Flexible **H**eat and **P**ower, connecting heat and power networks by harnessing the complexity in distributed thermal flexibility

D1.2 FHP Standard-based multi-agent interoperable framework architecture

Version number: 1.02
Dissemination Level: PU
Lead Partner: Tecnalia
Due date: 31/10/2017
Type of deliverable: Report
STATUS: Final

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731231

Published in the framework of:

FHP[1] Flexible Heat and Power, connecting heat and power networks by harnessing the complexity in distributed thermal flexibility

FHP website: www.fhp-h2020.eu

Authors:

Fernandez Dominguez, M. et al. (TECNALIA)

Dominic Ectors (VITO)

Chris Caerts (VITO)

Jens Brage (NODA)

Ondrej Holub (HON)

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Revision History

Version	Date	Author/Reviewer	Notes
1.0	31.10.2017	Mikel Fernandez, Tecnalia	Final version submitted
1.01	28.02.2018	Mikel Fernandez, Tecnalia	Broken references fixed. Executive summary and conclusions sections added. Incorporated improved Chapter 4 structure.
1.02	24.05.2018	Mikel Fernandez, Tecnalia	Remaining broken references fixed.

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Executive summary

This document constitutes deliverable D1.2 of the FHP EU-funded research project. The earlier project deliverable in this work package 1, D1.1 (FHP, deliverable D1.1, 2017), included the detailed definition of the three business use cases that the FHP system will tackle in the frame of avoiding RES curtailment providing by means of distribuited thermal flexibility, *localRESCurtailmentMitigation*, *systemRESCurtailmentMitigation* and *balancingServices*. This definition includes the definition of the sequence of internal processing functions and information exchanges between roles. D1.1 also included the formulation of the quantitative business models, defined as the monetary exchanges between all roles participating in each of these three business use cases

This document D1.2 goes a step further and develops the design of each collection of software agents that provide the functionalities of each role defined in D1.1. Apart from the functional requirements, the design also includes the non-functional specification. The design splits the functional design in 9 process interactions, which organized in different manners provide the whole functionality required by the 3 business use cases. For each of the interactions, the sequence of processing functions and messages exchanged, included the data objects, are provided. The design is completed with the definition of the communication protocols that will be used in each interface between agents. The whole design has been mapped using the SGAM methodology, and this mapping is reported also in D1.2.

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Glossary

Imbalance Settlement Period (ISP)

Period for which the BRP is settled for imbalances by the TSO due to the difference from the previously submitted energy programme and the actual consumption as measured by meters.

Program Time Step (PTU)

Time step of a certain duration, as defined in the process of energy sale at the spot markets.

Baseline Consumption forecast

Expected consumption profile in the current conditions of a vDER or a group of vDERs for a collection of PTUs. It is also called generically consumption profile.

Flex Activation plan

Planned Flex Activation of a group of vDERs, which is proposed by the planner to the tracker.

Consumption plan

Planned consumption profile of a vDER or a group of vDERs in case that the incentive offered by the tracker would be activated.

Agent

Independent software entity that holds part (or the whole) functionality of a role.

Platform

Collection of agents that all together holds the complete functionality of a role.

Function

Processing function of an agent.

Cluster

Collection of vDERs managed by a DCM.

Group

Logical group of vDERs within a cluster, which corresponds to either a grid zone or a balancing group.

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Abbreviation	Full name
BRP	Balancing Responsible Party
BSP	Balancing Service Provider
CHP	Combined Heat and Power device
CRO	Common Reference Operator
DA	Day-Ahead
DAM	Day-Ahead Market
DCM	Dynamic Coalition Manager (extension/specialisation of Aggregator)
DER	Distributed Energy Resource
DSO	Distribution System Operator
EAN	European Article Number
EV	Electrical Vehicle
ID	Intra-Day
ISP	Imbalance Settlement Period
IT	Information Technology
MS	Member-State
PCC	Point of Common Coupling
PTU	Programme Time Unit
RES	Renewable Energy Source
ToU	Time-of-Use
TSO	Transmission System Operator
UML	Unified Modelling Language
USEF	Universal Smart Energy Framework (www.usef.energy)

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1 Introduction

1.1 About FHP

The FHP project[2] – *Flexible Heat and Power: connecting Heat and Power networks by harnessing the complexity in distributed thermal flexibility* – was submitted under the call *LCE-01-2016-2017: Next generation innovative technologies enabling smart grids, storage and energy system integration with increasing share of renewables: distribution network*, more specifically under the *Synergies between Energy Networks* area.

The FHP concept is to use **distributed thermal flexibility**, such as provided by heat pumps in buildings, or large thermal storage solutions, such as the one provided by the Ecovat system, to make most effective use of available renewable energy, and to create the conditions to increase the amount of such renewable energy sources also at distribution system level.

We specifically focus on **RES curtailment mitigation**, i.e. minimizing curtailments of temporary excess RES generation that would result in either **market based** (economic reasons) or **grid related** (technical reasons) curtailment. For this, distribution grid connected thermal flexibility will be used, making optimal use of – but not surpassing – the distribution grid capacity. This requires that we:

- **Learn the flexibility**: adopt grey-box building modelling approaches to achieve a high level of replicability without or with minimal human expert intervention.
- **Manage the flexibility:** aggregate distribution grid connected thermal flexibility into **Dynamic Coalitions**[3] of flexibility, and interact with grid/system operators for either providing them a **local grid service** (e.g. preventing or solving congestion or voltage problems), or for providing a **system service** (e.g. balancing) making optimal (maximal but secure) use of distribution grid capacity.
- **Interface the flexibility:** developing a **multi-agent framework** connecting all stakeholders and systems, needed for the targeted services / use cases, and aligned with the ongoing work in the Smart Grid Task Force and its Experts Groups in the field of **standardization** in general and flexibility management specifically

1.2 About this document (structure/objective)

This document shows the architecture of the system, the subsystems involved, potential agents of each platform, the functions of the agents, interfaces, interactions and protocols between the agents/platforms. It should be regarded as a first high-level design architecture and if during design/implementation phase new insights are obtained, a newer version of the document can be released.

This document lays the foundation for the platform and agent development activities in the RTD work packages. It documents the results of T1.2 project task, Standard-based multi-agent functional architecture definition.

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[2] See http://www.fhp-h2020.eu/ and http://cordis.europa.eu/programme/rcn/700614_en.html

[3] Participation of the P2H resources is voluntary, and they have the freedom to decide when, how much, and for what incentive they offer flexibility. So, there is a dynamic pool of flexibility providing resources that each have a dynamic flex offering.

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- Chapter 2 contains the description of the proposed requirements management methodology and templates to support their documentation and traceability.
- Chapter 3 holds the conceptual, implementation agnostic, view of the functional architecture, and defines the platforms and agents with their respective functionalities.
- Chapter 4 details the interaction schemes and information exchanges among the agents.
- Chapter 5 contains the chosen implementation view, with the high level SW architecture leveraging the benefits of a webservices, based approach, and an overview of the proposed information exchange protocols and standards.
- Chapter 6 documents a mapping of the proposed multi-agent platform architecture using the SGAM methodology

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2 Requirements Management Methodology

This chapter provides a brief overview of the methodology that is used throughout the document for requirements documentation and management. It includes templates and conventions that are helpful for the reader to follow the remainder of the document.

2.1 Requirement taxonomy

Requirements that are most relevant to the design, development and commissioning of ICT systems, like the FHP multi-agent platform, can be largely classified into the four types illustrated in ***Table 1***.

Requirement type	Description	Example
Business requirements	They typically describe opportunities that an organization wants to pursue or problems it wants to solve.	The system should have the necessary features to solve a particular problem.
User/stakeholder requirements	They document the user expectations from the system	The system should provide a user friendly interface.
Functional requirements	They describe the capabilities, behaviour or functionality of the system, typically in a technical fashion.	A clock should display the local time.
Non-functional requirements	They usually describe the conditions under which the system must remain operational or essential attributes of the system that do not refer to its functionality.	The system should respond to a user input within 1 second.

Table 1: High-level requirement classification

Business, user and functional requirements are typically self-contained types which are not further sub-divided. Non-functional requirements, however, are a very broad and heterogeneous type. An extensive enumeration of all possible sub-types of non-functional requirements goes beyond the scope of this document. The list below illustrates the main sub-types of non-functional requirements that are likely to be relevant for the design, development, pilot testing and eventual commissioning of the FHP system:

- **Performance:** this is a critical requirement for systems with strict constraints on response time or throughput. Generating performance requirements per platform may require careful budgeting of the available time among platforms.
- **Look and feel:** this requirement type usually refers to the interaction between humans and (ICT) systems and describes the aesthetic aspects of the user interface/interaction with the system.
- **Usability:** refers to how easy it is to use and learn to operate a system.
- **Accessibility:** this may refer both to how accessible the particular system is to individuals with disabilities as well as to physical accessibility of the system for purposes of maintenance or replacement.
- **Scalability:** this requirement type generally refers to the capacity of the developed system to scale in order to satisfy the needs of more nodes or users or data, etc.

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- **Availability:** it refers to the percentage of time the system is operational or provides the intended services, e.g. 90% availability means that on average the system should be operational 9 out of 10 time units.
- **Reliability:** this requirement type refers to the ability of a system to perform its required functions under stated conditions for a specified period of time.
- **Interoperability:** refers to the ability of a system to work together (inter-operate) with other systems.
- **Extensibility:** refers to a system design principle where the implementation takes future growth into consideration.
- **Security**: security is a very broad concept that includes the protection of information from a number of hazards, such as unauthorized access, loss, modification, destruction, recording, disclosure, etc.
- **Privacy:** this requirement refers to the right of information owners to know and control what information about them is collected, stored and processed by third parties.
- **Portability:** such requirements typically refer to the ability of an IT system to be ported to computing infrastructure with heterogeneous characteristics, including different operating systems, database management systems, processing and storage capacity, etc.
- **Regulatory:** this requirement type aims to explicitly document actions that should be undertaken in order for the developed system to comply with applicable law and regulations. It is especially important because it is easy to neglect. Such requirements often arise when dealing with personal or sensitive information or involving humans in test pilots or trials.
- **Simulation:** such requirements define the simulation details (e.g. time steps, detail of information flow) that are acceptable to reach the simulation goals (e.g. testing, verification of result correctness)
- **Deployment:** this type of requirements describes the compatible hardware and software infrastructure where the system can be deployed

The list above is quite extensive in order for the classification to be as complete as possible for the given context of the FHP project which aims to develop an ICT system. It is not necessary that all agents will have non-functional requirements of all aforementioned types; actually this is rather unlikely. Enumerating all these types of non-functional requirements serves to aid the requirement proposers to think about potential requirements that may be important, but would be neglected otherwise.

Business and user requirements, albeit very important for defining the scope of the system under development, do not fall within the scope of this document. Deliverable D1.1 (FHP, deliverable D1.1, 2017)has elaborated on the requirement that each relevant role in RES curtailment mitigation business use case would impose. The user and business requirements are implicitly documented in section 3 of that document. Based on those, the business use cases that the FHP consortium deems more important to guide the eventual design and development of the ICT system were specified in section 5 of that document.

Furthermore, deliverable D1.1 has documented the functional requirements at the level of each role, in the description of the business use cases. Those requirements are found in the step by step analysis of the business use cases, and are subdivided in two categories:

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- Internal processing, which are elaboratedin section 3.2.1of this document D1.2.
- Communication requirements, which are elaborated in section 0 of this document D1.2.

2.2 Requirement characteristics

Good requirements should possess a number of characteristics. Requirements are the sole documentation of the expectation of users and system champions from the system to be developed. Once the technical staff initiates the system design and development process based on the requirements handed to them, any change in requirements becomes a very costly process because it will require re-design or re-engineering of parts of the system. It is thus extremely important that requirements satisfy a number of attributes before they are handed over to the staff responsible for system design and development.

The most important requirement attributes are highlighted below:

- **Unitarity**: Each requirement should address a single topic.
- **Completeness**: Each requirement should be fully explained in a single self-contained description.
- **Consistency**: Requirements should not contradict each other or the documentation from which they originated (business and use cases).
- **Atomicity**: Requirements should not contain conjunctions; otherwise they should be divided into multiple requirements.
- **Traceability**: Each requirement should address a specific need as explained in the business or use case and should traceable to the exact case.
- **Validity**: All requirements should remain valid and should not have been made obsolete due to the passage of time or other relevant developments.
- **Unambiguousness**: Each requirement should be described in a manner that is subject to a single interpretation. Technical jargon, vague and subjective wording as well as negative and compound statements should be avoided. Requirements should express objective facts.
- **Importance**: Each requirement should be annotated with its importance. Some requirements may be critical, because their lack may result in major or catastrophic deficiencies. Other requirements may be optional and will be implemented if time permits.
- **Verifiability**: The implementation of each requirement should be objectively verifiable using a stated method (e.g. inspection, demonstration, testing).

2.3 Requirement documentation template

In order to document the FHP component-level requirements we need to choose a documentation template. We have opted for the template proposed by the Volere (Volere requirements specification template, n.d.) methodology, since it:

- addresses all characteristics of good requirements that are not dependent on the requirement description,
- is elaborate and enables tracing and tracking of requirements and their relations with other requirements and use cases, and
- provides a complete description and context for each requirement in a single table.

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The selected requirement documentation template is illustrated in *Table 2*:

ID	Requirement identification code, for reference/traceability purposes
Component	Indicate the component that the requirement refers to
Source role req	Identify the role requirement that led to the generation of this requirement
Description	Short name/description of requirement
Type	Type according to the proposed taxonomy: functional/non-functional/other?
Author	Who proposed the requirement
Date	Date of proposal
Rationale	Why is this requirement important for the component implementation/operation
Use case	Which use case raised the need for this requirement
Fit & acceptance criteria	How we can measure and verify that this requirement has been satisfied in the final implementation
Priority	Is this a critical, must-have, nice-to-have or a requirement for a future update of the system implementation
Dependencies/Conflicts	Describe dependencies or conflicts with other requirements
Comments	Any other comments the proposer wants to add

Table 2: Requirements documentation template inspired from the Volere methodology

The four characteristics of good requirements that should be addressed in the documentation template are: consistency, traceability, importance and verifiability. The proposed template foresees separate fields for each of these attributes.

- **Consistency** is ensured through the use of the “Dependencies/Conflicts” field. Potential conflicts should be documented during requirement documentation and resolved at the earliest possible occasion to avoid percolation of conflicting requirements to the design and development phases where the consequences would be much higher.
- **Traceability** is implemented through the “Use case” field and the “Source Stakeholder Requirement” which documents which use case & stakeholder requirement gave rise to the particular component requirement.
- **Importance** is implemented through the “Priority” field which describes the implementation priority of the requirement. Obviously, critical requirements will have the highest priority for implementation, while optional requirements will have the lowest.
- **Verifiability** is implemented through the “Fit & acceptance criteria” field which describes exactly how one can verify that the stated requirement has been satisfied in the system implementation.

The remaining characteristics of good requirements are dependent on the way the requirements are documented rather than the template itself. Hence achieving them is the responsibility of the requirement author(s).

Apart from the aforementioned fields, this template includes a number of other important fields that serve the purpose of documenting the FHP component requirements. The Component and Type fields are necessary in order to ensure the completeness of the requirement by explicitly stating which component the requirement refers to and the type of requirement (e.g. functional or non-functional, if non-functional describe sub-type). It also includes fields like Rationale and Comments where the

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requirement proposer can explain why this requirement is necessary and provide any additional information he deems useful so that the reader can fully understand and appreciate the need and details of the specific requirement.

The ID tag of the requirements documentation template should have a structure that embeds information about the type of requirement and the component it refers to. This direct association will aid in traceability of requirements during implementation to ensure that no important requirement is neglected.

The structure of the ID tag will be: **XX.YYY.ZZZ**. **XX** refers to the type of requirement. For functional requirements XX will be equal to FR. For non-functional requirements, the value of XX should be selected from the following list.

- NF-Pe: Performance
- NF-LF: Look and feel
- NF-U: Usability
- NF-Ac: Accessibility
- NF-Sc: Scalability
- NF-Av: Availability
- NF-Rel: Reliability
- NF-I: Interoperability
- NF-E: Extensibility
- NF-Sec: Security
- NF-Pr: Privacy
- NF-Po: Portability
- NF-Reg: Regulatory
- NF-Si: Simulation
- NF-D: Deployment

The **YYY** field will depict the FHP component as they are explained in the system architecture of chapter 3) that the requirement refers to. It will take one of the following values:

- DSO platform
- BRP platform
- DCM platform
- DER platform

Finally, **ZZZ** will be an incremental number that differentiates between requirements of the same type for the same component.

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3 Functional architecture – Conceptual view

3.1 FHP Platforms and agents

Figure 1 lists the platforms and agents in the Functional architecture.

The BRP platform is owned by the BRP. It contains the Balancer agent that provides the business logic responsible for initiating the System RES curtailment mitigation actions.

The DSO platform is owned by the DSO. It contains the Safer agent that provides the business logic responsible for initiating the Local RES curtailment mitigation actions, and for ensuring that proposed flex activation (e.g. for the system RES curtailment mitigation) do not violate the local grid constraints. It also contains the functionality to forecast the consumption of the non-controllable buildings (i.e. buildings that are not contracted by a DCM).

The DER platform is owned by the flexibility providing DERs, and contains the:

- DER agent which is the agent interacting with and controlling the DER assets. This may include consumption profile and flex forecasting functionality. Each DER agent is associated with a unique and permanent electrical connection point to the distribution grid, and represents a building or ecovat.
- vDER agent which is a proxy for the DER agent running in the same cloud server as the DCM platform for efficiency reasons. This may include consumption profile and flex forecasting functionality. Each (v)DER agent is associated with a DER agent.

The DCM platform is owned by the DCM (typically a Technical or Market aggregator). It contains the:

- Usefer agent, that provides a USEF standard compliant interface between the Planner agent on the one hand, and the Balancer and Safer agents on the other hand.
- Planner agent, that is responsible for forwarding the per gridzone or balancing group aggregated total baseline consumption and flexibility forecast to the Safer or Balancer (via the Usefer). Optionally a DCM level optimisation for a local objective could be done (e.g. per group or over the groups to do a cluster level selfconsumption optimisation). Furthermore, the Planner agent is responsible for calculating an optimal and feasible flex activation plan that accommodates the flex request issued by the Safer or Balancer.
- Tracker agent, that disaggregates the by the Planner calculated flex activation plan per group over the (v)DERs belonging to that group. Furthermore, the Tracker monitors the actial consumption profile of all (v)DERs, and (tries to) take corrective actions in case (too large) deviations occur, compared to the agreed activation plan.
- Forecaster agent, that aggregates individual DER forecasts per grid zone and balancing group. These individual forecasts may be provided by the (v)DER, or they may be created by the Forecaster itself based on historic consumption profile and relevant contextual forecasts like market price forecasts, weather forecasts, …. Furthermore, the Forecaster may learn about the reliability of forecasts that are provided by the (v)DER, and use this information to create better aggregated forecasts.

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The top of the figure shows the link with the business actors described in D1.1. The functionality of each agent is explained in detail in the next section. ***Table 16*** and ***Table 17*** link these agent functions to the in-focus funtions described in D1.1 and the interactions described in section 4.

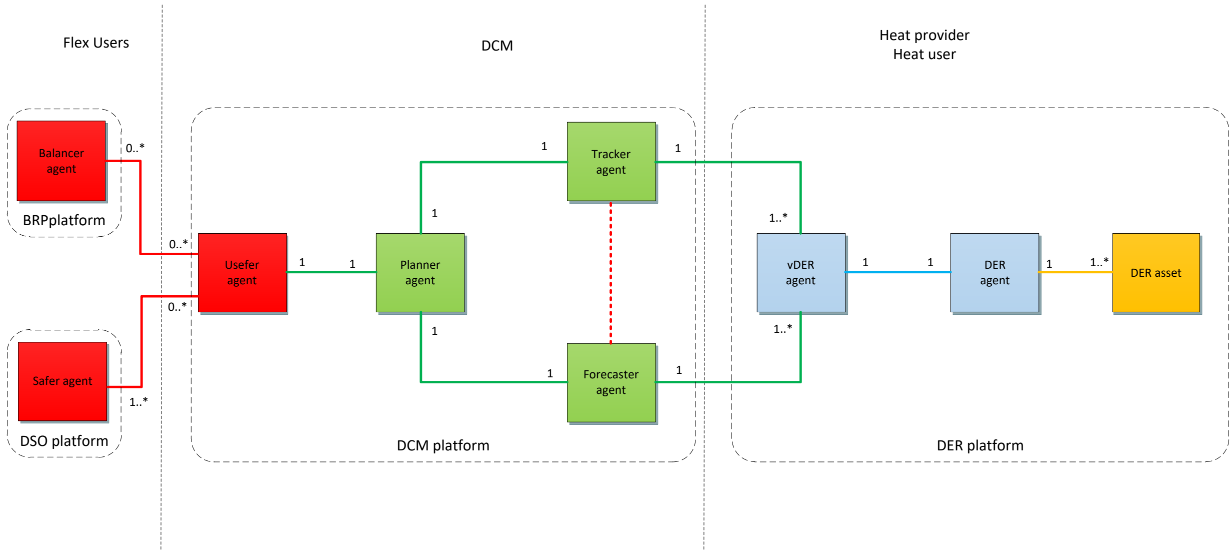

Figure 1: Functional architecture – conceptual view

In a given DSO area, multiple DERs are present, each being a unique and permanent electrical connection point to the distribution grid, and representing a building or ecovat. Also multiple DCMs may be present, each managing a dynamic cluster of DERs (e.g. buildings with controllable P2H flexibility and/or ecovats). The DER-to-DCM mapping is a dynamic mapping – hence the name Dynamic Coalition Manager - as DERs may freely switch between DCMs. The only constraint to this is a physical one – the actual assets controlled by a DER can belong to just one DCM at any moment in time.

DSO defines groups of DERs (connection points) that than be aggregated and treated as a single connection point. Such groups are referred to as grid zones. Similarly, a balancing group is a portfolio of DERs that all belong to the same BRP.

Figure 1 shows how the DERs belonging to a DCM coalition can belong to different grid zones and balancing groups. The orange squares in the figure are all DERs that are present in the distribution grid area. The blue oval shows the DERs managed by the DCM, the red dotted oval the balancing group of BRP 1 and BRP 2, and the blue dashed ovals show 2 DSO grid zones.

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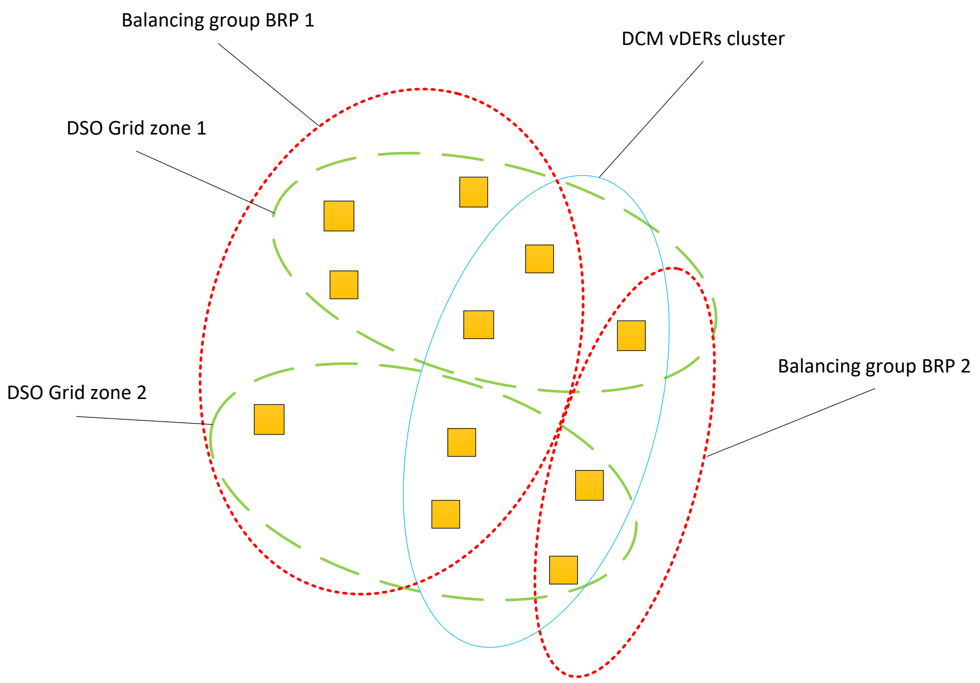

Figure 2: grouping of vDERs in grid zones and balancing groups

The DSO grid zones overlap with the DER cluster resulting into two DER grid zones that are relevant for the interaction with the DSO (green areas in *Figure 3*).

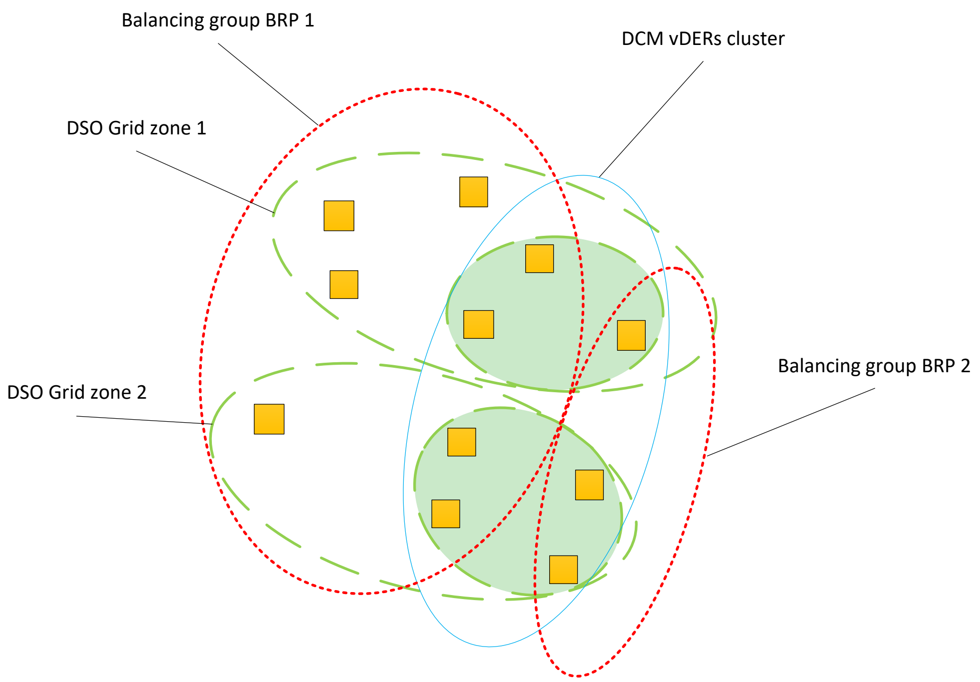

Figure 3: grouping of vDERs related to grid zones

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The BRP balancing group overlaps with the DCM DER cluster resulting in two DER balancing roups relevant for the interaction with the BRPs (red areas in *Figure 4*).

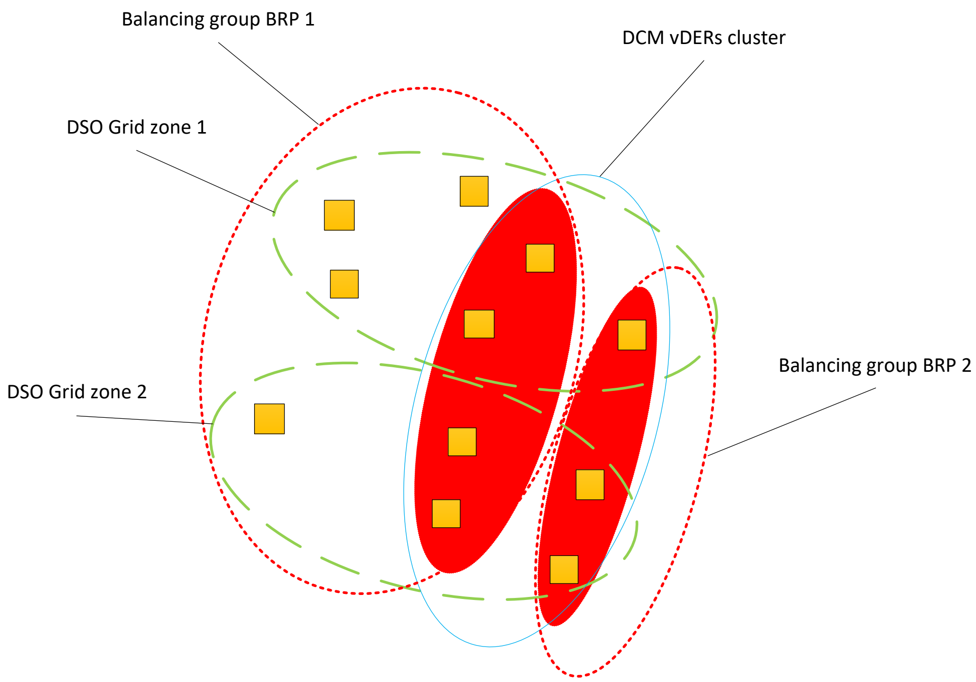

Figure 4: grouping of vDERs related to balancing groups

As shown by the cardinality numbers for each agent relation in *Figure 1* a DCM, consisting of Planner, Tracker, Forecaster, and Usefer, will have a relation with a least one DSO and zero or more BRPs. The DCM relates to multiple DERs (the cluster), and each DER has a relation with one vDER an DER agent. Each DER agent manages one or more DER flexible assets.

3.2 Functional requirements per platform

As expressed in the previous section, functional requirements for each role, in the scope of each defined business use case, were provided in D1.1. In the following two subsections these requirements are summarised.

The functional requirements per role served as the basis for the definition of the functions assigned for each agent and for the exchanged between agents:

- The functions described for each agent in section 3.3 correspond to those internal processing requirements described in section 3.2.1
- The messages exchanged between agents defined in section 4 represent the assignment of communication requirements per role summarized in section 0

3.2.1 Internal processing requirements

These requirements define the functionalities that are required to realize the defined business use cases of D1.1. . As a summary, the collection of requirements for localRESCurtailmentMitigation,

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systemRESCurtailmentMitigation and balacingServices business use cases are provided in ***Table 3***, ***Table 4*** and ***Table 5***.

Name of process/ activity	Platform	Description of process/ activity
DetermineGridZones	DSO	Decide which connection points can be clustered
UpdateHeatProviderContext	DER	Update (and retrieve) additional information (e.g. weather forecast, price forecast, …) that is needed for local consumption profile calculation(s)
CalculateP2HConsumptionProfiles	DER or DCM	Calculate admissible P2H consumption profiles
DetermineHeatProviderConsumptionProfile	DER or DCM	Select most optimal profile from all calculated ones.
DetermineDCMConsumptionProfile	DCM	Create aggregated baseline plan per Grid Zone
UpdateLocalGridContext	DSO	Update (and retrieve) additional information that is needed for doing the local grid check
PerformGridSafetyAnalysis	DSO	Perform a Load Flow Check
CalculateLocalFlexRequest	DSO	Determine what local flex request to send to which DCM.
CalculateHeatProviderIncentives	DCM	Determine what incentive to send to which Heat Provider
DetermineHeatProviderResponse	DER	Calculate optimal P2H consumption profile for the received incentive / price profile
CheckHeatProvider Responses	DCM	Aggregate all received P2H consumption profiles and check whether good enough (exit LOOP_2) or do another iteration
CheckLocalFlexOffer	DSO	Check the combination of all received DCM Local Flex Offers and decide whether good enough (exit LOOP_1) or do another iteration. (the LOOP_1 will also be exited if no appropriate solution can be found: in this case, the whole process stops and the DSO will partially curtail)
DetermineHeatProviderConsumptionPlan	DCM	Disaggregate the received flex order into a consumption plan per Heat Provider
DetermineHeatUserSettings	DER	If multiple Heat Users: disaggregate the Heat Provider consumption plan into a consumption plan per Heat User. Determine the corresponding P2H setpoints for the Heat User
DetermineBRPUpdate	DCM	Determine the flex activation plan corresponding to the received flex order per balancing group (BRP)
UpdateBRPPortfolio	BRP	Adjust the BRP consumption forecast with the received flex activation schedule information (improve the accuracy of the bids that will be made to markets)

Table 3: Functional requirements of localRESCurtailmentMitigation business use case

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Name of process/ activity	Platform	Description of process/ activity
DetermineGridZones	DSO	Decide which connection points can be clustered
UpdateHeatProviderContext	DER	Update (and retrieve) additional information (e.g. weather forecast, price forecast, …) that is needed for local consumption profile calculation(s)
CalculateP2HConsumptionProfiles	DER or DCM	Calculate admissible P2H profiles
DetermineHeatProviderConsumptionProfile	DER or DCM	Select most optimal profile from all calculated ones.
DetermineHeatProviderFlexibilityInformation	DER or DCM	Determine available flexibility (in relation to the optimal baseline consumption profile)
DetermineDCMConsumptionProfile	DCM	Create aggregated baseline plan per Grid Zone
DetermineDCMConstrainedFlexibilityInformation	DCM	Determine the cluster flexibility information based on the received flex information from all Heat Providers (using knowledge of balancing groups)
DetermineDCMFlexibilityInformation	DCM	Determine the cluster flexibility information based on the received flex information from all Heat Providers (using knowledge of balancing groups)
DetermineSystemFlexOffer	DCM	Calculate Flex Offer(s) (flex products) based on the determined flex model per balancing group
CalculateSystemFlexRequest	BRP	BRP calculates if, how much and when flex would be needed (to mitigate system RES curtailment)
UpdateDCMConsumptionProfile	DCM	Calculate proposed updated DCM local consumption profile (optimal baseline profile off-set with SystemFlexRequest = BRP proposed flex order)
UpdateLocalGridContext	DSO	Update (and retrieve) additional information that is needed for doing the local grid check
PerformGridSafetyAnalysis	DSO	Perform a Load Flow Check
CalculateLocalFlexRequest	DSO	Determine what local flex request to send to the DCM
CalculateHeatProviderIncentives	DCM	Determine what incentive to send to which Heat Provider
DetermineHeatProviderResponse	DER	Calculate optimal P2H consumption profile for the received incentive / price profile
CheckHeatProviderResponses	DCM	Aggregate all received P2H consumption profiles and check whether good enough (exit LOOP_2) or do another iteration
CheckLocalFlexOffer	DSO	Check the received local flex offer and decide whether good enough (exit LOOP_1) or do another iteration.
AdjustSystemFlexOffer	DCM	Recalculate/reshape the System Flex Offer so that it fits the local flex order.
CalculateSystemFlexRequest	BRP	BRP calculates if, how much and when flex would be needed (to mitigate system RES curtailment)
DetermineHeatProviderConsumptionPlan	DCM	Disaggregate the received system flex order into a plan per Heat Provider

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DetermineHeatUserSettings	DER	If multiple Heat Users: disaggregate the Heat Provider consumption plan into a consumption plan per Heat User. Determine the corresponding P2H setpoints for the Heat User.
UpdateBRPPortfolio	BRP	Update the BRP consumption forecast with the flex activation schedule information corresponding to the agreed system flex order (improve the accuracy of the bids that will be made to market)

Table 4: Functional requirements of systemRESCurtailmentMitigation business use case

Name of process/ activity	Platform	Description of process/ activity
DetermineGridZones	DSO	Decide which connection points can be clustered
UpdateHeatProviderContext	DER	Update (and retrieve) additional information (e.g. weather forecast, price forecast, …) that is needed for local consumption profile calculation(s)
CalculateP2HConsumption Profiles	DER or DCM	Calculate admissible P2H profiles
DetermineHeatProvider ConsumptionProfile	DER or DCM	Select most optimal profile from all calculated ones. (retrieve current one or determine new one, but within the latest agreed flex band constraints !)
Determine Heat Provider Flexibility Information	DER or DCM	Determine flexibility with respect to the optimal baseline consumption profile
Determine DCM Consumption Profile	DCM	Determine the DCM optimal consumption profile within the latest agreed flex band.
Determine DCM Constrained Flex Information	DCM	Determine flexibility with respect to the optimal baseline consumption profile
Determine System Flex Offer	DCM	Calculate Flex Offer(s) for possibly multiple BRPs (using knowledge of balancing groups)
Calculate System Flex Request	BRP	BRP calculates if, how much flex activation would be needed in the current ISP to mitigate system RES curtailment
Determine Heat Provider Consumption Plan	DCM	Disaggregate the received system OP flex order into a plan per Heat Provider
Determine Heat User Settings	DER	If multiple Heat Users: disaggregate the Heat Provider consumption plan into a consumption plan per Heat User. Determine the corresponding P2H setpoints for the Heat User.

Table 5: Functional requirements of balancingServices business use case

3.2.2 Communication requirements

These requirements define the information that has to be exchanged between the roles defined in D1.1. The list of requirements, and the which agent either produces or receives the information, is showed in ***Table 6***.

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localRESCurtailmentMitigation	systemRESCurtailmentMitigation	balancingServices	Name of process/ activity	Information producer (agent)	Information receiver (agent)	Information exchanged (IDs)	Description of process/ activity
X	X	X	Send GridZones	Safer	Usefer	IEX_01	Send list of grid zones with associated connection points to each DCM
X	X	X	Send Heat Provider Update Request	Forecaster	(v)DER	IEX_02	Request Heat Providers to provide the latest information
X	X	X	Get Heat User Settings	DER	DER	IEX_03	Retrieve actual comfort, temperature and willingness to offer flex information
X	X	X	Send Heat Provider Consumption Profile	(v)DER	Forecaster	IEX_04	Send optimal baseline profile
X	X		Send DCM Consumption Profile	Usefer	Safer	IEX_05	Send aggregated baseline plan per Grid Zone
	X	X	Send Heat Provider Flexibility Information	(v)DER	Forecaster	IEX_06	Send flexibility information
X	X		Send Local Flex Request	Safer	Usefer/Planner	IEX_07	Send a local flex request to each DCM
X	X		Send Heat Provider Incentive	Forecaster	(v)DER	IEX_08	Send a shadow price profile.

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X	X		Send Heat Provider Consumption Profile	(v)DER	Forecaster	IEX_09	Send the optimal P2H consumption profile for the received incentive / price profile
X	X		Send Local Flex Offer	Usefer/Planner	Safer	IEX_10	Send the DCM local flex offer in response to the received local flex request. (this can as well be a 'no offer' message if LOOP_2 was exited without an appropriate local flex offer has been found)
X	X		Send Local Flex Order	Safer	Usefer/Planner	IEX_11	Confirm accepted local flex offer by sending a local flex order. In this case, this order is still a proposed order because the DCM has the right to bail out because of Freedom to dispatch; so, in this case (in contrast to localRESCurtailmentMitigation) an explicit confirmation is needed by the DCM to the DSO
X	X	X	Send Heat Provider Consumption Plan	Forecaster	(v)DER	IEX_12	Update the Heat Provider consumption plans (this can be through a corresponding incentive signal for instance)
X	X	X	Send Heat Users Settings	DER	DER	IEX_13	Update Heat User's P2H setpoints (e.g. control plan for the heat pump)
X			Send BRP Update	Usefer/Planner	Balancer	IEX_14	Inform the BRP about the planned/scheduled flex activations that relate to his balancing group.
X	X	X	Send System Flex Offer	Usefere/Planner	Safer	IEX_15	Send updated System flex offers to BRP. This means that the BRP receives a new System Flex Offer – this time within the DSO cleared safe flex band – so that any matching System Flex Request can be honoured without causing local grid problems
	X		Send System Flex Request	Safer	Usefer/Planner	IEX_16	Send System Flex Requests(s)
	X		Send Local Flex Order Accept	Usefer/Planner	Safer	IEX_17	Confirm to DSO the acceptance of the local flex order
	X		Send Local Flex Order Decline	Usefer/Planner	Safer	IEX_18	Inform DSO that no local flex service will be provided

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	X		Send System Flex Request Accept	Usefer/Planner	Balancer	IEX_19	Inform BRP that the system flex request is accepted (so no more flex request needed)
	X	X	Receive System Flex Order	Safer	Usefer/Planner	IEX_20	BRP confirms the system flex request with a system flex order (can be No Order is no acceptable solution was found)
		X	Get Flex Capacity Range	Usefer/Planner	Safer	IEX_21	Ask and receive the flex capacity range that will constrain the balancing flex offers that can be made
		X	Send Imbalance Price Forecast	TSO	Balancer	IEX_22	Imbalance price that is expected for the inmediate ISP

Table 6: Communication requirements

3.3 Agents

3.3.1 Safer

The Safer agent in the DSO platform provides the business logic for the DSO to perform the functions mentioned in *Table 7*.

SA01	Define grid zones (list of connection points that can be grouped together) for the next timestep (based on historic profiles and other relevant forecast information) and send to the Usefer.
SA02	Collect or calculate additional information needed to execute function SA05. The required information for function SA05 consists of: • forecasts for/from generators specifically RES generators; • forecasts for non-active (i.e. not contracted by DCM) buildings; • grid related info 'e.g., tap changer settings, …
SA03	Collect baseline consumption profile (D-Prognosis) from the Usefer for the DCM contracted DERs.
SA04	Collect flex range information from the DCM Planner via the Usefer
SA05	Determine/calculate based upon the information gathered in functions SA02 and SA03 whether local grid problems, that would require local RES curtailment, are expected.
SA06	If the outcome of function SA05 indicates that local RES curtailment would be required, calculate a Local Flex Request per grid zone per DCM in relation to a (forecasted) local problem signalled by function SA05, taking into account the flex range information collected in SA04. And send this local flex request to Usefer.
SA07	Flex offer(s) (re)action: • Collect flex offers (could be collecting several offers before taking a decision)

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	• Determine to make use of the offer(s) or not (selecting the best (most economical) offer or combination of offers). • If decided to make use of an offer, send flex order to the Usefer.
SA08	Provide the flex request to the Usefer. The flex request specifies what flex activation is needed to mitigate the RES curtailment, and also provides constraints to the admissable flex offers.

Table 7: Safer agent functions

3.3.2 Balancer

The Balancer agent in the BRP platform provides the algorithms to act on the BRPs' imbalance position and to calculate the flexibility needed for RES curtailment mitigation at system level. It is assumed that the Balancer has forecasted information on the consumption and generation for its portfolio and/or for the system.

Function	Description
BA01	Define Balancing Group and send to Usefer.
BA02	Update its own consumption and generation forecast (DA/ID) based on the updated DCM consumption profile for the balaninc group provided by the Planner via the Usefer. These plans include the already committed flex activations. Offer up to date bids to markets.
BA03	Calculate if, how much and when flex (i.e., consumption profile changes) for its balancing group would be needed to mitigate system RES curtailment or to act on its imbalance position. To this end this function: • checks whether economic curtailment of RES would happen because there is a forecasted (DA/ID or intra-ISP) surplus of generation due to high amounts of RES, and for economic reasons the optimal decision would be to curtail RES. • will try to increase consumption by activating DCM flexibility instead. For this it will calculate an optimal System Flex Order based upon received System Flex Offers.
BA04	Decide which flex offers will be converted to flex orders, based on the specificities of the systemDERCurtailmentMitigation and balancingServices use cases.

Table 8: Balancer agent functions

3.3.3 Usefer

The Usefer agent is responsible for bridging the DCM platform (flexibility provision/aggregation) with flexibility needers (the BRPs, specifically, the Balancer agent, and DSOs, specifically yhe Safer agent) in a standard-based manner based on the USEF concepts and proposed information exchanges and flows. These three agents (Userfer, Balancer, Safer) will provide a USEF endpoint based upon the USEF reference implementation. The Usefer will convert the DCM messages towards the Balancer and Safer

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agent into a USEF message, and to converse the USEF messages from the Balancer and Safer agent towards the DCM into DCM messages.

The Universal Smart Energy Framework (USEF)[4] is a business framework for flexibility trading developed by the USEF Foundation (ABB, Alliander, DNV GL, Essent, IBM, Stedin, ICT) and provides non-discriminatory access to smart energy systems. By providing an open and consistent framework of specifications, designs, and implementation guidelines, USEF enables participants to seamlessly co-create a fully functional smart energy system. It specifies the interactions and the information exchanged between theflexibility providers/aggregators, BRPs and DSOs in the energy flexibility market.

In the USEF framework a consistent common reference between all participants is needed. This is accomplished by the Common Reference Operator (CRO). A CRO, the common reference, is defined as a system that holds information to relate congestion points to connections and to maintain an administration that lists the aggregator and DSO for each connection. DSOs consult the common reference to determine which aggregators will be sending D-prognoses. DSOs report congestion points and the connections that are impacted by that congestion point to the common reference. Aggregators consult the common reference to determine which of his connections are impacted by a congestion point. Aggregators report which connections they manage. The Usefer agent will interpolate the CRO to provide balancing group and grid zone info to the Planner agent.

The USEF market-based control mechanism operations scheme (***Figure 5***) as formalised in the USEF specification distinguishes four phases:

- **Plan**: In the planning phase, energy demand and supply are forecasted for the upcoming period, usually a calendar day. Both the BRP and the Aggregator carry out an initial portfolio optimization. During this phase, the BRP can procure flexibility from its Aggregators. The Plan phase results in an Aggregator plan (A-plan) agreed upon by the Aggregator and the BRP. The BRP then creates its energy program (E-program) as usual.
- **Validate**: In the validation phase, the DSO uses a D-prognosis to determine whether the forecasted energy demand and supply can be safely distributed without limitations. If the prognosis predicts congestion, the DSO can procure flexibility from Aggregators to resolve it. It is important to note that there can be multiple iterations between the Plan and Validate phases; that is, after validation, it is possible to go back to the Plan phase. These iterations continue until all the forecasted energy can be safely distributed without limitations.
- **Operate**: In the operation phase, the actual assets and appliances are dispatched and the Aggregator adheres to its D-prognoses and A-plan. When needed, DSOs and BRPs can procure additional flexibility from Aggregators to resolve unexpected congestion or to solve imbalance issues.
- **Settle**: In the settlement phase, any flexibility the Aggregator has sold to the BRPs and DSOs is settled.

[4] https://www.usef.energy/

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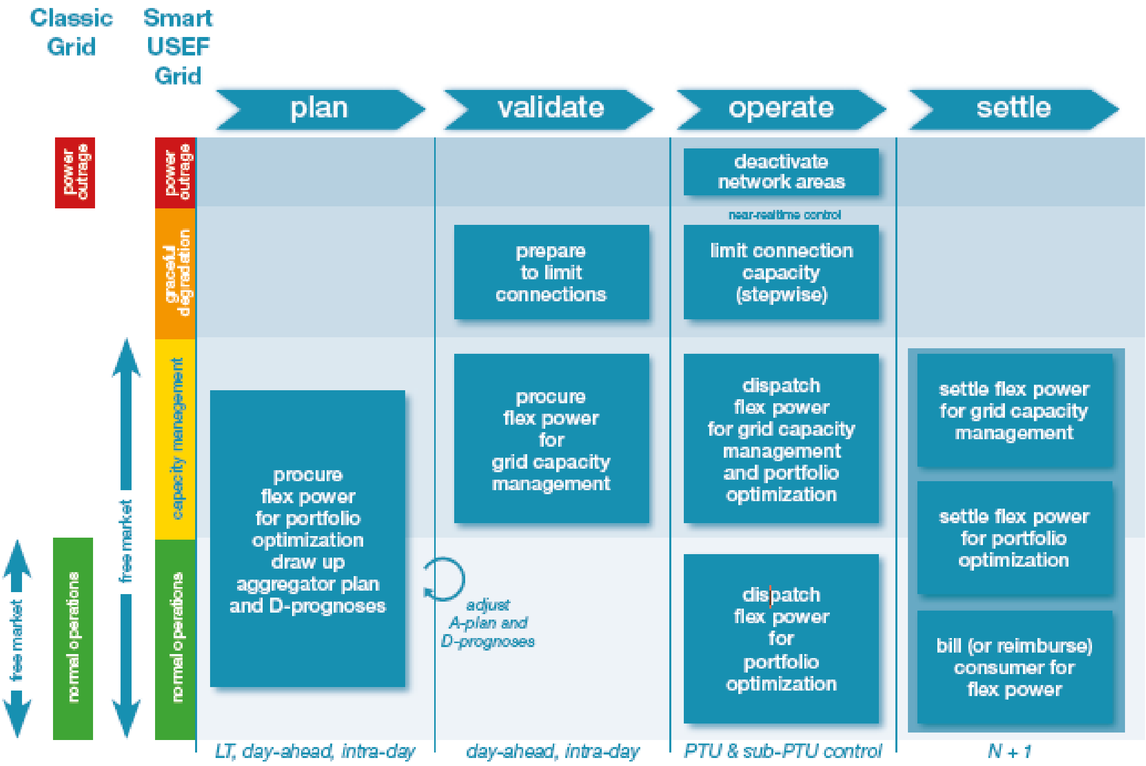

Figure 5: USEF operations scheme

The functions of the Usefer are:

Function	Description
US01	When receiving DCM cluster information, update/inform the USEF CRO system with this information.
US02	Collect grouping information (DSO grid zones, BRP balancing groups) from the USEF CRO system and send it to the Planner agent when requested for or when the grid zone or balancing group changed.
US03	Translate DCM Planner forecasts into USEF D-Prognosis messages and forward to the Safer (DSO).
US04	Translate DCM Planner forecasts into USEF A-plan messages and forward it to the Balancer (BRP).
US05	Translate USEF flex request messages coming from the Safer (DSO) and from the Balancer (BRP) into DCM Planner flex request messages.
US06	Translate USEF flex order messages coming from the Safer (DSO) and from the Balancer (BRP) to DCM Planner flex order messages.
US07	Translate DCM Planner flex offer messages to USEF flex offer messages towards the Safer (DSO) or the Balancer (BRP).

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US08	Provide a flexibility range towards the Safer (DSO). This is an extension on the current USEF standard and reference implementation.
US09	Translate DCM Planner flex order response messages to USEF flex order response messages towards the Safer (DSO) or the Balancer (BRP).

Table 9: Usefer agent functions

3.3.4 Planner

The Planner is responsible for supplying total baseline consumption profile and flexibility forecasts for each of the grid zones or balancing groups to the Usefer. Furthermore, it is responsible for calculating an optimal flex activation plan for each group, that complies with a received flex request (from the Safer or Balancer via the Usefer) and available flexibility for that group.

The functionality of the Planner is listed in *Table 10*.

Function	Description
PL01	Create the group list (which DERs, that belong to the cluster, belong to which group) for use by the Tracker and the Forecaster (i.e. combine group info received from Usefer with contracted DER info received from an internal procurement platform function). • *Receive DER list belonging to the cluster from the procurement function* • *Receive groups from the Usefer; These groups only list vDERs of this cluster.* • *Send groups to Tracker* • *Send groups to Forecaster*
PL02	Forward grouped forecasts (of total baseline consumption and flex) to the Usefer. • *Receive Forecasts per group (total consumption forecasts and flex forecasts) from the forecaster.* • *Send Forecasts per group to Usefer.*
PL03	Receive Flex requests for each group from the Usefer, and calculate an optimal and feasible consumption profile for each of the groups, and send these to the Tracker. the DCM-Planner will do an optimalisation that maximizes his profit i.e. the delta between what the DSO wants to pay, and the incentive that must be paid to the group. • *Receive Flex request per group from Usefer (assumption: the flex request is a flex band)* • *Determine optimal plan per group (if a flex band is received), taking into account the capacity range if provided by the DSO.* • *Send optimal plan per group to tracker*

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PL04	Receive flex offer per group from tracker (this may be the nth iteration if the previous plan could not be disaggregated).
	Receive response from Tracker:
	• *If OK (= flex offer):*
	  ○ *forward to Usefer*
	  ○ *wait for flex order*
	  ○ *forward flex order to tracker*
	• *If NOK:*
	  ○ *calculate another (less optimal) profile and send this to the Tracker.*

PL05	Receive flex order from the planner and activate the flex plan response previously sent by the tracker.

Table 10: Planner agent functions

3.3.5 Tracker

The tracker works on a group level to take the flex plan from the Planner and dispatch this among all the underlying vDERs.

Once the plan is generated from the planner, the tracker receives this and triggers an iterative process with the vDERs. It starts a negotiation with the vDERs by means of a distributed optimization strategy called *alternating direction method of multipliers* (ADMM), see (Boyd , Parikh, Chu, Peleato, & Eckstein, 2010). There are several formulations possible for setting up this optimization problem out of which two options are most relevant for us : The *"optimal exchange"* approach or the *"sharing"* approach. While in the first option, the problem is set up as a market clearing problem with the constraint that demands and supplies meet, the second problem is setup in a way of sharing a common resource. The optimal exchange problem has the following *constraint* in our case:

$$\sum_i P_i \; = P_{planner},$$

where P_i are the consumption of each vDER and as the name suggests, $P_{planner}$ is the flex plan foreseen by the planner. The sharing problem adds the following term to the objective, where there is a penalty added for deviating from the planner:

$$\alpha \left| \sum_i P_i - P_{planner} \right|.$$

Since the optimal exchange option results in the least information exchange between the involved agents, and very closely resembles the negotiation scheme by a similar simpler variant *dual decomposition*, we will use that option.

Both in dual decomposition as well as ADMM, the dual variables (can be interpreted as the price for energy in this case) are updated in a central location (Tracker) and broadcasted to the various entities participating in the distributed optimization process (vDERs). The entities then respond appropriately with their optimal strategy for the price information they received (in our case the consumption plans).

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The dual variables are again updated according to the deviation from the global objective and broadcasted – in our case the difference between the plan from the planner and the aggregated consumption plan from all the vDERs, decides the direction in which the price is updated. These dual variables that are broadcasted are virtual or indicative prices and we call them shadow prices. They reflect the time steps where more/less consumption is expected, and the vDERs react suitably subject to the available local flexibility. A convergence criteria is set for when the iterations can stop (the plan is met up to a certain tolerance, or the maximum number of iterations has passed).

The advantage of such an approach is that, if the vDER objectives are convex, we get the global optimum, which a centralized optimization method would have achieved, while restricting the private information of buildings with in the vDERs. The additional advantage of the ADMM scheme is that it improves convergence and stability compared to classical dual decomposition. Also, as the shadow prices are used to activate flexibility, they can be directly indicative of the price for activated flexibility in clusters.

Notation	
Controllable load Plan from the planner	$P_{planner}$
Number of agents/buildings	N
Shadow price in the k^{th} iteration	λ^k
Response of agent i in the k^{th} iteration (kW)	P_i^k
Average of all the agents' response in k^{th} iteration (kW)	$\overline{P^k}$
Local agent objective w.r.t to the heat load	$f_i(P_i)$

Table 11: symbol list

In this approach, the Tracker solves the following optimization problem:

- Objective

$$\text{minimize} \sum_i f_i(P_i)$$

- Subject to

$$\sum_i P_i = P_{planner}$$

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This is solved using the following update scheme:

$$P_i^{k+1} = \arg\min_{P_i}\left(f_i(P_i) + \lambda^k \cdot P_i + \frac{\rho}{2}\left\|P_i - \frac{P_{planner}}{N} - \left(P_i^k - \overline{P^k}\right)\right\|_2^2\right)$$

$$\lambda^{k+1} = \lambda^k + \rho\left(\overline{P^{k+1}} - P_{planner}\right)$$

Vectors to be passed from tracker to agent :$P_{planner}$(once), λ^k, $\overline{P^k}$

As a second functionality, the Tracker tracks the agreed control plan (hence the name), and tries to follow it as close as possible. This functionality runs in real time and is the same across all use-cases.

The functionality of the Tracker is listed in ***Table 12***.

Function	Description
TR01	Receive group info from the Planner.

TR02	Disaggregation of the flex request: calculate the incentives needed to distribute the flex request from the planner amongst the different vDERs of the group.
	ADMM negotiation functionality to determine flex offer. This is TR01 in the function list.
	• *Until an acceptable solution (= flex offer) is found:*
	  ○ *Receive for each group the requested consumption profile from the Planner*
	  ○ *ADMM negotiations with the (v)DERs to result in a requested profile for each DER so that the aggregated profiles per group are equal to or within an allowed deviation from the profile requested by the planner for that group..*
	  ○ *Send resulting flex offer or NOK to Planner*

TR03	Flex order disaggregation. • *Receive flex order from Planner* • *Disaggregate and send disaggregated profile to each vDER*
TR04	Profile logging/monitoring: • *Receive consumption profile information per DER from the vDER* • *Send profile information per vDER to the Forecaster (where it is used for –total-baseline and flex forecasting).*

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TR05	Realtime tracking and correction (comparing the realtime logged information against the requested profile and correct as needed). • *Receive profile information per DER from the vDER* • *Aggregate per group and compare against the group's requested profile* • *If needed (deviation above some threshold), compensate by changing the requested profile of other DERs belonging to the same group (calculation and communication).*

Table 12: Tracker agent functions

3.3.6 Forecaster

The Forecaster agent provides the forecasts at group level, both for the total consumption profiles and for flexibility. Forecasts may be received from the (v)DER, e.g. based on using building thermal models, or they may be created by the Forecaster himself, e.g. based on historic consumption profiles and other relevant information and forecasts (like price forecasts, weather forecasts, …). In addition, it learns the reliability of each (v)DER's forecast, and use this information to improve the forecasts that are forewarded to the Planner.

The functionality of the Forecaster is listed in ***Table 13*** .

Function	Description
FO01	Aggregate the vDERs consumption profile for each group into group consumption profiles. The consumption profile must be the sum of controllable and non-controllable loads of the DER.
FO02	Calculate consumption profile forecast of non-controllable loads based on historical overall consumption profile information (optionally: might as well be provided by the vDER: see FO04) per vDER. • Get/Receive profile information from the Tracker • Create forecasts (using ML) … this may be based on – and then include – price forecasting, weather forecasting, … that have an impact on the expected consumption.
FO03	Calculate flex forecast of controllable loads based on profile information (optionally: might be provided as well by the vDER) per vDER. • Receive Get profile information from the Tracker • Create forecasts (using ML)
FO04	Receive consumption profile forecasts of non-controllable loads per DER from the vDER (optionally: might as well be calculated in the forecaster: see FO02).
FO05	Receive baseline consumption and flex forecasts of controllable loads per DER from the vDER (optionally: might be calculated in the forecaster: see FO03).

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FO06	Create grouped forecasts (of total baseline consumption and flex) by aggregating forecasts (self-created in forecaster or provided by vDER) in line with the grouping list that it has constructed. The baseline consumption forecast must be the sum of controllable and non-controllable loads of the DER.
F007	Forecast tuning/adaptation. • Receive profile information from the Tracker • Compare against received or calculated forecast and decide on forecast tuning for future times steps based on learned reliability information.

Table 13: Forecaster agent functions

3.3.7 vDER

The vDER, is a virtual representation of a DER, being a building or an Ecovat system. Each bulding, or other flexibility resource, is represented by one vDER agent.
The functionality of the vDER is listed in ***Table 14***

Function	Description
VD01	Receive baseline and flex (providing information on how much it is capable of deviating from its planned day ahead consumption) forecasts from DER agent (optionally: only if forecasting is done in the DER instead of the forecaster) and forward to forecaster.
VD02	Calculate baseline and flex forecasts for DER based on a model (optionally: only if forecast is created from model, and this is done in the vDER instead of in the DER agent) and forward to forecaster.
VD03	Receive profile information from DER and forward to tracker (for profiling TR03 or realtime tracking TR04).

VD04	Engage with tracker in ADMM.
	• *Receive shadow price from tracker*
	• *Send response:*
	  ○ *Option 1 – if the model is in the vDER agent*
	    ▪ *calculate response using model*
	    ▪ *Send response to tracker*
	  ○ *Option 2 – if the model is in the DER agent:*
	    ▪ *Forward shadow price to DER*
	    ▪ *Receive response from DER*
	    ▪ *Forward response to tracker*

VD05	Instruct DER agent (agreed disaggregated flex offer). • *Receive disaggregated consumption plan* • *Send to DER (assuming the DER agent can locally do the sequencing (control command in real-time) to the DER asset, otherwise the sequencing must be in this function)*
VD06	Act as a proxy relaying messages from Tracker or Forecaster agent to the DER agent in case the above mentioned vDER functionality is located in the DER agent (for instance in case of Ecovat).

Table 14: vDER agent functions

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3.3.8 DER

The DER agent is the interaction endpoint for the vDER and manages the DER asset(s).

Function	Description
DE01	Calculate baseline consumption forecast of non-controllable loads (optionally: might as well be provided by the vDER or the Forecaster) and send to vDER.
DE02	Calculate baseline and flex forecasts of controllable loads (optionally: only if forecast is created from model, and this is done in the DER instead of in the vDER) and forward to vDER
DE03	Send historical consumption (one period or multiple periods) profile information to vDER (for forwarding to tracker for logging and realtime tracking)
DE04	Send other relevant (sensor) information to vDER (optionally: if forecasts are made in the vDER or forecaster and they need this data)
DE05	Engage with vDER in ADMM (optionally: in case the DER agent is acting as the ADMM endpoint). For instance in case of Ecovat, this done by the EAP in the DER agent. In this case the vDER agent is just relaying the ADMM messages to the DER agent: • *Receive shadow price* • *Calculate response using model* • *Send response to vDER*
DE06	Instruct DER (agreed disaggregated flex offer) • *Receive disaggregated consumption plan from vDER* • *Send control sequence to DER asset*
DE07	Back-up controller • *(Receive sequence and control DER asset)* • *Local monitoring of (comfort) constraints and if needed overrule the received sequence*

Table 15: DER agent functions

Concerning the DER assets, two types of P2H technologies are in the scope of FHP: dynamic coalitions (clusters) of heat pumps in buildings on the one hand, and the Ecovat system on the other hand. The DER asset is thus a building (or HVAC systems in the building) or a Ecovat system. These DER assets are described in section 4 in D1.1.

3.4 Mapping of in-focus functions to agents

The internal processing requirements per role, found in section 3.2.1, provides a catalogue of in-focus business use case functions. *Table 16* defines for each function the agent that provides this functionality.

In focus functions	Local RES curtailment mitigation	System RES curtailment mitigation	Balancing services	Platform	Agents							
					Safer	Balancer	Usefer	Planner	Tracker	Forecaster	vDER	DER
DetermineGridZones	✓	✓	✓	DSO	✓							
UpdateHeatProviderPContext	✓	✓	✓	DER							✓	✓

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CalculateP2HConsumptionProfiles	✓	✓	✓	DER, DCM							✓	✓
DetermineHPConsumptionProfile	✓	✓	✓	DER, DCM							✓	✓
DetermineHPFlexibilityInformation		✓	✓	DER, DCM							✓	✓
DetermineDCMConsumptionProfile	✓	✓	✓	DCM						✓		
DetermineDCMFlexibilityInformation		✓		DCM						✓		
DetermineDCMConstrained FlexibilityInformation		✓	✓	DCM						✓		
UpdateDCMConsumptionProfile		✓		DCM				✓				
UpdateLocalGridContext	✓	✓		DSO	✓							
PerformGridSafetyAnalysis	✓	✓		DSO	✓							
CalculateLocalFlexRequest	✓	✓		DSO	✓							
CalculateHPIncentives	✓	✓		DCM					✓			
DetermineHPResponse	✓	✓		DER							✓	✓
CheckHPResponses	✓	✓		DCM					✓			
CheckLocalFlexOffer	✓	✓		DSO	✓							
DetermineHPConsumptionPlan	✓	✓	✓	DCM						✓		
DetermineHUSettings	✓	✓	✓	DER							✓	✓
UpdateBRPPortfolio	✓	✓		BRP		✓						
DetermineBRPUpdate	✓			DCM						✓		
DetermineSystemFlexOffer		✓	✓	DCM				✓				
CalculateSystemFlexRequest		✓	✓	BRP		✓						
AdjustSystemFlexOffer		✓		DCM				✓				

Table 16: Mapping of in-focus functions to agents

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3.5 Mapping of agent functions to the in-focus functions and interactions

Table 17 shows for each agent functionality the related mapping on in-focus functions that were defined in D1.1.

	Interactions									In-focus functions (D1.1)																						
Function	AggregationLevel	ConsumptionProfile	FlexRange	DERFeedback	FlexNegotiaionBalancer	FlexNegotiationSafer	FlexActivation	IncentiveFlexPlan	AssetControl	DetermineGridZones	UpdateHPContext	CalculateP2HConsumptionProfiles	DetermineHPConsumptionProfile	DetermineHPFlexibilityInformation	DetermineDCMConsumptionProfile	DetermineDCMFlexibilityInformation	DetermineDCMConstrainedFlexibilityInfor	UpdateDCMConsumptionProfile	UpdateLocalGridContext	PerformGridSafetyAnalysis	CalculateLocalFlexRequest	CalculateHPIncentives	DetermineHPResponse	CheckHPResponses	CheckLocalFlexOffer	DetermineHPConsumptionPlan	DetermineHUSettings	UpdateBRPPortfolio	DetermineBRPUpdate	DetermineSystemFlexOffer	CalculateSystemFlexRequest	AdjustSystemFlexOffer
PL01	x																															
PL02		x	x															x														
PL03					x	X																										
PL04					x	X																										x
PL05							x																									
TR01	x																															
TR02				x				x														x		x								
TR03				x			x																									
TR04																																
TR05				x																												
FO01	x																															
FO02		x														x																
FO03		x														x	x															

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FO04		x																														
FO05		x																														
FO06															x	x																
FO07		x																														
VD01		x	x									x	x	x																		
VD02		x	x									x	x	x																		
VD03				x																												
VD04								x															x									
VD05							x																				x					
VD06																																
DE01		x	x									x	x	x																		
DE02		x	x									x	x	x																		
DE03																																
DE04																																
DE05								x																								
DE06							x		x																		x					
DE07									x																							
US01	x																															
US02	x																															
US03		x																														
US04		x																														
US05					x	X																										
US06					x	X																										
US07					x	X																										
US08			x																													
BA01	x																															
BA02		x																										x				
BA03					x																										x	

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BA04					x																										x	
SA01	x									x																						
SA02																			x													
SA03		x																														
SA04			x																													
SA05																				x												
SA06						X															x											
SA07						X																			x							
SA08						x																										

Table 17: Mapping of agent functions to interactions and in-focus functions

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3.6 Non-functional requirements

This chapter identifies and describes the complete set of requirements for each of the platforms defined in the FHP system architecture.

ID	NF-Pe.DCMPlatform.1
Platform	DCM platform
Source role Req	None
Description	The response time of the DCM platform to the flex requests and flex orders made by the DSO or the BRP platform must be adequate to comply the most restrictive business use case constraints
Type	Non-functional / Performance
Author	Tecnalia
Date	31/10/2017
Rationale	If the DCM platform is not answering fast enough the BRP or DSO would have to procure flexibility using other means
Use case	All
Fit & acceptance criteria	Communication timing requirements need to be defined, so each business case intended may be achieved
Priority	Must-have
Dependencies/Conflicts	No dependencies. No conflicts
Comments	

ID	NF-Pe.DERPlatform.1
Platform	DER platform
Source role Req	None
Description	The response time of the DER platform to the request for consumption profiles or consumption plans from the DCM platform must be adequate to comply the most restrictive business use case constraints
Type	Non-functional / Performance
Author	Tecnalia
Date	31/10/2017
Rationale	If the DCM platform is not answering fast enough the BRP or DSO would have to procure flexibility using other means
Use case	All
Fit & acceptance criteria	Communication timing requirements will be defined, so each business case intended may be achieved
Priority	Must-have
Dependencies/Conflicts	No dependencies. No conflicts
Comments	

ID	NF-Sc.DCMPlatform.1
Platform	DCM platform
Source role Req	None
Description	Multiple DSOs and BRPs will access simultaneously a the DCM platform

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Type	Non-Functional / Scalability
Author	Tecnalia
Date	31/10/2017
Rationale	The cluster of vDERs managed by a DCM can be connected to different distribution grids or have energy purchase contracts with retailer represented by different BRPs, so the DCM platform must be able to connect to several DSOs and BRPs
Use case	All
Fit & acceptance criteria	
Priority	Must-have
Dependencies/Conflicts	No dependencies. No conflicts
Comments	

ID	NF-Sc.DERPlatform.1
Platform	DER Platform
Source role Req	None
Description	The data model should be flexible enough to cope with future different DER assets.
Type	Non Functional / Scalability
Author	Tecnalia
Date	31/10/2017
Rationale	
Use case	All
Fit & acceptance criteria	Sufficient flexibility of data/information design.
Priority	Nice-to-have
Dependencies/Conflicts	No dependencies. No conflicts
Comments	

ID	NF-I.DCMPlatform.1
Platform	DCM platform
Source role Req	None
Description	The DCM platform must be able to trade flexibility with the flexibility users, the BRP or the DSO, by means of a standard protocol used by the frameworks of these users
Type	Non-Functional / Interoperability
Author	Tecnalia
Date	31/10/2017
Rationale	If the DCM would not be impelemnted using an standard protocol in its interface with the DSO or the BRP, the engineering costs associated to this retrofit would avoid that either DSOs or BRPs would be interested in using it
Use case	All
Fit & acceptance criteria	
Priority	Must-have
Dependencies/Conflicts	No dependencies. No conflicts
Comments	

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ID	NF-I.DERPlatform.1
Platform	DER platform
Source role Req	None
Description	The DER platform must be able to communicate with the DER assets, by means of a standard protocol widely used in building environments
Type	Non-Functional / Interoperability
Author	Tecnalia
Date	31/10/2017
Rationale	The vDER has to interface the buiding assets either directly or through a Buiding Management System (BMS), so it has to comply with the protocol specification of those assets that it will connect to
Use case	All
Fit & acceptance criteria	Assets used in the field trials will specify the communication protocols that will have to be used in the implementation of the DER platform in WP4
Priority	Must-have
Dependencies/Conflicts	No dependencies. No conflicts
Comments	

ID	NF-Pr.DCMPlatform.1
Platform	DCM Platform
Source role Req	None
Description	The DCM Platform must guarantee the privacy of the information as foreseen by the applicable law.
Type	Non-functional / Privacy
Author	Tecnalia
Date	31/10/2017
Rationale	Information/data privacy is a critical requirement for deployment and use of the DCM Platform, which should guarantee privacy of grouped information sent to the BRP or DSO and exchanged with the DER platform
Use case	All
Fit & acceptance criteria	Availability of a security/data privacy functionality in the Usefer, as it is the gate to the external communications of the DCM platform.
Priority	Must-have
Dependencies/Conflicts	Dependencies with security/privacy provisions of the DER platform may exist. No conflicts.
Comments	The FHP architecture should foresee all necessary provisions to ensure privacy of information.

ID	NF-Pr.DERPlatform.1
Platform	DER Platform
Source role Req	None

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Description	The DER Platform must guarantee the privacy of the information as foreseen by the applicable law.
Type	Non-functional / Privacy
Author	Tecnalia
Date	31/10/2017
Rationale	Privacy is also a critical requirement for deployment and use of the DER Platform, which should guarantee privacy of information managed from heat users. These issues should be taken into account: • Transparency: Means that data collection and processing can be verified and evaluated with reasonable effort. The applied method and the data traffic must be kept transparent to ensure observability, checkability and verifiability. This would be applied for instance, to the information sent to heat users before they participate in the FHP trials' data collection • Data minimization: It refers to the policy of gathering the minimum amount of personal information necessary to perform a given function. The goal is to process the least amount of private information in the data collection • Intervenability: Every person inside any of the FHP platforms should have control over their personal data. To assure this, it is necessary to implement appropriate processes so that heat users can ask for excerpts, the complete inquiry, the correction of data or deletion of personal data in dependence to EU und national law
Use case	All
Fit & acceptance criteria	Availability of a security/data privacy functionality in the vDER, who will not disclose sensitive information to the DCM platform.
Priority	Nice-to-have
Dependencies/Conflicts	Dependencies with security/privacy provisions of the DCM platform may exist. No conflicts.
Comments	The FHP architecture should foresee all necessary provisions to ensure privacy of information. The software implementation will be tested and demonstrated within well-controlled environments and with the consent of civilians who may offer their DER assets. Thus implementation of data privacy measures in the DER platform is strictly not necessary, but nice-to-have.

ID	NF-Av.DERPlatform.1
Platform	DER platform
Source role Req	None

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Description	The DER platform should be always available as it holds the functionality of optmimizing the operation of P2H systems.
Type	Non-functional / Availability
Author	Tecnalia
Date	31/10/2017
Rationale	
Use case	All
Fit & acceptance criteria	Ocasional failures of DER platofrm may not have a serious impact on the overall functionality of the system.
Priority	Nice-to-have
Dependencies/Conflicts	No dependencies. No conflicts
Comments	The optimization of the P2H systems must always be considered as a nice-to-have feature, as these systems must always have the local functionality of being operated autonomously following a default operation scheme when the optimization is not available.

ID	NF-Av.DCMPlatform.1
Platform	DCM platform
Source role Req	None
Description	The DCM platform should be robust and reliable.
Type	Non-functional / Availability
Author	Tecnalia
Date	31/10/2017
Rationale	Many business models for future smart grid applications may depend on the DCM platform availability and robustness. The DCM platform can only have a huge impact when it's reliable and trustable.
Use case	All
Fit & acceptance criteria	
Priority	Nice-to-have
Dependencies/Conflicts	The reliability of the DCM platform dependes on the availability of the DER platform. No conflicts
Comments	

ID	NF-Sec.DCMPlatform.1
Platform	All FHP Platforms
Source role Req	None
Description	Sensitive communications between the DCM Platform and the other platforms should be secure.
Type	Non-functional / Security
Author	Tecnalia
Date	31/10/2017
Rationale	Secure platforms, and their communications, are important for a number of reasons: • Confidentiality: Protection against unauthorized disclosure of information and access to systems and

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	services. Confidential data and services shall be accessible only for persons or parties who are authorized. Communications channel to and from the DCM platform need to be secured (i.e. using TLS) and encrypted of individual messages/commands exchanged is needed. • Integrity: Ensures the correctness (integrity) of data and the correct functioning of the FHP platforms. • Availability: IT systems must deliver information in dependence of their infrastructure. This aim can be endangered, for example by malware or denial of service attacks. • Authenticity: Ensures that a communication partner is actually the person, system or process, it claims to be (evidence of the sender and/or receiver) • Non-Repudiation: Assurance that someone cannot deny something. Typically, non-repudiation refers to the ability to ensure that a party of a communication (e.g. a contract) cannot deny the authenticity of their signature on a document or the sending of a message that they originated
Use case	All
Fit & acceptance criteria	
Priority	Nice-to-have
Dependencies/Conflicts	No dependencies. No conflicts
Comments	The FHP platforms will be run in a controlled environment in the trials, so the risks associated to the security will be minimized. Anyway, the risks defined in the rationale should be taken into account.

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4 Information architecture

This section describe the interactions and messages between agents, derived from the communication requirements per role summarised in section 0

4.1 AggregationLevel interaction

The DCM aggregates both vDER consumption profiles and consumption plans, so as to provide these information to the flexibility users, the DSO and the BRP.

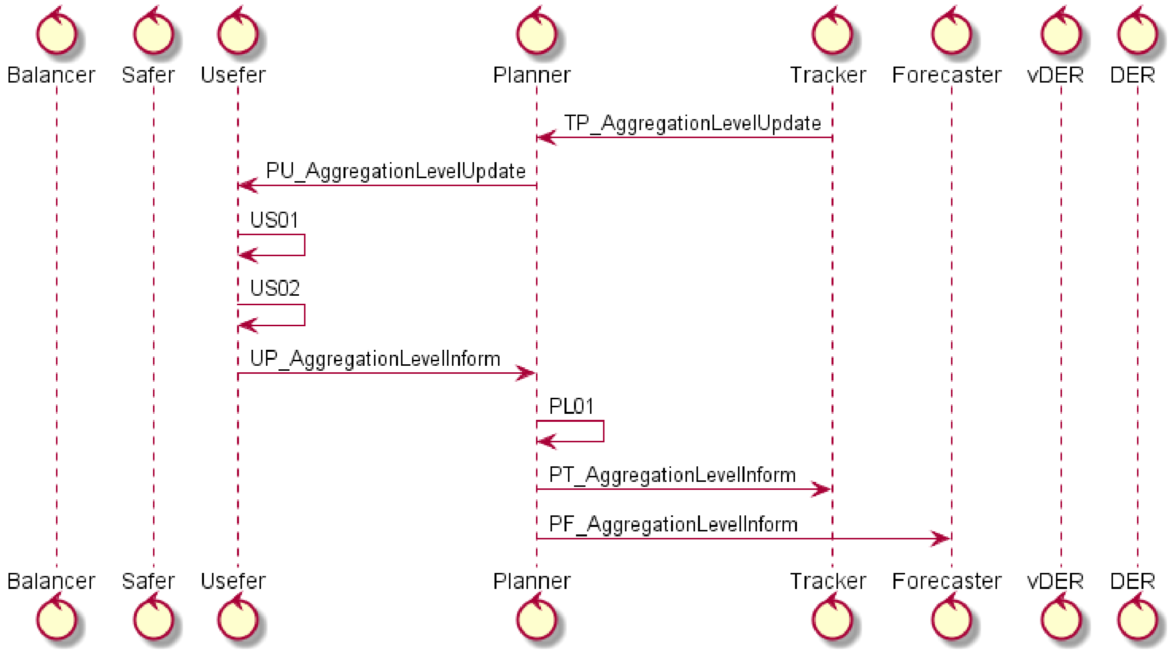

Figure 6: AggregationLevel interaction

The aggregation level (groups) are different for these two users:

- The DSO manages grid zones, each grid zone is a collection of connection points in which the reaction of any consumer provides the same effect on the grid. Each vDER has a unique and permanent connection point in the distribution grid, which is the electrical connection point in which the building is connected to the distribution grid.
- The BRP manages balancing groups, being each balancing group the portfolio of generators and consumers for which the BRP is accountable. Subsets of these consumers are the heat providers, and each heat provider has a contract with a retailer for electricity purchase. And each retailer has a contract with a BRP so that the BRP represents the retailer in its transactions in the market. So, at the end, all consumers of a retailer are in the balancing group of the same BRP.

The tracker is the agent in charge of delivering the list of vDERs within the cluster of the DCM to USEF, while the aggregation level will be received both by the tracker and the forecaster, as it has to be known by the tracker to aggregate vDER consumption plans into group consumption plans, and by the forecaster to aggregate vDER consumption profiles into group consumption profiles.

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The tracker knows which vDERs are in the cluster and therefore has to inform to an entity in the USEF framework of which vDERs are in the cluster, which is their location in the grid (identifier of the connection code, usually an EAN code). This code is unique and refers to the identifier which is both known by the DSO and the retailer contracted by the heat provider. The entity which knows in USEF which are the relationships between the DSOs, the BRPs and the connection points is the Common Reference Operator (CRO)[5]. The DCM has to communicate to the CRO which vDERs are in its cluster. This information is sent by the tracker to the planner (**TP_AggregationLevelUpdate** message) and forwarded by the planner to the usefer (**PU_AggregationLevelUpdate** message), whenever there is a change in the components of the cluster. Then the Usefer has the responsibility to send the information about which vDERs are in the cluster to the CRO, using function US01[5].

Once the DCM has updated the info at the CRO, USEF establishes the mechanisms that the DSO and the BRP need to define which vDERs are in each balancing group and in each grid zone respectively. The necessary function to support his mechanism at the balancer and safer side are represented by the BA01 and SA01 functions[5].

Once the DSO and the BRP provide the grouping information to the CRO, the CRO has the duty to communicate to the DCM which vDERs in its cluster are included in each grid zone defined by the DSO and which vDERs are in the balancing group of each BRP. The Usefer implements function US02 to gather the groups from the CRO[5] and sends the info to the planner (**UP_AggregationLevelInform** message) and the planner distributes it to the tracker and the forecaster (**PT_ AggregationLevelInform** and **PF_AggregationLevelInform** messages). This information is distributed at the beginning of the FHP use case with the longest time horizon, i.e. before the day ahead market gate is opened. Once the grouping information gets to both the tracker and the forecaster they use this information on both the IncentiveFlexPlan and ConsumptionProfile interactions respectively to aggregate either consumption plans or consumption profiles.

4.1.1 TP_AggregationLevelUpdate message

Message name	TP_AggregationLevelUpdate
Source	Tracker
Destination	Planner
Functional requirement D1.1	
localRESCurtailmentMitigation	True
systemRESCurtailmentMitigation	True
balancingServices	True
Interaction	AggregationLevel
Interface	I_TD, I_PD
Description	Message used by the tracker to provide to the planner information about which vDERs form the cluster
Return values	Succes/Fail

[5] The communications between the CRO and the Usefer are standard USEF based communications and therefore they are not represented in the interaction diagram, as they are out of the scope of the FHP developments.

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Atribute name	***Type of entry***	***Description***
ConnectionPointID	Mandatory	List of ConnectionPointID in the cluster. Each vDER is identified by a ConnectionPointID (EAN code) that is unique and known by the DSO and BRP

4.1.2 PU_AggregationLevelUpdate message

Message name	PU_AggregationLevelUpdate
Source	Planner
Destination	Usefer
Functional requirement D1.1	
localRESCurtailmentMitigation	True
systemRESCurtailmentMitigation	True
balancingServices	True
Interaction	AggregationLevel
Interface	I_PD, I_UD
Description	Message sent to the Usefer with the info coming in an TP_AggregationLevelUpdate message
Return values	Succes/Fail

Atribute name	***Type of entry***	***Description***
ConnectionPointID	Mandatory	List of ConnectionPointID in the cluster. Each vDER is identified by a ConnectionPointID (EAN code) that is unique and known by the DSO and BRP. Copied from PU_AggregationLevelUpdate

4.1.3 UP_AggregationLevelInform message

Message name	UP_AggregationLevelInform
Source	Usefer
Destination	Planner
Functional requirement D1.1	Send GridZones - IEX_01
localRESCurtailmentMitigation	True
systemRESCurtailmentMitigation	True
balancingServices	True
Interaction	AggregationLevel

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Interface	I_UD, I_PD
Description	The Usefer informs to the planner about which vDERs passed in the AggregationLevelUpdate message are in each grid zone and in each balancing group
Return values	Succes/Fail

Atribute name	***Type of entry***	***Description***
DCMID	Mandatory	Identifier of the destination DCM
GridZoneID	Optional	List of GridZoneID defined by the DSO
BalancingGroupID	Optional	List of BalancingGroupID managed by the BRP (most likely to be one)
ConnectionPointID	Conditional. Needed for each GridZoneID and BalancingGroupID	List of ConnectionPointID in each GridZoneID and in each BalancingGroupID

4.1.4 PT_AggregationLevelInform message

Message name	PT_AggregationLevelInform
Source	Planner
Destination	Tracker
Functional requirement D1.1	Send GridZones - IEX_01
localRESCurtailmentMitigation	True
systemRESCurtailmentMitigation	True
balancingServices	True
Interaction	AggregationLevel
Interface	I_PD, I_TD
Description	The planner forwards to the tracker the grouping information from the UP_AggregationLevelInform message
Return values	Succes/Fail

Atribute name	***Type of entry***	***Description***
GridZoneID	Optional	List of GridZoneID defined by the DSO
BalancingGroupID	Optional	List of BalancingGroupID managed by the BRP (most likely to be one)
ConnectionPointID	Conditional. Needed for each GridZoneID and BalancingGroupID	List of ConnectionPointID in each GridZoneID and in each BalancingGroupID

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4.1.5 PF_AggregationLevelInform message

Message name	PF_AggregationLevelInform
Source	Planner
Destination	Forecaster
Functional requirement D1.1	Send GridZones - IEX_01
localRESCurtailmentMitigation	True
systemRESCurtailmentMitigation	True
balancingServices	True
Interaction	AggregationLevel
Interface	I_PD, I_FD
Description	The planner forwards to the forecaster the grouping information from the UP_AggregationLevelInform message
Return values	Succes/Fail

Atribute name	***Type of entry***	***Description***
GridZoneID	Optional	List of GridZoneID defined by the DSO
BalancingGroupID	Optional	List of BalancingGroupID managed by the BRP (most likely to be one)
ConnectionPointID	Conditional. Needed for each GridZoneID and BalancingGroupID	List of ConnectionPointID in each GridZoneID and in each BalancingGroupID

4.2 ConsumptionProfile interaction

Information about the latest consumption expectations should flow from the buildings towards those roles which need to take into account the consumptions as an input which influences their business decisions, namely the DSO and the BRP. The interaction scheme defined below follows two rules:

- We assume that those agents which hold the capacity to generate consumption forecasts have the obligation to distribute it upwards. For example, we start from the basis that the building is the element which holds the most accurate skills to predict its consumption for a certain time horizon.
- Whenever there is a change in the expected consumption it has to be reported. It is not considered that the cause of the consumption change has to be reported, the responsibility is just to report on any change in the consumption profile itself.

The interaction will be described starting at the building level and moving towards the final destination in Balancer and Safer, as can be seen in ***Figure 7***.

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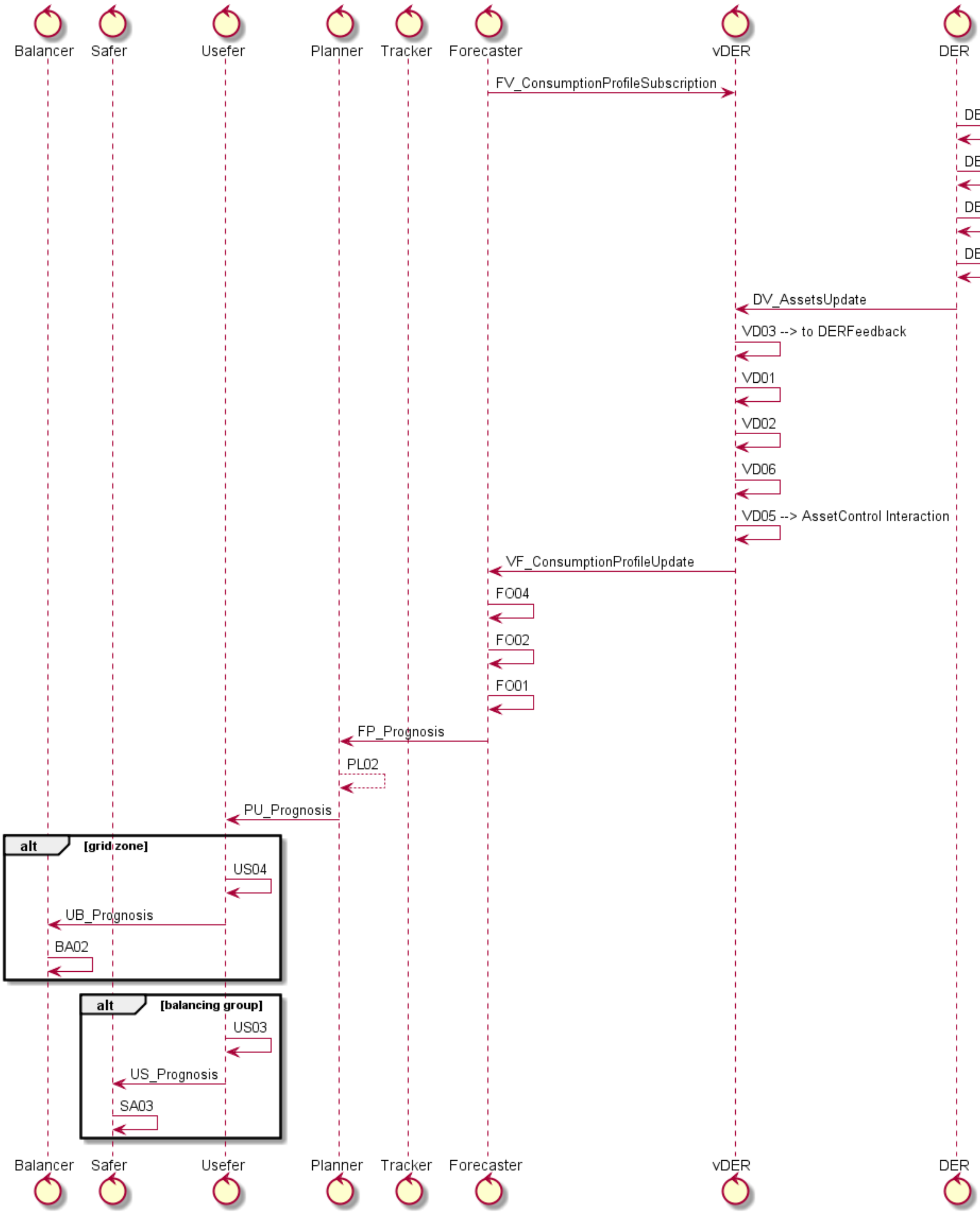

Figure 7: ConsumptionProfile interaction

The prediction is based on operating conditions coming from the assets of the building, by means of the **DV_AssetsUpdate** message. Whenever there is a new measurement associated to the assets, it will be reported to the vDER, which will store the data. These measurements represent all the inputs that the vDER would need to make the prediction from the building side, and come from different building assets (HP and other HVAC equipment, BMS, temperature sensors, inputs from heat users…). Examples of these data are:

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- Measurements on operating conditions (external temperature, occupancy)
- Heat pump measurements (accumulator tank temperature, supply water temperature, electrical demand, thermal production)
- Other HVAC data (thermal demand, room temperatures, room setpoint temperatures forced by users)

Al these assets measurements represents just one of the inputs that the vDER will need to predict the consumption of the P2H devices. The vDER will trigger the execution of the P2H optimisation for a certain time horizon (collection of PTUs). Information about these categories has to be managed:

- Building assets measurements: Reflect the historic and current state of the building assets (operating conditions, HP and other HVAC equipment)
- Operating conditions predictions[6]: During the prediction time horizon
- Activated incentives: Already agreed incentives for flexibility from the tracker and prices for electrical consumption with the retailer, both for the prediction time horizon
- Offered incentives: Optionally, this message can contain a set of incentives that the tracker would offer to the vDER to influence in its P2H consumption profile.
    - If present the message will be ConsumptionProfileRequestType = VirtualOptimization: This means that the consumption profile request is a consequence of an IncentiveFlexPlan interaction, so the tracker has offered an incentive and the vDER would have to predict how the P2H system should behave in that case.
    - If not present then ConsumptionProfileRequestType = RealOptimization. This condition reflects the necessity to redo the P2H operation plan as a consequence of new building operating conditions (AV_AssetsUpdate message) or a change in the predictions of the operating conditions.

A number of fucntions will be optionally executed either at the DER or the vDER side, depending on which agent has the duty to make the consumption profile forecasts and to make the forecast of the uncontrollable loads:

- DE01 Calculate baseline consumption forecastconsumption profiles of non-controllable loads
- DE02 Calculate baseline and flex forecasts of controllable loads
- DE03 Send historical consumption profile information to vDER (for forwarding to tracker for logging and realtime tracking)
- DE04 Send other relevant (sensor) information to vDER
- VD01 Receive baseline and flex forecasts from DER agent
- VD02 Calculate baseline and flex forecasts for DER based on a model
- VD06 Act as a proxy relaying messages from Tracker or Forecaster agent to the DER agent
- VD05 Send to DER control commands
- FO04 Receive consumption profile of non-controllable loads
- FO02 Calculate consumption profile of non-controllable loads

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[6] We assume that the vDER has the ability to acquire these predictions from an external weather service provider, which is not in the scope of the FHP development

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- FO01 Aggregate consumption profiles

Whenever there is a substantial change in any of the data associated to these categories, the vDER should redo the consumption profile. Note that any change in the activated incentives will come in a **TV_ActivateFlexOrder** message (reflected in ***Figure 12***), while any change in the offered incentives will come in a **TV_IncentiveOffer** message (see in ***Figure 11***).

Once the optimization process concludes the following information will be available:

- The P2H consumption profile: The forecast of how much electricity will be consumed for each PTU in the prediction time horizon
- The assets control schedule: Whatever setpoint, or schedule, that would have to be sent to the building assets to comply with the optimization objective.

This information will be always stored by the vDER, and depending on the corresponding ConsumptionProfileRequestType It will:

- VirtualOptimization: Send the consumption profile to the tracker with an VT_IncentiveResponse message (see ***Figure 11***). In this case, as the consumption profile represents what would happen if incentives would be accepted, we refer to it as a consumption plan.
- RealOptimization: Launch the delivery of the assets control schedule in VD05 with a **VD_AssetControl** (see ***Figure 13***) and inform to the forecaster of the new expected consumption profile with a **VF_ConsumptionProfileUpdate** message in case that the forecaster has previously subscribed itself for receiving forecasts for that time period.

In both cases, the P2H consumption profile will be complemented by the vDER before being sent to the tracker/forecaster with the expected consumption profile of the rest of the building loads[7], as the heat provider has the responsibility to purchase electricity for the whole building uses. Then, the P2H consumption profile is converted to a vDER consumption profile.

In the case of RealOptimization, the forecaster must have sent before a **FV_ConsumptionProfileSubscription** in which it informed about the range of time in which any variation of the vDER consumption profile would be reported.

The new vDER consumption profile reported in the **VF_ConsumptionProfileUpdate** message could significatively vary the latest cluster consumption profile that the forecaster has sent to the planner with the **FP_Prognosis** message, for those aggregation levels (grid zones or balancing groups) in which the forecaster knows that this vDER is included. Or it could happen that the forecaster did not send yet a prognosis for that period. In both cases the forecaster has to decide if it has to (re)send the prognosis:

- If it deviates significatively for a previous prognosis sent for the same period time horizon

[7] This forecast is not in the scope of the FHP project, so we will use constant synthetic dataset to represent these consumptions

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- If it has the commitment to send a prognosis at a predefined time (for instance, once the day ahead market preparation is initiated in localDERCurtailmentMitigation or systemDERCurtailmentMitigation)

Anyway, some addictional functions have to be optionnaly executed by the forecaster, just to construct the **FP_Prognosis** that it will send to the planner:

- FO04: Receive consumption profile of non-controllable loads
- FO02: Calculate consumption profile of non-controllable loads
- FO01: Aggregate consumption profiles

If a new prognosis is sent to the planner, the planner will always forward it to the Usefer by means of function PL02 (**PU_Prognosis** message) and depending of which aggregation levels are found in it:

- it will forward it to the safer using US03 (**US_Prognosis** message containing a D-Prognosis, when it is referred to a grid zone). Once a new D-prognosis gets to the safer, the safer stores its using function SA03.
- or to the balancer using US04 **(UB_Prognosis** message containing a A-plan, when it is referred to a balancing group).The balancer also stores the received A-plans, that let him update the purchase bids that it will present at the market (see function BA02)

4.2.1 DV_AssetsUpdate message

Message name	DV_AssetsUpdate
Source	DER
Destination	vDER
Functional requirement D1.1	Get Heat User Settings - IEX_03
localRESCurtailmentMitigation	True
systemRESCurtailmentMitigation	True
balancingServices	True
Interaction	ConsumptionProfile
Interface	I_VD
Description	Update of telemetry from the assets needed to make the consumption profile or consumption plan. The vDER receives the power consumption of the P2H assets such as heat pumps. The vDER further receives additional information from the HVAC system (such as temperatures from the HP) and measurements from indoor temperature sensors.
Return values	Succes/fail

Atribute name	***Type of entry***	***Description***
AssetID	Mandatory	Identifier of the asset
AssetType	Mandatory	Type of the asset (temperature controller, temperature sensor, heat pump…)
AssetMagnitude	Mandatory	Magnitude of the asset (active power, voltage, SOC…)

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TimeStart	Mandatory	Timestamp from which the measurement is applicable
TimeEnd	Mandatory	Timestamp from until which the measurement is applicable. For instantaneous measurements it is equal to the TimeStart
Value	Mandatory	Value of the measurement
Units	Mandatory	Units used for expressing the value of the magnitude

4.2.2 FV_ConsumptionProfileSubscription message

Message name	FV_ConsumptionProfileSubscription
Source	Forecaster
Destination	vDER
Functional requirement D1.1	Send Heat Provider Update Request - IEX_02
localRESCurtailmentMitigation	True
systemRESCurtailmentMitigation	True
balancingServices	True
Interaction	ConsumptionProfile
Interface	I_FD, I_DV
Description	The forecaster requests the vDER to calculate its consumption profile for a certain set of PTUs. From there on, the forecaster remains subscribed for any change in the forecasted consumption plan
Return values	Succes/fail

Atribute name	***Type of entry***	***Description***
Subscription TimeStart	Mandatory	Timestamp from which the forecaster wants information about the consumption profiles
Subscription TimeEnd	Mandatory	Timestamp until which the forecaster wants information about the consumption profiles
ConsumptionProfileType	Mandatory	Type of profile (P2H, BUILDING, UNCONTROLLABLE_LOADS)

4.2.3 VF_ConsumptionProfileUpdate message

Message name	VF_ConsumptionProfileUpdate
Source	vDER
Destination	Forecaster
Functional requirement D1.1	Send Heat Provider Consumption Profile - IEX_04
localRESCurtailmentMitigation	True
systemRESCurtailmentMitigation	True
balancingServices	True
Interaction	ConsumptionProfile
Interface	I_FD, I_DV

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Description	The vDER sends to the forecaster its expected consumption profile extracted from OV_ConsumptionProfileUpdate message. The consumption profile consists in predicted electrical energy consumption in each PTU.
Return values	Succes/fail

Atribute name	***Type of entry***	***Description***
ConsumptionProfilePTUs	Mandatory	List of PTUs included, defined each one by its beginning, end and duration
ConsumptionProfileValues	Mandatory	Average power during each PTU that is forecasted
ConsumptionProfileType	Mandatory	Type of profile (P2H, BUILDING, UNCONTROLLABLE_LOADS)

4.2.4 FP_Prognosis message

Message name	FP_Prognosis
Source	Forecaster
Destination	Planner
Functional requirement D1.1	Send DCM Consumption Profile - IEX_05
localRESCurtailmentMitigation	True
systemRESCurtailmentMitigation	True
balancingServices	
Interaction	ConsumptionProfile
Interface	I_FD, I_PD
Description	The forecaster sends to the planner the prognosis for a grid zone or a balancing group, composed by a group of consumption profiles
Return values	Succes/fail

Atribute name	***Type of entry***	***Description***
BRPID	Conditional. Needed if the message goes to the balancer	Identifier of the destination BRP
DSOID	Conditional. Needed if the message goes to the safer	Identifier of the destination DSO
GridZoneID	Conditional. Needed if the message goes to the safer	GridZoneID defined by the DSO

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BalancingGroupID	Conditional. Needed if the message goes to the balancer	BalancingGroupID defined by the BRP
PTUs	Mandatory	List of PTUs included, defined each one by its beginning, end and duration
ConsumptionProfile	Mandatory	Average power during each PTU that is forecasted that the DCM will consume for a balancing group or grid zone

4.2.5 PU_Prognosis message

Message name	PU_Prognosis
Source	Planner
Destination	Usefer
Functional requirement D1.1	Send DCM Consumption Profile - IEX_05
localRESCurtailmentMitigation	True
systemRESCurtailmentMitigation	True
balancingServices	
Interaction	ConsumptionProfile
Interface	I_PD, I_UD
Description	The prognosis in the FP_Prognosis is forwarded to the usefer
Return values	Succes/fail

Atribute name	***Type of entry***	***Description***
BRPID	Conditional. Needed if the message goes to the balancer	Identifier of the destination BRP. Copied from the FP_Prognosis
DSOID	Conditional. Needed if the message goes to the safer	Identifier of the destination DSO. Copied from the FP_Prognosis
GridZoneID	Conditional. Needed if the message goes to the safer	GridZoneID. Copied from the FP_Prognosis
BalancingGroupID	Conditional. Needed if the message goes to the balancer	BalancingGroupID. Copied from the FP_Prognosis
PTUs	Mandatory	List of PTUs included, defined each one by its beginning, end and duration. Copied from the FP_Prognosis
ConsumptionProfile	Mandatory	Average power during each PTU that is forecasted that the DCM will consume for a balancing group or grid zone. Copied from the FP_Prognosis

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4.2.6 UB_Prognosis message

Message name	PS_Prognosis
Source	Usefer
Destination	Balancer
Functional requirement D1.1	Send BRP Update - IEX_14
localRESCurtailmentMitigation	True
systemRESCurtailmentMitigation	True
balancingServices	
Interaction	ConsumptionProfile
Interface	I_BU
Description	The prognosis in the PU_Prognosis is forwarded to the balancer
Return values	Succes/fail

Atribute name	***Type of entry***	***Description***
BRPID	Mandatory	Identifier of the destination BRP
BalancingGroupID	Mandatory	BalancingGroupID defined by the BRP
PTUs	Mandatory	List of PTUs included, defined each one by its beginning, end and duration
ConsumptionProfile	Mandatory	Average power during each PTU that is forecasted that the DCM will consume for a balancing group

4.2.7 US_Prognosis message

Message name	US_Prognosis
Source	Usefer
Destination	Safer
Functional requirement D1.1	Send DCM Consumption Profile - IEX_05
localRESCurtailmentMitigation	True
systemRESCurtailmentMitigation	True
balancingServices	
Interaction	ConsumptionProfile
Interface	I_SU
Description	The prognosis in the PU_Prognosis is forwarded to the safer
Return values	Succes/fail

Atribute name	***Type of entry***	***Description***
DSOID	Mandatory	Identifier of the destination DSO
GridZoneID	Mandatory	GridZoneID defined by the DSO
PTUs	Mandatory	List of PTUs included, defined each one by its beginning, end and duration

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ConsumptionProfile	Mandatory	Average power during each PTU that is forecasted that the DCM will consume for a grid zone.

4.3 FlexRange interaction

As a requirement from the DSO, the DCM can provide apart from the D-prognosis, an estimation of the flexibility range that its coalition could achieve. The agent which would be the responsible for constracting the flexibility forecast would be the forecaster, although it could count with the support of both the vDER and the tracker.

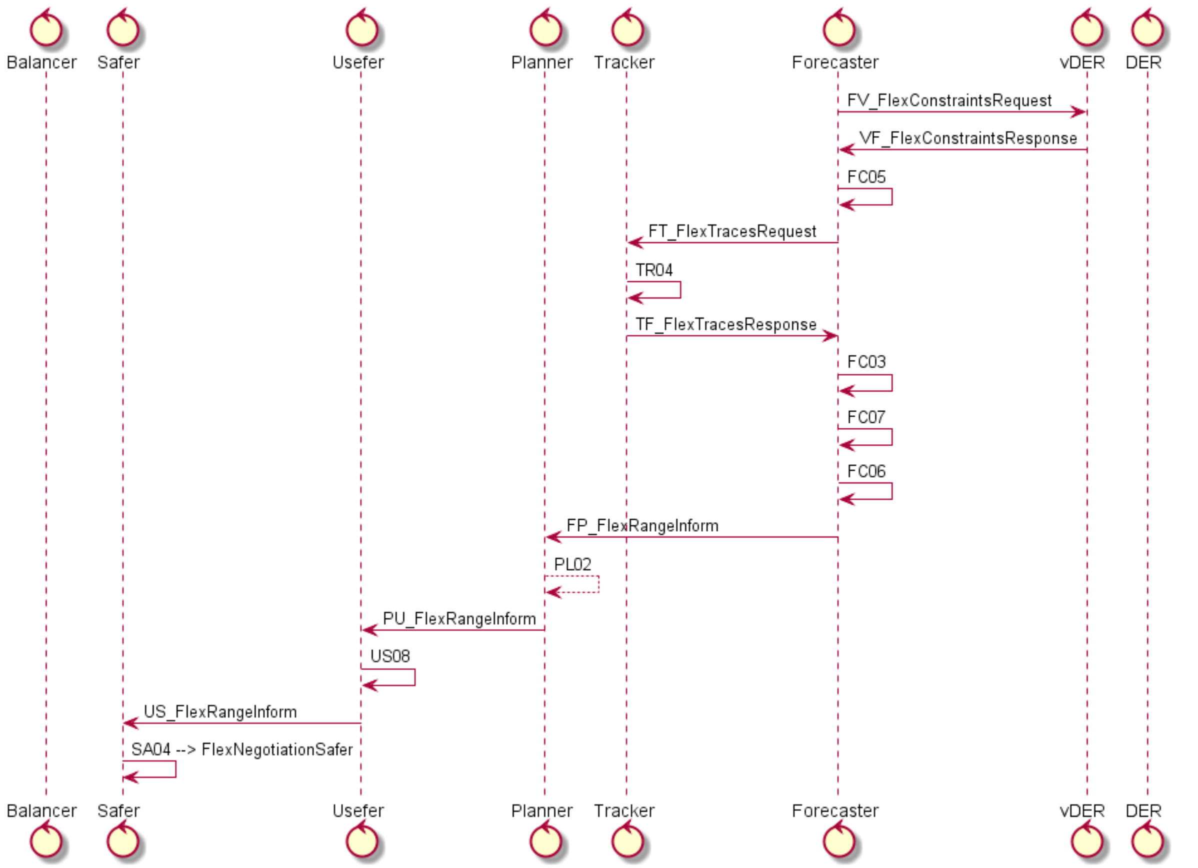

Figure 8: FlexRange interaction

The forecaster could issue a **VF_FlexConstraintsRequest** requesting each vDER to provide a definition of the flexibility that it could provide. This flexibility could be expressed as a collection of inequality constraints that would define the electrical consumption boundaries and inter-PTU relationships that would be delivered to the forecaster with a **VF_FlexConstraintsResponse** message. These forecast will be processed by the FC05 function.

The flexibility capabilities of each vDER could also be derived from the learnings of the response to incentives offered by the tracker, as defined in FC03 (and tune this forecasts with FC07). The forecaster could query the tracker about what has been the response to certain incentive profiles with a

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FT_FlexTracesRequest. As a response, the tracker would get the traces with TR04 and deliver to the forecaster that set of traces, which are defined as couples of incentives profiles versus consumption plans. These couples would be enclosed in a **TF_FlexTracesResponse**.

At the end, it is up to the forecaster which information would it use to compound the cluster flexibility constraints that it would deliver to the planner in the **FP_FlexRangeInform** message. The aggregation of vDER flex ranges will be done always at the FC06 function. What it makes sense is that it would express this flexibility range also in the form of inequality constraints, in spite of other ways of defining flexibility, like flexibility upper and lower bounds. This has been decided due to the characteristics of P2H systems, in which the thermal inertia of the buildings and their HVACs is the major flexibility source, given that the heat demand will always be in the range defined by the users to guarantee their confort.

This clustered flexibility will be processed by the planner function PL02 and forwarded as it is by the planner to the usefer (**PU_FlexRangeInform** message) and from the usefer by menas of US08 to the safer (**US_FlexRangeInform** message), who would process that info in SA04 and use this information to assure that the flexibility that it would request to the DCM (**SU_FlexRequest** in ***Figure 10***) will be inside its capabilities.

Below an overview with the possible mentioned structures to quantify and communicate flexibility that we took into account[8]:

- Traces: N possible power consumption profiles are generated by the vDER to provide an overview of its possibilities. Methods exist to describe the underlying distributions and correlations with a minimum number of traces. The receiving party can select the most appropriate trace. We did this in Symbioptima. The main problems are that the selection of the optimal trace is a discrete optimization problem, which is problematic to solve.
- Modelled traces: A possible solution is to construct a model for these traces and learn the flexibility by matching this model on these traces. This can for example be a linear model. This model can be used to get an idea about the potential flexibility present. Maybe it is not possible to follow the power profile generated by this model, due to model errors.
- Flex graphs: One method to visualize the flexibility is to construct flex graph, these are plots of the energy consumption in function of time and provide an under and upper bound for the possible energy consumption. Next, an optimal power profile can be sought between these bounds. No guarantee can be given that this power profile can be realised. It does not take ramp rates; defrost cycles, anti-Pendle time, etc.
- Inequality constraints (generalized traces): This seems a rather complete description of the available flexibility. These flex graphs can be generalized by communicating the flexibility by an inequality constraint (A*p <= b, where the matrix A is given and can contain a minimum energy consumption, a maximum energy consumption, a minimum power, a maximum power, ramp rates and many more constraints, the future power consumption is p and b are its limitations.

4.3.1 FV_FlexConstraintsRequest message

Message name	FV_FlexConstraintsRequest

[8] In the message definition we have just considered traces and inequality constraints

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Source	Forecaster
Destination	vDER
Functional requirement D1.1	
localRESCurtailmentMitigation	True
systemRESCurtailmentMitigation	
balancingServices	
Interaction	FlexRange
Interface	I_FD, I_DV
Description	Request vDER flexibility information as inequality constraints
Return values	Success/fail

Atribute name	***Type of entry***	***Description***
RequestTime Start	Mandatory	Timestamp from which the forecaster wants information about the inequality constraints
RequestTime End	Mandatory	Timestamp until which the forecaster wants information about the inequality constraints

4.3.2 VF_FlexConstraintsResponse message

Message name	VF_FlexConstraintsResponse
Source	vDER
Destination	Forecaster
Functional requirement D1.1	Send Heat Provider Flexibility Information - IEX_06
localRESCurtailmentMitigation	True
systemRESCurtailmentMitigation	
balancingServices	
Interaction	FlexRange
Interface	I_FD, I_DV
Description	Send vDER flexibility information as inequality constraints
Return values	Success/fail

Atribute name	***Type of entry***	***Description***
RequestTime Start	Mandatory	Timestamp from which the forecaster wants information about the inequality constraints
RequestTime End	Mandatory	Timestamp until which the forecaster wants information about the inequality constraints
Start	Mandatory	Timestamp from which the forecaster gets information about the inequality constraints
Stop	Mandatory	Timestamp until which the forecaster gets information about the inequality constraints
Contents	Mandatory	A vector a with coordinates a_i ≥ 0 expressing the power over Start, Stop subject to Resolution, with [Start, Started] composed of historical

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		data, and a system of linear inequalities expressing flexibility, i.e., A * (x – a) ≤ 1, where A is a (rectangular) matrix, x is a vector with coordinates x_i ≥ 0, and x – a is a vector expressing the deviation from the forecast a.
Resolution	Mandatory	Time delta
Started	Mandatory	DateTime when the process started.
Stopped	Mandatory	DateTime when the process stopped, or when it can be expected to stop.

4.3.3 FP_FlexRangeInform message

Message name	FP_FlexRangeInform
Source	Forecaster
Destination	Planner
Functional requirement D1.1	Send DCM Consumption Profile - IEX_05
localRESCurtailmentMitigation	True
systemRESCurtailmentMitigation	
balancingServices	
Interaction	FlexRange
Interface	I_FD, I_PD
Description	Send group flexibility information as inequality constraints
Return values	Success/fail

Atribute name	***Type of entry***	***Description***
Start	Mandatory	Timestamp from which the forecaster gets information about the inequality constraints
Stop	Mandatory	Timestamp until which the forecaster gets information about the inequality constraints
Contents	Mandatory	A vector a with coordinates a_i ≥ 0 expressing the power over Start, Stop subject to Resolution, with [Start, Started] composed of historical data, and a system of linear inequalities expressing flexibility, i.e., A * (x – a) ≤ 1, where A is a (rectangular) matrix, x is a vector with coordinates x_i ≥ 0, and x – a is a vector expressing the deviation from the forecast a.
Resolution	Mandatory	Time delta
Started	Mandatory	DateTime when the process started.
Stopped	Mandatory	DateTime when the process stopped, or when it can be expected to stop.
GridZoneID	Mandatory	GridZoneID defined by the DSO

4.3.4 PU_FlexRangeInform message

Message name	PU_FlexRangeInform
Source	Planner

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Destination	Usefer
Functional requirement D1.1	Send DCM Consumption Profile - IEX_05
localRESCurtailmentMitigation	True
systemRESCurtailmentMitigation	
balancingServices	
Interaction	FlexRange
Interface	I_PD, I_UD
Description	Send coallition flexibility information as inequality constraints
Return values	Succes/fail

Atribute name	***Type of entry***	***Description***
Start	Mandatory	Timestamp from which the forecaster gets information about the inequality constraints
Stop	Mandatory	Timestamp until which the forecaster gets information about the inequality constraints
Contents	Mandatory	A vector a with coordinates a_i ≥ 0 expressing the power over Start, Stop subject to Resolution, with [Start, Started] composed of historical data, and a system of linear inequalities expressing flexibility, i.e., A * (x – a) ≤ 1, where A is a (rectangular) matrix, x is a vector with coordinates x_i ≥ 0, and x – a is a vector expressing the deviation from the forecast a.
Resolution	Mandatory	Time delta
Started	Mandatory	DateTime when the process started.
Stopped	Mandatory	DateTime when the process stopped, or when it can be expected to stop.
GridZoneID	Mandatory	GridZoneID defined by the DSO
DSOID	Mandatory	Identifier of the destination DSO

4.3.5 US_FlexRangeInform message

Message name	US_FlexRangeInform
Source	Usefer
Destination	Safer
Functional requirement D1.1	Send DCM Consumption Profile - IEX_05
localRESCurtailmentMitigation	True
systemRESCurtailmentMitigation	
balancingServices	
Interaction	FlexRange
Interface	I_SU
Description	Send coallition flexibility information as inequality constraints
Return values	Succes/fail

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Atribute name	***Type of entry***	***Description***
Start	Mandatory	Timestamp from which the forecaster gets information about the inequality constraints
Stop	Mandatory	Timestamp until which the forecaster gets information about the inequality constraints
Contents	Mandatory	A vector a with coordinates a_i ≥ 0 expressing the power over Start, Stop subject to Resolution, with [Start, Started] composed of historical data, and a system of linear inequalities expressing flexibility, i.e., A * (x – a) ≤ 1, where A is a (rectangular) matrix, x is a vector with coordinates x_i ≥ 0, and x – a is a vector expressing the deviation from the forecast a.
Resolution	Mandatory	Time delta
Started	Mandatory	DateTime when the process started.
Stopped	Mandatory	DateTime when the process stopped, or when it can be expected to stop.
GridZoneID	Mandatory	GridZoneID defined by the DSO
DSOID	Mandatory	Identifier of the destination DSO

4.3.6 FT_FlexTraceRequest message

Message name	FT_FlexTraceRequest
Source	Forecaster
Destination	Tracker
Functional requirement D1.1	
localRESCurtailmentMitigation	True
systemRESCurtailmentMitigation	
balancingServices	
Interaction	FlexRange
Interface	I_FD, I_TD
Description	Request flexibility information, including constraints on the shape and level of incentives and any other information relevant to cluster consumption profiles
Return values	Succes/fail

Atribute name	***Type of entry***	***Description***
vDERID	Mandatory	Identifier of the vDER
Start	Mandatory	Timestamp from which the forecaster wants information about traces
End	Mandatory	Timestamp until which the forecaster wants information about traces
Constraints	Optional	Constraints that the forecaster wants to apply in the search for traces

4.3.7 TF_FlexTraceResponse message

Message name	TF_FlexTraceResponse

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Source	Tracker
Destination	Forecaster
Functional requirement D1.1	Send Heat Provider Flexibility Information - IEX_06
localRESCurtailmentMitigation	True
systemRESCurtailmentMitigation	
balancingServices	
Interaction	FlexRange
Interface	I_FD, I_TD
Description	Send flexibility information, as a set of traces which include incentives vs consumption plans
Return values	Succes/fail

Atribute name	***Type of entry***	***Description***
vDERID	Mandatory	Identifier of the vDER
Start	Mandatory	Timestamp from which the forecaster gets information about traces
End	Mandatory	Timestamp until which the forecaster gets information about traces
ConsumptionProfilePTUs	Mandatory	List of PTUs included, defined each one by its beginning, end and duration
ConsumptionProfileValues	Mandatory	Average power during each PTU that is forecasted
ConsumptionProfileType	Mandatory	Type of profile (P2H, BUILDING, UNCONTROLLABLE_LOADS)
IncentiveValues	Mandatory	Value of the incentive for each PTU
IncentiveType	Mandatory	ABSOLUTE or RELATIVE
BaselineID	Conditional	Baseline reference used for RELATIVE incentives
IncentiveUnit	Mandatory	Units used for the incentive

4.4 FlexNegotiationBalancer interaction

The negotiation of flexibility between the BRP and the DCM follows the following steps

- The balancer calculates the flexibility that it would need from each DCM, by means of function BA03, and sends a **BU_FlexRequest** (see ***Figure 9***) to each Usefer, and this is translated, US05 function, and forwarded to the planner (**UP_FlexRequestBalancer** message). The content of the flex request is how much consumption increase does the BRP desire in each PTU. In the scope of systemDERCurtailmentMitigation use case it is to avoid that some DERs cannot sell their production due to low or even negative market prices, while in the case of the balancingServices the intention is to act on the imbalance position of the BRP. In most of the cases the amount of flex requested by the balancer is defined, but in the case of balancingServices, when the BRP

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has a power shortfall and the imbalance prices are negative, then the amount of flex requested would be unconstrained.

- Then, as a consequence of the reception of a flex request, the planner executes the PL03 function which launches the execution of the IncentiveFlexPlan interaction (see ***Figure 11***). Once this interaction comes to an end, in planner function PL04, the execution thread returns to the FlexNegotiationBalancer interaction.
- As a response to the flex request, the planner will send one or more flex offers, each one in a **PU_FlexOfferBalancer** message. The Usefer will translate those messages in to **UB_FlexOffer** using the US07 function and deliver the messages to the balancer. The flex offer contains the amount of flex per PTU that the DCM offers to deliver, together with a price requested for the service. Several different offers can be presented by the same planner, with different flex profiles and prices.
- Then the BRP will assess which combination of flex offers presented by the planners will be selected and ordered (BA04 function), depending on the business logic of each business case. For each selected offer (one per DCM as maximum), the balancer will send **a BU_FlexOrder**. Each flex offer will be ordered in its totality, i.e. the ordered flex profile has to be identical to the offered flex profile. This constraint is introduced due the nature of P2H systems, as flex offers come from a rescheduling in which energy is shifted in time, so no concrete flex can be ordered separately in some PTUs. The Usefer will translate those messages into **UP_FlexOrderBalancer** messages using the US06 function.
- Anyway, once the order comes to the planner, the planner has the right to either decline or accept the order via the **PU_FlexOrderResponse** message. This is due to the fact that in the systemDERCurtailmentMitigation use case, the DCM has the chance to make the DSO and the BRP compete for its flexibility, once the flex is ordered to the planner. The Usefer will translate those messages into **UB_FlexOrderResponse** messages using the US09 function.

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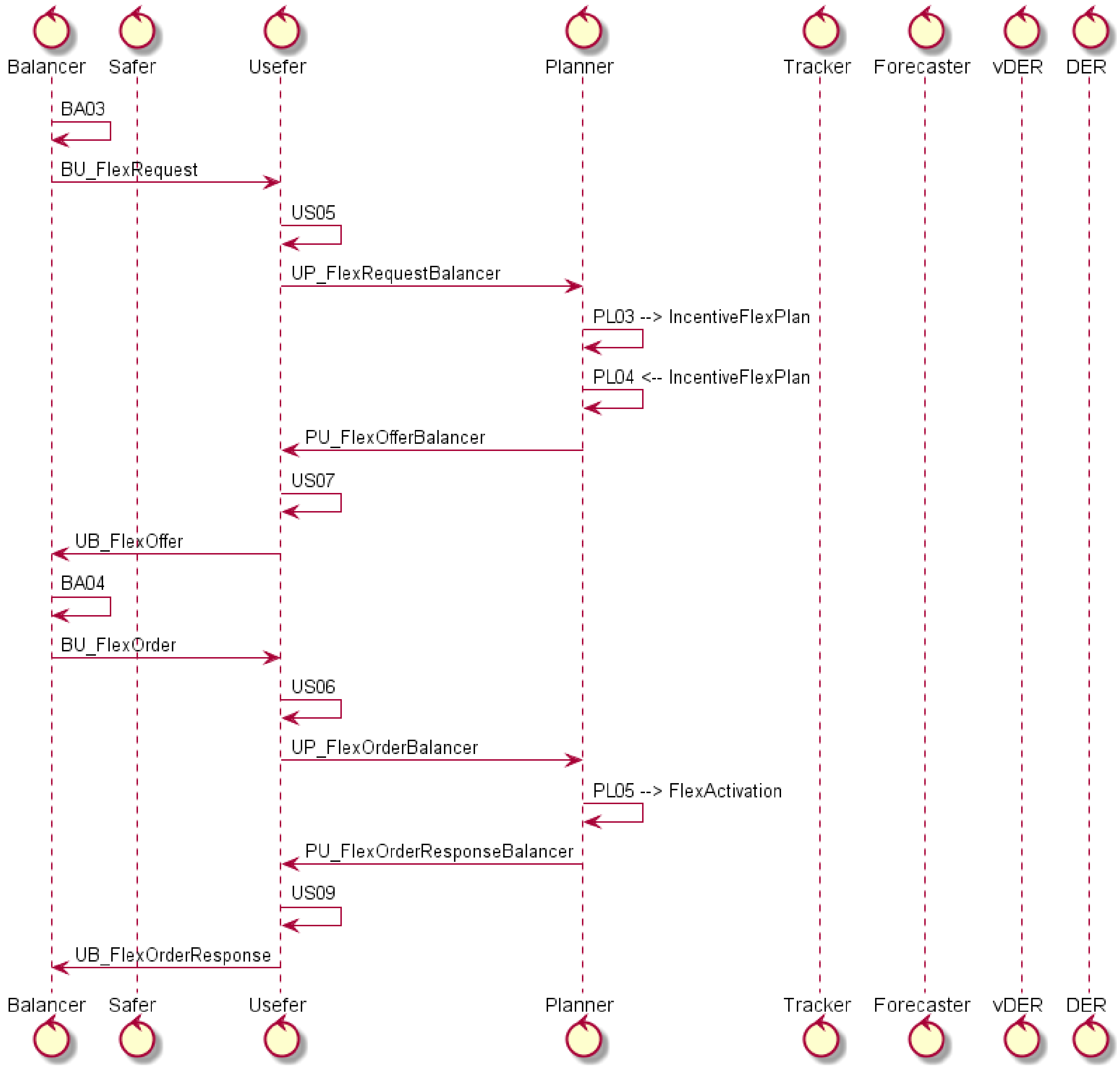

Figure 9: FlexNegotiationBalancer interaction

4.4.1 BU_FlexRequest message

Message name	BU_FlexRequest
Source	Balancer
Destination	Usefer
Functional requirement D1.1	Send System Flex Request - IEX_16
localRESCurtailmentMitigation	
systemRESCurtailmentMitigation	True
balancingServices	True
Interaction	FlexNegotiationBalancer
Interface	I_BU
Description	The balancer sends a flex request to a DCM
Return values	Succes/fail

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Atribute name	***Type of entry***	***Description***
DCMID	Mandatory	Identifier of the destination DCM
PrognosisID	Mandatory	Identifier of the UB_Prognosis that has originated the reaction of the balancer
BalancingGroupID	Mandatory	BalancingGroupID defined by the BRP
PTUs	Mandatory	List of PTUs included, defined each one by its beginning, end and duration
Disposition	Mandatory	"Requested" for all PTUs
RequestedFlex	Mandatory	Variation of average power during each PTU that is requested to the DCM for the BalancingGroupID, refered to a certain PrognosisID. A negative value means decrease of consumption and a positive value increase of consumption

4.4.2 UP_FlexRequestBalancer message

Message name	UP_FlexRequestBalancer
Source	Usefer
Destination	Planner
Functional requirement D1.1	Send System Flex Request - IEX_16
localRESCurtailmentMitigation	
systemRESCurtailmentMitigation	True
balancingServices	True
Interaction	FlexNegotiationBalancer
Interface	I_UD, I_PD
Description	SThe usefer sends a system flex request to the planner
Return values	Succes/fail

Atribute name	***Type of entry***	***Description***
DCMID	Mandatory	Identifier of the destination DCM. Copied from the BU_FlexRequest
PrognosisID	Mandatory	Identifier of the UP_Prognosis that has originated the reaction of the balancer
BalancingGroupID	Mandatory	BalancingGroupID managed by the BRP. Copied from the BU_FlexRequest
PTUs	Mandatory	List of PTUs included, defined each one by its beginning, end and duration. Copied from the BU_FlexRequest
Disposition	Mandatory	"Requested". Copied from BU_FlexRequest
RequestedFlex	Mandatory	Variation of average power during each PTU that is requested to the DCM for the grid zone, refered to a certain UB_Prognosis . Copied from the BU_FlexRequest

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4.4.3 PU_FlexOfferBalancer message

Message name	PU_FlexOfferBalancer
Source	Planner
Destination	Usefer
Functional requirement D1.1	Send System Flex Offer - IEX_15
localRESCurtailmentMitigation	
systemRESCurtailmentMitigation	True
balancingServices	True
Interaction	FlexNegotiationBalancer
Interface	I_UD, I_PD
Description	The planner sends to the usefer a system flex offer
Return values	Succes/fail

Atribute name	***Type of entry***	***Description***
BRPID	Mandatory	Identifier of the destination BRP
FlexRequestID	Mandatory	Identifier of the UP_FlexRequestBalancer associated to this FlexOrder
BalancingGroupID	Mandatory	BalancingGroupID defined by the BRP
PTUs	Mandatory	List of PTUs included, defined each one by its beginning, end and duration.It can contain addtional PTUs to those contained in the UP_FlexRequest
OfferedFlex	Mandatory	Variation of average power during each PTU that is offered to the BRP for the balancing group, refered to a certain FlexRequest. A negative value means decrease of consumption and a positive value increase of consumption
OfferedPrice	Mandatory	Payment that the DCM asks for the offered flex

4.4.4 UB_FlexOffer message

Message name	UB_FlexOffer
Source	Usefer
Destination	Balancer
Functional requirement D1.1	Send System Flex Offer - IEX_15
localRESCurtailmentMitigation	
systemRESCurtailmentMitigation	True
balancingServices	True
Interaction	FlexNegotiationBalancer
Interface	I_BU
Description	The usefer sends to the balancer a system flex offer
Return values	Succes/fail

Atribute name	***Type of entry***	***Description***

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BRPID	Mandatory	Identifier of the destination BRP
FlexRequestID	Mandatory	Identifier of the FlexRequest associated to this FlexOffer
BalancingGroupID	Mandatory	BalancingGroupID defined by the BRP
PTUs	Mandatory	List of PTUs included, defined each one by its beginning, end and duration. It must contain at least all the PTUs contained in the FlexRequest, but other PTUs can be contained if the flex offered affects other PUTs, i.e. if the group consumption plan differs from the consumption plan for other PTUs. The reason is that the DCM in order to get the requested flex could need to alter its consumption profile for other PTUs, as the P2H assets managed by the vDERs hold thermal inertia, and the BRP would need to accept also the payback effect related to the flexibility provision in case of accepting the flex offer
OfferedFlex	Mandatory	Variation of average power during each PTU that is offered to the BRP for the balancing group, refered to a certain FlexRequest. A negative value means decrease of consumption and a positive value increase of consumption
OfferedPrice	Mandatory	Payment that the DCM asks for the offered flex

4.4.5 BU_FlexOrder message

Message name	BU_FlexOrder
Source	Balancer
Destination	Usefer
Functional requirement D1.1	Receive System Flex Order - IEX_20
localRESCurtailmentMitigation	
systemRESCurtailmentMitigation	True
balancingServices	True
Interaction	FlexNegotiationBalancer
Interface	I_BU
Description	BRP confirms the system flex offer with a system flex order
Return values	Succes/fail

Atribute name	***Type of entry***	***Description***
DCMID	Mandatory	Identifier of the destination DCM
FlexOfferID	Mandatory	Identifier of the FlexOffer associated to this FlexOrder
BalancingGroupID	Mandatory	BalancingGroupID defined by the BRP
PTUs	Optional	List of PTUs (which must be identical to those included in the flex offer), defined each one by its beginning, end and duration
OrderedFlex	Optional	Variation of average power during each PTU that is ordered to the DCM for the balancing group, refered to a certain FlexOffer. A negative value means decrease of consumption and a positive value increase of consumption. It has to be identical to the flex offered by the DCM, OfferedFlex, as the

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		BRP just can accept the flex offer as it is presented by the DCM (not a part of it)
OrderedPrice	Optional	Payment that the DSO offers for flex to the DCM, as response to the OfferedPrice. If not included, the OfferedPrice is applied

4.4.6 UP_FlexOrderBalancer message

Message name	UP_FlexOrderBalancer
Source	Usefer
Destination	Planner
Functional requirement D1.1	Receive System Flex Order - IEX_20
localRESCurtailmentMitigation	
systemRESCurtailmentMitigation	True
balancingServices	True
Interaction	FlexNegotiationBalancer
Interface	I_UD, I_PD
Description	The Usefer sends to the planner a system flex order
Return values	Succes/fail

Atribute name	***Type of entry***	***Description***
DCMID	Mandatory	Identifier of the destination DCM. Copied from the BU_FlexOrder
FlexOfferID	Mandatory	Identifier of the PU_FlexOffer associated to this FlexOrder
BalancingGroupID	Mandatory	BalancingGroupID managed by the BRP. Copied from the BU_FlexOrder
PTUs	Conditional. Present if included in the BU_FlexOrder or SU_FlexOrder	List of PTUs (which must be identical to those included in the PU_FlexOffer), defined each one by its beginning, end and duration. Copied from the BU_FlexOrder
OrderedFlex	Conditional. Present if included in the BU_FlexOrder or SU_FlexOrder	Variation of average power during each PTU that is ordered to the DCM for thebalancing group, identical to those in the PU_FlexOfferBalancer. Copied from the BU_FlexOrder
OrderedPrice	Conditional. Present if included in the BU_FlexOrder or SU_FlexOrder	Payment that the BRP offers for flex to the DCM, as response to the OfferedPrice. If not included, the OfferedPrice is applied. Copied from the BU_FlexOrder

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4.4.7 PU_FlexOrderResponseBalancer message

Message name	PU_FlexOrderResponseBalancer
Source	Planner
Destination	Usefer
Functional requirement D1.1	Send System Flex Request Accept - IEX_19
localRESCurtailmentMitigation	
systemRESCurtailmentMitigation	True
balancingServices	True
Interaction	FlexNegotiationBalancer
Interface	I_PD, I_UD
Description	The planner confirms to the Usefer the acceptance or denial of a system flex order
Return values	Succes/fail

Atribute name	***Type of entry***	***Description***
BRPID	Mandatory	Identifier of the destination BRP
FlexOrderID	Mandatory	Identifier of the UP_FlexOrder associated to this FlexOrderResponse
BalancingGroupID	Mandatory	BalancingGroupID defined by the BRP
PTUs	Optional	List of PTUs included, defined each one by its beginning, end and duration. Identical to those ones in the UP_FlexOrder
OrderedFlex	Optional	Variation of average power during each PTU that has been ordered by the BRP for the balancing group, refered to a certain FlexRequest. A negative value means decrease of consumption and a positive value increase of consumption. Identical to those ones in the UP_FlexOrder
OrderedPrice	Optional	Payment that the BRP included in the UP_FlexOrder
Result	Mandatory	"Accepted" or "Rejected"

4.4.8 UB_FlexOrderResponse message

Message name	UB_FlexOrderResponse
Source	Usefer
Destination	Balancer
Functional requirement D1.1	Send System Flex Request Accept - IEX_19
localRESCurtailmentMitigation	
systemRESCurtailmentMitigation	True
balancingServices	True
Interaction	FlexNegotiationBalancer
Interface	I_BU
Description	Inform BRP that the system flex order is accepted or rejected
Return values	Succes/fail

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Atribute name	*Type of entry*	*Description*
BRPID	Mandatory	Identifier of the destination BRP
FlexOrderID	Mandatory	Identifier of the FlexOrder associated to this FlexOrderResponse
BalancingGroupID	Mandatory	BalancingGroupID defined by the BRP
PTUs	Optional	List of PTUs (which must be identical to those included in the flex offer), defined each one by its beginning, end and duration
OrderedFlex	Optional	Variation of average power during each PTU that is ordered by the BRP, identical to that included in the FlexOrder. A negative value means decrease of consumption and a positive value increase of consumption
OrderedPrice	Optional	Payment that the BRP included in the FlexOrder
Result	Mandatory	"Accepted" or "Rejected"

4.5 FlexNegotiationSafer interaction

The process of flex negotiation between the safer and the planners is systematically identical to that one described in the previous section (FlexNegoatiationSafer interaction).

The only differences that can be found are:

- The DSO knows the flex range for each group, as gathered in SA04 from the FlexRange interaction
- DSO executes function SA02 to collect the forecasts from generators and non-active buildings that it will need to execute function SA05
- The DSO executes function SA05 to determine if it envisages any grid constraint violation
- If that is the case, the DSO executes function SA06 to determine its flexibility needs
- The DSO executes function SA08 to compose the flex requests and include the grid capacity constraints, as in the SU_FlexRequest message the DSO can additionnaly impose some capacity range constraints in the PTUs that are not included in the flex request itself. The concept of the capacity range is applied also in balancingServices, in which there is no time for the DSO to check if the flexibility provided by the DCM to the grid produces any local grid constraint violation. In order to avoid this local check, the DSO calculates for the subsequent PTU, which is the capacity range for each grid zone and for each DCM. The capacity range represents the allowed variation of D-prognosis, both upwards and downwards, in which a DCM can modify its consumption without explicit permission of the DSO, because that scheduling does not compromise grid constraints.
- Flex is requested, offered and ordered per grid zone instead of per balancing group.
- The DSO decides which flex offers to be ordered thsnks to SA07

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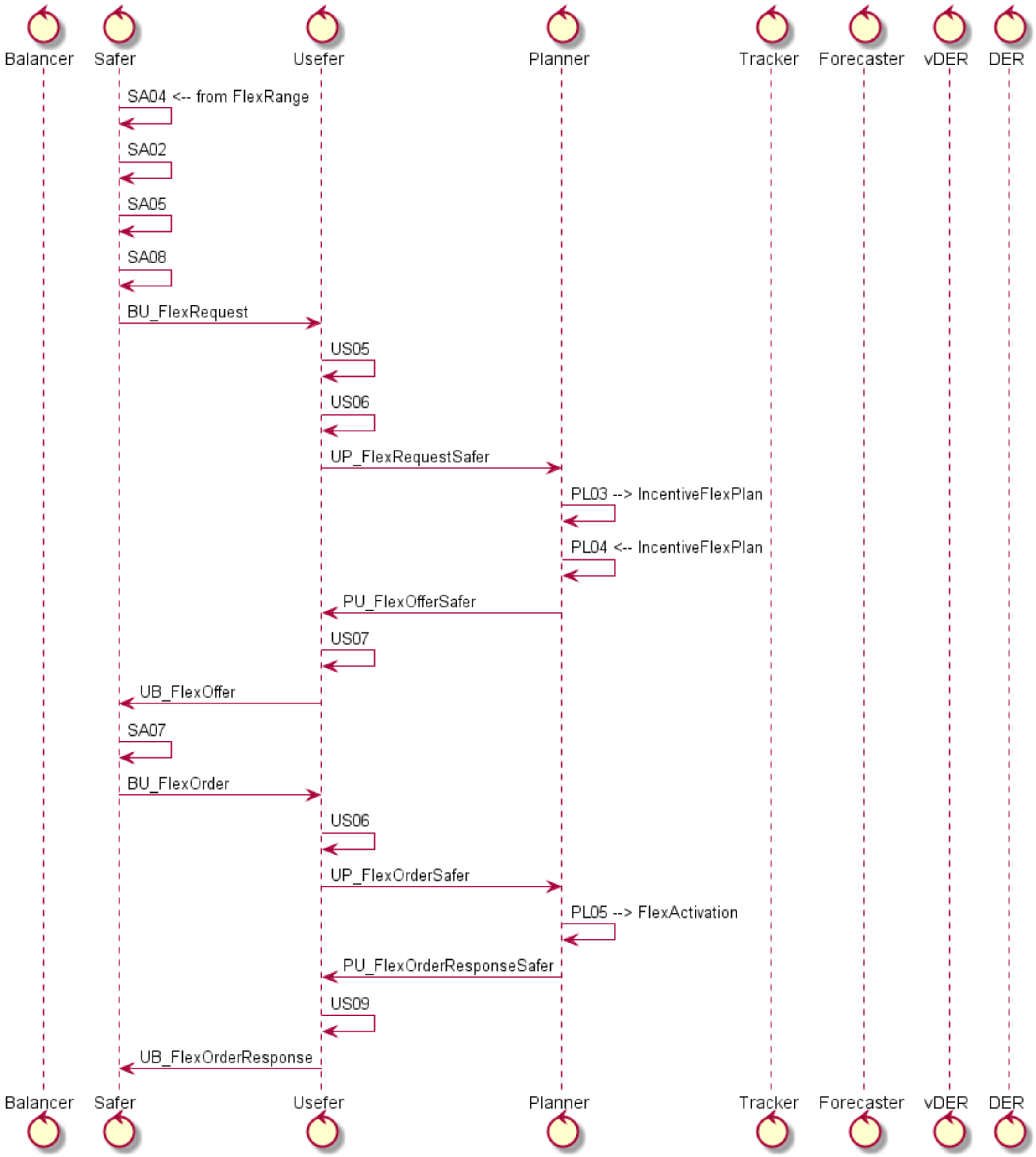

Figure 10: FlexNegotiationSafer interaction

4.5.1 SU_FlexRequest message

Message name	SU_FlexRequest
Source	Safer
Destination	Usefer
Functional requirement D1.1	Send Local Flex Request - IEX_07
localRESCurtailmentMitigation	True
systemRESCurtailmentMitigation	True
balancingServices	
Interaction	FlexNegotiationSafer

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Interface	I_SU
Description	The safer sends a local flex request to a DCM
Return values	Succes/fail

Atribute name	***Type of entry***	***Description***
DCMID	Mandatory	Identifier of the destination DCM
PrognosisID	Mandatory	Identifier of the US_Prognosis that has originated the reaction of the safer
GridZoneID	Mandatory	GridZoneID defined by the DSO
PTUs	Mandatory	List of PTUs included, defined each one by its beginning, end and duration
Disposition	Mandatory	"Requested" if flex is requested for a PTU or "available" if it refers to a capacity range
RequestedFlex	Mandatory	Variation of average power during each PTU that is requested to the DCM for the grid zone, refered to a certain PrognosisID. A negative value means decrease of consumption and a positive value increase of consumption

4.5.2 UP_FlexRequestSafer message

Message name	UP_FlexRequestSafer
Source	Usefer
Destination	Planner
Functional requirement D1.1	Send Local Flex Request - IEX_07
localRESCurtailmentMitigation	True
systemRESCurtailmentMitigation	True
balancingServices	
Interaction	FlexNegotiationSafer
Interface	I_PD, I_UD
Description	The usefer sends a local flex request to the planner
Return values	Succes/fail

Atribute name	***Type of entry***	***Description***
DCMID	Mandatory	Identifier of the destination DCM. Copied from the SU_FlexRequest
PrognosisID	Mandatory	Identifier of the UP_Prognosis that has originated the reaction of the safer
GridZoneID	Mandatory	GridZoneID defined by the DSO. Copied from the SU_FlexRequest
PTUs	Mandatory	List of PTUs included, defined each one by its beginning, end and duration. Copied from the SU_FlexRequest
Disposition	Mandatory	"Requested" or "Available", Copied from the SU_FlexRequest

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RequestedFlex	Mandatory	Variation of average power during each PTU that is requested to the DCM for the grid zone, refered to a certain US_Prognosis Copied from the SU_FlexRequest

4.5.3 PU_FlexOfferSafer message

Message name	PU_FlexOfferSafer
Source	Planner
Destination	Usefer
Functional requirement D1.1	Send Local Flex Offer - IEX_10
localRESCurtailmentMitigation	True
systemRESCurtailmentMitigation	True
balancingServices	
Interaction	FlexNegotiationSafer
Interface	I_PD, I_UD
Description	The planner sends to the usefer a local flex offer
Return values	Succes/fail

Atribute name	***Type of entry***	***Description***
DSOID	Mandatory	Identifier of the destination DSO
FlexRequestID	Mandatory	Identifier of the UP_FlexRequest associated to this FlexOrder
GridZoneID	Mandatory	GridZoneID defined by the DSO
PTUs	Mandatory	List of PTUs included, defined each one by its beginning, end and duration.
OfferedFlex	Mandatory	Variation of average power during each PTU that is offered to the DSO for the grid zone, refered to a certain FlexRequest. A negative value means decrease of consumption and a positive value increase of consumption
OfferedPrice	Mandatory	Payment that the DCM asks for the offered flex

4.5.4 US_FlexOffer message

Message name	US_FlexOffer
Source	Usefer
Destination	Safer
Functional requirement D1.1	Send Local Flex Offer - IEX_10
localRESCurtailmentMitigation	True
systemRESCurtailmentMitigation	True
balancingServices	
Interaction	FlexNegotiationSafer
Interface	I_SU
Description	The usefer sends to the safer a local flex offer
Return values	Succes/fail

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Atribute name	*Type of entry*	*Description*
DSOID	Mandatory	Identifier of the destination DSO
FlexRequestID	Mandatory	Identifier of the FlexRequest associated to this FlexOrder
GridZoneID	Mandatory	GridZoneID defined by the DSO
PTUs	Mandatory	List of PTUs included, defined each one by its beginning, end and duration. It must contain all the PTUs contained in the FlexRequest, it is not needed to provide the payback effect in other PTUs has the DSO may already have informed to the DCM about the capacity range in those PTUs of the FlexRequest in which the Disposition was "Available". It is assumed that the DCM must follow that capacity range constraints
OfferedFlex	Mandatory	Variation of average power during each PTU that is offered to the DSO for the grid zone, refered to a certain FlexRequest. A negative value means decrease of consumption and a positive value increase of consumption
OfferedPrice	Mandatory	Payment that the DCM asks for the offered flex

4.5.5 SU_FlexOrder message

Message name	SU_FlexOrder
Source	Safer
Destination	Usefer
Functional requirement D1.1	Send Local Flex Order - IEX_11
localRESCurtailmentMitigation	True
systemRESCurtailmentMitigation	True
balancingServices	
Interaction	FlexNegotiationSafer
Interface	I_SU
Description	DSO confirms the local flex offer with a local flex order
Return values	Succes/fail

Atribute name	*Type of entry*	*Description*
DCMID	Mandatory	Identifier of the destination DCM
FlexOfferID	Mandatory	Identifier of the FlexOffer associated to this FlexOrder
GridZoneID	Mandatory	GridZoneID defined by the DSO
PTUs	Optional	List of PTUs (which must be identical to those included in the flex offer), defined each one by its beginning, end and duration
OrderedFlex	Optional	Variation of average power during each PTU that is ordered to the DCM for the grid zone, refered to a certain FlexOffer. A negative value means decrease of consumption and a positive value increase of consumption

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OrderedPrice	Optional	Payment that the BRP offers for flex to the DCM, as response to the OfferedPrice. If not included, the OfferedPrice is applied

4.5.6 UP_FlexOrderSafer message

Message name	UP_FlexOrderSafer
Source	Usefer
Destination	Planner
Functional requirement D1.1	Send Local Flex Order - IEX_11
localRESCurtailmentMitigation	True
systemRESCurtailmentMitigation	True
balancingServices	
Interaction	FlexNegotiationSafer
Interface	I_PD, I_UD
Description	The Usefer sends to the planner a local flex order
Return values	Succes/fail

Atribute name	***Type of entry***	***Description***
DCMID	Mandatory	Identifier of the destination DCM. Copied from the SU_FlexOrder
FlexOfferID	Mandatory	Identifier of the PU_FlexOffer associated to this FlexOrder
GridZoneID	Mandatory	GridZoneID defined by the DSO. Copied from the SU_FlexOrder
PTUs	Conditional. Present if included in the BU_FlexOrder or SU_FlexOrder	List of PTUs (which must be identical to those included in the PU_FlexOffer), defined each one by its beginning, end and duration. Copied from the SU_FlexOrder
OrderedFlex	Conditional. Present if included in the BU_FlexOrder or SU_FlexOrder	Variation of average power during each PTU that is ordered to the DCM for the grid zone, identical to those in the PU_FlexOfferSafer. Copied from the SU_FlexOrder
OrderedPrice	Conditional. Present if included in the BU_FlexOrder or SU_FlexOrder	Payment that the BRP offers for flex to the DCM, as response to the OfferedPrice. If not included, the OfferedPrice is applied. Copied from the SU_FlexOrder

4.5.7 PU_FlexOrderResponseSafer message

Message name	PU_FlexOrderResponseSafer
Source	Planner

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Destination	Usefer
Functional requirement D1.1	Send Local Flex Order Accept - IEX_17 Send Local Flex Order Decline - IEX_18
localRESCurtailmentMitigation	True
systemRESCurtailmentMitigation	True
balancingServices	
Interaction	FlexNegotiationSafer
Interface	I_PD, I_UD
Description	Inform DSO that the local flex order is accepted or rejected
Return values	Succes/fail

Atribute name	***Type of entry***	***Description***
DSOID	Mandatory	Identifier of the destination DSO
FlexOrderID	Mandatory	Identifier of the UP_FlexOrder associated to this FlexOrderResponse
GridZoneID	Mandatory	GridZoneID defined by the DSO
PTUs	Optional	List of PTUs included, defined each one by its beginning, end and duration. Identical to those ones in the UP_FlexOrder
OrderedFlex	Optional	Variation of average power during each PTU that has been ordered by the DSO for the grid zone, refered to a certain FlexRequest. A negative value means decrease of consumption and a positive value increase of consumption. Identical to those ones in the UP_FlexOrder
OrderedPrice	Optional	Payment that the BRP included in the UP_FlexOrder
Result	Mandatory	"Accepted" or "Rejected"

4.5.8 US_FlexOrderResponse message

Message name	US_FlexOrderResponse
Source	Usefer
Destination	Safer
Functional requirement D1.1	Send Local Flex Order Accept - IEX_17 Send Local Flex Order Decline - IEX_18
localRESCurtailmentMitigation	True
systemRESCurtailmentMitigation	True
balancingServices	
Interaction	FlexNegotiationSafer
Interface	I_SU
Description	Inform DSO that no local flex service will be provided
Return values	Succes/fail

Atribute name	***Type of entry***	***Description***

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DSOID	Mandatory	Identifier of the destination DSO
FlexOrderID	Mandatory	Identifier of the FlexOrder associated to this FlexOrderResponse
GridZoneID	Mandatory	GridZoneID defined by the DSO
PTUs	Optional	List of PTUs (which must be identical to those included in the flex offer), defined each one by its beginning, end and duration
OrderedFlex	Optional	Variation of average power during each PTU that is offered to the DSO for the grid zone, refered to a certain FlexOrder. A negative value means decrease of consumption and a positive value increase of consumption
OrderedPrice	Optional	Payment that the DSO included in the FlexOrder
Result	Mandatory	"Accepted" or "Rejected"

4.6 IncentiveFlexPlan interaction

When a flex request comes to the planner, either from the balancer or from the safer, the function PL04 of the planner is launched. This function is triggered by either the FlexNegotiationSafer or FlexNegotiationBalancer activities. Then, the planner will propose a flex plan to the tracker for the involved aggregation levels (clusters), as a continuation of the execution of PL03. The consumption plan will be calculated based in the latest previous prognosis of those clusters sent to the safer/balancer before the flex request, and adding to it the flex requested in form of a flex range. The result of this addition is the cluster consumption plan that the tracker would follow, which will be the content of the **PT_FlexPlanRequest** message.

The tracker will execute in TR02 an algorithm that will propose incentives to the vDERs so as to stimulate a change in its consumption profile (a new consumption plan) aligned with the cluster flex plan. The incentives will be sent in a **TV_IncentiveOffer** message. Two kinds of incentives are defined:

- Absolute incentives (or shadow prices): The heat provider receives an incentive (per PTU) that is applied to its whole consumption. If the incentive is positive the heat provider gets money from the coalition manager for each kwh consumed in that PTU, and if the incentive is negative it is the heat provider who pays for it[9]. The incentive from the DCM is independent from the price that the heat provider pays for the electricity purchased to the retailer, so at the end, the incentive can be seen by the heat provider as a penalty or discount over the standard retail price.
- Relative incentives: The heat provider earns money for the flex provided, i.e. for the deviation from the baseline when this deviation is in the same direction proposed by the tracker (either increase or decrease of consumption).

Anyway, once an incentive is received the vDER will calculatein VD04 how would it be its consumption profile in those conditions, what is called a consumption plan. This new offer of incentives is indeed one

[9] In the contract between these roles some rules for defining the compensation between negative and positive absolute incentives should be defined, so that the distribution of incentives is balanced.

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of the input conditions for the need for update the vDER consumption profile. The vDER consumption plan will be sent to the tracker using a **VT_IncentiveResponse** message.

The business logic in the tracker function TR02 will callback and decide up to what point iterate the incentive offers until the cluster responded flex plan converges to the requested cluster flex plan. In this process it is possible that the tracker could decide several different flex plans, based on different levels of incentives offered to the vDERs. For each of the flex plans the tracker will generate a **TP_FlexPlanResponse** message in which the cluster flex plan is given together with a requested price for enabling this flexibility. This price will be calculated taking into account both the expected spending (or incomes) on incentives plus the commercial margin of the DCM.

Then, based on these cluster flex plans, the planner will continue with the execution of PL04 and hence the the flex negotiation interaction, offering the flex to the balancer/safer that results from the difference between each flex plan and the reference flex profile.

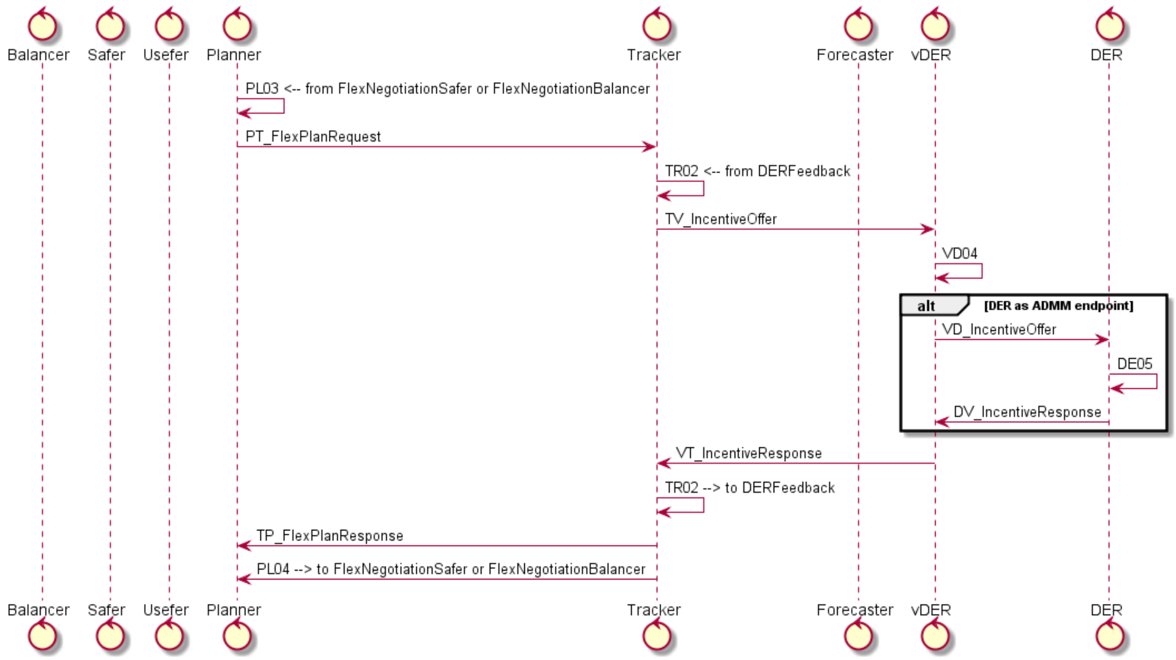

Figure 11: IncentiveFlexPlan interaction

4.6.1 PT_FlexPlanRequest message

Message name	PT_FlexPlanRequest
Source	Planner
Destination	Tracker
Functional requirement D1.1	
localRESCurtailmentMitigation	True
systemRESCurtailmentMitigation	True
balancingServices	
Interaction	IncentiveFlexPlan
Interface	I_TD, I_PD

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Description	The planner has received an external flex request and cerates a consumption plan that communicates to the tracker
Return values	Success/Fail

Atribute name	***Type of entry***	***Description***
FlexPlan	Mandatory	Active energy per PTU that the tracker should try to get from a cluster of vDERs, either associated to a balancing group or to a grid zone. The active energy value would be the result of the sum of the latest prognosis for that PTU plus the requested flex by the balancer/safer
PrognosisID	Mandatory	Identifier of the prognosis that has originated the reaction of the safer/balancer
GridZoneID	Conditional. Needed if the message comes from the safer	GridZoneID defined by the DSO
BalancingGroupID	Conditional. Needed if the message comes from the balancer	BalancingGroupID defined by the BRP
PTUs	Mandatory	List of PTUs included, defined each one by its beginning, end and duration
Disposition	Mandatory	"Requested" if flex is requested for a PTU or "available" if it refers to a capacity range

4.6.2 TP_FlexPlanResponse message

Message name	TP_FlexPlanResponse
Source	Tracker
Destination	Planner
Functional requirement D1.1	
localRESCurtailmentMitigation	True
systemRESCurtailmentMitigation	True
balancingServices	
Interaction	IncentiveFlexPlan
Interface	I_TD, I_PD
Description	The result of the FlexPlan gets to the planner
Return values	Success/fail

Atribute name	***Type of entry***	***Description***
ConsumptionPlan	Mandatory	Cluster consumption plan that the tracker has achieved, for a grid zone or balancing group, in response to the flex plan

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FlexRequestID	Mandatory	Identifier of the FlexRequest that has originated the reaction of the DCM
GridZoneID	Conditional. Needed if the message goes to the safer	GridZoneID defined by the DSO
BalancingGroupID	Conditional. Needed if the message goes to the balancer	BalancingGroupID defined by the BRP
PTUs	Mandatory	List of PTUs included, defined each one by its beginning, end and duration

4.6.3 TV_IncentiveOffer message

Message name	TV_IncentiveOffer
Source	Tracker
Destination	vDER
Functional requirement D1.1	Send Heat Provider Incentive - IEX_08
localRESCurtailmentMitigation	True
systemRESCurtailmentMitigation	True
balancingServices	
Interaction	IncentiveFlexPlan
Interface	I_TD, I_DV
Description	The tracker requests the vDER the consumption plan based on the submitted shadow prices.
Return values	Success/fail

Atribute name	***Type of entry***	***Description***
IncentiveValues	Mandatory	An incentive (shadow) price profile send by Tracker to each vDER (this signal would be identical for each vDER)
ADMMsetting	Once Needed for each Building	some additional ADMM parameters to increase convergence rate. (Gowri, can you elaborate more on this?)
PTUs	Mandatory	List of PTUs included, defined each one by its beginning, end and duration
IncentiveUnit	Mandatory	Units used for the incentive
IncentiveType	Mandatory	ABSOLUTE or RELATIVE

4.6.4 VT_IncentiveResponse message

Message name	VT_IncentiveResponse

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Source	vDER
Destination	Tracker
Functional requirement D1.1	Send Heat Provider Consumption Profile - IEX_09
localRESCurtailmentMitigation	True
systemRESCurtailmentMitigation	True
balancingServices	
Interaction	IncentiveFlexPlan
Interface	I_DV, I_TD
Description	Send the consumption plan associated to the received incentive / price profile
Return values	Succes/fail

Atribute name	***Type of entry***	***Description***
Response	Accept/Reject	Indicates if the vDER is willing to modify its consumption profile in response to the incentive received
ConsumptionPlan	Mandatory	Consumption profile that a vDER estimates it would have, if the incentives for which the plan is calculated are activated
IncentiveOfferID	Mandatory	Identifier of the IncentiveOffer that has originated the reaction of the vDER
PTUs	Mandatory	List of PTUs included, defined each one by its beginning, end and duration

4.7 FlexActivation interaction

Coming from a PL05 function in a flex negotiation interaction, and as a consequence of the acceptance of a flex order by the planner, either coming from the safer or from the balancer, the planner will send to the tracker a **PT_ActivateFlexOrder**.

The tracker will recover the incentives associated with the flex plan from which the flex offer was generated, and will send to the vDER an activation command, **TV_ActivateIncentives** message, for those incentives.

Once an incentive is activated, the vDER will check in VD05 if the operating conditions associated with the referred flex plan is identical to the current operating conditions. In case so, the AssetControl interaction will be launched as the control schedules that correspond to the flex plan are up to date. If there have been variations in the operating conditions, the vDER should previously get the updated control schedules with the current operating conditions and the activated incentives.

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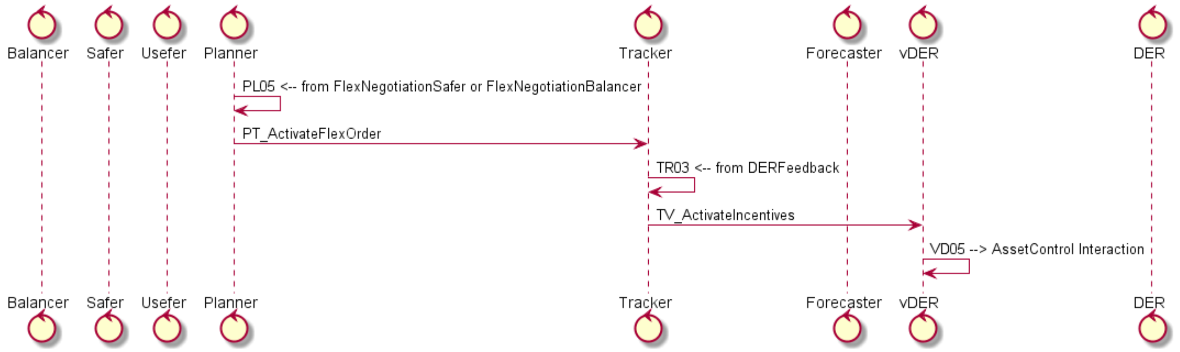

Figure 12: FlexActivation interaction

4.7.1 PT_ActivateFlexOrder message

Message name	PT_ActivateFlexOrder
Source	Planner
Destination	Tracker
Functional requirement D1.1	Send Heat Provider Consumption Plan - IEX_12
localRESCurtailmentMitigation	True
systemRESCurtailmentMitigation	True
balancingServices	True
Interaction	FlexActivation
Interface	I_PD, I_TD
Description	Update the Heat Provider consumption plans (this can be through a corresponding incentive signal for instance)
Return values	Succes/fail

Atribute name	***Type of entry***	***Description***
FlexPlanResponseID	Needed	Identifier of the FlexPlanResponse to which this activation refers to
ConsumptionPlan	Optional	Cluster consumption plan that was offered by the tracker in the FlexPlanResponse
PTUs	Conditional. Needed if Consumption Plan is included	List of PTUs included

4.7.2 TV_ActivateIncentives message

Message name	TV_ActivateIncentives
Source	Tracker
Destination	vDER
Functional requirement D1.1	Send Heat Provider Consumption Plan - IEX_12

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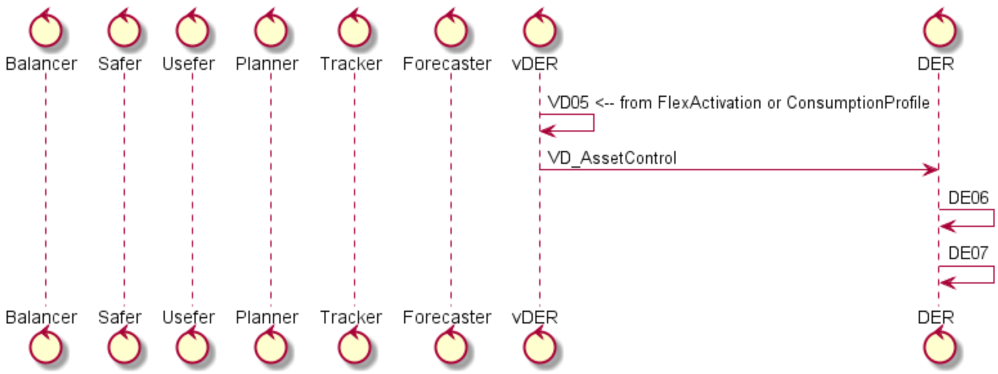
localRESCurtailmentMitigation	True
systemRESCurtailmentMitigation	True
balancingServices	True
Interaction	FlexActivation
Interface	I_TD, I_DV
Description	Update the Heat Provider consumption plans (this can be through a corresponding incentive signal for instance)
Return values	Succes/fail

Atribute name	***Type of entry***	***Description***
IncentiveResponseID	Needed	Identifier of the IncentiveResponse to which this activation refers to
PTUs	Conditional. Needed if Consumption Plan is included	List of PTUs included, defined each one by its beginning, end and duration
ConsumptionPlan	Optional	vDER consumption plan that was offered by the vDER in the IncentiveResponse

4.8 AssetControl interaction

This interaction is launched once a vDER remakes its consumption profile in VD05, due to a variation in the operating conditions (from the ConsumptionProfile interaction) or to the activation of incentives (from the FlexActivation interaction). The control schedules, sent to the DER in the **VD_AssetControl** message, include the control setpoints of whatever P2H system which has been the objective of the building optimization algorithm (room temperature setpoints, heat pump supply temperature, heat pump electrical consumption, heat pump thermal production, accumulator tank temperature…). These sequences will be forwarded to the DER assets in DE06[10] and backup-controller in DE07 will optionally supervise its execution and execute an override if comfort constraints are violated



[10] The message between the DER and the DER asset will be mapped on the propietary protocolo of the DER asset

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Figure 13: AssetControl interaction

4.8.1 VD_AssetControl message

Message name	VD_AssetControl
Source	vDER
Destination	DER
Functional requirement D1.1	Send Heat Users Settings - IEX_13
localRESCurtailmentMitigation	True
systemRESCurtailmentMitigation	True
balancingServices	True
Interaction	AssetControl
Interface	I_VD
Description	The vDER dictates the power consumption of the heat pump The vDER dictates the supply temp of the heat pump The vDER dictates some room setpoint temperatures
Return values	Succes/fail

Atribute name	***Type of entry***	***Description***
AssetType	Mandatory	Type of the asset. These assets would be controlled in P2H systems: Set point supply temp from heat pump Set auxiliary heater on or off and step Set value hot water Set value room temp KWhhp – Set heat-Pumps electrical energy consumption
AssetMagnitude	Mandatory	Magnitude of the asset (active power, voltage, SOC…)
TimeStart	Mandatory	Timestamp from which the setpoint is applicable
TimeEnd	Mandatory	Timestamp from until which the setpoint is applicable. For discrete setpoints it is equal to the TimeStart, for schedules it is different
Value	Mandatory	Value of the setpoint
Units	Mandatory	Units used for expressing the value of the magnitude
AssetID	Mandatory	Identifier of the asset

4.9 DERFeedback interaction

This interaction is about how the observation of the DER behaviour influences the DCM. We have defined in the ConsumptionProfile interaction that the DER sends to the vDER any update of the information about the monitoring of the assets. In VD03, all the information that could be used by the tracker to make profiling (TR04) or real time tracking (TR05) is sent to the tracker using a **VT_ResponseUpdate**.

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In case that the cluster of vDERs is deviating from the consumption profile, some of the vDERs could be incentiveized to compensate the deviation of those vDERs who are not complying with its consumption profile. In this case, the execution would be transferred to the TR02 of the IncentiveFlexPlan interaction. And once the incentives have been fixed, the execution thread would come back to TR03, moment in which the incentives would be activated calling the FlexActivation interaction

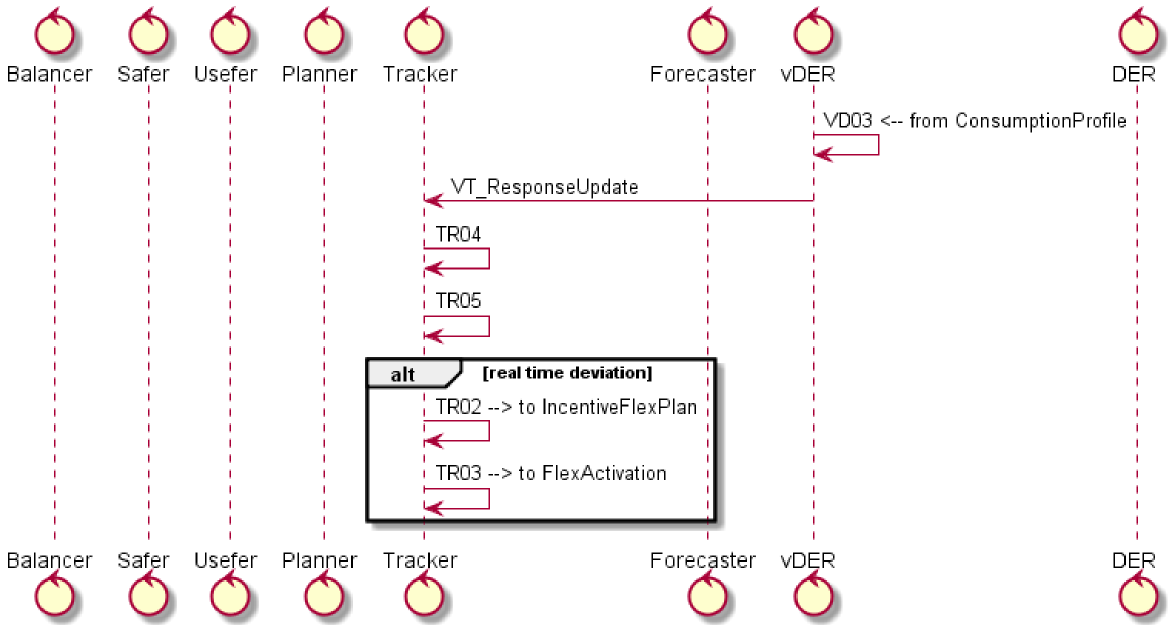

Figure 14: DERFeedback interaction

4.9.1 VT_ResponseUpdate message

Message name	VT_ResponseUpdate
Source	vDER
Destination	Tracker
Functional requirement D1.1	
localRESCurtailmentMitigation	
systemRESCurtailmentMitigation	
balancingServices	True
Interaction	DERFeedback
Interface	I_DV, I_TD
Description	Send to the tracker the measurements associated to the incentive response
Return values	Success/fail

Atribute name	***Type of entry***	***Description***
AssetID	Mandatory	Identifier of the asset

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AssetType	Mandatory	Type of the asset. In relation to heta pumps, the following types have been preliminarily identified: Tout-ret - Return temperature for the primary energy source, brine out Tout-sup - Supply temperature for the primary energy source, brine in Thp-ret - Return temperature (from the tank) to the heat-pump Thp-sup - Supply temperature from the heat pump Troom – Indoor room temperature KWhhp - Heat-Pumps electrical energy consumption Set compresser 1…n On/Off Set compressor speed (VSD heat pump) Auxiliary heater step 1…n On Off Toutdoor - Measured outdoor temperature Set point - set point supply temp, Outdoor temp for heating start and stop, start set point auxiliary heater, start set point compressor, auxiliary heater on or off and step, set value hot water, active temp hot water, active integral value or similar Safety control set point - Lowest brine temp, min stop time, latest stop time Set Brine pump speed** (GSHP) Set heating circuit pump speed** (GSHP & ASHP*) Set evaporator fan speed** (ASHP) Set condenser fan speed** (ASHP) Set valve heating/DHW position (GSHP & ASHP*) Set reversible heat pump operation function (heating/cooling) (ASHP)
AssetMagnitude	Mandatory	Magnitude of the asset (active power, voltage, SOC…)
TimeStart	Mandatory	Timestamp from which the measurement is applicable
TimeEnd	Mandatory	Timestamp from until which the measurement is applicable. For instantaneous measurements it is equal to the TimeStart
Value	Mandatory	Value of the measurement
Units	Mandatory	Units used for expressing the value of the magnitude

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5 Functional Architecture – Implementation View

5.1 Software Agents view

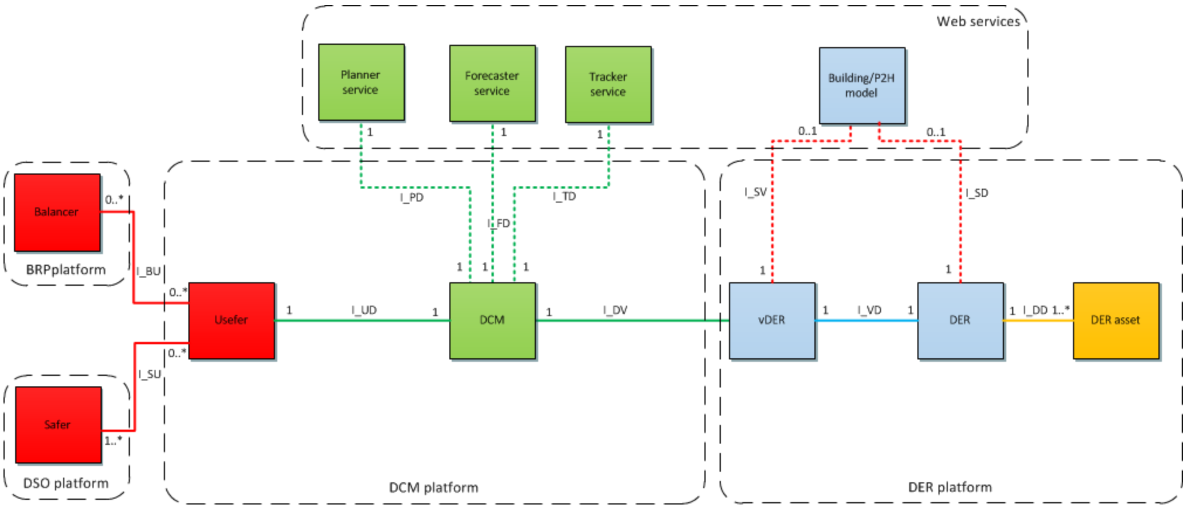

Figure 15: Functional architecture – implementation view

The implementation view of the functional architecture translates and elaborates the conceptual implementation agnostic functional architecture of section 3.1 into implementation aware/specific software architecture. At this level, architectural patterns are used to make a coarse-grained software design. Functional decomposition is applied to refine the platforms and agents defined in the conceptual view in functional terms. Defining the software components of platforms and agents, the functionality of each agent and the interactions and interfaces between the agents is a common architectural pattern used to handle complexity of a system. At the same time it facilitates the organisation of the implementation fase, splitting up the work into subtasks related to software agents, and clearly defines who is responsible for implementing an agent and providing the appropriate technical readiness level (TRL).

Figure 15 shows a high level implementation view. A more detailed view will be developed during the design and implementation phase, by splitting up these software agents even further. In this high level view a DCM software component is introduced that schedules and coordinates the Planner, Tracker and Forecaster functionalities provided by respectively the Planner, Tracker and Forecaster web services. The same for the vDER agent and/or the DER agent that can make use of functionality that embeds building thermal models. It is up to the implementation and the kind of DER asset to decide if it is the vDER or the DER which is going to implement the functions.

Web services (section 5.2.2) are used as a means to integrate SW components from different partners into a pre-commercial platform. Such loose integration is a means to clearly delimit responsibilities and offers separation of concerns, and at the same time guarantees the intellectual property provided by these partners. On the other hand web services running on different IT platforms introduce additional complexity. For instance the DCM software component has to deal with web service reliability,

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communication delays or even a loss of communication, and must take the appropriate action in each situation.

Although these web services can run on different IT platforms, and should be designed to be highly IT platform independent, it is recommended to run these web services on a single cloud server that hosts the DCM platform and the DCM SW component. This will improve the reliability of the system, reduce communication delays and outages, at the same time still providing functional decomposition and guaranteeing protection of Intellectual Property. Additionally having the services run on one IT platform facilitates error tracking, the debugging process and real-time operation management of the system.

5.2 Communciation protocols

5.2.1 USEF

USEF (see section 3.3.3) uses a technology and implementation-agnostic IT architecture with a strong focus on interoperability. To achieve the desired interoperability and enable system components to evolve independently, all participants in a USEF market system must share a common logical architecture and standardized interfaces. USEF defines the logical interface standard, but does not define how to implement it.

The Safer and Balancer agents will communicate with the Usefer by means of USEF. These three agents will provide a USEF endpoint based upon the USEF reference implementation.

USEF provides a message model that covers the information exchange required by USEF its Market-based Control Mechanism. To ensure reliable operation of the distributed USEF system, each participant must operate a message queue, both for outgoing and for incoming messages, in order to achieve fully asynchronous and decoupled operations. Communications between these queues must support the HTTP version 1.1 protocol over TLS. Participants may implement different standardized secure protocols, such as AQMP-over-TLS or HTTP 2.0, but due to uncertainties about interoperability, any alternative protocols are optional and fallback to the common protocol must be supported.

As this project will make use of the USEF reference implementation, the next bullet list shows the main characteristics of the communication layer in the USEF reference implementation:

- It uses a point-to-point integration between the different actors exchanging messages between each other. No hub or central broker is used.
- It uses a synchronous message exchange mechanism. Inbound messages are always validated before allowing them into the backend and trigger business logic. ‘Synchronous’ is defined in the USEF context as returning the validation result of the inbound message to the sender in the http response. The synchronous message exchange is realized by using REST over HTTPS.
- The information exchange is asynchronously. The message exchange is decoupled from actual business logic execution, and is realized by using queues.
- the USEF reference implementation offers one inbound and one outbound channel per actor instance. These single in- and outbound channels are used for all exchanged messages. As a consequence each actor instance will have one REST endpoint to receive inbound messages, one inbound message queue and one outbound message queue.

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- It encrypts the message payload using the NaCl library, a software library for network communication, encryption, decryption and signatures.

5.2.2 Web services

As explained in 'Smart Grid Set of Standards' specification[11] Smart grid applications and standards rely heavily on Web Services for the higher layers protocols. Web Services are defined to be the methods to communicate between applications over communication networks, generally IP based. Two major classes of Web Services can be distinguished:

- RESTfull Web Services (Representational State Transfer): applications are fully defined via representations (e.g. XML) of resources that can be manipulated using a uniform interface that is composed of four basic interactions, i.e. CREATE, UPDATE, DELETE and READ. Each of these operations is composed of request and response messages. The most common implementation of REST is HTTP, whereby the REST operations are mapped into the HTTP methods: CREATE is mapped on HTTP POST, READ on HTTP GET, UPDATE on HTTP PUT and DELETE on HTTP DELETE. However other implementations are possible: CoAP (Constrained Application Protocol), XMPP (Extensible Messaging and Presence Protocol), etc.
- SOAP/RPC based Web Services: applications expose interfaces that are described in machine processable format, the Web Service Description Language (WSDL). It is also possible for applications to interact through SOAP interfaces which provide a means to describe message format. These messages are often transported over HTTP and encoded using XML.

In this project the communication technique used for Restful Web Services will be used to communicate with some agents of the overall system and to integrate the functionality provided by these agents into the system. The provided web services may not be stateless, which is a requirement for Restful web services. For instance when the vDER service builds a model based upon information provided in the service request, and it stores this model in the web service itself to accommodate services requests that need the model, then it is not stateless. The service could be implemented stateless, meaning the model should be returned by the vDER to the requester. In this case the requester includes the model in all subsequent service requests that need the model information. The decision to go for stateless or for state full web services will be done in the implementation phase.

Web services provided via a REST API can be deployed on any platform or server. The clients, making use of the web service, are agnostic of the used platform, server or location. The clients only need the address (URL) of the service.

For the DCM agents, provided and deployed by NODA, NODA has selected the Amazon Web Services platform as the cloud platform. As mentioned in section 3.6 the web services should be developed with a minimum of (or none) dependencies to the actual cloud platform. This will facilitate the integration of the web services on the platform used by NODA.

[11] SEGCG/M490/G_Smart Grid Set of Standards, Version 4.1 draft, section 9.3.5 Higher layer communication protocols, 2017

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By implementing the main functionality of the Tracker, Planner, Forecaster and vDER as web services the same service can be offered to NODA by several parties, on the condition that these web services adhere to the same REST API. In a commercial setup, NODA could for instance select the service with the best performance, the best reliability or the best price.

5.2.3 Message Queuing Telemetry Transport (MQTT) communication

MQTT[12] stands for Message Queuing Telemetry Transport and is a publish/subscribe, extremely simple and lightweight messaging protocol, designed for constrained devices and low-bandwidth, high-latency or unreliable networks. MQTT v3.1.1. has been approved as an OASIS standard[13]. As depicted in ***Figure 16*** publishers publish data in the form of messages which can be subscribed to by subscribers. Actually the publisher publishes a message to a MQTT topic, which can be regarded as a particular message queue, and a the subscriber subscribes to a MQTT topic. The design principles are to minimize network bandwidth and device resource requirements whilst also attempting to ensure reliability and some degree of assurance of delivery. These principles also turn out to make the protocol ideal of the emerging "machine-to-machine" (M2M) or "Internet of Things" world of connected devices.

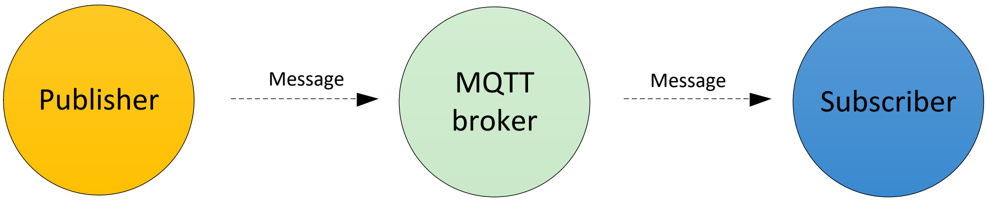

Figure 16: MQTT concept

The protocol specification has been openly published and the protocol has a royalty-free license. It runs on top of TCP/IP, for which port 1883 is reserved by default. MQTT can also run over Transport Layer Security(TLS) / Secure Socket Layer (SSL). In this case TCP port 8883 is the default port. TLS and SSL are cryptographic protocols to provide encrypted communication (transport encryption) between a client and a server, preventing eavesdropping of the communication. The server provides a X509 certificate, issued by a trusted authority or self-signed, which clients use to verify the identity of the server. MQTT provides a built-in username/password authentication mechanism via the MQTT CONNECT message. This message must be sent over a secure connection. Besides authentication also authorization is supported by MQTT. Without proper authorization each authenticated client can publish and subscribe to all kinds of topics. In order to restrict a client to publish or subscribe only to topics it is authorized to, it is necessary to implement topic permissions on the broker side. These topic permissions could specify per client the allowed topic (exact topic or wild card topic) and the allowed operation (publish, subscribe, both).

For the communication between the vDER and the DER, the MQTT protocol will be used. Both the vDER and the DER will publish information and subscribe to particular information. For instance a building may publish data regarding the temperature in the building. The vDER subscribes to this type of data. In the other direction the building will subscribe for control commands issued by the vDER. A MQTT broker

[12] http://mqtt.org
[13] http://docs.oasis-open.org/mqtt/mqtt/v3.1.1/mqtt-v3.1.1.pdf

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relays the messages from the publisher to the subscribers. The MQTT broker is a separate server/cloud function running in the NODA platform.

5.2.4 NODA protocol

This is an proprietary protocol used by Noda to communicate between the DCM and the vDER.

5.3 Interfaces

5.3.1 Interfaces between the software agents

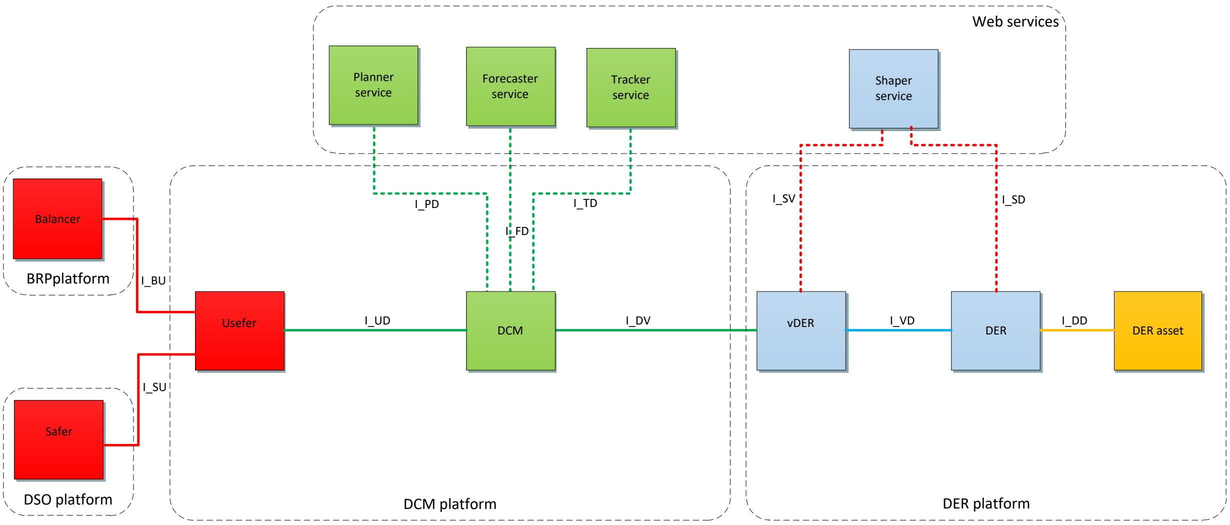

Figure 17: Communication architecture

Table 18 lists all the interfaces in the communication architecture shown in *Figure 17*. For each interface the table defines the communication endpoints, being a software component, the used protocol and the indication which endpoint is the client or the server. All web service and USEF communication is bidirectional. At the communication level the communication is synchronously, meaning all transfers return a result indicating whether the message was accepted at the server side. At the information level all information exchange is asynchronously. The response to a message containing a request is not sent as a HTTPS response, but is sent as new HTTPS POST message. Information exchange over MQTT is by definition asynchronously. The vDER as well as the DER are both publisher and subscriber.

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Interface	Endpoint A	Endpoint B	Protocol	Client	Server
I_BU	Balancer	Usefer	USEF (= REST over HTTPS)	Balancer	Usefer
				Usefer	Balancer
I_SU	Safer	Usefer	USEF (= REST over HTTPS)	Safer	Usefer
				Usefer	Safer
I_UD	Usefer	DCM	REST over HTTPS	Usefer	DCM
				DCM	Usefer
I_PD	Planner	DCM	web service (REST over HTTPS)	DCM	Planner
I_TD	Tracker	DCM	web service (REST over HTTPS)	DCM	Tracker
I_FD	Forecaster	DCM	web service (REST over HTTPS)	DCM	Forecaster
I_DV	DCM	vDER	NODA	DCM	vDER
I_VD	vDER	DER (building, Ecovat)	MQTT	DER	MQTT broker
I_DD	DER	DER asset	Asset related	NA	NA

Table 18: communication interfaces

Although the information exchanged between a vDER and an Ecovat type DER compared to the information exchanged between a vDER and a building type DER is not of the same type, the same protocol is used for information transport.

5.3.2 Communciation inside a DER agent in case of a building

This section looks at the communication architecture in case of a building agent as DER agent. In particular the focus is on the interface (I1) from the gateway to a BMS, HVAC controller or HVAC system. The gateway could be provided by the provider of the vDER agent, but it could also be provided by an independent manufacturer. Its functionality could also be part of a building management system (BMS) for instance.

Figure 18 shows several variants for the interfacing between the gateway and the flexibility providing P2H system. The interface from the building gateway to the vDER is elaborated in 5.3 and 5.2.3. *Table 19* shows as an example some protocols that can be applied for the I1 interface, but it is not the intention to provide here an exhaustive list of all protocols that could be used for this interface.

A BMS can contain several functionality sets like fire alarms, security, lighting control, elevator, energy management, access control and HVAC control. Recently the BMS industry is also integrating demand-

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response functionality and the interfacing to the aggregator into the BMS. This variant is not shown in ***Figure 18***. Architecturally, it means that the gateway functionality is part of the BMS.

The main function of the gateway is to provide a communication channel between the vDER and the DER endpoint (BMS, HVAC controller or HVAC). Because the vDER and the DER endpoint may not use the same communication protocol, this function includes also the translation of the vDER-gateway application protocol (e.g. MQTT) to the gateway-DER application protocol (e.g. MODbusTCP). This means that the gateway not only provides a communication endpoint for the vDER-gateway and the I1 (and I2) interface, but also has to map the data model of one application protocol (for instance message parameter ‘room temperature’) to the data model of the other application protocol (for instance room temperature represented by register address 2700 in MODbusTCP).

In variant 1 there is a BMS linked to a HVAC controller system. The HVAC controller manages the HVAC devices and gets status information or desired set points from a thermostat. Variant 2 is similar to variant 1, except that the HVAC controller functionality is part of the BMS. In case of variant 3 there is no BMS and the gateway is directly connected to the HVAC controller. Variant 4 is similar to variant 3, except that the HVAC controller functionality is part of the gateway functionality. As shown in variant 1 and 3 the HVAC controller functionality is not necessarily implemented in a separate device, but can be part of a HVAC device.

For the vDER it doesn’t matter if it talks to a gateway device that communicates with a BMS or HVAC controller or to a BMS that by itself provides the required communication functionality. This is abstracted in ***Figure 17*** by introducing the DER agent. The DER agent is the communication endpoint for the vDER and manages DER asset(s). It must contain communication capabilities to talk to a vDER and must contain logic to safely operate a DER asset (for instance in a BMS or in a HVAC controller).

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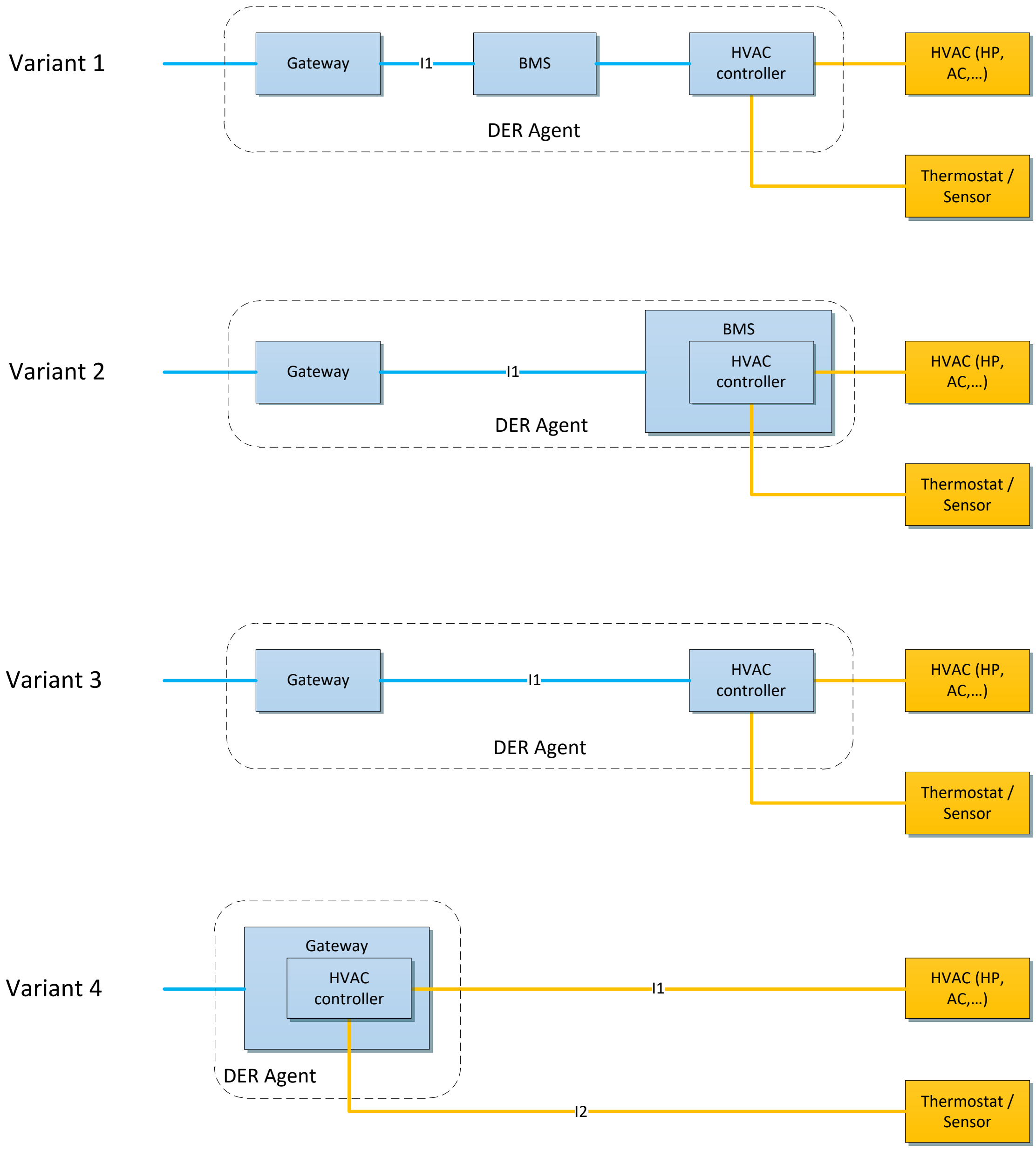

Figure 18: Communication architecture variants in the building

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Variant	Interface	Application protocol	Data model
Variant 1	I1	Imposed by BMS manufacturer. Examples are ModbusTCP, Modbus RTU, REST API, BACnet.	Proprietary. Specified by BMS manufacturer.
Variant 2	I1	Equal to variant 1	Equal to variant 1
Variant 3	I1	Imposed by HVAC controller manufacturer. Examples are ModbusTCP, Modbus RTU, REST API.	Proprietary. Specified by HVAC controller manufacturer.
		EEBus SHIP, EEBus SPINE resources as part of other application protocols like for instance OCF.	EEBus SPINE
Variant 4	I1/I2	Imposed by HVAC manufacturer. Examples are ModbusTCP, Modbus RTU, REST API.	Proprietary. Specified by HVAC manufacturer.
		EEBus SHIP, EEBus SPINE resources as part of other application protocols like for instance OCF.	EEBus SPINE

Table 19: building gateway communication interface

Although ModbusTCP or REST over HTTPS are standard application protocols, these standards do not impose a data model. The used data model is specific and specified by the server side implementer of the protocol.

EEBus[14] SPINE, which is standardized in the European Smart Appliance Standard prEN 50631, stands for Smart Premises Interoperable Neutral-message Exchange and defines a neutral layer which helps connecting different technologies to build a smart home system. SPINE defines the generic data model, the messages and procedures on application level (ISO-OSI layer 7) to communicate with smart appliances on demand-response and energy related topics. The initial focus was on white goods, but also HVAC and eMobilty are in the scope of the ongoing SPINE standardisation work. SPINE is transport protocol agnostic, and can be used over several types of transport layers.

SPINE is mentioned here as a manufacturer independent interface standardization initiative to inspire the definition of a generic and cost-effective flexibility interface for the active controlling of heating/cooling devices.

One of the objectives of this project is to propose a heat pump with direct control. This direct control interface a standard interface could be inspired by or aligned with EEBus SPINE.

[14] https://www.eebus.org/

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5.3.3 Communciation inside a DER agent in case of a Ecovat

Figure 19 shows the communication interfaces in case of a Ecovat DER agent.

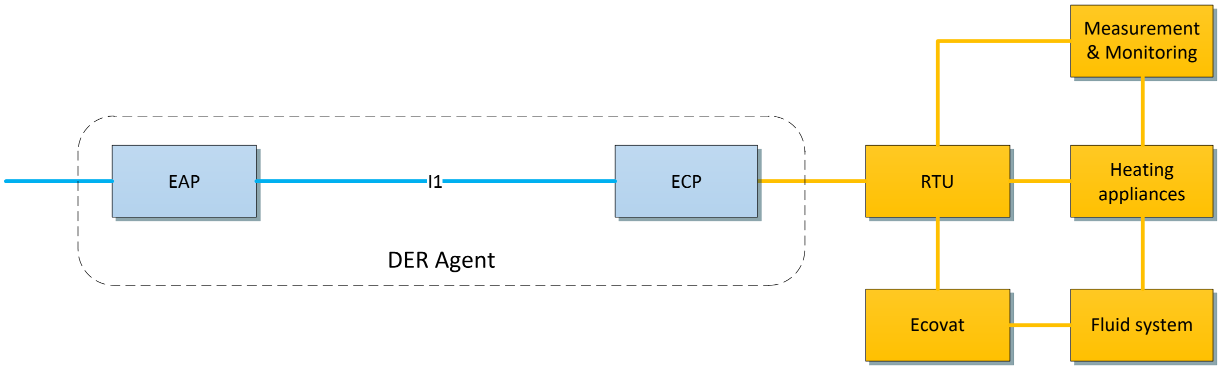

Figure 19: Ecovat communication architecture

5.4 Data representation

For sensor data SenML is used as a data model to describe the sensor and actuator data. The SenML specification "Media Types for Sensor Measurement Lists (SenML)" [15] defines the media types for representing simple sensor measurements and device parameters, in other words it defines a common SenML data model. This model can be represented using different representation formats (also called serializations of the data model) like JavaScript Object Notation (JSON), Concise Binary Object Representation (CBOR), eXtensible Markup Language (XML), and Efficient XML Interchange (EXI). In this project JSON is used to represent the sensor data. Not only is SenML used to get sensor data, it also used to set an actuator, for instance to set the set point of a thermostat.

The messages described in section 4 and also the information exchanged between the vDER and the Ecovat EAP will be represented by means of JSON, and have to comply to a common JSON scheme. This scheme will be defined during the implementation phase.

[15] Media Types for Sensor Measurement Lists (SenML), draft-ietf-core-senml-10, https://tools.ietf.org/pdf/draft-ietf-core-senml-10.pdf

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6 SGAM

The Smart Grid Architecture Model (SGAM) was created by the Smart Grid Coordination Group, formed by the European standardization organisations CEN, CENELEC and ETSI, in the context of Smart Grid standardization mandate M/490. It provides a structured approach for modelling smart grid use cases to a common architecture model. Different approaches can be analysed by mapping the different implementations onto the same reference framework. The model (and SGAM methodology) can also be used to identify the appropriate standards and to identify potential gaps in standardization.

SGAM is a three-dimensional framework consisting of domains, zones, and layers (***Figure 20***). The domains depict the traditional layout of the electrical energy infrastructure: generation, transmission, distribution, Distributed Energy Resources (DER), and customer premises. The zones are derived from the hierarchical levels of information management in power systems: market, enterprise, operation, station, field, and process. These two axes form a smart grid plane. In the third dimension the different layers show the interoperability aspect. The component layer is the physical layer with the electrical process zone and the hardware/software systems for information management in the other zones. On top of this layer we have the communication, information, function, and business layer.

This section links the different sections in this document to the SGAM model. The business layer, with the use cases, is defined in D1.1. The function layer, defining the different agents and their functions, is described in section 3.3. The Information layer, describing the interactions between the agents, in section 4 and the communication layer in section 5.

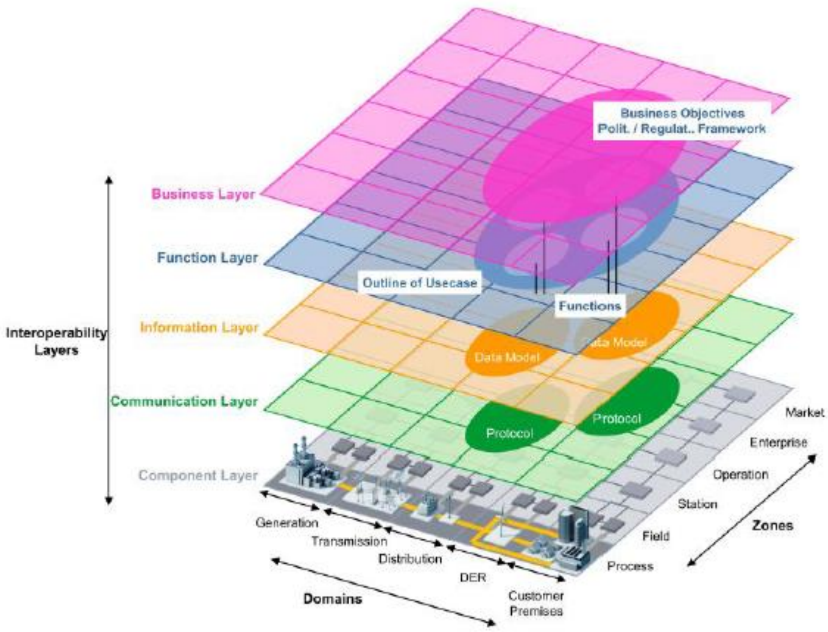

Figure 20: Smart Grid Architecture Model - SGAM

This section maps the different agents to the different zones and domains on the component layer as shown in ***Figure 21***. Not all components should be regarded as unique physical components. Most of

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them are representing a software application. These applications could run on a hardware system dedicated to this application or could run on a server/cloud system hosting several applications. The Balancer agent could be for instance a separate software application or function running on a BRP server system. The Safer agent will likely be part of the DSOs SCADA or EMS system. In the project setup, the Usefer agent, Planner agent, Forecaster agent, Tracker agent and vDER agent could run on the same platform, with some part of the functionality provided by web services running on different (partner) platforms. The DER agent typically runs on premise (field zone) close to the DER assets (in process zone) it manages. Part of the DER agent functionality could also run in the station zone if multiple DER assets, like heat pumps in different buildings, would be controlled due to organisational aspects by one entity.

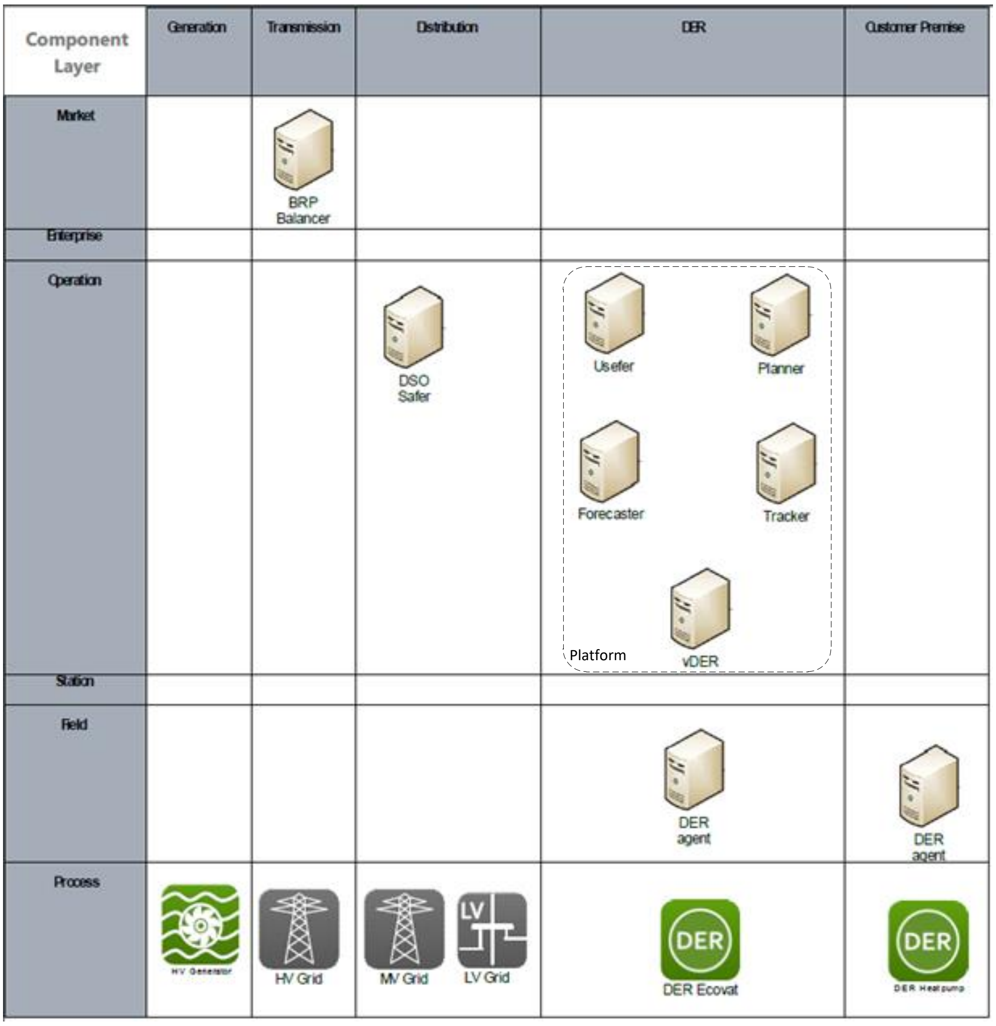

Figure 21: SGAM – Component layer

As an example Figure 22 illustrates the connections between the agents and some of the standards mentioned in section 5.

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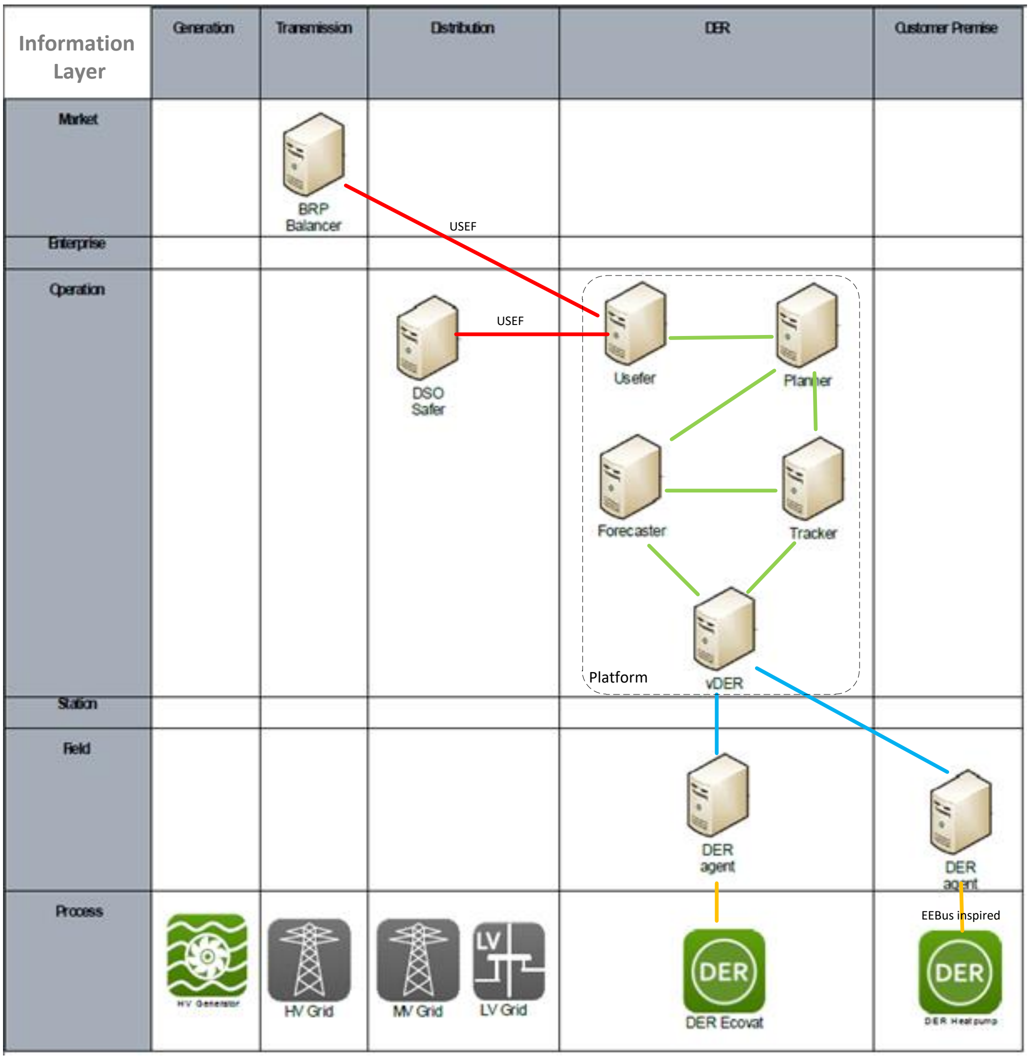

Figure 22: SGAM – Information layer

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7 Conclusions

The design of the multiagent framework presented in this deliverable has been based on the business use cases defined in D1.1. The design has been done first at the platform level, and for each platform, the design includes the specification of which software agents will be contained (a platform is defined as the collection of agents that provide the whole functionality of a role defined in D1.1)

For each participating role depicted in D1.1 a specific software platform has been designed in such a manner that all functional requirements for that role, as expressed in D1.1, have been covered. Hence, a specific agent platform for each of the BRP, DSO, DCM and DER (Heat Provider/Heat User) roles have been designed. Additionnaly, at each platform level, non-functional requirements covering performance, scalability, availability, interoperability, security and privacy issues have been settled for these platforms.

Which communication protocol will be used in each interface between these platforms has also been specified, taking into account the adequacy of the available protocols. USEF will be used between the BRP, DSO and DCM platforms, while the NODA protocol will be used between the DCM and DER platforms. The utilization of these protocols will provide the needed interoperability and scalability of the FHP system for further deployments and exploitation in the future.

At the agent level, the functional sequences for each of the business use cases have been defined. These sequences are composed by both agent internal processing functions (algorithms) and information exchanges (messages) between agents. This function blocks have been organized in 8 different interaction processes, so the complete sequence of steps of each business use is represented by a conjunction of these interactions. This generalization facilitates enormously the system design, as the same processing functions and messages are used for all the business cases, by means of the proper parametrization of these items. Between each agent of the same platform, the interplatform communication protocols have also been defined (MQTT and restfull web services).

In conclusion, this deliverable has provided the definition of the agents that will be developed both in WP2 (DER platform → vDER and DER agents) and in WP3 (DSO platform → safer agent, BRP platform → blancer agent and DCM platform → Usefer, tracker, planner and forecaster agents).

The data model and the communication protocol that will be used in each interface has been provided, so that the WP2 and WP3 developers have, for each algorithm to be developed, the collection of inputs and outputs that they either will use or have to provide.

In summary, the deliverable D1.2 holds the specification of how the algorithms and the agents to be developed in WP2 and WP3 have to be interfaced and implemented, in order to be successfully tested and validated in the WP4 pliots.

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9 Annex I – Functional specification for the building agent

This annex provides functional specification for the building agent – the in-building part of the FHP solution to be developed in WP2. The specification is derived from detailed analysis of expected usage.

In the scope of FHP, building HVAC systems are the key source of flexibility in electricity consumption. The HVAC systems are controlled by one or more feedback loops. In general, there are two options to alter the HVAC load: either by changing set-points of the loops, or by direct control of the HVAC equipment (overriding the loops). The building agent is designed to enable all flavors of HVAC load adjustment.

There is a number of stakeholders whose needs are taken into account for the architectural design. Despite variety in building stock, the stakeholders can be largely grouped as building owners, operators and occupants. For their buy-in, the architecture aims to retain the right amount of stakeholder control and to provide them with clear information about impact of the load adjustments.

9.1 Usage scenarios and user needs

From the in-building point of view, the flexibility-related use cases of FHP (tasks T3.1, T3.2 and T3.3 of WP3) result in the following sequence of steps:

Inform: the building agent tells to the DCM its current planned consumption profile

Negotiate: two options:

- The DCM can propose an incentive profile and the building responds with a predicted load profile
- Optionally, the building agent can offer a flexible load profile along with a certain incentive requirement

The DCM either accepts the response or can reiterate with another request

Implement: the flexibility is implemented by the building agent

Validate: the grid and the building need to settle the load flexibility

The usage scenario stems from the needs of individual stakeholders during system operation. For the sake of this particular analysis, the in-building stakeholders were segmented in more detail compared to the 'functional roles' of D1.1[16]: user needs were identified for DCM, building occupant, building tenant, building operator and building owner. These roles apply to most building types (houses, apartment blocks, offices, shops, hospitals, schools and other service buildings). Indeed, the role of tenant applies only to rented buildings.

DCM needs reliable load adjustments

[16] D1.1 distinguishes two in-building roles: heat user and heat provider. Here the functional role of heat user is further refined to occupant, tenant, operator and owner.

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DCM needs to negotiate load adjustments and get the individual buildings follow the negotiated profiles as accurately as possible so as to ensure performance in the grid. Hence it is natural to distinguish two phases of the workflow – negotiation of the load adjustment with the building agent and implementation of the confirmed load adjustment by the building agent, respectively.

Building tenant needs quality service for its business

Primary objective of building tenants is indeed their business. As such, they need to be informed about impact of the load adjustments on quality and cost of the service so as to make sure their business is not compromised.

Building occupant needs to stay in control of the environment

Building occupant needs to stay in control of the service so as to remain comfortable and/or productive. In the typical case of occupant thermal comfort, users can adjust temperature set-points via thermostats in conditioned spaces of the building. User control needs to be retained even during flexibility events.

Building operator needs to keep critical systems running properly

Building operator is responsible for the quality of service provided by the HVAC system. As such, the operator needs to closely monitor operation and health of the HVAC system. Moreover, the operator needs the option to opt out from the load adjustments as needed – primarily to keep the system in good condition and ensure quality of service for tenants and/or occupants.

Building owner needs the building generate value

Building landlords seek to maximize revenue generated by their buildings. Similarly, home owners seek to maximize comfort and minimize costs of their living. Having the final say on participation in load flexibility programs, building owners are likely to judge them based on impact the program would have on quality of service and operating costs of the building.

The most stakeholders are interested in impact of flexibility on service quality

The negotiated load flexibility will likely not be met during implementation – be it due to user opt-outs or inaccurate load predictions. As such, the most stakeholders are interested in validation of load flexibility and its impact on quality of service. Indeed, individual stakeholders will be after different impact, e.g. occupants are interested in comfort, facility managers in equipment health.

Every building needs its own configuration

Every building is different. And if not building, then definitely its users have their unique preferences. As such, the building agent should be configured to the specific needs of each building, its systems and its stakeholders. Such configuration would be done outside any load adjustment sequence, as can be seen in Figure 23 which depicts the complete high-level workflow[17].

[17] The workflow is sketched with emphasis on flexibility: the building agent will likely spend considerable amount of time idling in the 'Configuration' phase – whenever the building automation system will be operating nominally without activated flexibility (and no negotiation in progress)

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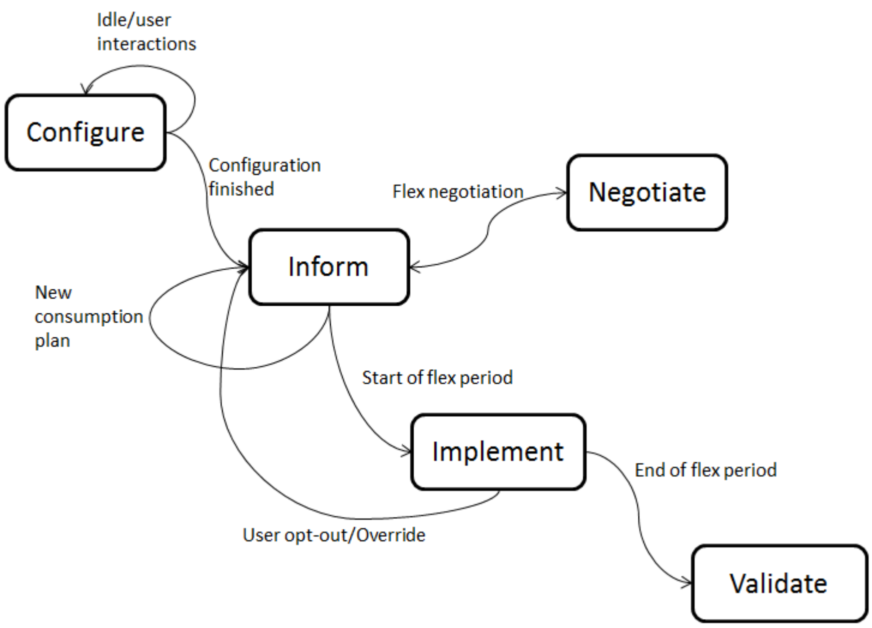

Figure 23: Flexibility-centric overview of the building agent workflow

9.2 High-level requirements

The high-level requirements are derived from the needs of individual stakeholders during each phase of the expected usage scenario.

Requirements of DCM

Flexibility negotiation with the grid (DCM) requires interface for the reception of incentive offers and the delivery of consumption profiles. There is a number of options for the negotiation mechanism between the building (building agent) and the grid (DCM). Two favorite options for flexibility negotiation were identified:

- DCM sends a variable price tariff and the building agent responds with flexible load profile. This approach is preferred for day-ahead or intraday load plannings
- The building agent offers short term flexibility to the DCM along with a price it requests for doing so

The architecture is defined so that more options are possible.

Negotiation as well as implementation of the flexibility require strategy to predict and optimize building load in response to incentives. Dependent on the negotiation type, the optimizer might include a component to monetize the load adjustments (and request a compensation from the DCM). The optimizer might also include a specific component for real-time corrections of the flexible consumption to minimize gap between negotiated and actual flexible load.

Reporting and settlement of the flexibility require methods for measurement and verification of impact the actions had on energy consumption and quality of service.

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All the requirements induced by the needs of DCM are summarized in ***Table 20***. These rather general requirements will be specified in more detail in the next section. Before doing that, high-level requirements of the building-level users are derived from their needs below.

Requirement	Phase				
	Inform	Configure	Negotiate	Implement	Validate
Configuration tool	mandatory	-	mandatory	-	-
Occupant notifications	-	mandatory	-	mandatory	-
Occupant opt-out	mandatory	-	-	-	-
Real-time monitoring	-	-	mandatory	mandatory	-
Operator controls	-	-	optional	-	-
Impact validation	-	-	-	optional	-

Table 20: Functional requirements to satisfy needs of DCM

Requirements of the building-level users

Configuration phase requires user interfaces for operators and/or occupants to define the required quality of service (such as thermal comfort). Similarly, user interface is needed for building operators to provide context information about the building and the HVAC system, and to specify actions eligible for load adjustments.

During implementation phase, occupants expect to receive notifications about adjustments being made to the operation of the terminal equipment and largely require ability to override the actions in case their comfort is compromised. Building operators require monitoring of the system operation and ability to override the load adjusting actions if needed due to occupant complaints or equipment stress.

In validation phase, tenants expect fair compensation for any comfort violations. Building operators want to learn impact on equipment health and runtime to reconfigure the adjustments if needed. Finally, reporting on the profit (or savings) brought by the participation is needed by building owners to decide if and to what extent the building should participate in the load adjusting scheme.

All the requirements induced by the needs of in-building users are summarized in ***Table 21***.

Requirement	Phase				
	Inform	Configure	Negotiate	Implement	Validate
Interface with DCM	mandatory	-	mandatory	-	-
Interface to building	-	mandatory	-	mandatory	-
Load prediction	mandatory	-	-	-	-
Load optimization	-	-	mandatory	mandatory	-
Flexibility monetization	-	-	optional	-	-
RT compensation	-	-	-	optional	-
Impact validation	-	-	-	-	mandatory

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Table 21: Functional requirements to satisfy needs of in-building users

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10 Annex II – Overview of forecasting options and approaches

Several quantities need to be forecasted and different tools and algorithms will be used for each of these quantities. The forecaster will mainly work in the day ahead time line. The quantities to be forecasted and the corresponding tools are:

- **Baseline consumption profiles** of the vDERs: There are two approaches for this. In the first approach each vDER provides its baseline consumption profile forecast. This will be based on models from WP2. In the second approach, in the absence of a model, machine learning techniques are applied to forecast baseline consumption profiles of the entire group. For this purpose, there are forecasters available based on ensemble methods, like expert advice systems (Cesa-Bianchi & Lugosi, 2006). The expert advice system works with a bucket of forecasters that are trained on historical load data, and weather forecasts. The forecasters at the moment include neural networks, extra tree regressors, a linear regressor and support vector machines. The input features are lags in the load and the weather forecasts. The expert system relies on the forecasts made by all these forecasters, and assigns to weights to each of them, which evolve in time, based on the performance of each forecaster. This system will be extended with a few more regressors and features, with an automatic feature selection and more hyper parameter tuning. BTW also for the second approach, machine-learning techniques could be used in the Forecaster to learn about the uncertainty/reliability of the forecasts provided by the building agents, and this information could be used to transform the received forecasts.
- Total **flexibility** available in a group. Flexibility information can either come from the individual vDERs of each building or learnt on a aggregated level by the Forecaster.

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