price. The component has also decided how much capacity can be made available to the Market based on the requested flexibility. Given that there are several programs inside the Balance market (SFFR, Constraint management, capacity, STOR) to which an aggregator could sell its available flexibility, the SPEB component should allocate its asset in the best way possible that maximises its profit without being penalized.

The component has identified the most profitable strategy and therefore the aggregator will make its Assets/portfolios available for bidding to the best paying markets. AHO will receive the strategies from SPEB and analyse the probability of occurrence of multiple events happening simultaneously and decide if and when to commit the assets to multiple programs or just to one program aiming to employ most profitable strategy. Therefore, the AHO allocates any extra capacity to the best paying services in the market. Each assets profile will be revised taking into account the offered flexibility. The aggregator can make a decision to make its assets available for multiple programs (STOR and constraint management) and get rewarded for it. However, if an event occurs in one of them he will get a penalty for withdrawing his committed availability. At the beginning of the settlement period, the aggregator will dispatch contracted capacity. An aggregator is paid in two ways: First by the power made available to the program such ex: 1.5£/MW per hour and also when it actually delivers the contracted energy 60£/MWh. If an event occurs in more than one program the Aggregator will get a penalty for withdrawing his committed availability.

4.8 Technical Specification

4.8.1 Assign Flexibility to Assets

The DR&FF component generates flexibility requests for the Aggregator. The SPEB will use this information to generate profiles that will assign flexibility requests to the different assets in the network. The total of the aggregated flexibility requested from specific assets should cover the total flexibility requested by DR&FF. This will allow the SPEB component to compare the forecasted flexibility with the historical data of the flexibility offered so far from that particular component and it will identify whether the component can respond to the request and if it can how much capacity can be made available to the Market. In order for our platform to support electrical networks of various topologies we create universal labels for assets.

4.8.2 Identify most profitable strategy

The OpenADR Security Services CIM will store the smart contracts that will later be given to the SPEB. The main indicators included in each smart contract would be the points earned/kW of DR-enabled capacity, which will be translated in a realistic respective rewards to the customer (monetary or behavioural based) through social collaboration and awards-based gamification schemes. These contracted prices will be fed to the SPEB component which will look for potential markets and will prioritize the markets based their profitability.

The OpenADR Security Services CIM component will inform SPEB with the available contracted prices for the next trading period and the energy volumes likely to clear at that price therefore enabling purchases, through bids to buy; sales, through offers to sell; and short term trading, generally in the form of financial or obligation swaps. In some cases, some of the assets included in the aggregator might be obligate to long-term trades because of already existing contracts similar to power purchase agreements and generally considered private bilateral transactions between counterparties.

The electricity market can be divided into two different types: the spot market, where the electrical energy is traded for immediate physical delivery, and the futures market, where the delivery is at a later date and normally does not involve physical delivery. Given that there are several programs inside the Balance market (SFFR, Constraint management, capacity, STOR) to which an aggregator could sell its available flexibility, the SPEB component should find the best combination to allocate assets in the best way possible that maximises profit without being penalized. The SPEB component will prioritize the markets based their profitability aiming to cover the total amount of flexibility requested by DR&FF. The algorithm will use combinatorial optimization to decide the optimal selection of markets to bid along with the associated asset that will offer its flexibility. This algorithm will receive as input the requested flexibility in MW and the associated clearing price as defined by the contract of the corresponding market. SPEB will then try to cover the total flexibility as requested by DR&FF while trying to minimise the total price of the requested flexibility or maximise the total price of the offered flexibility. This algorithm solves the optimisation problem in polynomial time and finds the maximum or minimum price value by applying this algorithm iteratively while increasing the value of the requested flexibility.

5. Energy Portfolio Segmentation & Classification

The aim of this component is to establish the allocation of the DELTA Virtual Nodes underneath the DELTA Aggregator. This classification is based on a clustering algorithm performed at the Aggregator level to the entire portfolio based on certain characteristics, towards creating virtual medium/large clients that can be handled more efficiently. After this first step, the Nodes would re-act and re-arrange themselves autonomously, based on indicators infused by the Aggregator Architectural Requirements.

As this component is part of the activities of T4.2, a more elaborate description along with detailed implementation documentation is expected in D4.2.

5.1 Architectural Requirements

5.1.1 Interface Requirements

A system requirement is classified as an interface requirement when it involves an interaction with another system through an associated interface. An interface requirement indicates or implies the conditions that need to be satisfied concerning the interfaces of the DELTA platform.

Table 29: Energy Portfolio Segmentation & Classification Interface Requirements

ID	Description	Type	Rationale	Fit Criterion	Priority	Associated Use Cases
1	Modification of the segmentation and classification parameters	F	The platform should allow the aggregator to pre-specify the configuratio n parameters of the algorithms	The platform is able to run simulation s on different values of the main parameters	Must Have	5.3.1

5.1.2 Hardware Requirements

Hardware requirements describe the compatible hardware devices for a particular software system. These requirements describe the conditions that do not need to be exceeded including the minimum processor speed, memory, and disk space required to install the system.

Table 30: Energy Portfolio & Segmentation Hardware Requirements

ID	Description	Type	Rationale	Fit Criterion	Priority	Associated Use Cases
1	4 Processor Cores, 32 GB RAM, In case the quantity of	F	The platform will be implemented in Windows VM deployed on	GPU oriented Tensorflow, Pytorch and Python can be	Must Have	5.3.1

	the data justify the usage of deep learning algorithms GPU would be required for fast training of clustering and classification models. The implementations will be using CUDA libraries thus GPU must be NVIDIA, to reduce time for simulations a GTX1080 minimum.		Windows server 2012 on UCY server at the UCY campus in Nicosia	installed		

5.1.3 Software requirements

Software requirements convey the expectations and needs of the stakeholders into a viable set of conditions that validate the success of a software product. Specifically, they describe the functionalities and features of a software product that solves the needs of the end user.

Table 31. Energy Portfolio & Segmentation software requirements

ID	Description	Type	Rationale	Fit Criterion	Priority	Associated Use Cases
1	Generate clusters of DVNs with similar profile	F	In order to allow the DSS to create optimal DR requests and provide useful information to the Aggregator	Provable demonstration that strategies employed avoided cost and/or generated	Must have	5.3.1
2	Assign/remove a FEID to an already existing cluster	F	To avoid re-clustering from the scratch	The newly classified FEIDs should be classified to correct clusters	Must have	5.2.1 5.2.2
3	Repeat clustering process after the accumulation of many new DVNs	F	To ensure that clusters are coherent and separable	Results to accepted clustering metrics	Must Have	5.2.1 5.2.2
4	Request assessment of	F	To request information from the	Provides the correct	Must Have	5.3.2

	the available flexibility in the target area		relevant DVNs	information.		

5.1.4 Communication Interfaces

Communication requirements convey the conditions under which the various components consisting a software communicate. Specifically, it describes the communication in either direction between two or more connected parties or devices.

Table 32: Energy Portfolio & Segmentation Engine Communication Interfaces

ID	Description	Type	Rationale	Fit Criterion	Priority	Associated Use Cases
1	Respond in real-time operation regardless of the incoming DR signals	NF	To reduce investment of time and expertise	Setting of bounds for automated operation and demonstration of automated functioning	Could have	5.3.1

5.2 Reference Architecture

5.2.1 Interfaces with other DELTA components

One of the core functionalities of this segmentation tool is to give the Aggregator the ability to have overall and structured view of his portfolio energy capacity. In particular, the NFDM&P will supervise each Nodes' flexibility and contextual data, for activating profiling mechanisms for each Node and decide upon their DR request strategies. The NFDM&P will therefore feed the tool with profiling data in order to create the appropriate clusters. Regarding the Segmentation tool when a new FEID arrives, a classification process is triggered and the FEID is automatically assigned to one of the existing DVNs, in order to avoid executing the whole segmentation process from scratch. Both tools feed the NFDM&P with the resulted clusters.

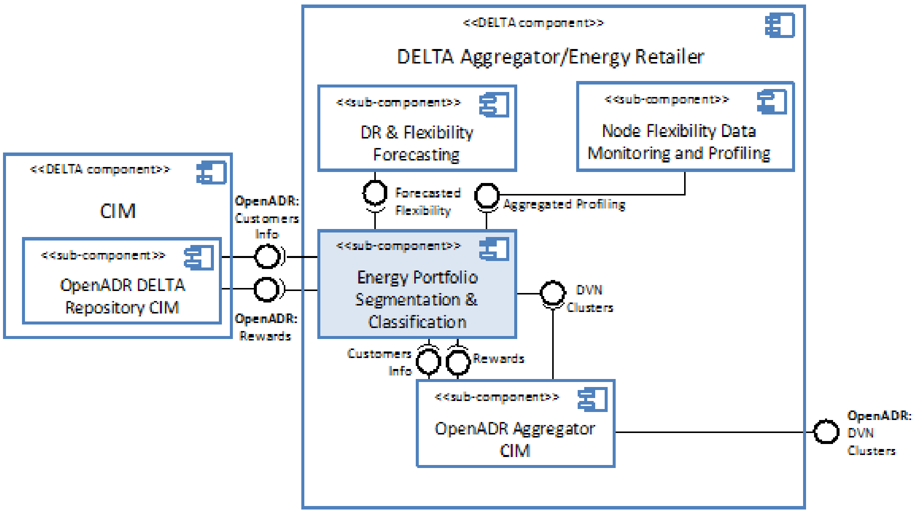

Figure 24: Energy Portfolio Segmentation & Classification

The following table describes the read and write interfaces between the EPS&C and other DELTA components.

Table 35: Energy Portfolio Segmentation & Classification

Interface	R/W	Description
Node Flexibility Data Monitoring and Profiling	R	This interface allows the EPS&C to receive Real-time consumption and production datasets from the NFDM&P. This data follows the DELTA data model specification.
Forecasted Flexibility	R	This interface receives the forecasted flexibility provided locally by the *DR & Flexibility Forecasting* based on the monitoring and load forecast activities. The forecasted flexibility follows the DELTA data model specification.
Customers Information	R	This interface provides all the information related to each DELTA customer.
Rewards	R	This interface provides the rewards to each consumer that were assigned during the gamification process.
DVNs Clusters	W	This interface results to the labels from the Segmentation & Classification process that correspond to the DVNs.

5.2.2 *Energy Portfolio Segmentation and Classification*

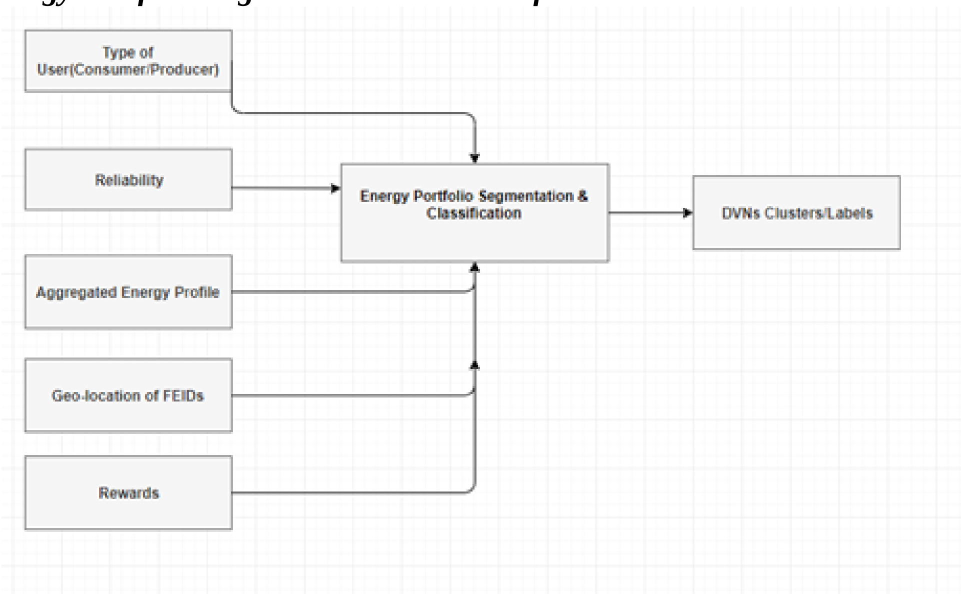

Figure 25: Energy Portfolio & Segmentation Engine Architecture

The DELTA Energy Portfolio & Segmentation aims at establishing the allocation of the Virtual DELTA Nodes underneath the DELTA Aggregator / Energy Retailer. The segmentation algorithm is based on different types of input features, resulting to DVNs clusters. DVNs are autonomously re-arranged when the composition of the DVNs is modified by the arrival of a new customer or when the attributes of the existing customers have been changed.

5.2.3 *Inputs and Outputs*

The table below gives an overview of the inputs and outputs of each module with a short description respectively.

Table 10: Energy Portfolio & Segmentation Engine Inputs/Outputs

Output	Output Description	Inputs needed	Input Description	Format
DVNs clusters/labels	Clusters *Virtual Nodes* with similar profiles	Type of user (consumer/producer)	Describes the type of customer	CSV
		Aggregated Energy Profile	Real consumption/production data provided by the NFDM&P tool	CSV
		Geo-location	Indicated the location of the customer	CSV
		Reliability	Gives the responsiveness of the customer to the DR	CSV

			signals	
		Rewards	Rewards that are assigned during the gamification process	CSV

5.2.4 Functionality

In the above picture the workflow of the segmentation & clustering tool is depicted. The component of the segmentation tool receives the input features and a clustering process is conducted in order to extract the clusters of DVNs with similar profiles. In the case of the arrival of a new FEID a classification algorithm is applied and the FEID is classified into one of the existing DVNs. Meanwhile, the Segmentation tool periodically checks for changes into the DVNs profiles. Factors that contribute to the alteration of the profile of a cluster can be the decision of an Aggregator to change the business model, the addition, removal or behavior change of a critical FEID.

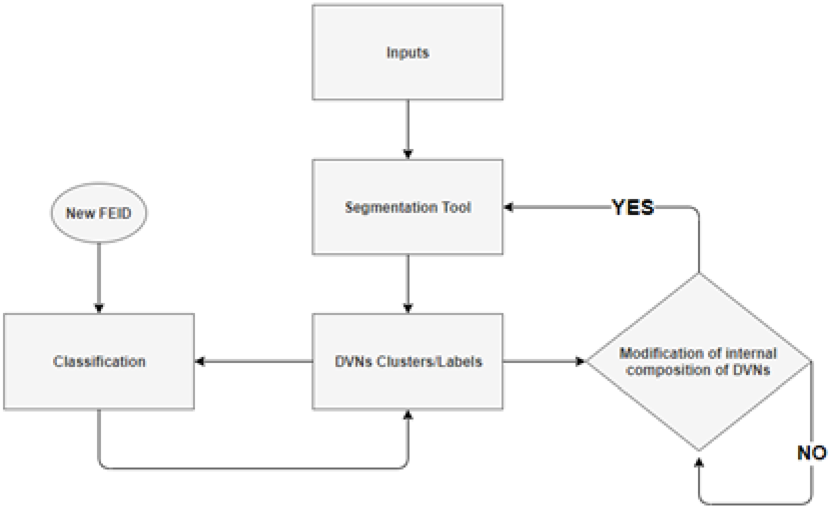

Figure 26: Energy Portfolio & Segmentation Engine Functionality

6. DR & Flexibility Forecasting

The DR&FF component is of crucial importance in the DELTA architecture, for the Aggregator to conform to their balance responsibility. The Aggregator needs to forecast the energy consumption profiles of the prosumer Nodes lying in their portfolio, before and after a DR request is activated. Similar methods as the ones used for price forecasting can be applied in this case. In order to provide accurate and state of the art forecasting results, a simulation suite will be running all possible scenarios utilising the developed testbed for more effective and robust computational efficiency. This activity is achieved with the inputs from the load forecast component and the respective training data of the DELTA DVNs & FEIDs.

6.1 Functionality

6.1.1 Workflows

Details on the technical implementation of this component, and in accordance with the information provided in D1.2 [2] are presented in a publication led by JRC [6]. In brief a non-intrusive approach is followed towards delivering a load flexibility estimation following the below workflow.

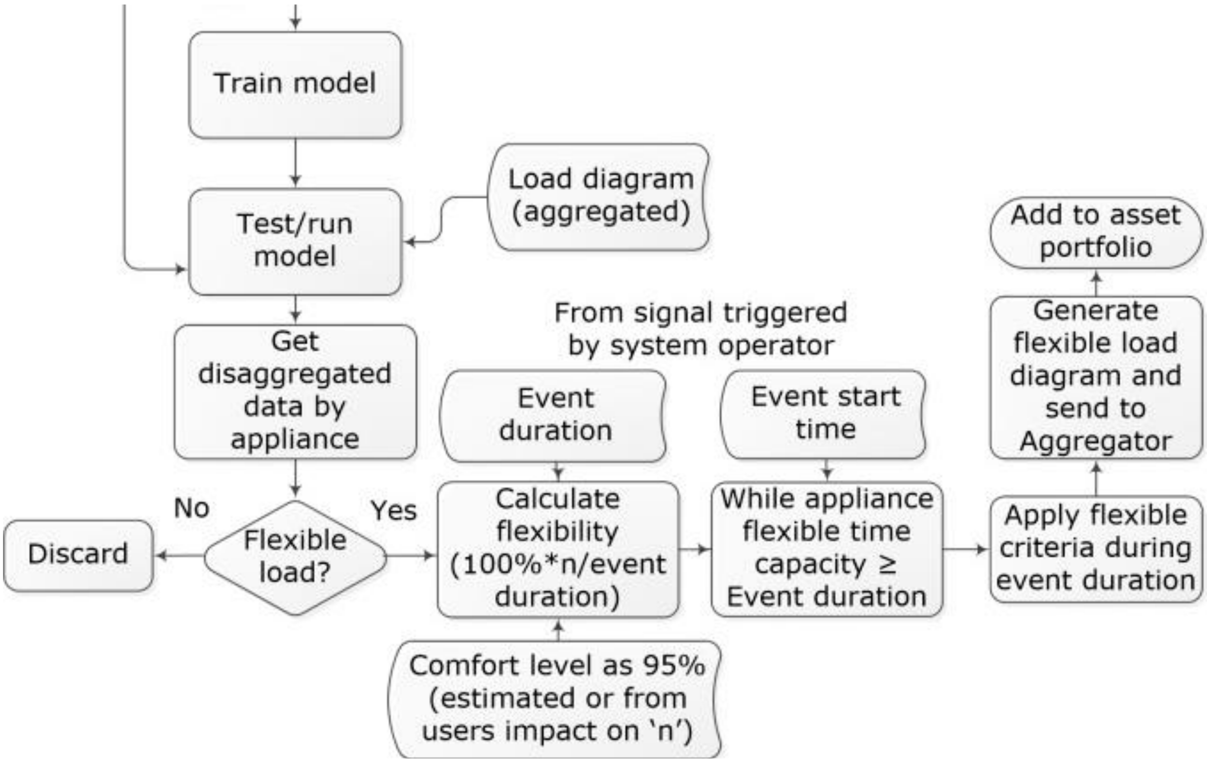

Figure 20 Model implementation diagram for load flexibility estimation

As this component is part of the activities of T4.3, a more elaborate description along with detailed implementation documentation is expected in D4.3.

7. Energy Market Price Forecast

The EMPF component is activated when the Aggregator needs to exploit their participation in the wholesale markets (if such scheme is supported by the market regulatory frameworks). Typical factors that influence electricity prices will be reviewed (such as season/day, weather, fuel prices, demand elasticity etc.) and price forecasting techniques will be employed (regression techniques/SVM/neural networks etc.). However, for use cases involving bilateral agreements and participation in e.g. capacity markets, the market price will be perceived as a known-constant value. Given the participation of the Aggregator to both intra and inter-day markets, in some cases the pricing scheme selected to be follow will have already been defined by more long-term planning activities beyond the Aggregators capacity. In these scenarios, the EMPF will mainly retrieve the appropriate pricing schemes and distribute internally to other Aggregator components.

As this component is part of the activities of T4.3, a more elaborate description along with detailed implementation documentation is expected in D4.3.

8. Asset Handling Optimization

The AHO will be responsible in analysing incoming DR signals and (re-)distribute them based on information provided by the other DSS and Aggregator components for a balanced, stable and DR profitable (both in terms of energy and cost) way. AHO is a tool of Decision Support System at aggregator level that connects with the NFDM&P, DR and Flexibility forecasting and Energy Market to receive data from DVN level: Reliability, DR flexibility, Energy Generation, System Marginal Price and generates and distributes Implicit and Explicit incentives among DVNs in the direction of aggregator's profit maximization and energy exploitation. Intermittent nature of renewable energy sources requires to manage energy through the day in an efficient and smooth way that prevents high consumption peaks during the rush hour and eliminate conditions of potential system's imbalance. Except from profit, AHO takes into account system's fairness and robustness.

As a result, AHO respects clients' reliability offering respective incentives that act as a motivation/deterrent for the DVNs. Implicit incentives are represented through Real Time Pricing whereas explicit incentives can take many forms of direct rewards. The algorithmic implementation is based on Genetic Algorithms that is an evolutionary, stochastic approach that can optimize the system's objective function.

As this component is part of the DELTA DSS, a more elaborate description along with detailed implementation documentation is expected through the activities of T4.4 and in D4.4.

8.1 Architectural Requirements

8.1.1 Interface Requirements

A system requirement is classified as an interface requirement when it involves an interaction with another system through an associated interface. An interface requirement indicates or implies the conditions that need to be satisfied concerning the interfaces of the DELTA platform.

Table 17: Asset Handling Optimization Interface Requirements

ID	Description	Type	Rationale	Fit Criterion	Priority	Associated Use Cases
1	Specified general DR strategies	NF	The platform should allow the aggregator to select profit margin and general strategy	Set the aggregator strategy	Could Have	5.1.2
2	Specified DR constraints	F	The platform should allow the aggregator to add any constraint	Set the aggregator's constraints	Could Have	5.1.2

8.1.2 Hardware Requirements

Hardware requirements describe the compatible hardware devices for a software system. These requirements describe the conditions that do not need to be exceeded including the minimum processor speed, memory, and disk space required to install the system.

Table 18: Asset Handling Optimization Hardware Requirements

ID	Description	Type	Rationale	Fit Criterion	Priority	Associated Use Cases
1	4 Processor Cores, 16 GB RAM	F	The platform will be implemented in Windows VM deployed on Windows	Python Installed	Must Have	5.1.1

8.1.3 Software Requirements

Software requirements convey the expectations and needs of the stakeholders into a viable set of conditions that validate the success of a software product. Specifically, they describe the functionalities and features of a software product that solves the needs of the end user.

Table 19: Asset Handling Optimization Software Requirements

ID	Description	Type	Rationale	Fit Criterion	Priority	Associated Use Cases
1	Generate Implicit incentives and distribute them among the DVNs	F	To Generate Real Time Price to motivate/deter DVNs	Set the implicit incentives	Must Have	5.2.3.1
2	Generate Explicit incentives and distribute them among the DVNs	F	To Generate direct rewards used as motivation	Set the explicit incentives	Must Have	5.2.3.3
3	Evaluate aggregator's profit	NF	To evaluate total aggregator revenues according to the specified strategy	Evaluation	Could Have	5.1.2

8.1.4 Communication Interfaces

Communication requirements convey the conditions under which the various components consisting a software communicate. Specifically, it describes the communication in either direction between two or more connected parties or devices.

Table 20: Asset Handling Optimization Communication Interfaces

ID	Description	Type	Rationale	Fit Criterion	Priority	Associated Use Cases
1	Respond in real time operation regardless of the incoming DR signals	NF	To reduce investment of time and expertise	Setting of bounds for automated operation and demonstration of automated functioning	Could have	5.1.2

8.2 Reference Architecture

8.2.1 Interfaces with other DELTA components

One of the core functionalities of the DELTA Aggregator is that of the AHO engine. AHO is a tool of Decision Support System at aggregator level that connects with NFDM&P, SPEB and Energy Market stakeholders to receive data about: reliability, DR flexibility, energy generation, System Marginal Price.

Since not all assets are expected to be included in the DVNP, the aggregator should be able to monitor the entire distribution network under its supervision. In particular, the NFDM&P will supervise each Nodes' flexibility and contextual data, for activating profiling mechanisms for each Node and decide upon their DR request strategies. The NFDM&P will therefore feed the AHO with profiling data in order to be able to monitor the flexibility, energy consumption and generation, reliability within the available portfolio.

Another component known as the EMPF will receive the violations in order to review the typical factors that influence electricity prices and employ the appropriate price forecasting techniques that will deliver to AHO the System Marginal Price Estimation.

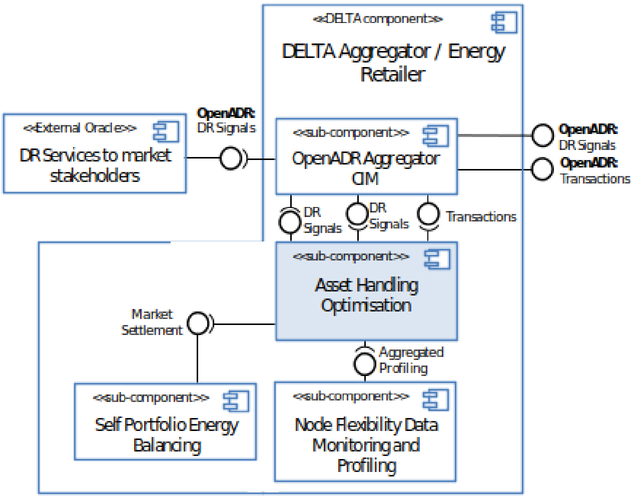

Figure 19. Asset Handling Optimization interfaces

The following table describes the read and write interfaces between the AHO engine and other DELTA components.

Table 21: Asset Handling Optimization R/W

Interface	R/W	Description
Node Reliability	R	This interface allows the *AHO* to receive all aggregated assets in the entire distribution network under its supervision, along with each Nodes' reliability, from the NFDM&P.
Forecasted Flexibility	R	This interface receives the forecasted flexibility provided locally by the *DR&FF, based on the flexibility monitoring and load forecast activities.* The forecasted flexibility follows the DELTA data model specification
Forecasted Energy Generation	R	This interface allows the *AHO Engine* to receive energy consumption and production datasets from the NFDM&P. This data follows the DELTA data model specification.
Forecasted Energy Consumption	R	This interface allows the *AHO Engine* to receive energy forecasted consumption from the NFDM&P. This data follows the DELTA data model specification.
System Marginal Price	R	This interface receives the energy price profile computed by the EMPF. The

		price profile follows the DELTA data model
Implicit Incentive	W	Real Time Pricing for each DVN for the next 24h
Explicit Order	W	Downwards/Upwards orders for each DVN for the next 24h

8.2.2 *Asset Handling Optimization Architecture*

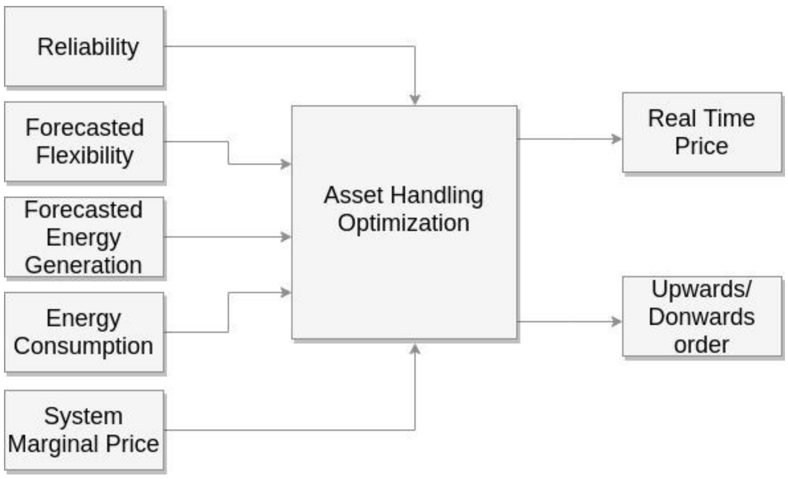

Figure 20. Asset Handling Optimization Architecture

AHO engine will be responsible to generate Implicit and Explicit incentives that are represented through Real Time Prices and Upwards/Downwards energy orders. The general goal of the engine is aggregator's profit maximization, energy exploitation and the occupants' reliability reward. The algorithmic implementation is based on Genetic Algorithms.

As input the implementation will receive data about the nodes Reliability from the Profiling engine. The AHO is inclined towards the rewarding of reliable nodes in a direct or indirect way.

8.2.3 *Inputs and Outputs*

Table 22: Asset Handling Optimization Inputs/Outputs

Output	Output Description	Input	Input Description	Format
Real Time Price	RTP describes the optimized price that aggregator decides to sell	Reliability, Forecasted Flexibility, Energy Generation,	All these features comprise the Profiling characteristics	CSV

	the energy to the DVN in order to ensure constraints satisfaction	Energy Consumption, SMP	and forecasting metrics of DVN	
Upwards/Downwards order	U/D describe the upwards/downwards orders that the aggregator demands from each DVN in order to preserve a desirable system condition.	Reliability, Forecasted Flexibility, Energy Generation, Energy Consumption, SMP	All these features comprise the Profiling characteristics and forecasting metrics of DVN	CSV

8.3 Functionality

8.3.1 Workflows

This section describes the technical part of the algorithmic implementation of AHO engine. AHO is based on Genetic Algorithms that is a heuristic approach that solves optimization problems under specific constraints.

Constraints definition is a crucial part of the sequences rating. Constraints actually define the objective function and lead the system to convergence towards a specific solution. Constraints have a penalty role that punish misbehaviours and diminish erroneous solutions. In that way, the system rates each solution and identifies the fittest ones. The following part is the selection of the Mating Pool. The algorithm selects a percentage of the fittest solutions and applies on them crossover and mutation operations according to a pre-specified probability in order to evolve the sequences with an adjusted exploitation-exploration trade-off. Finally, the algorithm returns to the rating step and repeats the same algorithmic sequence. That happens for a specified number of generations.

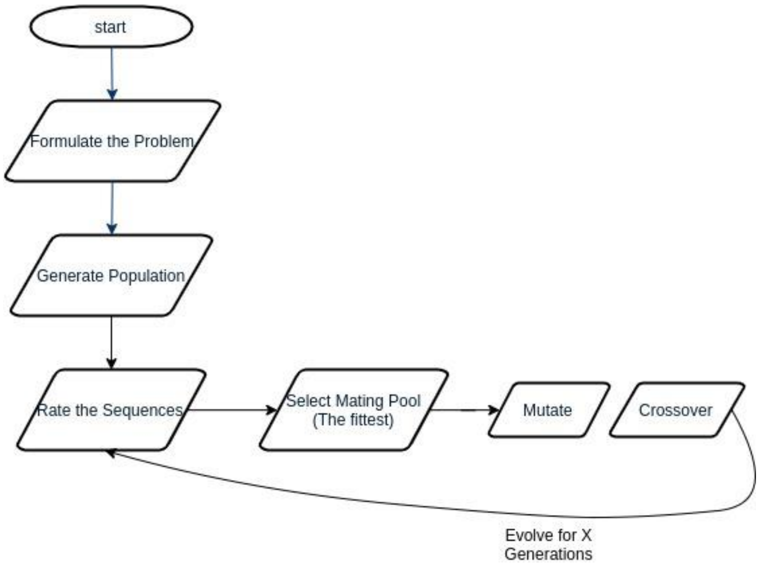

Figure 21. Asset Handling Optimization Workflow

9. Node Flexibility Data Monitoring and Profiling

The NFDM&P aims at gathering information of the underneath DELTA components that a certain DELTA Aggregator / Energy Retailer is in charge of, i.e., the Virtual DELTA Nodes that DELTA Aggregator / Energy Retailer handles. NFDM&P component specifically collects aggregated data at DVN level about the Flexibility, Energy Consumption, Energy Generation and Reliability measurements at periodic intervals. The scope of this sub-component is to allow the aggregator to have a clear real-time overview of its assets. In that way, the aggregator is capable to supervise each Nodes' flexibility and contextual data, for activating profiling mechanisms for each Node and decide upon their DR request strategies.

As this component is part of the DELTA DSS, a more elaborate description along with detailed implementation documentation is expected through the activities of T4.4 and in D4.4.

9.1 Architectural Requirements

9.1.1 Interface Requirements

A system requirement is classified as an interface requirement when it involves an interaction with another system through an associated interface. An interface requirement indicates or implies the conditions that need to be satisfied concerning the interfaces of the DELTA platform.

Table 23: Consumer/Prosumer Flexibility Data Monitoring and Profiling requirements

ID	Description	Type	Rationale	Fit Criterion	Priority	Associated Use Cases
1	Specified Time Intervals of monitoring and Profiling	NF	The platform should allow the aggregator to select the time period and interval of Monitoring and Profiling	Configure Monitoring and Profiling	Could Have	5.1.2
2	Select Parameter of Monitoring and Profiling	NF	The platform should allow the aggregator to select the preferred visualization parameter(Positive/ Negative Flexibility) of	Select Visualization Parameter	Could Have	5.1.2

			Monitoring and Profiling			

9.1.2 *Hardware Requirements*

Hardware requirements describe the compatible hardware devices for a software system. These requirements describe the conditions that do not need to be exceeded including the minimum processor speed, memory, and disk space required to install the system.

Table 24: Consumer/Prosumer Flexibility Data Monitoring and Profiling hardware requirements

ID	Description	Type	Rationale	Fit Criterion	Priority	Associated Use Cases
1	4 Processor Cores, 16 GB RAM	NF	The platform will be implemented in Windows VM	Python Installed	Must Have	5.1.1

9.1.3 *Software Requirements*

Software requirements convey the expectations and needs of the stakeholders into a viable set of conditions that validate the success of a software product. Specifically, they describe the functionalities and features of a software product that solves the needs of the end user.

Table 25: Consumer/Prosumer Flexibility Data Monitoring and Profiling Software requirements

ID	Description	Type	Rationale	Fit Criterion	Priority	Associated Use Cases
1	Collect Aggregated data per DVN about Positive Flexibility	NF	Determine DR strategy based on PF	Monitoring & Profiling	Must Have	5.1.2 5.2.3
2	Collect Aggregated data per DVN about Negative Flexibility	NF	Determine DR strategy based on NF	Monitoring & Profiling	Must Have	5.1.2 5.2.3

3	Collect Aggregated data per DVN about Energy Consumption	NF	Determine DR strategy based on EC	Monitoring & Profiling	Must Have	5.1.2 5.2.3
4	Collect Aggregated data per DVN about Reliability	NF	Determine DR strategy based on Reliability	Monitoring & Profiling	Must Have	5.1.2 5.2.3
5	Collect Aggregated data per DVN about Energy Generation	NF	Determine DR strategy based on EG	Monitoring & Profiling	Must Have	5.1.2 5.2.3
6	Forecasting DVN Consumption, Generation and Flexibility based on historical data	F	Forecast Consumption, Generation and Flexibility	Forecasting	Must Have	5.1.2

9.1.4 Communication Interfaces

Communication requirements convey the conditions under which the various components consisting a software communicate. Specifically, it describes the communication in either direction between two or more connected parties or devices.

Table 26: Consumer/Prosumer Flexibility Data Monitoring and Profiling Communication interfaces

ID	Description	Type	Rationale	Fit Criterion	Priority	Associated Use Cases
1	Respond in real time operation regardless of the incoming DR signals	NF	To reduce investment of time and expertise	Setting of bounds for automated operation and demonstration of automated functioning	Could have	5.1.2

9.2 Reference Architecture

9.2.1 Interfaces with other DELTA components

The NFDM&P engine is the interface between Aggregator and DVNS. Its core functionality is focused on the supervision of DVNs in order to offer assistive services to the aggregator. NFDMP collects aggregated data about the Positive, Negative Flexibility, Energy Consumption, Energy Generation and Reliability of each DVN preparing the appropriate DR strategy that will maximize energy exploitation.

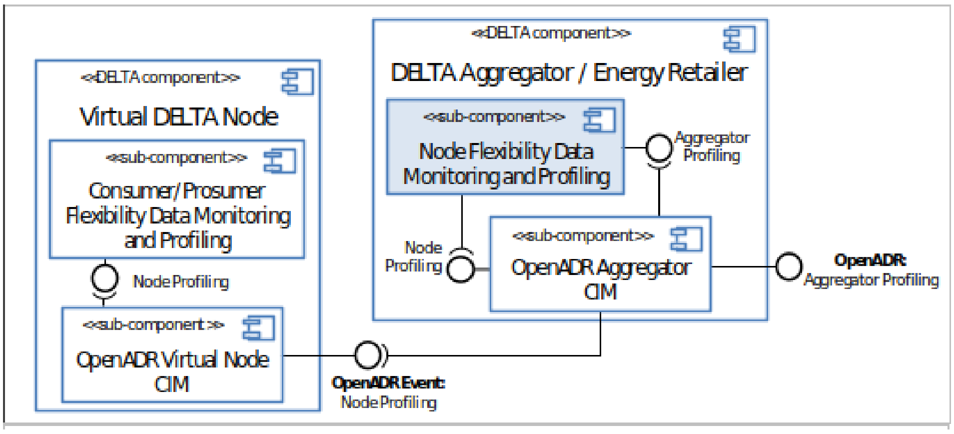

Figure 22. Node Flexibility Data Monitoring and Profiling Interfaces

The following table describes the read and write interfaces between the NFDM&P and other DELTA components.

Table 27: Consumer/Prosumer Flexibility Data Monitoring and Profiling requirements

Interface	R/W	Description
Aggregated Profiling	R	This interface exposes the computed aggregated profiling that offers an overview of the status of *Virtual DELTA Nodes* that a certain aggregator handles. The aggregated profiling follows the DELTA data model
Node Profiling	W	This interface receives the node profiling provided by the *Virtual DELTA Nodes* underneath, which are forwarded by the *OpenADR Aggregator CIM*. The Node Profiling follows the DELTA data model

9.2.2 Node Flexibility Data Monitoring and Profiling Architecture

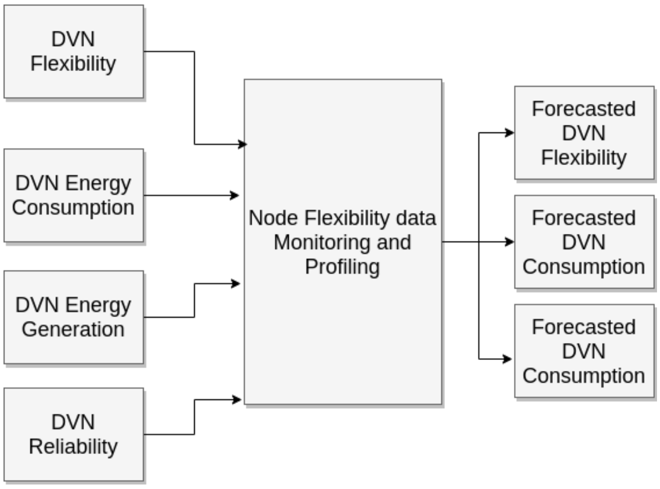

Figure 23. Node Flexibility Data Monitoring and Profiling Architecture

Data Monitoring and Profiling will supervise each Node flexibility and contextual data using smart meters for gathering and analysing real time data. The NFDM&P will also provide the Engine with Day-Ahead forecasted data that correspond to the predicted amount of consumption/production for the duration of the next 24 hours. These Forecasted data will be updated during the day with new predictions provided by the NFDM&P based in order to improve the forecasting with new close to real time data.

9.2.3 Inputs and Outputs

Table 28: Consumer/Prosumer Flexibility Data Monitoring and Profiling requirements

Output	Output Description	Input	Input Description	Format
Forecasted Energy Consumption, Generation and Flexibility at DVN level	Forecasted Energy Consumption, Generation and Flexibility at DVN level based on historical data	Aggregated data about Energy Consumption, Generation and Flexibility at DVN level	Energy Consumption, Generation and Flexibility data at DVN level	CSV

10. Component Verification

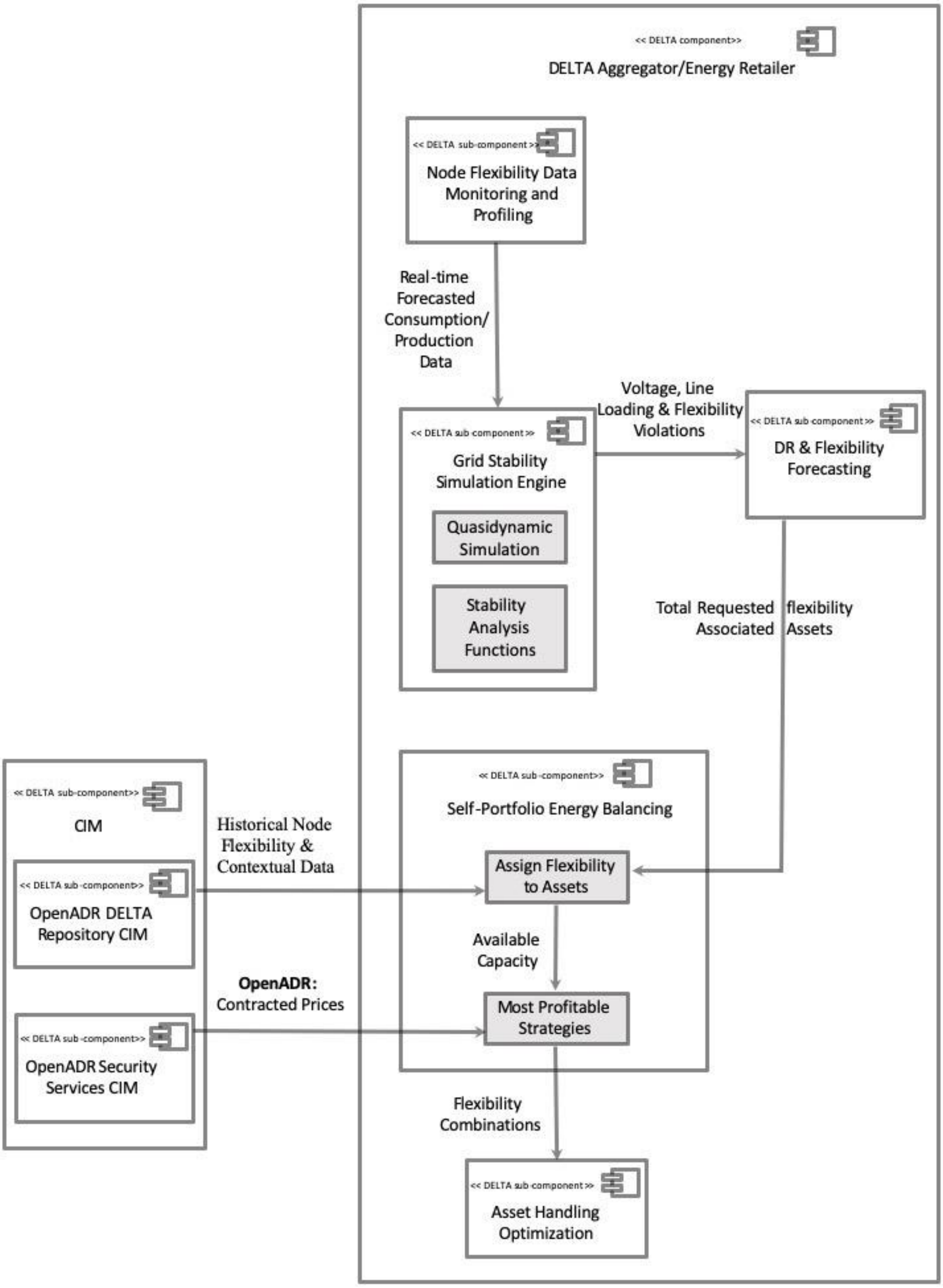

Figure 21 The DELTA Aggregator's components architecture

Node Flexibility Data Monitoring And Profiling

NFDM&P will supervise each Nodes' flexibility and contextual data using smart meters for gathering and analysing real time data. The NFDM&P will also provide the GSSE with Day-Ahead forecasted data that correspond to the predicted amount of consumption/production for the duration of the next 24 hours. These Forecasted data will be updated during the day with the revised profiles after market settlements provided by the SPEB in order for NFDM&P to make t new predictions and improve the forecasting with new close to real time data. The DSS component known as Node profiling Energy Balancing will provide once a day forecasted data for the next 24 hours for every pre-specified time step. The forecasted data will be updated during the hour with new predictions based on data over the day.

Grid Stability Simulation Engine

As inputs, the Engine will entail the topological information of the DR customers and the continuously updated Forecasted data or real data in order to quantify DR-related grid constraints with potential risks, including assets that are in the DVNP or not. The grid structure and components (RES/ critical non-curtailed load/voltage regulators such as tap changers etc.) at the distribution level and at the substations which will be affected from the DR deployment would be made known by the DSO, for the most accurate grid representation.

In particular, the Engine will produce Voltage, Loading Constraints by using Quasi-Dynamic Simulation. Multiple load flow calculations are carried out with user-defined time step sizes. When the engine predicts forecasted congestion in a line during the quantification of DR-related gird constraints, it will calculate and request flexibility from a neighbouring line. The forecasted load will be calculated individually for each substation and flexibility will be requested in both directions within the grid. The engine will also use RMS simulation tool to analyse mid-term and long-term flexibility deviations under both balanced and unbalanced conditions. RMS provides A-stable numerical integration algorithms supporting long-term stability simulations with integration step sizes ranging from milliseconds to minutes, individually selectable for each model.

DR & Flexibility Forecasting

To achieve its goal the SPEB relies in the output of the DR&FF through the interface Total Requested Flexibility & Associated Assets. The DR&FF component will forecast the energy consumption profiles of the prosumer Nodes lying in their portfolio, before and after a DR request is activated. In order to provide accurate and state of the art forecasting results, a simulation suite will be running all possible scenarios that will forecast future availability. The total requested flexibility along with the associated assets will be fed to the SPEB which will decide how much capacity can be made available to the Market. The Asset association will indicate whether flexibility should be requested from particular assets or the selection could be made based on the most profitable strategy.

OpenADR Security Services CIM

The SPEB aims at considering the contracted energy market behaviour into account to produce assessments in the DELTA Aggregator / Energy Retailer portfolio. Therefore, another component known as the OpenADR Security Services CIM will store the smart contracts that will later be given to the SPEB. The main indicators included in each smart contract would be the points earned/kW of DR-enabled capacity, which will be translated in a realistic respective rewards to the customer (monetary or behavioural based) through social collaboration and awards-based gamification schemes. Smart Contracts designed over a (DELTA) blockchain-based distributed ledger will be used to ensure the security of the energy information exchange within the DELTA energy network, enabling both energy data traceability and secure access for stakeholders through the use of certificates, relevant security standards and state of the art security and privacy algorithms. These contracted prices will be fed to the SPEB component which will look for potential markets and will prioritize the markets based their profitability.

Self-Portfolio Energy Balancing
The aggregator, via the DR&FF component, forecasts future availability and decides how much capacity can be made available to a DR procurement. The DR&FF component will generate total requested flexibility along with a list of all the possible assets that could participate. Thereafter the SPEB component will be able to compare the forecasted flexibility with the historical data of the flexibility offered so far from that particular component and it will identify whether the component can respond to the request.

The SPEB component also receives contracted from the OpenADR Security Services CIM for the next trading period and the energy volumes likely to clear at that price. Given that there are several programs inside the Balance market (SFFR, Constraint management, capacity, STOR) to which an aggregator could sell its available flexibility, the SPEB component should decide the best way to allocate assets in the best way possible that maximises its profit without being penalized. It will then prioritize the markets based their profitability aiming to cover the total amount of flexibility requested by DR &FF. SPEB will then try to cover the total flexibility as requested by DR&FF while trying to minimise the total price of the requested flexibility or maximise the total price of the offered flexibility.

AHO will the receive the best flexibility combinations and will analyse the probability of occurrence of multiple events happening simultaneously and decide if and when to commit the assets to multiple programs or just to one program aiming to employ most profitable strategy. It will then allocate any extra capacity to the best paying services in the market. Each assets profile will be revised taking into account the offered flexibility. The aggregator can make a decision to make its assets available for multiple programs (STOR and constraint management) and get rewarded for it. However, if an event occurs in one of them he will get a penalty for withdrawing his committed availability. At the beginning of the settlement period, the aggregator will dispatch contracted capacity. An aggregator is paid in two ways: First by the power made available to the program such ex: 1.5£/MW per hour and also when it actually delivers the contracted energy 60£/MWh. If an event occurs in more than one programs the Aggregator will get a penalty for withdrawing his committed availability.

10.1 Verification Study

The functionalities and the synergies of the developed GSSE and SPEB component were verified through a case study including the two following scenarios:

- Scenario 1: A certain amount of flexibility is required (DR event) that can be met by the contribution of various customers under the Aggregator portfolio.

- Scenario 2: A DR event occurs due to a specific grid constraint violation, therefore the required flexibility must be met by the assets associated to the violation (based on their location and connection to the grid).

The two Scenarios were tested using the single line diagram of the UCY campus as depicted in the figure below. The distribution grid model of the campus was simulated using DIgSILENT.

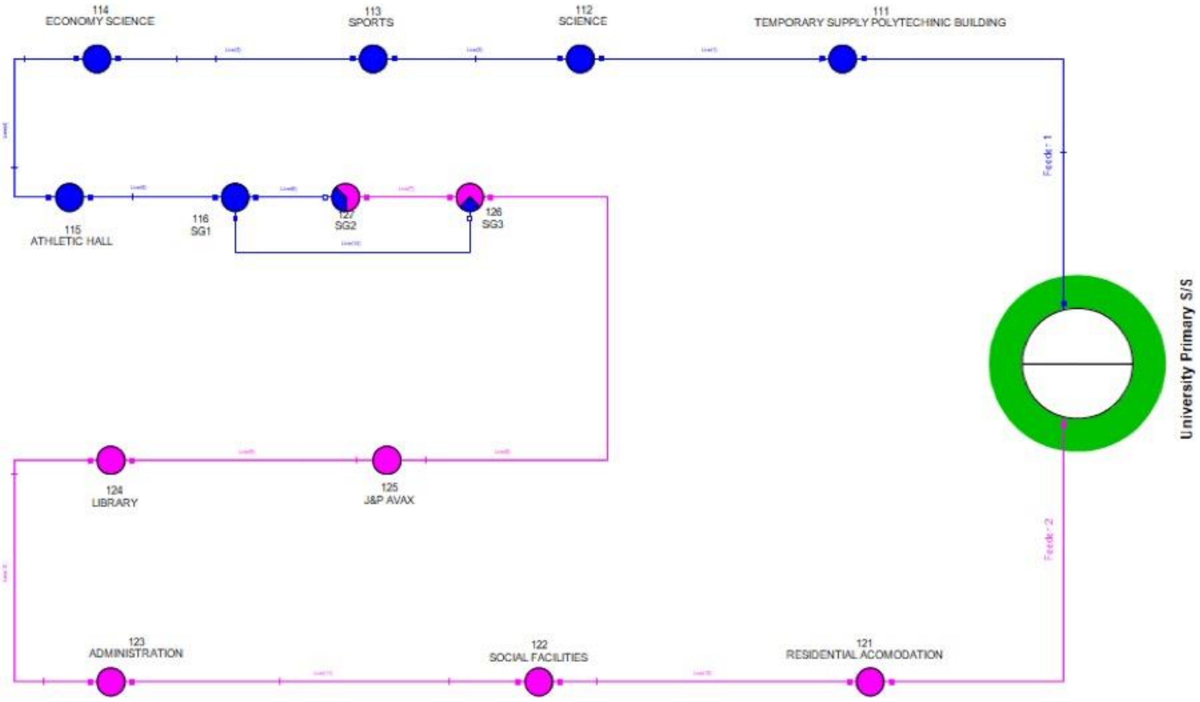

Figure 22. Grid Topology UCY campus.

Under normal operating conditions (steady state) the voltage is limited between 0.95 and 1.05 p.u. while the expected line loading is at 100%. Any deviation occurring out of the aforementioned limits are considered violations. The typical daily voltage and line loading profiles of the UCY under normal operating conditions are illustrated in Figure 21 and 22, respectively.

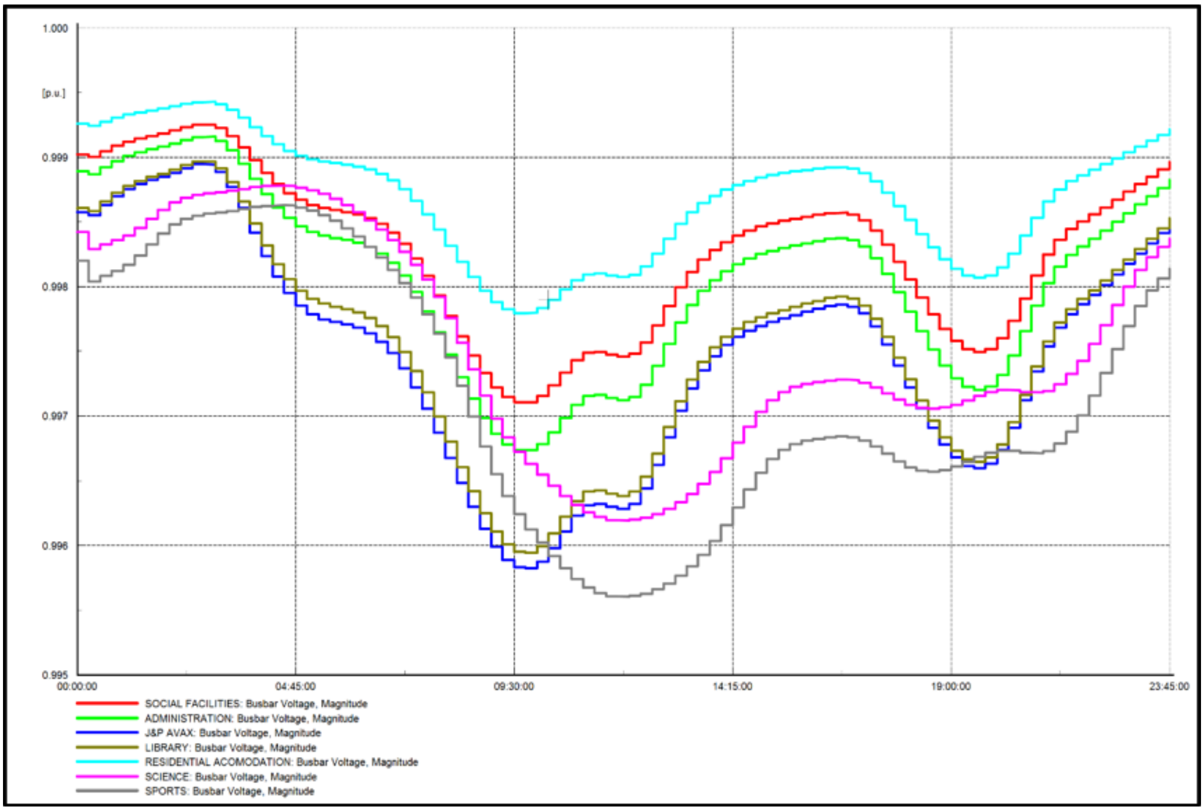

Figure 23. Daily voltage profiles of the UCY.

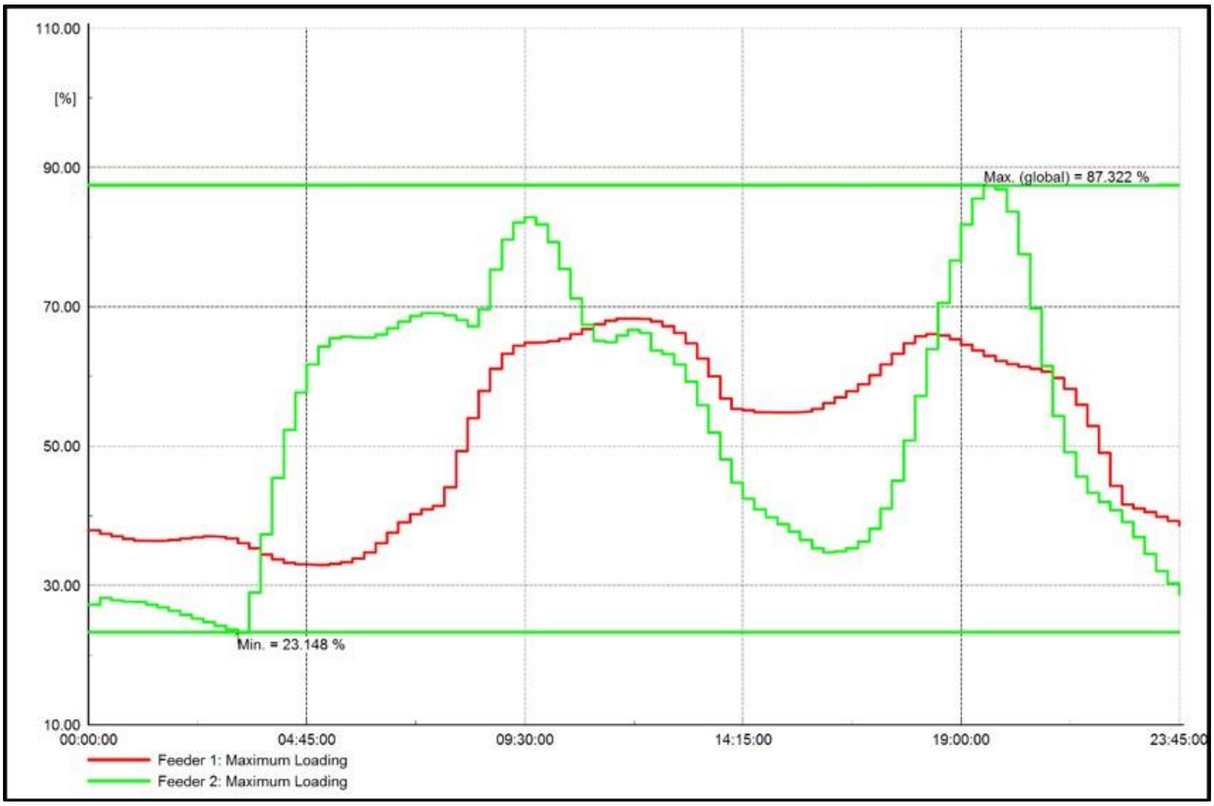

Figure 24. Daily line loading profiles of UCY.

10.1.1 Scenario 1:

The candidate location selections for DR implementation is crucial for MV networks, as there are many consumers connected in each bus of MV networks. Identifying effective locations for DR implementation which have the maximum influence on network voltage and loss improvement, will reduce the load control volume (DR size), optimisation search space and time, disruptions to consumers, as well as DR costs.

For this scenario, it is assumed that a line loading violation will occur within the next 24 hours at the distribution grid of the UCY campus due to an increase in day-ahead forecasted electricity demand. The deviation from the nominal value, the time and duration as well as the location of this violation are identified by the GSSE component as described in the previous sections of this deliverable. The following figures show the line loading and voltage levels of the UCY campus as estimated by the Quasi Dynamic analysis performed by the GSSE component.

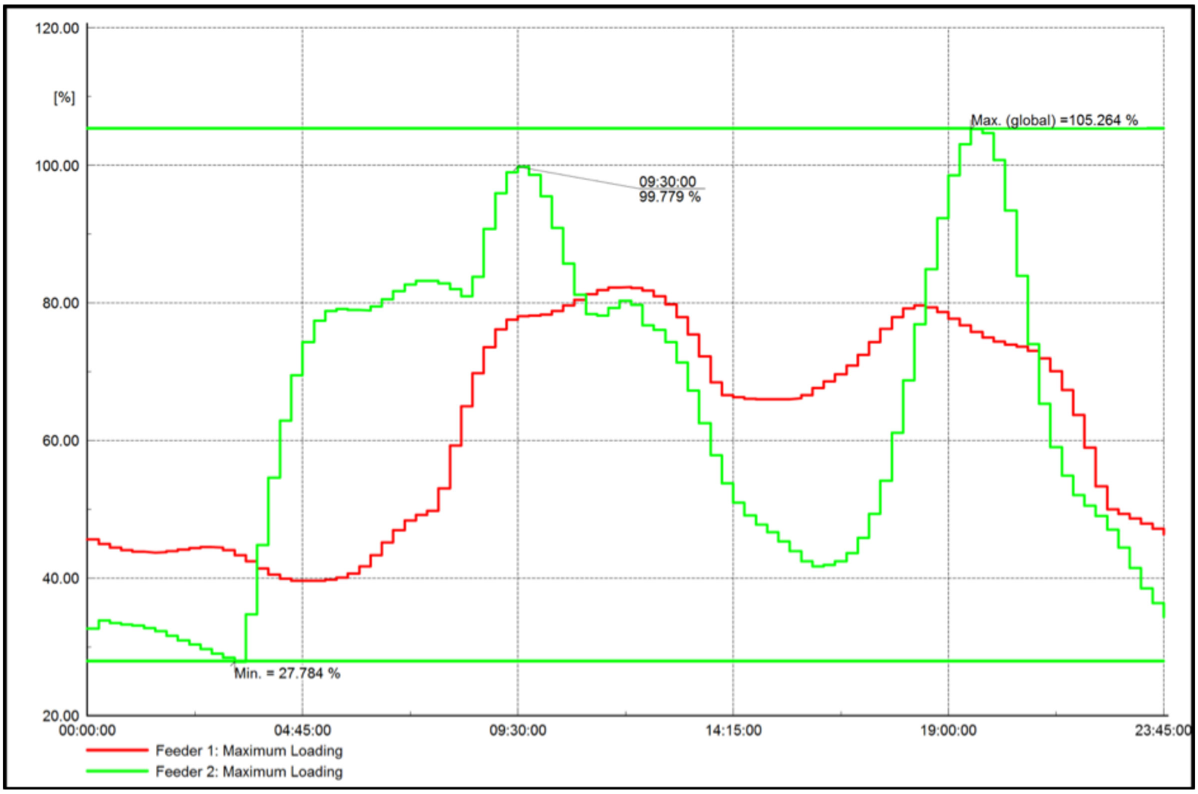

Figure 25. Feeder levels of UCY from quasi-dynamic analysis.

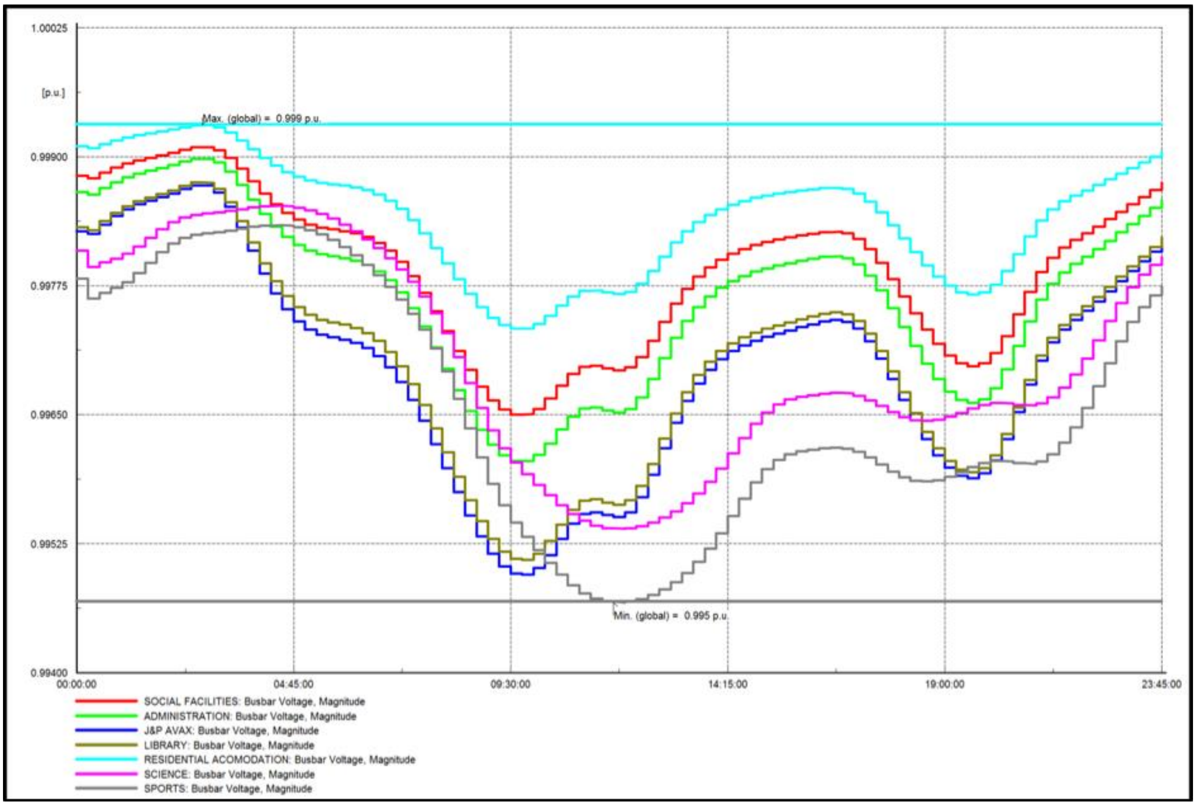

Figure 26. Voltage levels of UCY from quasi-dynamic analysis

The results highlight that the max loading is 105.264% (an increase equal to 5.264%) at the second feeder (location) between 19:15 and 20:00 (time and duration). Moreover, all associated assets that can contribute to the restoration of the line at nominal operating conditions are included in the output information of the GSSE component.

Table 17 Feeder prediction (GSSE)

Quasi-Dynamic Simulation AC	Feeder 1	Feeder 2
Time	Max. Loading in %	Max. Loading in %
0:00:00	45.590603	32.655099
0:15:00	44.95357	33.849077
0:30:00	44.452756	33.438988
0:45:00	44.052221	33.249966
1:00:00	43.804782	33.105364
1:15:00	43.701982	32.739967
1:30:00	43.751947	32.231174
1:45:00	43.893901	31.634234
2:00:00	44.090057	30.949072
2:15:00	44.333457	30.308289
2:30:00	44.485723	29.667837
2:45:00	44.431387	29.017011
3:00:00	44.085896	28.422251
3:15:00	43.341654	27.784357
3:30:00	42.398383	34.738517
3:45:00	41.356143	44.809835
4:00:00	40.513815	54.584348
4:15:00	39.916845	62.892093
4:30:00	39.618718	69.451278
4:45:00	39.573428	74.29861

5:00:00	39.574386	77.391917
5:15:00	39.721143	78.807975
5:30:00	40.021351	79.115793
5:45:00	40.620584	78.926912
6:00:00	41.710381	78.891291
6:15:00	43.299503	79.496039
6:30:00	45.143769	80.542046
6:45:00	46.937107	81.705966
7:00:00	48.333378	82.692405
7:15:00	49.139267	83.195236
7:30:00	49.79245	83.174716
7:45:00	53.020794	82.782916
8:00:00	59.275645	82.019008
8:15:00	64.965921	80.949154
8:30:00	69.739971	83.80129
8:45:00	73.533672	90.716485
9:00:00	76.132619	95.954232
9:15:00	77.550393	98.960382
9:30:00	78.05432	99.778515
9:45:00	78.165394	98.588417
10:00:00	78.307492	95.485498
10:15:00	78.817936	90.879541
10:30:00	79.599224	85.717332
10:45:00	80.466388	81.173804
11:00:00	81.277899	78.398849
11:15:00	81.880825	78.117489
11:30:00	82.242461	79.250308
11:45:00	82.286548	80.281908
12:00:00	82.15519	79.714175
12:15:00	81.739857	76.734342
12:30:00	80.964321	76.092447
12:45:00	79.742549	74.316501
13:00:00	77.934185	71.343588
13:15:00	75.399548	67.22116
13:30:00	72.239938	62.484569
13:45:00	68.404009	57.810651
14:00:00	66.608953	53.79146
14:15:00	66.295933	50.976287
14:30:00	66.08395	49.10381
14:45:00	65.973628	47.77139
15:00:00	65.966008	46.61674
15:15:00	66.007341	45.32452
15:30:00	66.105059	43.879844
15:45:00	66.579609	42.413346
16:00:00	67.600963	41.707353
16:15:00	68.585993	41.882517
16:30:00	69.609012	42.426316
16:45:00	70.89297	43.608043
17:00:00	72.414042	45.836317
17:15:00	74.296974	49.330653
17:30:00	76.220564	54.160177
17:45:00	77.948468	61.101197
18:00:00	79.193645	68.767159
18:15:00	79.593734	76.894725
18:30:00	79.346364	84.911933
18:45:00	78.650535	92.303816
19:00:00	77.705652	98.535854
19:15:00	76.723168	103.021646
19:30:00	75.778284	105.263732
19:45:00	74.933508	104.643204
20:00:00	74.350654	100.770856
20:15:00	73.955298	93.392319
20:30:00	73.610454	83.908519

20:45:00	73.017525	74.006137
21:00:00	71.940555	65.28794
21:15:00	70.057832	59.044058
21:30:00	67.29855	54.861982
21:45:00	63.667626	52.025397
22:00:00	58.96193	50.489981
22:15:00	53.28935	49.046189
22:30:00	50.00462	46.996133
22:45:00	49.295665	44.434257
23:00:00	48.642026	41.493005
23:15:00	47.89034	38.501875
23:30:00	47.140547	36.34031
23:45:00	46.338255	34.358177

Furthermore, as shown in Fig. 26, the voltage levels at all busbars remain within the expected limits. The output information is summarized in the Table below:

Table 18 Voltage levels

Location	Time	Max Loading (%)	Associated Assets
Feeder 2	19:15:00	103.021646	J&P Avax Library Administration Social Facilities Residential Accommodation
Feeder 2	19:30:00	105.263732	J&P Avax Library Administration Social Facilities Residential Accommodation
Feeder 2	19:45:00	104.643204	J&P Avax Library Administration Social Facilities Residential Accommodation
Feeder 2	20:00:00	100.770856	J&P Avax Library Administration Social Facilities Residential Accommodation

The aforementioned information is directly fed to the DR & Flexibility Forecasting component where the flexibility that is required for restoring the normal operation of the line is estimated. In our case it was assumed that the required flexibility estimated by the DR & Flexibility Forecasting component is equal to 0.07 kW per time slot. This information is utilised by the SPEB component in order to prioritize the available assets based on their availability and profitability. In this scenario, the available assets are limited to the ones that are associated to the second feeder, as shown in the figure below.

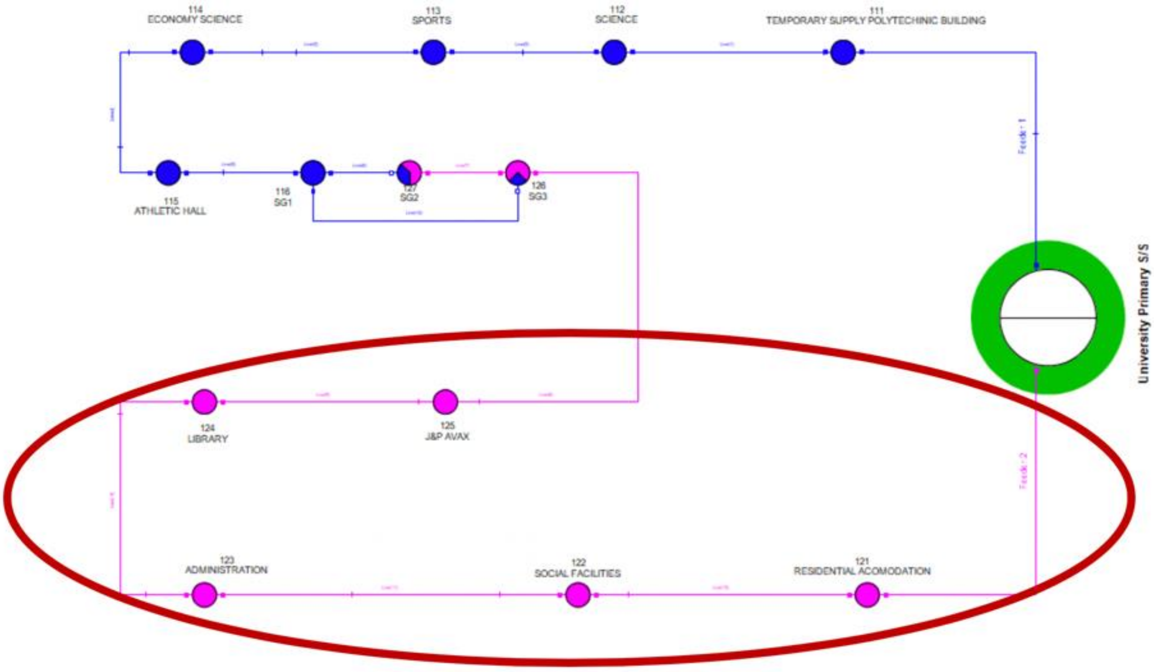

Figure 27. Grid Topology of second feeder.

However, due to the nature of the University, during the DR event (non-working hours) the only available assets that can be considered as a source of flexibility are the Library and Residential Accommodation Buildings. The availability hours of each asset can be identified based on the predetermined preferences of each DR asset as described in the Smart Contracts. In this context and assuming that the Residential Accommodation Building can provide flexibility at a cheaper price, the SPEB component creates a list as follows:

Table 19. Requested flexibility from specific assets.

Priority	Combination of Assets	Flexibility Price €/kW	Flexibility (kW)	Market
1	Residential Accommodation	0.03	0.07	Congestion Management
2	Library	0.032	0.07	Congestion Management

This information is utilized by the AHO component in order to identify if any of the proposed assets or combination of assets are already committed to other DR events or if it's more profitable to participate in other markets. In this scenario, it is assumed that the Residential Accommodation Building is the source of flexibility that will reduce the electricity demand during the DR event. The electricity demand reduction is presented in Table 20, while the restoration of the line loading within the permitted limits is depicted in Table 21 and illustrated in Fig. 28.

Table 20. Electricity demand reduction.

Time	Consumption before DR event	Consumption after DR event
0:00:00	0.43007	0.43007
0:15:00	0.44573	0.44573
0:30:00	0.440365	0.440365

0:45:00	0.4379	0.4379
1:00:00	0.436015	0.436015
1:15:00	0.43123	0.43123
1:30:00	0.42456	0.42456
1:45:00	0.41673	0.41673
2:00:00	0.40774	0.40774
2:15:00	0.39933	0.39933
2:30:00	0.39092	0.39092
2:45:00	0.382365	0.382365
3:00:00	0.374535	0.374535
3:15:00	0.366125	0.366125
3:30:00	0.358295	0.358295
3:45:00	0.351625	0.351625
4:00:00	0.34626	0.34626
4:15:00	0.343215	0.343215
4:30:00	0.342635	0.342635
4:45:00	0.343795	0.343795
5:00:00	0.34626	0.34626
5:15:00	0.351045	0.351045
5:30:00	0.357135	0.357135
5:45:00	0.364965	0.364965
6:00:00	0.374535	0.374535
6:15:00	0.38657	0.38657
6:30:00	0.40658	0.40658
6:45:00	0.43964	0.43964
7:00:00	0.49155	0.49155
7:15:00	0.56637	0.56637
7:30:00	0.659895	0.659895
7:45:00	0.765455	0.765455
8:00:00	0.87696	0.87696
8:15:00	0.98803	0.98803
8:30:00	1.091705	1.091705
8:45:00	1.17972	1.17972
9:00:00	1.24613	1.24613
9:15:00	1.28412	1.28412
9:30:00	1.294415	1.294415
9:45:00	1.279335	1.279335
10:00:00	1.24004	1.24004
10:15:00	1.181605	1.181605
10:30:00	1.11592	1.11592
10:45:00	1.05792	1.05792
11:00:00	1.022395	1.022395
11:15:00	1.01877	1.01877
11:30:00	1.03327	1.03327
11:45:00	1.046465	1.046465
12:00:00	1.039215	1.039215
12:15:00	0.9976	0.9976
12:30:00	0.931915	0.931915
12:45:00	0.856515	0.856515
13:00:00	0.787785	0.787785
13:15:00	0.736455	0.736455
13:30:00	0.700205	0.700205
13:45:00	0.67309	0.67309
14:00:00	0.64786	0.64786
14:15:00	0.6206	0.6206
14:30:00	0.592325	0.592325
14:45:00	0.56695	0.56695
15:00:00	0.547665	0.547665
15:15:00	0.53621	0.53621
15:30:00	0.532005	0.532005
15:45:00	0.530845	0.530845
16:00:00	0.530845	0.530845
16:15:00	0.53012	0.53012

16:30:00	0.533745	0.533745
16:45:00	0.548245	0.548245
17:00:00	0.58087	0.58087
17:15:00	0.636405	0.636405
17:30:00	0.7105	0.7105
17:45:00	0.8004	0.8004
18:00:00	0.89929	0.89929
18:15:00	1.00369	1.00369
18:30:00	1.106205	1.106205
18:45:00	1.20031	1.20031
19:00:00	1.279335	1.279335
19:15:00	1.33603	1.26603
19:30:00	1.364305	1.294305
19:45:00	1.356475	1.286475
20:00:00	1.30761	1.23761
20:15:00	1.21423	1.21423
20:30:00	1.09359	1.09359
20:45:00	0.96686	0.96686
21:00:00	0.85463	0.85463
21:15:00	0.773865	0.773865
21:30:00	0.719635	0.719635
21:45:00	0.682805	0.682805
22:00:00	0.653805	0.653805
22:15:00	0.62553	0.62553
22:30:00	0.59595	0.59595
22:45:00	0.56637	0.56637
23:00:00	0.53621	0.53621
23:15:00	0.50663	0.50663
23:30:00	0.478355	0.478355
23:45:00	0.4524	0.4524

Table 21. Restoration of the line loading within the permitted limits.

Quasi-Dynamic Simulation AC	Feeder 1	Feeder 2
Time	Max. Loading in %	Max. Loading in %
00:00:00	45.590603	32.655099
00:15:00	44.953570	33.849077
00:30:00	44.452756	33.438988
00:45:00	44.052221	33.249966
01:00:00	43.804782	33.105364
01:15:00	43.701982	32.739967
01:30:00	43.751947	32.231174
01:45:00	43.893901	31.634234
02:00:00	44.090057	30.949072
02:15:00	44.333457	30.308289
02:30:00	44.485723	29.667837
02:45:00	44.431387	29.017011
03:00:00	44.085896	28.422251
03:15:00	43.341654	27.784357
03:30:00	42.398383	34.738517
03:45:00	41.356143	44.809835
04:00:00	40.513815	54.584348
04:15:00	39.916845	62.892093
04:30:00	39.618718	69.451278
04:45:00	39.573428	74.298610
05:00:00	39.574386	77.391917
05:15:00	39.721143	78.807975
05:30:00	40.021351	79.115793
05:45:00	40.620584	78.926912
06:00:00	41.710381	78.891291
06:15:00	43.299503	79.496039

06:30:00	45.143769	80.542046
06:45:00	46.937107	81.705966
07:00:00	48.333378	82.692405
07:15:00	49.139267	83.195236
07:30:00	49.792450	83.174716
07:45:00	53.020794	82.782916
08:00:00	59.275645	82.019008
08:15:00	64.965921	80.949154
08:30:00	69.739971	83.801290
08:45:00	73.533672	90.716485
09:00:00	76.132619	95.954232
09:15:00	77.550393	98.960382
09:30:00	78.054320	99.778515
09:45:00	78.165394	98.588417
10:00:00	78.307492	95.485498
10:15:00	78.817936	90.879541
10:30:00	79.599224	85.717332
10:45:00	80.466388	81.173804
11:00:00	81.277899	78.398849
11:15:00	81.880825	78.117489
11:30:00	82.242461	79.250308
11:45:00	82.286548	80.281908
12:00:00	82.155190	79.714175
12:15:00	81.739857	76.734342
12:30:00	80.964321	76.092447
12:45:00	79.742549	74.316501
13:00:00	77.934185	71.343588
13:15:00	75.399548	67.221160
13:30:00	72.239938	62.484569
13:45:00	68.404009	57.810651
14:00:00	66.608953	53.791460
14:15:00	66.295933	50.976287
14:30:00	66.083950	49.103810
14:45:00	65.973628	47.771390
15:00:00	65.966008	46.616740
15:15:00	66.007341	45.324520
15:30:00	66.105059	43.879844
15:45:00	66.579609	42.413346
16:00:00	67.600963	41.707353
16:15:00	68.585993	41.882517
16:30:00	69.609012	42.426316
16:45:00	70.892970	43.608043
17:00:00	72.414042	45.836317
17:15:00	74.296974	49.330653
17:30:00	76.220564	54.160177
17:45:00	77.948468	61.101197
18:00:00	79.193645	68.767159
18:15:00	79.593734	76.894725
18:30:00	79.346364	84.911933
18:45:00	78.650535	92.303816
19:00:00	77.705652	98.535854
19:15:00	76.723168	97.752971
19:30:00	75.778284	99.872046
19:45:00	74.933508	99.284157
20:00:00	74.350654	95.615861
20:15:00	73.955298	93.405477
20:30:00	73.610454	83.908451
20:45:00	73.017525	74.006137
21:00:00	71.940555	65.287940
21:15:00	70.057832	59.044058
21:30:00	67.298550	54.861982
21:45:00	63.667626	52.025397
22:00:00	58.961930	50.489981

22:15:00	53.289350	49.046189
22:30:00	50.004620	46.996133
22:45:00	49.295665	44.434257
23:00:00	48.642026	41.493005
23:15:00	47.890340	38.501875
23:30:00	47.140547	36.340310
23:45:00	46.338255	34.358177

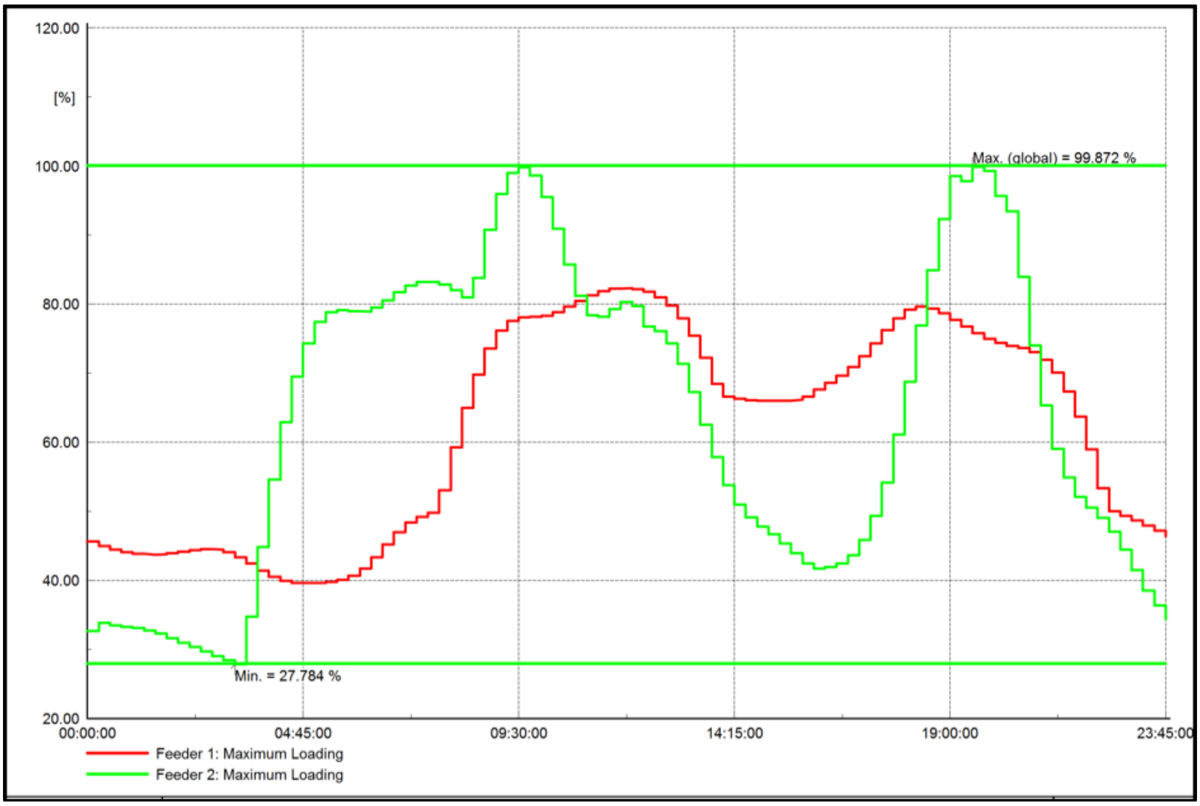

Figure 28. Restoration of the line loading within the permitted limits

10.1.2 Scenario 2:

Consumers sign for the DR contract due to economic benefits they receive from the utility. At the same time, the main business model of the Aggregator is to maximise his profits, thus the most profitable combination of available assets that can contribute in each DR event must be identified. Unlike the previous scenario, here it is assumed a certain amount of flexibility is required however it is not related with any grid constraint violation and therefore it not associated with specific assets.

For this scenario, it is assumed that the required flexibility estimated by the DR and Flexibility Forecasting component for the next settlement period is equal to 0.75 kW and targets assets that are under a Capacity market contract. All the available assets for this scenario are summarized in the table below.

Table 22. Available Assets.

Asset	Assigned Market	Flexibility Price	Average Flexibility
111CA – Polytechnic Building	STOR, VOLTAGE, CAPACITY	0.02, 0.04, 0.03	0.2, 0.15, 0.27
116CA – SG1	STOR,	0.04,	0.4,

	VOLTAGE	0.02	0.28
112CA – Science Department	STOR, VOLTAGE	0.03, 0.02	0.5, 0.3
112CB – Science Department	STOR, CAPACITY	0.031, 0.044	0.5, 0.25
121CA – Residential Accommodation	CAPACITY	0.04	0.5
122CA – Social Facilities	VOLTAGE, CAPACITY	0.035, 0.034	0.35, 0.25
113CA – Sports Facilities	STOR	0.033	0.2
123CA – Administration Building	STOR	0.023	0.3
114CA – Economics Department	VOLTAGE, CAPACITY	0.03, 0.025	0.5, 0.4
124CA – Library	VOLTAGE	0.05	0.25
115CA – Athletic Hall	VOLTAGE	0.047	0.23

The SPEB component will prioritise the available assets by based on the following steps:

1. The selection of asset/combination of assets is limited by the market that each asset is assigned to.
2. The selection asset/combination of assets must meet or slightly excess the requested flexibility.
3. The selection asset/combination of assets is prioritized base on the total cost, which is the product of flexibility price and provided flexibility.

The results shown in the table below demonstrate that the cheapest combination of assets is prioritised as the total cost of the first combination is smaller than the total cost of the second.

Table 23. Most profitable combination.

Priority	Combination of Assets	Flexibility Price €/kW	Flexibility (kW)	Total Cost	Market
1	121CA – Residential Accommodation 122CA – Social Facilities	0.04 0.034	0.5 0.25	0.04*0.5+ 0.034*0.25=0.0285	Capacity Capacity
2	112CB – Science Department 121CA – Residential Accommodation	0.044 0.04	0.25 0.5	0.044*0.25+ 0.04*0.5=0.031	Capacity Capacity

In a similar manner as the Scenario 1, the final selection is made by the AHO Component based on the confirmation that the proposed assets or combination of assets are not already committed to other DR events or if it’s more profitable to participate in other markets.

11. Conclusions

The general objective of this work was to specify and document a common platform that will act as a reference for the development and deployment of components within the DELTA aggregator layer. We have presented the specification and documentation of the aggregator layer, the review of the DELTA specifications for Business Models, Use Cases and the requirements pertaining to the aggregator layer. We have specified the operation of the aggregator layer components, namely: Grid Stability Simulation Engine (GSSE), Self-Portfolio Energy Balancing (SPEB), Asset Handling Optimisation (AHO), Node Flexibility Data Monitoring and Profiling (NFDM&P), and Energy Portfolio Segmentation & Classification (EPS&C).

Architectural and operational requirements were derived from the DELTA specification and documentation that have been used to improve the implementation of user requirements and the relationships between the components. The fundamental components of the domain and the relations between them were defined in a reference architecture in order to identify any missing architectural information and to enable consistent architectural practices. We have presented the product's functionality which is used to identify product features and to enable users to have a set of system capabilities. Consequently, we have defined the provisional specifications for the DELTA platform in order to understand the configuration and guide production of the system. The Final chapter has provided an example case study of how the two DELTA components communicate and how they produce the required outputs.

As activities of WP4 are still ongoing, in parallel with other technical WPs, some of the information provided will change through the implementation course. For example, the OpenADR DELTA Repository CIM will be updated and it will not perform any computation beyond data translation, retrieval and in overall information exchange processes. As such, the interfaces described in the presented work are expected to be updated in future reports. Any updates related to the Aggregator layer will be included in deliverables D4.2, D4.3 and D4.4.

12. References

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