Horizon 2020 – LCE-2017 - SGS

FLEXCoop

Democratizing energy markets through the introduction of innovative flexibility-based demand response tools and novel business and market models for energy cooperatives

WP3 – DEMAND FLEXIBILITY MODELLING AND FORECASTING

D3.5 – Local Demand Manager Specifications and Intra-building Optimization Algorithms

Due date: 31.03.2019 **Delivery Date**: 29.03.2019

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Dissemination level: Public **Nature of the Deliverable:** Report

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FLEXCOOP KEY FACTS

Topic:	LCE-01-2016-2017 - Next generation innovative technologies enabling smart grids, storage and energy system integration with increasing share of renewables: distribution network
Type of Action:	Research and Innovation Action
Project start:	01 October 2017
Duration:	36 months from **01.10.2017** to **30.09.2020** (Article 3 GA)
Project Coordinator:	Fraunhofer
Consortium:	13 organizations from nine EU member states

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Disclaimer: FLEXCoop is a project co-funded by the European Commission under the Horizon 2020 – LCE-2017 SGS under Grant Agreement No. 773909.

EXECUTIVE SUMMARY

The current deliverable is the outcome of the FLEXCoop Task 3.5 on Prosumer –centric local optimization strategies definition. This task aims at delivering the algorithmic process at the prosumer's side for the optimized signalling to the devices during DR Campaigns. This algorithm will involve the maintenance of and updated and ranked list of available assets ready for offering their flexibility for the next 24 hours, and the behaviour of that process once a DR Event is received on the prosumers side, activating the mechanism for sending the different signals to every involved asset at each step of time and the monitoring process for ensuring that everything goes as expected for the entire duration of the DR Event.

To address all the aspects relevant to the scope of the T3.5, the deliverable has been structured as follows:

In Chapter 3 *Demand Response Strategies* the terminology about DR is explained. That includes the benefits of using it, all the considerations in terms of time restrictions that must be considered during the duration of a DR event and all the signals involved, and how the different types of controllable devices at the prosumer's side can be categorized.

Following, in Chapter 4 *FLEXCoop Architecture in the context of Prosumer-centric local optimization strategies*, it is explained the different strategies levels within this project and how the other tasks of this WP have a direct impact on the whole algorithm process.

Later, the different type of devices (during the demonstration phase) that could receive signals for modifying their consumption are detailed in Chapter 5 *Interaction with local assets,* and also the signals can be sent to them.

The full algorithmic process is described in detail in Chapter 6 *Demand Response Optimization Framework.*

Finally, Chapter 7 *Conclusion* is the conclusion of the document, containing a brief summary of the main results achieved as the outcome of the work performed in the task 3.5 and presented in the current deliverable.

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CODE LISTINGS

ABBREVIATIONS

aFFR	automatic Frequency Restoration Reserve
ADS	Active Demand & Supply
BRP	Balance Responsible Parties
CO	Confidential, only for members of the Consortium (including the Commission Services)
D	Deliverable
DoW	Description of Work
DER	Distributed Energy Resources
DR	Demand Respond
DSO	Distribution System Operator
ENTSO-E	European Network of Transmission System Operators for Electricity
ESB	Message Oriented Middleware
EV	Electric Vehicle
FAT	Full Activation Time
FLOSS	Free/Libre Open Source Software
GDEM	Global Demand Manager for Aggregators
GUI	Graphical User Interface
H2020	Horizon 2020 Programme
HV	High Voltage
IPR	Intellectual Property Rights
LDEM	Local Demand Manager for Prosumers
LV	Low Voltage
MCM	Market-based Coordination Mechanism
MV	Medium Voltage
mFRR	manual Frequency Restoration Reserve
MGT	Management
MS	Milestone
O	Other
OS	Open Source
OSB	Open Smart Box
P	Prototype
P2H	Power-to-Heat
PM	Person Month
PTU	Program Time Unit
PU	Public
R	Report

RES	Renewable Energy System
RR	Replacement Reserves
RTD	Research and Development
SEAC	Security Access Control
SEDC	Smart Energy Demand Coalition
TSO	Transmission System Operator
USEF	Universal Smart Energy Framework
VPP	Virtual Power Plant
VPP	Virtual Power Plant Manager
VTES	Virtual Thermal Energy Storage
WP	Work Package
Y1	Year 1

1. Introduction

Under the premise of reducing the CO_2-Emissions and the dependency on fossil fuels, the European Union is moving towards a more sustainable energy sector and the way that energy is used. To meet this sustainable energy goals, energy flexibility and demand-side response are becoming essential for the European Union. Therefore, with the idea to minimize the consumption of fuel-burning energy resources for environmental reasons, this flexibility needs to take new forms.

First, companies and individual users shift from consumer to prosumers by installing their own renewable sources and taking energy from the grid or injecting it depending of some conditions. Although the flexibility they can offer at individual level is small, by grouping that flexibility, it becomes something that can contribute to the power system balancing. For serving this goal, the role of the Aggregator is created, and it is in charge of bundling many small flexibility resources into a useful aggregated flexibility volume.

For unlocking the value of flexible energy, the Universal Smart Energy Framework (USEF) describes a standard converting that energy into a tradeable resource [1], and by defining the structure for the market and its associated rules and processes for making it work properly. For converting that energy into something tradeable, the framework makes a clear differentiation between the *energy supply chain* and the *flexibility supply chain*, while the physical transport remains the same for both chains. Related to its physical transport, that energy is distributed and transported to and from prosumers using the HV transport and MV and LV distribution networks operated by the TSO and DSO respectively. Therefore, every prosumer is connected to the network of the DSO, describing in the connection contract the terms and conditions for accessing to the grid (Figure 1).

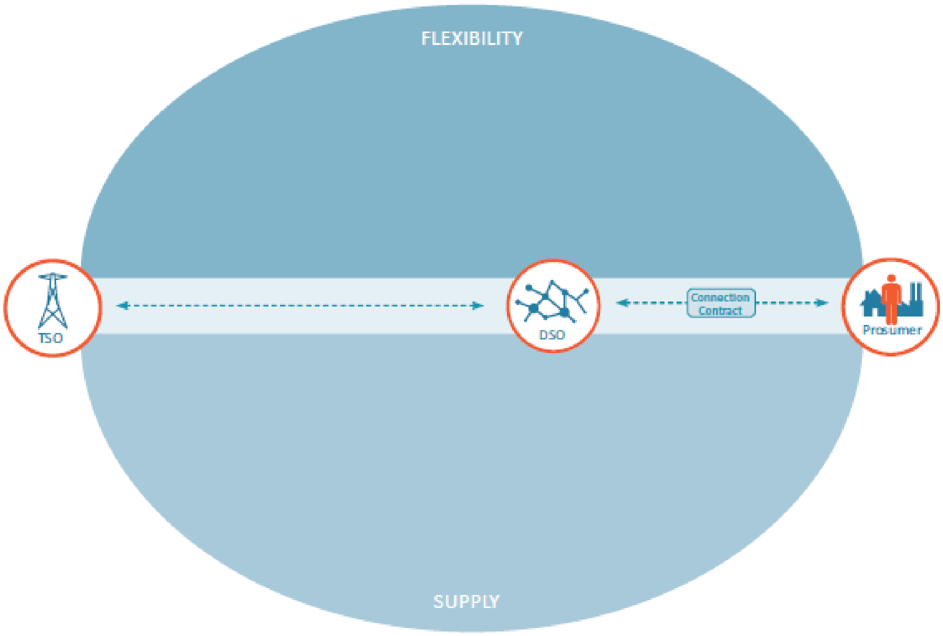


Figure 1: USEF interaction model for energy supply chain and flexibility supply chain

Regarding the *energy supply chain*, it remains unaffected in the USEF model; it is aligned with the European liberalized energy market model (which is out of the scope of this Deliverable). On the other hand, the *flexibility supply chain* is designed to maximize the demand and supply flexibility; for that end, Prosumers and Aggregator establish contracts describing the terms and conditions under which the second one will be able to exploit their flexibility (Figure **2**).

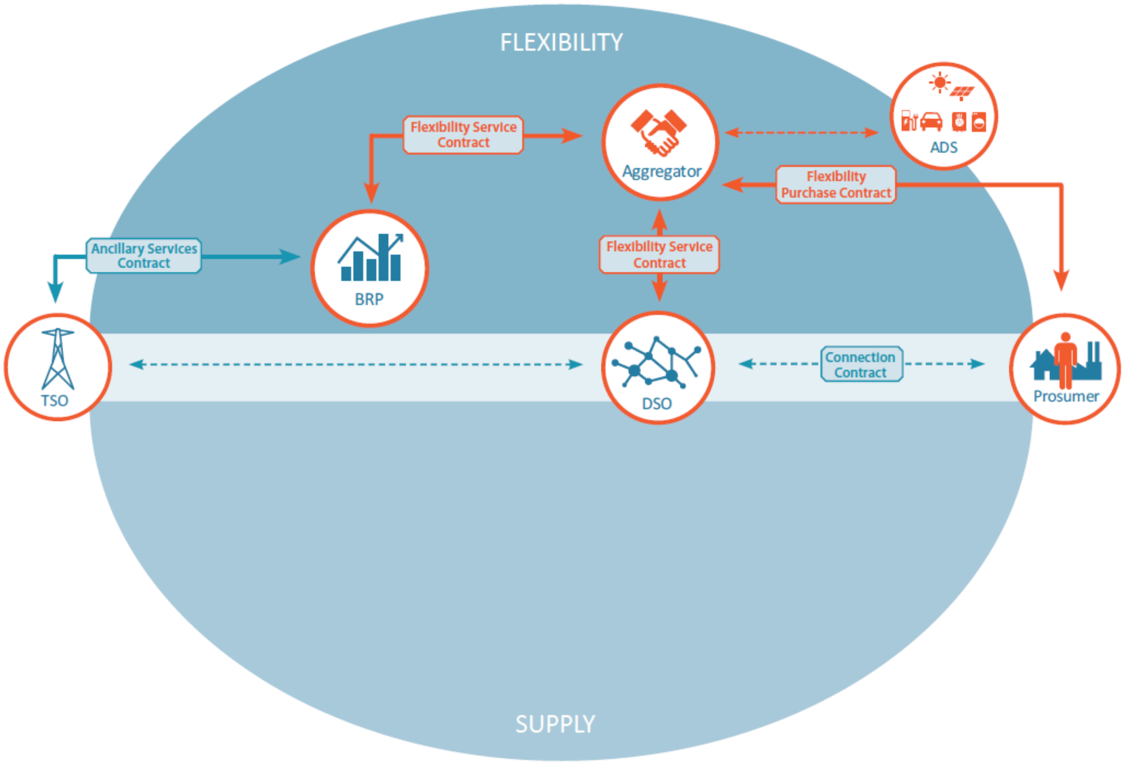


Figure 2: The USEF flexibility supply chain[1]

Summarizing, the full USEF interaction model combines both energy supply chain and flexibility supply chain. The actors in the *supply chain value* are responsible for supplying the energy, while the roles in the *flexibility value chain* are just responsible for creating that flexibility that can be traded (**Figure 3**).

[1] The idea of this Figures is to show a general overview of the USEF interaction model. There are some involved actors that are out of the scope of this project. It has been added short explanation about each actor to the *Appendix B: The USEF roles model*.

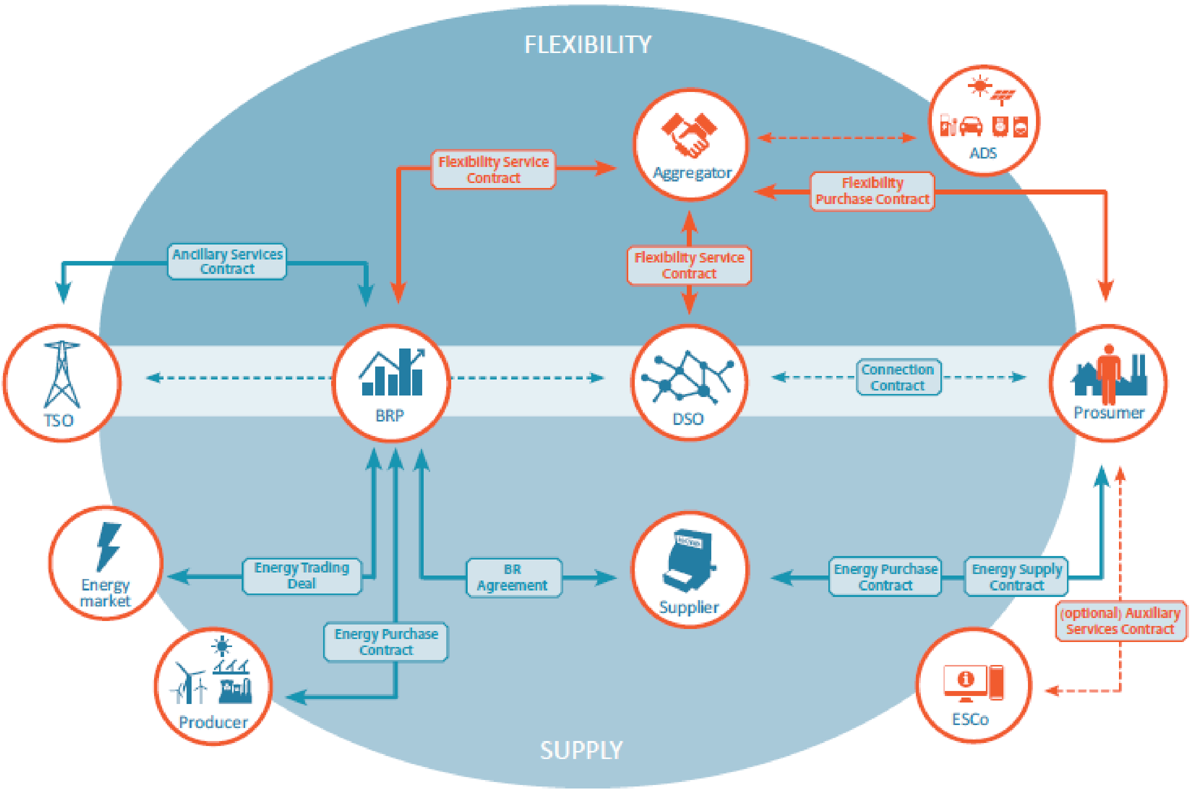


Figure 3: The full USEF interaction model

2. Concept and Deliverable Objectives

Deliverable D3.5 presents the prosumer-centric local optimization strategies definition as result of the T3.5. This task will establish the algorithmic framework to support optimized decision making for the dispatch of personalized DR signals to consumers based on their identified flexibility and response capability. Flexibility-based optimization algorithms for intra-building DR optimization (Local Demand Manager) will be defined to break down global flexibility requirements communicated by the aggregator into individual flexibility that can be offered per load at the consumer side and dispatch the corresponding control signals/ actions to the loads (following a human-centric approach preserving comfort and indoor quality).

Local optimization will be a dynamic process since the defined algorithms will enable the continuous monitoring of the DR event evolution to identify overrides of the implemented strategies or failures to respond and automatically revise the initially defined strategies so as to achieve the provision of the anticipated amounts of flexibility and in this sense, optimize business functions and energy transactions of all stakeholders involved, while resolving operational constraints at the DSO side.

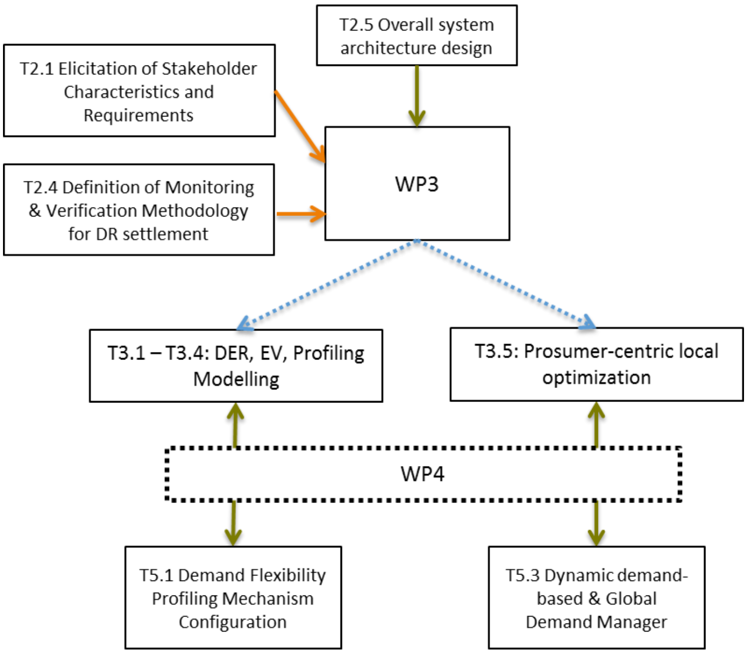


Figure 4: FLEXCoop WP3 interrelations

As depicted in Figure 4, this task 3.5 is impacted by the other tasks:

- T2.1 “Elicitation of Stakeholders’ Characteristics and Requirements”
- T2.4 “Definition of Monitoring & Verification Methodology for DR settlement and remuneration and Key Performance Indicators”
- T2.5 “Smart Grids Interoperability Standards Analysis and overall system architecture design”

And has direct impact on the tasks:

- The whole WP4 “Data Acquisition, Management and Security”
- T5.3 “Dynamic demand-based & Global Demand Manager”

3. Demand Response Strategies

A number of provisions dealing with demand side participation are stipulated in various EU policy documents. In this context, as part of the Network Code on Demand Connection – Article 21 [2] states:

1. Demand response services provided to system operators (either the TSO and/or the DSO) shall be distinguished based on the following categories:
    a. Remotely controlled:
        i. Demand response active power control;
        ii. Demand response reactive power control;
        iii. Demand response transmission constraint management.
    b. Autonomously controlled:
        i. Demand response system frequency control;
        ii. Demand response very fast active power control.
2. Demand facilities and closed distribution systems may provide DR services to relevant system operators and relevant TSOs. DR services can include, jointly or separately, upward or downward modification of demand.
3. The categories referred to in paragraph 1 are not exclusive and this Regulation does not prevent other categories from being developed. This Regulation does not apply to demand response services provided to other entities than relevant system operators or relevant TSOs.

3.1. DR provided values

In general, DR can add energy, capacity, flexibility, and network values as depicted in the Figure **5** below. The services that DR may provide depend on their characteristics (flexibility, location, activation and response time, potential frequency of activation etc.). The next section describes the service requirements for the participation of any type of asset either stand alone or aggregated in the energy markets.

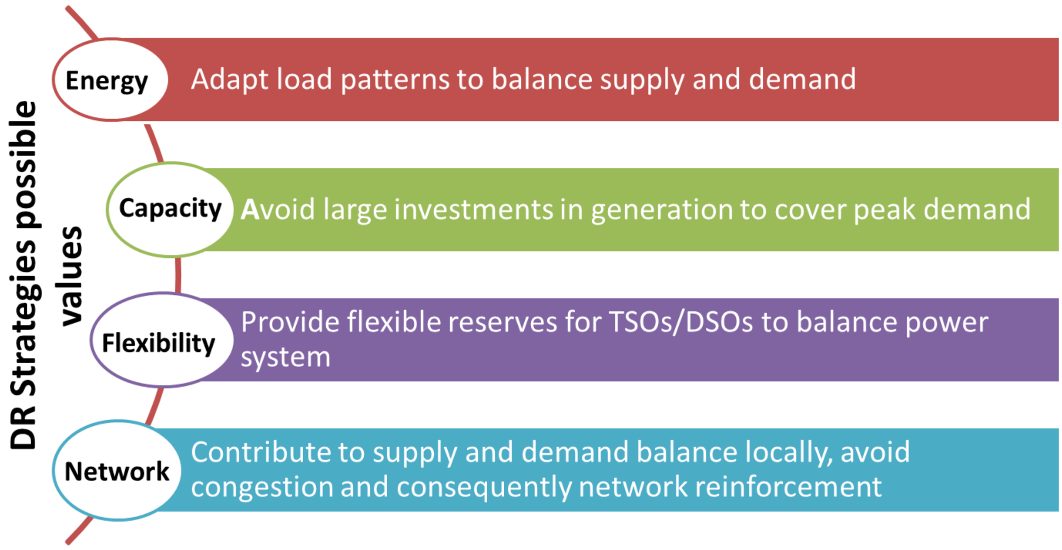


Figure 5: Values that DR can add to the energy system

3.2. Service Requirements

Smart Energy Demand Coalition (SEDC) has stated that the energy market is designed to reflect the capacities of bulk conventional generation units with slow ramp up times and long durations. This prevents flexible loads and local small generation units from participating in the market. To this end, markets should be designed in a granular manner allowing the full range of resources to enter and compete. Product descriptions are historically oriented towards generation standards. ENTSO-E has determined the main service or product requirements, as follows [3]:

- Full Activation Time (FAT) is the period between the activation request by TSO and the corresponding full delivery of the concerned product;
- Minimum and maximum quantity is the power (or change of power) that is offered in a bid, which will be reached at the end of the full activation time;
- Delivery period means a time period of delivery during which the Balancing Service Provider delivers the full requested change of power in-feed or withdrawals to the system;
- Full delivery period refers to the time period starts at the beginning of the ramping period and ends at the end of the deactivation period;
- Mode of Activation of balancing energy bids can be *manual* or *automatic*, and depends on whether balancing energy is triggered manually by an operator or automatically in a closed-loop manner.

Figure **6** illustrates the DR Service requirements described above in a schematic manner.

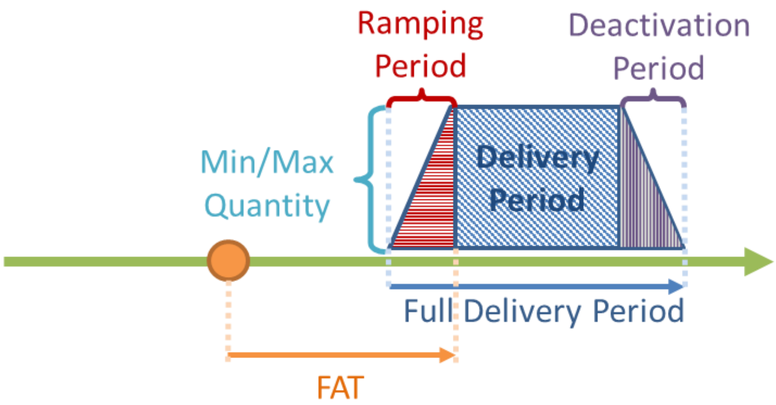


Figure 6: Schematic representation of DR Service requirements

3.2.1. Required DR Service properties

In this section, we present the required DR service properties for wholesale market and Balancing Market and Ancillary Services, which are the basic markets involved in FLEXCoop business scenarios and corresponding use-cases. The analysis provided below is based on ENTSO-E [3], [4], [5], [6] and reports by Smart Energy Demand Coalition (SEDC) [7] and the information given reflect the cases of EU countries with the most advanced DR market (unless otherwise is stated).

3.2.1.1. Wholesale Market

In countries where flexible loads are - in principle - allowed to participate in the wholesale markets, DR services can act as shock absorbers, increasing the price during peak demand periods and enhancing grid reliability. The required DR Service properties for wholesale participation are summarized in the Table 1 below.

Table 1: DR Service properties for wholesale market participation.

Market	Service	Service Properties				
		FAT	Min / Max Quantity	Delivery Period	Mode of Activation	Frequency of Activation
Whole sale market	Day Ahead	Day before the operation day	Minimum of 0.1MW / no upper limit as time/demand variable	From half hour blocks to longer periods	Manual/ Scheduled	Demand/ Price variable
	Intraday	Continuous throughout the 24h period / lead times 5 – 60 min	Minimum of 0.1MW / no upper limit depended on the demand	From half hour blocks to longer periods	Manual/ Scheduled	Demand/ Price Variable

3.2.2. Balancing Market and Ancillary Services

The Frequency Containment Reserves (FCR) products are the first reserve type to secure controllable frequency deviations. These products are capable of frequency drop and/or increase stabilization almost immediately. The automatic Frequency Restoration Reserve (aFRR)[2], manual Frequency Restoration Reserve (mFRR)[3] and Replacement Reserves (RR)[4] products can be activated to restore the frequency in the longer term (a few seconds to few hours). As the balancing products are important to counter the first deviations of the system as well as the longer ones, there are specifications in place by ENTSO-E concerning their requirements as presented in Table 2. Due to the lack of harmonization between EU countries, there are deviations to the characteristics from country to country. Thus, the table below

[2] aFRR: Its purpose is to return the frequency to the nominal value. aFRR is a centralized activated reserve. Its activation is based on a power change signal and sent by the TSO. It is activated automatically and in a continuous manner, it is by its nature more deeply integrated with the TSO systems [11];

[3] Frequency Restoration Reserves (FRR) means the Active Power Reserves activated to restore System Frequency to the Nominal Frequency and for Synchronous Area consisting of more than one LFC Area power balance to the scheduled value [3];

[4] Replacement Reserves (RR) means the reserves used to restore/support the required level of FRR to be prepared for additional system imbalances. This category includes operating reserves with activation time from Time to Restore Frequency up to hours [3];

illustrates the proposed values from ENTSO-E for the mFRR and RR products and the current situation in EU countries by emphasizing on the range of this deviation.

Table 2: DR Service properties for balancing market / ancillary services participation.

Market	Service [7]	FAT	Mini / Max Quantity	Delivery Period	Mode of Activation	Frequency of Activation
Balancing and Ancillary Services Market	**FCR**	1 – 30 sec / product specific requirements	Min. of 1MW aggregated load in 0.1MW increments / Max. is part of the TSO bilateral contract	Continuous throughout the 24h day period in 30 seconds blocks (or less if required)	Automatic	Constant
	mFFR [3]	15 min (ENTSO-E proposes 5min)	Min. of 1MW aggregated load in 0.1MW increments /Max. 9999MW	5 – 60 minutes (depends on the product FAT specific values)	Manual /not scheduled	Depends on network health (indicatively every hour)
	aFFR	30 sec	Min. of 1MW aggregated load in 0.1MW increments		Automatic	Constant
	RR [3]	30 min	Min. of 1MW aggregated load in 0.1MW increment /Max. 9999MW	15 – 60 minutes in 15 minutes blocks	Manual / not scheduled	Depends on network health (up to several times per day)

3.3. Device Characterization

In this section, a classification of devices based on their capability to be used for DR programs is provided. The Section starts with some general aspects and respective characterisation of appliances and then, it focuses on the specific devices that fall under FLEXCoop scope, namely, HVAC, lights, Domestic Hot Water (DHW) and Electric Vehicles (EVs).

3.3.1. Device classification based on operational cycle and occupants' comfort

Considering their operational cycle and the occupant's comfort bounds, the appliances can be divided into:

- **Interruptible or Controllable Appliances,** whose power profile can be managed during their operation, either by interrupting it or controlling its power usage.
- **Deferrable or Shiftable Appliances,** where starting time can be shifted across the day in response to DR services or price variations.

- **Critical Appliances,** which are uncontrolled and have to be preserved without intervention. Consequently, appliances that are non-interruptible and non-deferrable are considered critical and they are not favorable for participation in automated DR programs.

In general, every electrical device inside a residential dwelling can be characterized as:

- Interruptible or non-interruptible depending on its ability to interrupt (or not) their operation.
- Controllable or non-controllable depending on whether it is possible to control their power usage.

Simultaneously, every electrical device can also be characterized as deferrable (or not) depending on whether its operation can be shifted to a different time-period to reduce or increase load consumption to cover specific DR needs. The period in which the deferrable appliance can be shifted is called the deferrable period. This time period is actually a subject of negotiation and should be configured in DR Services taking into account the occupant's comfort bounds and daily habits. Finally, critical devices that need to be always in full operational mode are naturally considered to be non-interruptible and non-deferrable.

3.3.2. Device classification based on electric properties

Depending on the electric properties of their internal circuits the in-home devices can be divided to resistive, inductive, capacitive, or non-linear based on how they draw current in relation to voltage, which in an AC system varies along a smooth sinusoidal pattern [8].

3.3.2.1. Resistive

Resistive are the loads that consist of any heating element. These include incandescent lights, toasters, ovens, space heaters and coffee makers. A load that draws current in a sinusoidal waxing-and-waning pattern combined with a sinusoidal variation in voltage – that is, the maximum, minimum and zero points of the voltage and current values over time line up – is a purely resistive load and includes no other elements.

3.3.2.2. Inductive

Loads that power electrical motors are known as inductive loads. These are found in a variety of household items and devices with moving parts, including fans, vacuum cleaners, dishwashers, washing machines and the compressors in refrigerators and AC. In a purely inductive load, current follows a sinusoidal pattern that peaks after the voltage sine wave peaks, so the maximum, minimum and zero points are out of phase.

3.3.2.3. Capacitive

Capacitive loads are the dual of inductive loads. While many loads have capacitive elements, inductive and resistive characteristics dominate their overall behaviour. Thus, there are no significant capacitive loads in residential buildings. If a load draws current along a sinusoidal pattern that peaks before the voltage sine wave, i.e., the current waveform leads the voltage waveform, the load is purely capacitive.

3.3.2.4. Non-linear

Any load that does not draw current along a sinusoidal pattern is called non-linear. Non-linear loads may also be resistive, inductive, or capacitive according to when their current waveform peaks. The most predominant non-linear (and largely inductive) loads are electronic devices, including desktop computers and TVs. The non-linear nature of these loads is primarily due to the use of switched-mode power supplies (SMPS). Fluorescent lights are another example of a non-linear (inductive) load. Smaller electronic devices that convert AC to low-voltage DC, such as battery chargers for portable devices and digital clocks, are also non-linear [9].

3.3.3. Properties of the devices used in FLEXCoop

Table 3 presents the list of devices examined in FLEXCoop along with their properties. From this table, conclusions can be derived concerning the amount of power that can be shifted or reduced as well as the potential of each device to be used in DR strategies. The characterization of high, medium or low is derived from their different properties combined with the potential load reduction and flexibility they can provide.

Table 3: Device and Control Properties

Device	Device Type	Device Properties			Control Properties		
		Average Consumption (W)	**Length of use**	**Energy Consumption/ Year (KWh)**	**Interruption**	**Deferral Period**	**DR Potential**
Water Heater	Resistive	4500	48 weeks - 5h/day	7538	Controllable	Up to 30min	High
Window AC	Inductive	900- 3250	48 weeks - 5h/day	1508-5444	Controllable	Up to 30min	High
HVAC Central	Inductive	3250- 3800	48 weeks - 5/day	5444-6365	Controllable	Up to 30min	High

CFL Bulb[5]	Capacitive	11- 30	48 weeks – 5h/day	18-50	Controllable	Up to several hours	Medium
LED Bulb [6]	Resistive	10- 23	48 weeks - 5h/day	17-39	Controllable	Up to several hours	Medium
Plug in Electrical Vehicle	Resistive	25-30kWh/ 100miles	52 weeks - 200miles/week	2600-3200	Interruptible	Up to several hours	High

3.4. Demand Response – Flexibility Source Suitability Matrix

The scope of this section is to align DR products and attributes with the device properties of the previous section to assess the capability of specific devices to participate in DR under an aggregation framework provided by aggregators.

3.4.1. Demand Response Attributes

DR resources have characteristic response patterns when called to participate in providing grid services. These characteristics – known as *DR attributes* - can affect significantly the capabilities of DR resources. This should be carefully considered when scheduling the participation of DR resources in grid services.

The identified DR attributes are [10]:

- ***Response Frequency/ Activation Frequency***
  It concerns the frequency of control signals to which a DR resource can respond. If high response frequency is required, DR resources must either be capable of quickly modulating their energy consumption, or be a part of an aggregated load that can respond more frequently than the individual loads themselves. All other attributes being equal, resources capable of responding with high frequency can offer more flexibility to the grid, as they can participate in more products.

- ***Response Duration/ Delivery period***
  It concerns the length of a load shed or shift before returning to normal operation. The maximum response duration is related to assumed acceptable length of reduced service or

[5] CFL Bulb 40-100W Equivalent
[6] LED Bulb 40-100W Equivalent

the presence of integrated energy storage. Longer response durations may be achieved in an aggregated load. Furthermore, longer response durations enable resources to participate in more products, while shorter maximum response durations often restrict them to participating only in ancillary services.

- ***Response Time/ Full Activation Time***

  This is the time between issuing a request for load modification and the full response of the DR resources (see also Section 3.2).

  Response time may consist of several components e.g. advance notification, signal latency, control latency, and equipment response time, as shown in Figure 7. Advance notification is the time required between scheduling a DR event and actual event start. Signal latency is the time between sending and receiving signal by program participants. Control latency is the time between signal receipt by the participant and DR controlled equipment trigger. Finally, equipment response time is the time it takes for the controlled equipment to achieve full response.

- ***Resource Magnitude***

  Resource magnitude refers to the magnitude of DR availability per individual control unit. As mentioned before in Section 3.2, electricity markets define specific minimum and maximum quantities. Therefore, resources with low magnitude (small loads) may be excluded from participating individually in DR programs. However, low-magnitude resources are still capable of participating as part of an aggregated load gaining a rational portion of the revenue during responses.

- ***Energy Re-Charge/ Pre-Charge Requirement***

  For some DR resources, the primary strategy for reducing consumption during an event is to shift it to non-event times rather than shedding it. Load shifting can be achieved either by re-scheduling equipment to be used to non-event hours or by using storage devices. In case of resorting to a storage device as a flexibility source, then the resource must be re- or pre-charged. The re-charge/pre-charge requirement is important, as there is usually a need to balance the total energy delivered with total energy received.

- ***Alignment of Availability***

  DR resources can only respond if they are available during an event. Their availability may vary throughout the year due to weather conditions and occupants' schedules. For example, depending on the weather conditions, it is possible that electric heating or cooling is not in operation and, therefore, cannot participate as DR resource.

Figure 7 provides a schematic representation indicating the DR attributes of DR resources as described above.

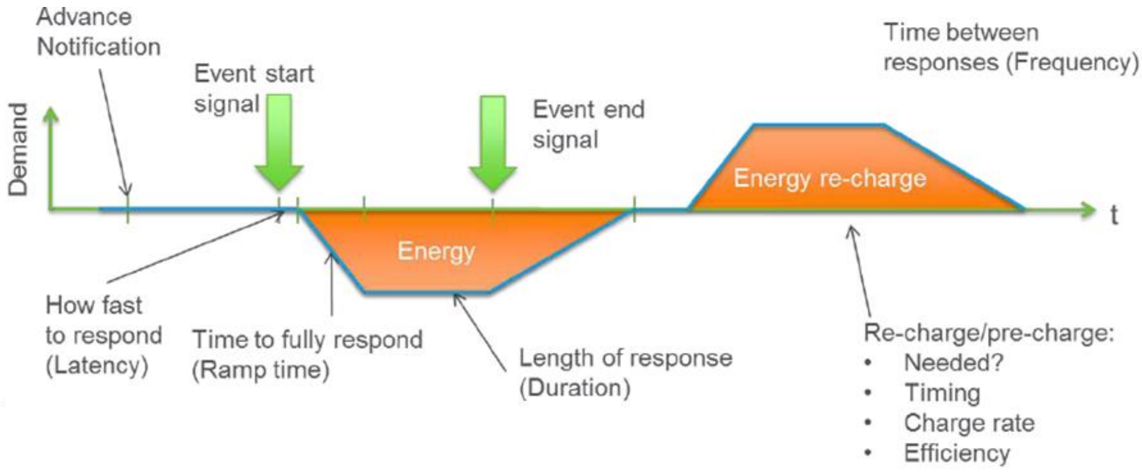


Figure 7: Schematic diagram of demand response with DR attributes [10]

3.4.2. Devices as Demand Response Resources

Through the analysis of each device's consumption and control properties in Section 3.3, and taking into account the DR Attributes presented in the previous section, three broad categories of capabilities of DR resources can be assumed:

- ***Category 1:***

  It includes resources that can provide a ***quick, short response at high frequency***, without the need for "charging". Controllable devices whose load can be spontaneously reduced, such as lighting and HVACs, belong to this category. Lighting devices have a response time less than 30sec while HVACs have a response time less than 1min and they both can provide high response frequency.

- ***Category 2:***

  This category includes resources that can provide a ***long response, but cannot respond quickly or frequently***, and require ***energy recharge***. Storage devices that need to be charged before they are available again as a DR resource belong to this category. Furthermore, load devices with long operation cycle that once started, they can't be interrupted, also belong to this category.

- ***Category 3:***

  It includes resources that can provide a response with characteristics of Category 1 or Category 2. Devices that are not controllable but are interruptible and referrable, which means that their consumption can't be reduced but their operation can be interrupted and shiffted in time, belong to this category.

These three categories can be used towards facilitating the choice on how DR resources can be used in different DR products. *Resources of Category 1* are ideal for providing regulation and flexibility products, while those falling under *Category 2* are best suited for providing contingency, energy and capacity DR products. Finally, *Category 3* resources have the potential to participate in all markets. Therefore, depending on the DR attributes of the aggregated load the aggregator must assess the most suitable market for participation. Resources may also be combined to a virtual resource to combine certain requirement, e.g. combine a quick and long response.

In Table 4, the different device types and their potential to be a DR product and participate via an aggregated manner to specific electricity markets are summarised along with the related services.

Table 4: Devices examined in FLEXCoop as DR Resources in Electricity Markets

Device	Type	DR Potential	Participation in Electricity Markets	Services
Lighting	Load	Medium	Ancillary Services & Balancing Markets	FCR, FRR, RR, Voltage Control
HVAC	Load	High	Ancillary Services & Balancing Markets	FCR, FRR, RR, Voltage Control
Air Conditioner	Load	High	Ancillary Services & Balancing Markets	FCR, FRR, RR, Voltage Control
Plug in EV	Load	High	All Markets	FCR, FRR, RR, Voltage Control, Black Start, Intraday, Day ahead
Water Heater	Load	High	All Markets	FCR, FRR, RR, Voltage Control, Black Start, Intraday, Day ahead
Batteries	Storage	High	All Markets	RR, Voltage Control, Black Start, Intraday, Day Ahead
PVs	Generation	High	All Markets	FCR, FRR, RR, Voltage Control, Black Start, Intraday, Day Ahead

4. FLEXCoop Architecture in the context of Prosumer-centric local optimization strategies

FLEXCoop will use instances of the profiling modelling framework presented in WP3 "Demand Flexibility Modelling and Forecasting" in order to deliver a bundle of appropriate and personalized explicit DR strategies. DR strategies in FLEXCoop will be applied:

- At aggregated district level by exploiting and combining the optimisation provided by the Global and Local Demand Managers in FLEXCoop architecture; and
- At the building/ load level using the DSS layer provided by the Local Demand Manager.

The flexibility profiles comprise the basis for the participation in automated explicit DR strategies preserving occupants' comfort and daily schedules. The modelling framework presented in the various deliverables of the WP3 until now, can be used as a basis towards associating energy uses and loads in residential buildings (i.e. HVAC, lighting, DHW, EVs) with a variety of services that can be used to ensure grid stability and security of supply. In other words, flexibility sources/loads will be associated with different services based on their suitability-for-service, DR capacity, response time and duration of response. This way, optimized DR strategies will be defined to ensure stable grid operation, maximize benefits for all actors involved, while ensuring the preservation of occupants' comfort and indoor environment quality.

The algorithmic framework presented in this document has been structured based on the human centric approach that has already been defined and detailed in the WP3. The prosumer-centric local optimisation aims to support optimized decision making for the dispatch of personalized DR signals to consumers based on their identified flexibility and response capability. Flexibility-based intra-building DR optimization presented herein is used to break down flexibility requirements communicated by the aggregator (through the Global Demand Manager) into individual flexibility that can be offered per load at the prosumer level following a human-centric approach preserving comfort and indoor quality, as depicted in Figure 8.

Local optimization will be a dynamic process enabling the continuous monitoring of the DR event evolution to identify overrides of the implemented strategies or failures at the building level to respond and automatically revise the initially defined strategies to achieve the provision of the anticipated amounts of flexibility.

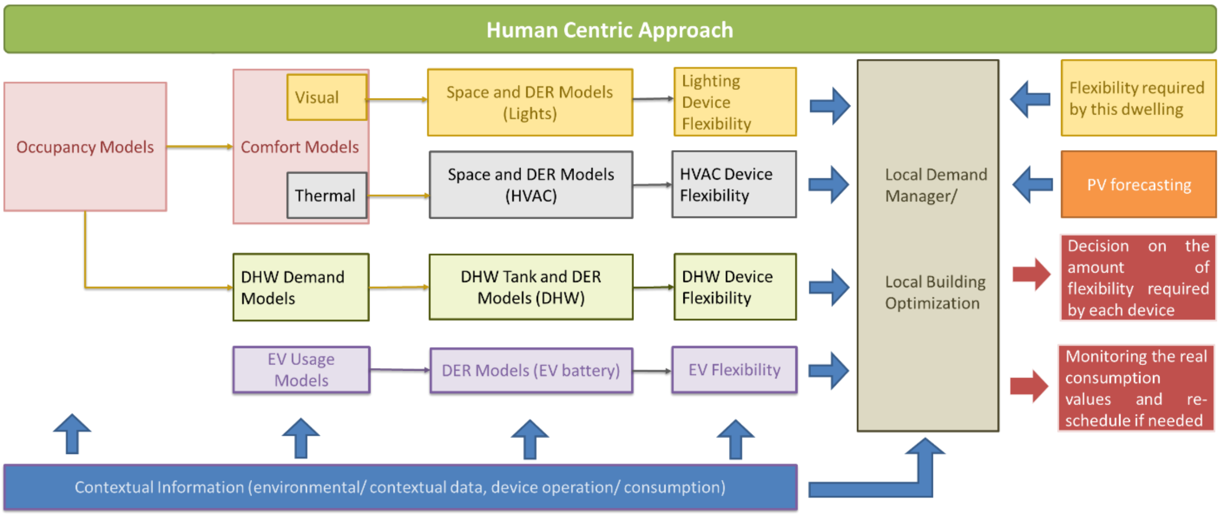


Figure 8: FLEXCoop prosumer-centric local optimisation

5. Interaction with local assets

This section describes all the control signals that can be sent to the OSB towards controlling the operation of the connected controllable DER devices namely:

- Domestic Hot Water (DHW)
- Heating Ventilation and Air Conditioning (HVAC)
- Lights

A critical note should be made at this point. Other local DER devices will also be included in the FLEXCoop DR optimization framework as for example rooftop PVs and Electric Vehicles (EVs). However, this DER devices will not be controlled in the frame of FLEXCoop demonstration phase. These DER devices will be monitored and taken into account in the overall optimization to demonstrate the FLEXCoop use cases and business scenarios but they will not be controlled in pilot demonstration phase. This is further explained in the following paragraphs.

The production of rooftop PVs (that are found in the pilot users) will be continuously measured and the measurements will be used for PV production forecasting that will be further included in the overall FLEXCoop optimization mechanism. However, no control actions are foreseen in the inverter of such PVs.

The reason for this is twofold:

- Currently, from information gathered so far from potential pilot users, we have only grid connected PV systems, thus, curtailment at local level is not possible and, in any case, it is out of the scope of the project itself.
- Intervention aiming at controlling power electronics devices like inverters may have irreversible negative impacts in the product's warranty while it imposes high safety risks.

All these reasons have led us to include no control action in the domestic PV systems found in the pilot sites.

A similar choice has been made for the EVs, although the situation is a bit different and is further explained below. Currently, we have found two full electric EVs in our pilot sites supporting only V2G operation. So, after the detailed survey on such pilot users (which is currently being performed), we will be able to gather consumption data from EV charger when EV is charged at home. This data can then be used for profiling purposes and EV usage forecasting. However, no automated control actions in terms of EV charging are going to be performed and demonstrated in the project. Notifications may be sent to the EV owners on the proposed optimum way to charge their EVs, but not specific automated actions will be made in the charging process of the EVs. Such actions may have significant negative impacts in the EV battery lifecycle as well as in their warranty. Thus, it is a common decision of the FLEXCoop Consortium that no automated control actions are going to take place in the FLEXCoop demonstration phase. Simulations using CIRCE's lab will be run instead to demonstrate how efficient a DR strategy may be proven in case EVs (in both V2G and G2V operation modes) are incorporated in the FLEXCoop holistic DR optimization framework.

5.1. HVAC

Integration and interfacing with the HVAC devices is achieved through the use of appropriate hardware module from INTESISHOME company (see D4.1 “FLEXCoop OSB Prototype Design” for more details). This hardware acts as a gateway that translates the proprietary protocol of an HVAC system to an IP based ASCII protocol.

The interfaces that have already been developed and can be used for sending control actions to HVAC devices are:

- **status**: Defines the ON/OFF operational status of the device
- **mode**: Defines the operational mode of the device, namely,
    - "heat"
    - “cool"
    - “auto"
    - “dry"
    - "fan"
- **fanspeed**: This is a meta information related to the intensity of fan for ventilation purposes. The number of applicable fan positions depends on the HVAC model and the operations that it supports by itself. The maximum possible positions are five, plus the auto mode:
    - "auto"
    - “position-one"
    - “position-two"
    - “position-three"
    - “position-four"
    - “position-five"
- **temperature**: Defines the set-point of the HVAC unit and more specifically:
    - max_value 32.0 ^{o}C
    - min_value 16.0 ^{o}C
    - step 0.5 ^{o}C

  Note: The maximum and minimum set-point values depend on the HVAC model itself.

5.2. DHW

Integration and interfacing with the DHW devices is achieved through a Smart Switch (see D4.1 "FLEXCoop OSB Prototype Design" for more details).

The interfaces that have already been developed and can be used for sending control actions to DHW devices are:

- **status**: Defines the ON/OFF operational status of the device

5.3. Lights

Integration and interfacing with lights is achieved through a dedicated gateway e.g. TRÅDFRI Gateway for TRÅDFRI Bulbs (see D4.1 "FLEXCoop OSB Prototype Design" for more details).

The interfaces that have already been developed and can be used for sending control actions to the lights are:

- **status:** Defines the ON/OFF operational status of the device
- **dimming:** Defines the dimming level of the light as follows:
    - max_value 100 %
    - min_value 0 %
    - step 1 %

6. Demand Response Optimization Framework

Considering that all the roles involved in the DR chain process in this project can be identified with the roles defined by the USEF framework, and the different phases of that process can be mapped with some of the modules of FLEXCoop's architecture, the USEF framework fits perfect with the needs of this project for the flexibility delivery entire sequence.

With the introduction of Distributed Energy Resources (DERs) into the grid and the electrification of energy use, the peak load on the distribution grid will increase. This can cause that, at some points of the grid and due to the high demand at peak times, its capacity is exceeded. Based on USEF framework, the DSO will be able to identify and publish the concrete points of the grid where that overload can happen (Congestion Points). The DSO, based on the analysis of the trends in energy flows on its grids, can identify the Congestion Points with time enough to respond against an overloading situation. Then, it informs the Aggregators about those Congestion Points falling under their control. This is the main reason why the DR Campaigns can be triggered, to avoid those overloads on the grid.

To introduce the value of the flexibility across all the involved roles, USEF introduces a Market-based Coordination Mechanism (MCM) and new processes, providing equal access to the smart energy system to all the involved actors. The MCM has 5 different phases, and the Local Demand Manager has a direct impact in 3 of them; those 5 phases are [1]:

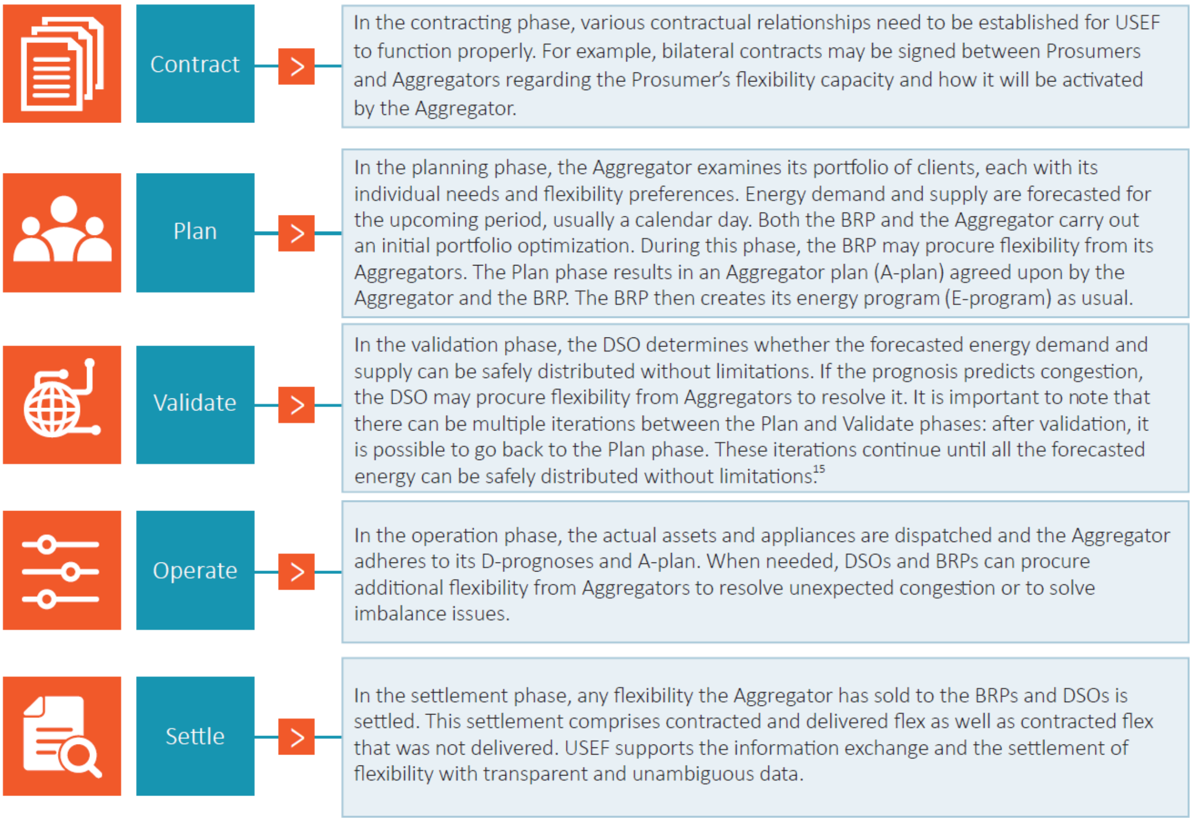


Figure 9: USEF market coordination mechanism

This Deliverable won't go into detail with the *Contract* phase (which takes place between T5.3 "Dynamic demand-based VPP module and Global Demand Manager", T6.3 "Open Flexibility

Pooling and Sharing Marketplace and Associated Standardized Contract Templates" and T6.3 "Prosumer Portal and User Interfaces for Prosumers") and the *Settle* phase (which is part of the T5.4 "Demand Response Settlement and Remuneration Module"). The optimization process on the Local Demand Manager(s) begins when the Aggregator launches the *Planning* phase, gathering all the flexibility they can offer to him. The *Validation* process is delegated to the Global Demand Manager (this process will be examined in T5.4 "Demand Response Settlement and Remuneration Module"), which are located at the Aggregators. Finally, the *Operation* phase is triggered on the Local Demand Manager when the time arrives, sending the proper signals to the selected devices and delivering the expected flexibility to the Global Demand Manager.

6.1. Flexibility delivery sequence in FLEXCoop

As mentioned above, and before going into detail with the DR value chain process, it must be taken noted that it does not involve only the Local Demand Manager (examined in this task and described in the current deliverable) but also the Global Demand Manager (Task 5.3 "Dynamic demand-based VPP module and Global Demand Manager"), which is the entry point for the DR process explained in this section.

Each one of the LDEM located in the buildings is executing each 15 minutes the different optimization algorithms (one algorithm per each defined strategy) and storing the results of each one on their own local data base (step 1 of the Figure 10). The result of each optimization includes the amount of flexibility that can be obtained from each controllable asset for the next 24 hours, in intervals of 15 minutes, and the terms and conditions defined in the contracts between the Aggregator and the owner of that device.

Once the LDEM has the results of all the executed algorithms, it communicates them to the Virtual Power Plant Manager (VPPM), which are defined in the GDEM, it belongs to. As soon as the VPPM receives the results from all the LDEMs under its control, the aggregated amount of flexibility that it can provide for the next 24 hours is updated (step 2 of the Figure 10).

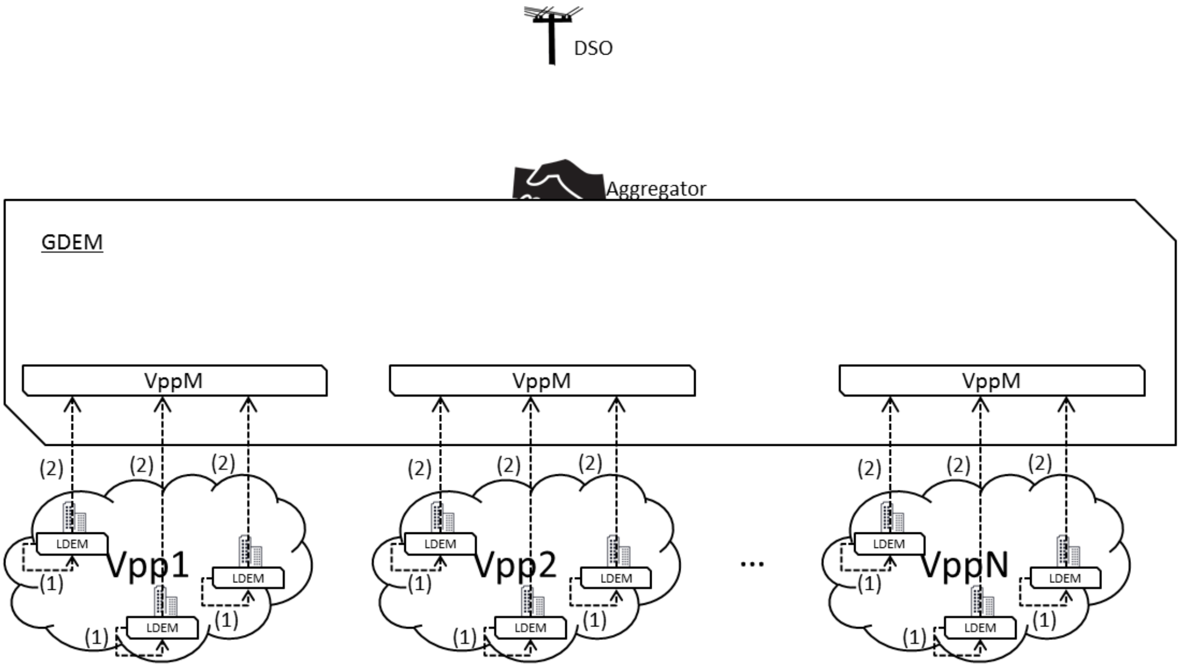


Figure 10: Flexibility delivery sequence – Available flexibility at VPP level

When the GDEM, located at the Aggregator, receives a DR signal coming from the DSO requesting some flexibility (step 3 of the Figure 11), it expands that signal to all the VPPM (step 4 of the Figure 11). Depending on the needs of the GDEM (and the DSO), each VPPM will evaluate the amount of flexibility needed at each interval of time for the duration of the DR signal and how many they will be able to provide and the terms and conditions of it, and they communicate their offer back to the GDEM (step 5 of the Figure 11).

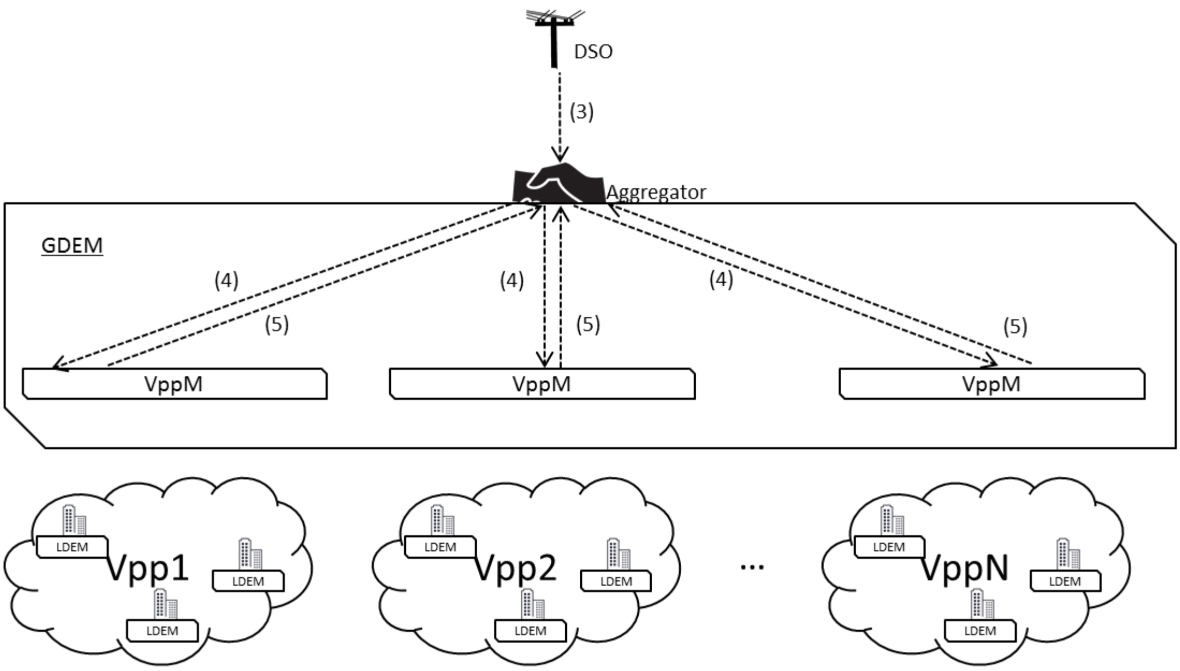


Figure 11: Flexibility delivery sequence – Triggering of a DR Campaign

After evaluating the different offers, the GDEM elaborates the plan to be executed for accomplishing the needs of the DSO, which can involve one or more VPPs. All the VPPs involved on that plan receive a signal from the GDEM containing the amount of flexibility needed from them at each interval of time, and the beginning and ending dates/ time of that DR campaign (step 6 of the Figure 12). A similar process must be done on the selected VPPs, the involved LDEMs on that DR campaign must be selected, requesting to them the amount of flexibility needed at each interval of time for the duration of the campaign (step 7 of the Figure 12).

When the time arrives, each LDEM translates that flexibility into signals to the proper devices, to increase or decrease the consumption according with what is needed (step 8 of the Figure 12).

During the execution phase of the DR campaign, what has been planned must be monitored to ensure that everything goes as expected, and in case that one part of the chain fails, to seek for an alternative for still being able to provide the requested flexibility. In the worst scenario possible, if there are no alternatives for providing the needed amount of flexibility at some moment, the GDEM must notify the DSO about that. However, before notifying to the DSO that, the GDEM will seek that amount in all the LDEM under its control to check if some other can cover it.

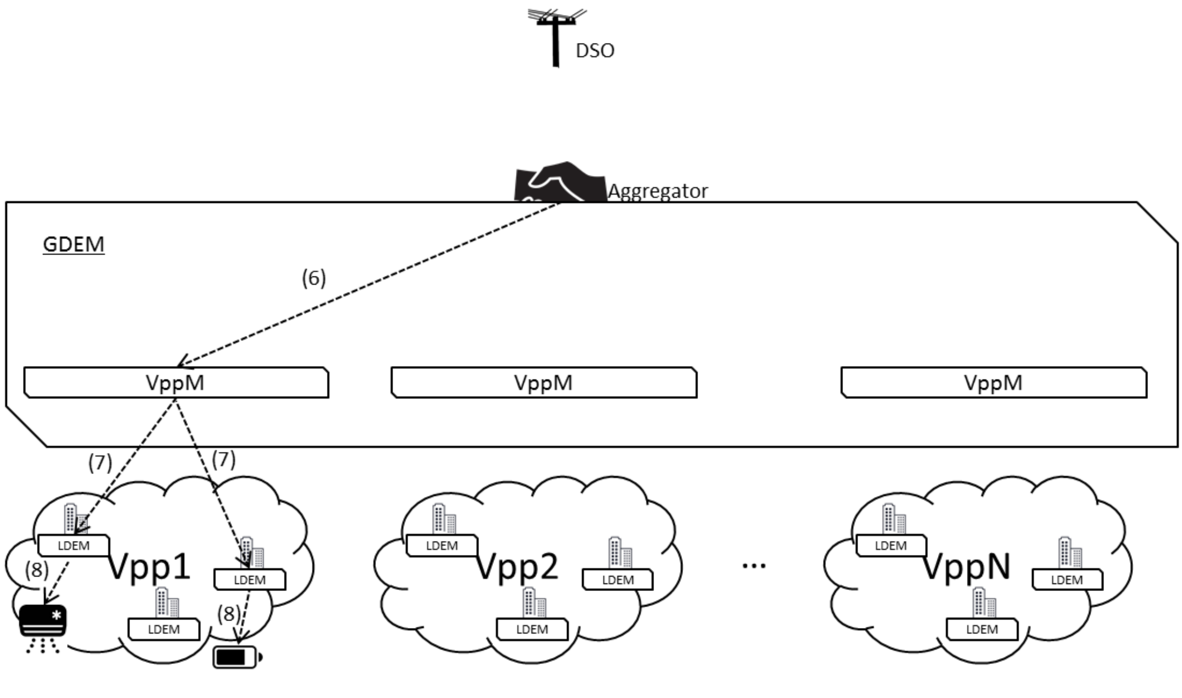


Figure 12: Flexibility delivery sequence – Operation phase

Finally, as soon as the campaign ends the remuneration process takes place.

6.2. Architecture of the local optimization process

Considering how demand response is defined in USEF:

"On a system balance level the reduction of the load is identical to the increase of the generation."

USEF: The Framework Explained

That means that, in the formal description of the system, it has no sense to differentiate between these two options, only the sign is relevant. Therefore, considering the LDEM will manage two kinds of DR signals over time:

- To reduce consumption.
- To increase consumption (i.e. because of a high generation of renewables).

The general architecture of the optimization process can be shown in the Figure 13. Before going into detail with each part of it, let us have a general overview of each sub-process involved on this.

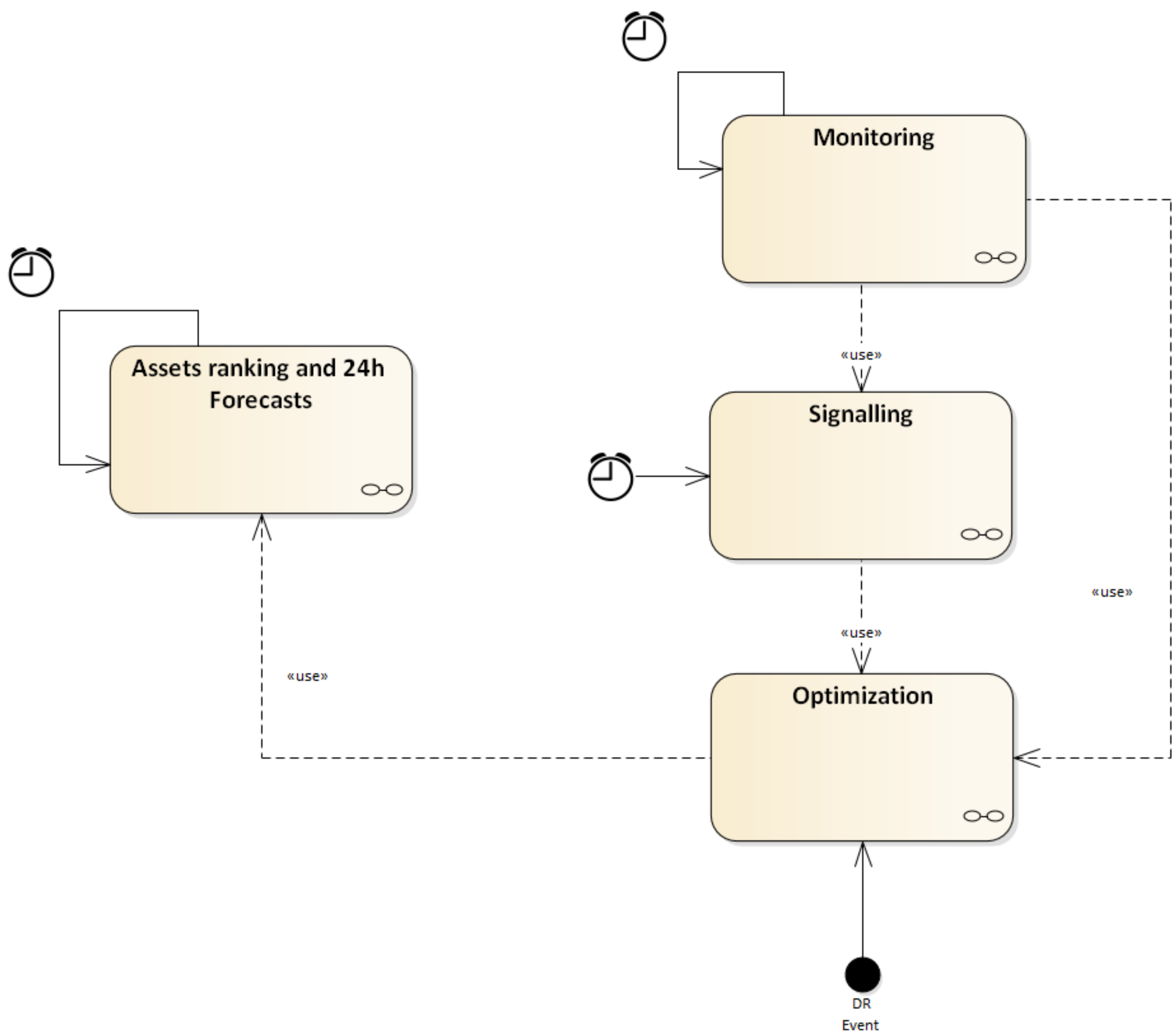


Figure 13: Full optimization process at LDEM level

Continuously, the *Assets ranking and 24h forecasts* sub-process will keep updated two ranked lists with the available assets for the next 24 hours, and the flexibility that each one of them can offer; the first list will contain the assets that could be used on a "reduce consumption" signal, and the second one the ones for a "increase consumption" signal.

Now that a DR Event is received, the LDEM knows at each interval of time how many flexibility it is needed and the amount that the assets under its control can provide. With the updated list of assets and the requested amount of flexibility, the *Optimization* sub-process is able to elaborate a plan for accomplishing those needs. The output of this will be a list of assets and how many consumption must be increased/decreased on each one of them and when.

The *Signalling* sub-process will execute every order of the elaborated planning when the time arrives; ensuring that it is received by the proper asset and it is correctly applied. If some signals can't be received to the expected asset or it can' execute it, this sub-process will select other asset(s) for being able to provide that expected amount of flexibility. The result of every sent signal (including the rejected ones and the new ones decided on the fly) will be logged on the system; this will be useful for the remuneration phase and for knowing the reliability of each asset for future optimizations.

The last sub-process, the *Monitoring* one, is continuously running but only if there are ongoing DR Campaigns. Once a signal has been sent, it must be ensured that the affected assets do not change their behaviour during the expected amount of time, and in case that happens, the system must react as soon as possible to still provide the expected amount of flexibility.

6.2.1. Assets ranking and 24h forecasts

One of the goals of FLEXCoop is to provide automatic and immediate response to a DR Event, and due to it is not possible to predict the amount of flexibility that will be needed during a DR Campaign until it is received the signal, what can be done in advance is to know where the flexibility could be obtained from when the time arrives.

The whole sub-process will be executed two times each 15 minutes, and it will involve 3 different modules, some of them interacting with other components of the FLEXCoop architecture (via the **Message Oriented Middleware**), storing the result of the two executions on a local Data Base. The output of the first execution will be the assets selection and their forecast for the "reduce consumption" campaigns, while the second execution will be the same but for the "increase consumption" campaigns.

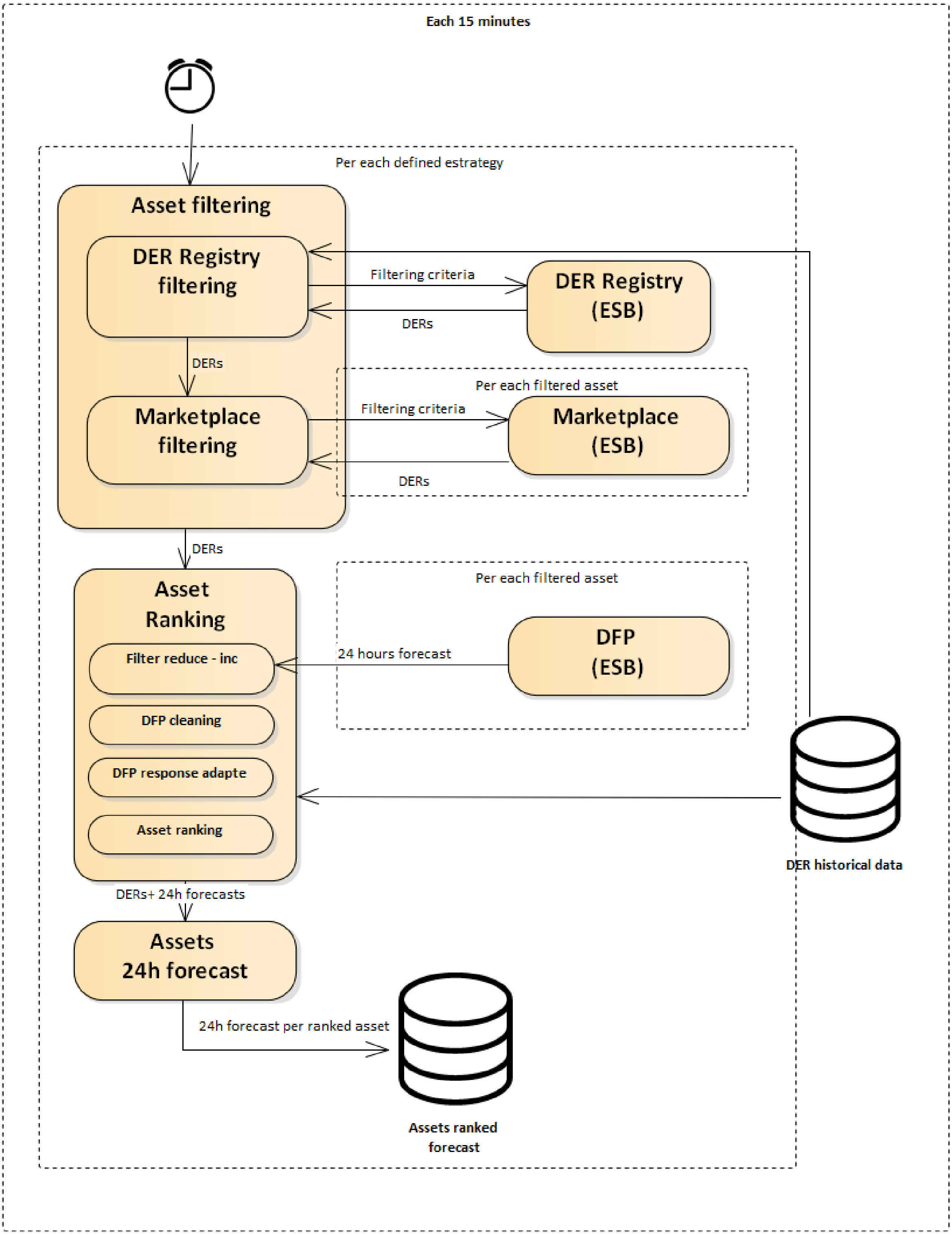


Figure 14: Assets ranking and 24h Forecasts components

6.2.1.1. Asset filtering

At the beginning of each execution of this *Assets ranking and 24h forecasts* sub-process, firstly it is needed to know the currently available assets that could provide some flexibility, so the combination of some of them will be able to cover that amount.

This list of assets will be obtained in a two steps process. Firstly requesting to the **DER Registry** the assets under the control of this LDEM (*DER Registry filtering* sub-module), and after that, those assets are filtered again (*Marketplace filtering* sub-module) following some other criteria but this time interacting with the **Open Marketplace** (in both cases, the interaction is done through the **Message Oriented Middleware**).

For getting the available assets of the LDEM, the *DER Registry filtering* sub-module takes into account the following criteria when consulting the **DER Registry**:

- Location: Each LDEM can only interact with the assets under its control.
- Availability: Apart from the assets belonging to the LDEM, all of them must be available. A second filter about this will be applied when interacting with the **Open Marketplace** to check the range of dates they are expected to be available and other contractual aspects as for example their times for participation in DR strategies (this information is part of the contract terms between the Aggregator and the Prosumer's assets). *More information can be found in Marketplace filtering* sub-module below.
- Type: For the purpose of the demonstration phase, there will only be possible to send signal to three types of devices (as depicted on Chapter 5): DHW, HVAC and lights. The type(s) of requested devices will depend on the type of signal. So, for "reduce consumption" signals all of them are requested; while for the "increase consumption" ones, only the DHW type (which are the only type of assets with the capability of consuming energy for doing some work in advance, which on this case is to heat the water).
- DR attributes: Assets that have already participated recently on a DR Campaign need some time to be available again. Two parameters must be considered for this: the Response Frequency and Response Duration (both are detailed at section 3.4.1). Response Frequency will consider the last time the device received a control signal from the LDEM, while the Response Frequency when the last DR Campaign where this asset participated finished. The information about that is obtained from the *Der historical data* local Data Base (its details can be seen at *Appendix C: DER Historical Data*). If no information about that is found, then this filter is ignored (the asset hasn't participated yet on a DR Campaign).

With the available assets of the LDEM, the *Marketplace filtering* sub-module checks their contracts to analyse how they will offer flexibility during the next 24 hours. Per each one of those assets, their contract data will be obtained from the **Open Marketplace**, and with that extended information about them the second filter can be applied, considering on this case:

- Assets with a contract with the aggregator: There is no need to analyse the answer of the request. If the requested asset is not on the marketplace, then there is no active contract for it and therefore it cannot participate on a DR Campaign.

- Dates: This *Assets ranking and 24h Forecasts* sub-process is constantly updating the list of available assets for the next 24 hours, but not all of them will be available during the whole time. This filter will remove the assets that will not be available at any point during the next 24 hours.

- Status of the contact: Only the assets with an active contract can provide some flexibility.

- Other: Depending of the information contained in the contracts, this filter can be tuned even more.

The output of this two steps module will be a non-ordered list of assets containing each one the next information[7]:

```
"type_of_campaign": "reduce_consumption" | "increase_consumption"
"assets": [
   {
      "id": "string",
      "location": "string",
      "type" : "Light" | "HVAC" | "DHW",
      "contract_details":
         {
            "contract_start_date": "date",
            "contract_end_date": "date",
            "availability_price":
               {
                  "value": "double",
                  "unit": "€/MW"
               },…
         },
      "DR_attributes":
         {
            "activation_frequency": "double",
            "delivery_period": "double",
            "full_activation_time": "double"
         },…
     },…
]
```

Code Listing 1: Asset filtering module output

6.2.1.2. Asset ranking

With the available list of assets for the next 24 hours, now it is time to order them and to know how many amount of flexibility they will be able to provide and when. For ranking them, some different aspects will be taken into account per each device:

- Total available flexibility: The total amount of flexibility the asset is able to provide for the next 24 hours, taking into account its availability according with its contract (the range of dates where it will be available). This information is obtained from the **Demand Flexibility Profiling**.
- Reliability: How effectively the asset has responded to past DR requests. For this it will be necessary the support of a local Data Base containing historical data per each asset.
- Number of participations in DR events: How many times an asset has participated on a DR Campaign. Once again, for obtaining this information the support of a local Data Base with the historical data of past DR Campaigns is needed.
- Price: The price for the energy offered by the asset.

Per each asset, after obtaining its forecast from the **Demand Flexibility Profiling**, the retrieved data must be treated in three steps:

[7] It must be taken into account that the name of the parameters can be different to the implemented version, it will depend of how they are defined on the Common Information Model. The idea of this piece of code is just to show the content of the output of this sub-process.

1. For the "reduce consumption" scenario, only the downwards flexibility offered is needed (which will contain negative values). On the other hand, for the "increase consumption" scenario only the upwards flexibility offered (which will contain positive values).
2. The values out of the date range established on the contracts must be removed (or set to 0). This is needed for the correct calculation of the total available flexibility value because the flexibility offered out of that range is not usable, which in terms of the mathematical formulation is the same as 0.
3. The 24 hours forecast of the **Demand Flexibility Profiling** has to be unified for all the assets. This third step is being explained with detail in the incoming lines.

For unifying the forecasts, the received time series must be converted on a time series with intervals of 15 minutes, which is the Program Time Unit (PTU) that this algorithm will work with. That arises 3 possible scenarios:

1. The response is given with a PTU of 15 minutes. No adapting job must be done

Figure 15: DFP response adaptation – 15' PTU scenario

2. The response is given with PTUs lower than 15 minutes. The intervals corresponding with a 15 minutes are taken, and for the missing ones the value immediately before[8].

Figure 16: DFP response adaptation – less than 15' PTU scenario

[8] If the flexibility data is not accumulated, then this approach will have loss of data. On that case a better approach could be to interpolate the accumulated values, so the linearity would keep the same for the 15 min intervals.

3. The response is given with PTUs higher than 15 minutes. First of all it must be identified the granularity and how many slices of 15 minutes are on it. After that, per each 15 minutes the value of it is proportional to the total amount of the original PTU where these 15 minutes were located.

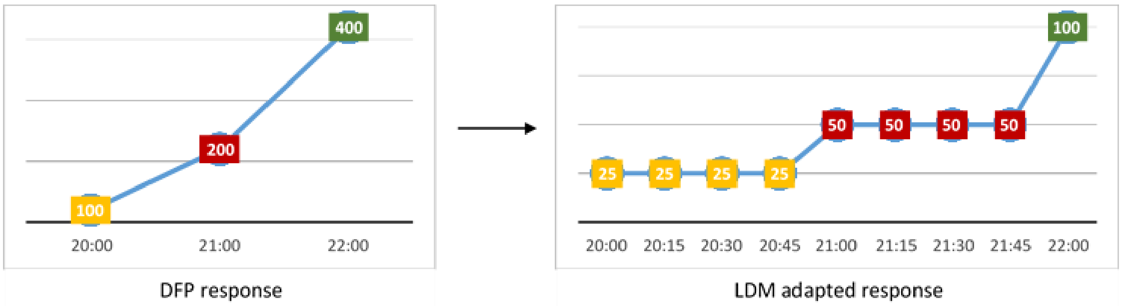


Figure 17: DFP response adaptation – higher than 15' PTU scenario

At the end of this adapting process, the response will contain 4 values each hour, having a total amount of 96 values.

After this adaptation, all the flexibility values before the start date of the contract and after the end date of the contract are set to 0. Posterior to that adapting and cleaning processes, the total available flexibility is calculated using the following equation:

$$J_{flex}^{asset} = \sum_{j}^{N} f(j)$$

Where j ∈ [0, N) is the time-step (15 minutes), N is the time-horizon (24 hours from now), and f represents the potential flexibility at time interval j.

Regarding the reliability of each asset, it must be taken into account its behaviour on past DR Campaigns. The information about that is obtained from the *DER Historical Data* local Data Base. This average ratio is calculated:

$$J_{DRresponsiveness}^{asset} = \frac{1}{D} \sum\nolimits_{i}^{D} \frac{DR_{asset\ performed}}{DR_{asset\ requested}}$$

Where D is the total number of DR signals sent to the respective asset, $DR_{asset\ requested}$ represents the historical amount of flexibility requested to it, $DR_{performed}$ is the actual flexibility given. This equation measures how much trustable an asset is (%). Initially, it will be assumed that every asset is 100% reliable.

In respect to the total number of participations in DR Campaigns, it is considered how many times a signal has been successfully sent to the asset:

$$J_{triggers}^{asset} = D$$

Last but not least, the price set on the contract for using the flexibility of that asset:

$$J_{price}^{asset} = P$$

The ranking of the assets is then performed by using a weighted objective function:

$$J = w_1 * J_{flex}^{asset} + w_2 * J_{DRresponsiveness}^{asset} + w_3 * J_{triggers}^{asset} + w_4 * J_{price}^{asset}$$

By adjusting those weights[9], each parameter will have different impact on the final result. The weight depends on the importance of each one of them. Therefore, if a parameter is not considered, its w_i value is set to 0. The only constraint about that weight is that the sum of the absolute value of all of them must be 1:

$$|w_1| + |w_2| + |w_3| + |w_4| = 1$$

Based on this equations, comfort-based demand flexibility is characterised for each asset, which makes easier the definition and execution of highly effective DR strategies. The output of this module will be an extension (it appears in bold on the Code Listing 2) of the input received from the

Asset filtering module, adding to each asset the flexibility they could be able to provide for the next 24 hours and the weight (J) of that device, which will be used on the *Optimization* sub-process for deciding at each PTU where the flexibility can be obtained from:

```
"type_of_campaign": "reduce_consumption" | "increase_consumption"
"assets": [
   {
      "id": "string",
      "location": "string",
      "type" : "Light" | "HVAC" | "DHW",
      "contract_details":
         {
            "contract_start_date": "date",
            "contract_end_date": "date",
            "availability_price":
               {
                  "value": "double",
                  "unit": "€/MW"
               },…
         },
      "DR_attributes":
         {
            "activation_frequency": "double",
            "delivery_period": "double",
            "full_activation_time": "double"
         },
      "weight": "double",
      "flexibility":
         {
            "timestamp": "date",
            "value": "double",10
         },…
     },…
]
```

[9] Those weights are adjusted through the GDEM depending on the already defined strategies. Every time a new LDEM is registered on the system, the GDEM will communicate to it those values; also, if there is a change on those values, the GDEM will notify about that to every LDEM under its control. This will be explained in more detail in the D5.3 "FLEXCoop Global Demand Manager – Preliminary Version".

[10] For "type_of_campaign" = "reduce_consumption", these values will be ≤ 0, for "increase_consumption", they will be ≥ 0

Code Listing 2: Asset ranking module output

6.2.1.3. Assets 24h forecast

At this point, the available assets for the next 24 hours and how much flexibility they will be able to provide have been given a priority for using them when the time arrives. This module will create a timeline where per each PTU (15 minutes) there will be an ordered list of assets with the capability to provide some flexibility at that moment. It is important to highlight at each PTU the total amount of flexibility (and its price) that can be offered.

This information is needed when the GDEM queries the availability of each one of its LDEM, to decide which ones will provide flexibility when a DR Campaign is triggered.

Due to the information about the assets can change over time, the gathered data from them will be also saved, so once an optimization is planned it will use the last updated information about them at the moment of starting it, and also for the remuneration phase. Once again, this output will be built upon the input received from the *Asset ranking* module (the new information appears in bold).

```
"timestamp11": "date"
"type_of_campaign": "reduce_consumption" | "increase_consumption"
"timeline12": [
   {
      "timestamp": "date",
      "total_amount": "double",
      "total_price": "double",
      "assets": [
         {
            "id": "string",
            "weight"": "double",
            "location": "string",
            "flexibility": "double",
            "type" : "Light" | "HVAC" | "DHW"
         },…
      ],…
   },…
],
"assets": [
   {
      "id": "string",
      "location": "string",
      "type" : "Light" | "HVAC" | "DHW",
      "contract_details":
         {
            "contract_start_date": "date",
            "contract_end_date": "date",
            "availability_price":
               {
                  "value": "double",
                  "unit": "€/MW"
               },…
         },
      "DR_attributes":
         {
            "activation_frequency": "double",
            "delivery_period": "double",
            "full_activation_time": "double"
         },
      "weight": "double",
      "flexibility":
```

[11] The date time at the moment of creating this output

[12] There will be 96 steps, with a difference of 15 minutes between each timestamp

```
          {
             "timestamp": "date",
             "value": "double",
          },…
      },…
]
```

Code Listing 3: Assets24h forecasts module output

The output of this *Assets 24h* forecast will be the result of each iteration of the *Assets 24h forecast* sub-process, and this is what is being stored, and updated iteration after iteration for both types of campaigns, on the *Assets Ranked Forecast* local Data Base (its details can be found at *Appendix C: Assets Ranked Forecast*).

6.2.2. Optimization

The Optimization sub-process is only triggered when a DR Event signal is received. According to the type of that received signal (to increase or to reduce consumption), the *Message Handler* module will get the most updated list of devices that can be used for offering the requested flexibility.

Considering that an immediate response has to be provided as soon as the DR signal is received, this sub-process will, first of all, provide the flexibility requested at the first PTU of that signal (*Optimized asset selection (1st PTU))*, and after ensuring that is has successfully been done it will elaborate the full plan for the rest of the campaign (*Optimized asset selection*).

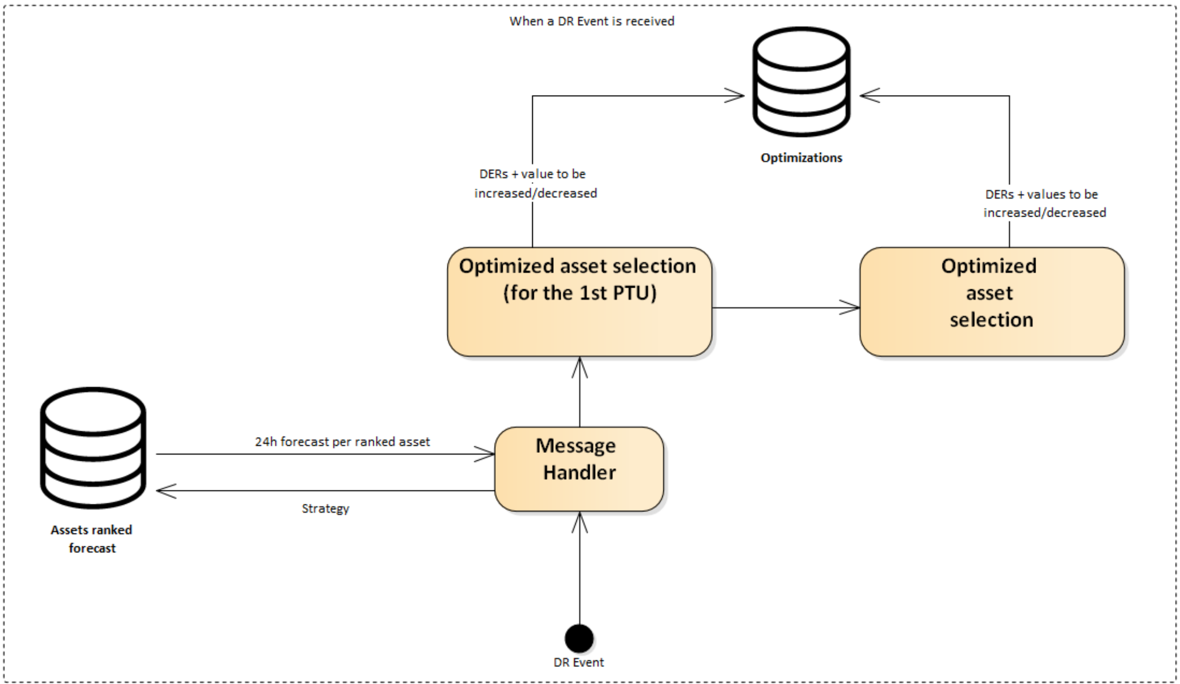


Figure 18: Optimization components

6.2.2.1. Message Handler

As soon as a DR Event is received, this process will check the type of DR Event received (to increase or to decrease consumption) and according with that it will get from *Assets Ranked Forecast* local Data Base the last result about that type of campaign.

6.2.2.2. Optimized asset selection (1st PTU)

For providing the first amount of flexibility, it is considered the result obtained from the *Assets Ranked Forecast* local Data Base by the *Message Handler*, and it will be selected from the 1st step of the timeline enclosed on that result enough assets to cover the requested demand at the 1st PTU of the DR Event. Usually the timestamps of the DR Event won't match the timestamps on the timeline of the response, so the selected step from that timeline will be the one whose timestamp is immediately before than the current timestamp of the DR Event (this situation will be repeated per each step of the DR Event, so the way to solve this is the same for all the steps).

Once it has been selected enough assets for covering that amount of flexibility, the rest of assets of that step of the timeline are also considered, but as "backup" assets just in case when the signals are sent, some of the selected devices fail. With this information a new optimization plan can be created and stored in the *Optimizations* local Data Base, containing the information depicted in Code Listing 1.

A last consideration must be done: If the last selected asset is able to provide more flexibility than the requested to it, then that asset will be the first on the backup list but offering only the remaining amount of that. It still has to be considered its Activation Frequency if it has to be selected again.

As commented in the *Assets 24h forecast* section, the status of the devices and the properties of their contracts can change over time, so it is needed to know the actual status of them at the beginning of the optimization process for using those values at the end of this process when the remuneration phase takes place. This means that it must be kept the complete information about all the assets that are selected to take part on the campaign. That information about them is obtained from the "assets" section of the data provided by the *Message Handler*.

```
"timestamp": "date",
"type_of_campagin": "reduce_consumption"| "increase_consumption",
"planning": [
   {
      "step": "date",
      "requested_amount": "double",
      "assets": [
         {
            "id": "string",
            "location": "string",
            "amount": "double",
            "type": "Light" | "HVAC" | "DHW"
         },…
      ],
      "backup_assets": [
         {
            "id": "string",
            "location": "string",
            "amount": "double",
            "type": "Light" | "HVAC" | "DHW"
         },…
      ]
   },…
],
```

```
"result": [

],
"assets": [
   {
      "id": "string",
      "location": "string",
      "type" : "Light" | "HVAC" | "DHW",
      "contract_details":
         {
            "contract_start_date": "date",
            "contract_end_date": "date",
            "availability_price":
               {
                  "value": "double",
                  "unit": "€/MW"
               },…
         },
      "DR_attributes":
         {
            "activation_frequency": "double",
            "delivery_period": "double",
            "full_activation_time": "double"
         },
      "weight": "double",
      "flexibility":
         {
            "timestamp": "date",
            "value": "double",
         },…
     },…
],
"used_assets": [

]
```


Code Listing 4: Optimized asset selection (1st PTU) module output

Once the first step has been decided, then it is time to send the proper signals to the selected devices and it must be ensured they are correctly applied. The entire *Signalling* module is explained in details in the section 6.2.3.

6.2.2.3. Optimized asset selection

With the aim of being the less intrusive as possible, once a device has been selected for providing some flexibility at a PTU, that asset will remain selected as much time as possible. That means that for the next PTUs it must be considered which devices are currently providing some flexibility and if they can continue doing so.

Based on this, the algorithm process will:

1. Get from the list of assets (from the "assets" section of the data provided by the *Message Handler*), the list corresponding with the timestamp equals to the current PTU of the DR Event, or the immediately before.
2. From the "planning" section of the optimization that is being calculated, get the assets of the last calculated PTU (but not the "backup" ones).
3. Per each asset obtained in 2, select them again if they are still available on the list obtained in 1.
4. If after 3 there is still some flexibility to be provided, select new assets from the ordered list obtained at 1 until that amount is covered.

These four steps will be repeated for each PTU of the DR Signal. At the end of this full process, the *Optimizations* local Data Base will contain the entire plan (*Code Listing 5*, but with the "planning" section completed). The *Signalling* module and the *Monitoring* module will use this information for sending the proper signals and checking that everything goes as expected, respectively.

6.2.3. Signalling

Signals are sent in two different situations: just after the first step of the optimization has been planned, and every time the times arrive for the rest of the optimization plan.

Whatever the situation is, every time a signal is sent it must be ensured it is correctly applied. If this is not the case, then some "backup" assets have to be selected (taking into account their order on the "backup" list) and sending signals to them until the expected flexibility is fully covered. In the worst scenario possible, when not all the expected flexibility can be obtained from the assets, the GDEM must be informed about that for seeking for alternatives and still being able to provide the expected flexibility (this is part of the T5.3 "Dynamic demand-based VPP module and Global Demand Manager").

After each step is executed and the signals have been sent, the "result" section of the optimization stored in the *Optimizations* local Data Base is updated, adding the results of applying that signal, and if the devices have failed then the "backup" ones that have been used (also considering if they have failed or not).

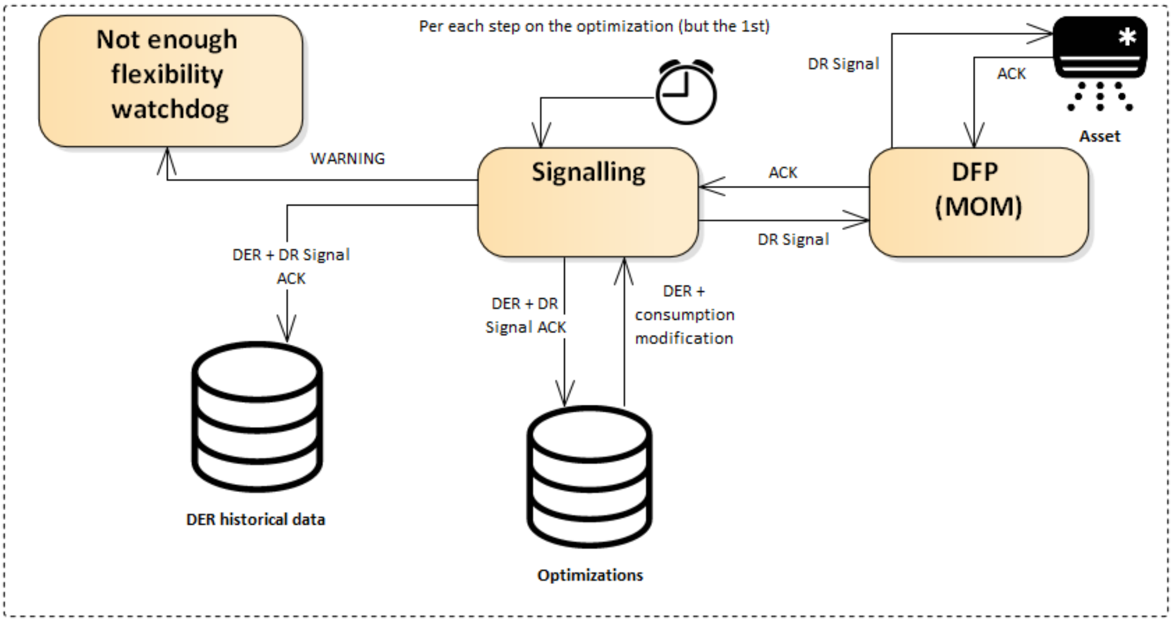


Figure 19: Signalling components

Also, every time a signal is properly applied on an asset, that device is moved from the "assets" section to the "used_assets" section of the optimization plan. This will make *Monitoring* process much easier; using that information it will ensure that once the signal has been applied, the expected consumption of the device doesn't change for the rest of the duration of the campaign, and if that happens then it must be obtained from other device(s). On the assets moved to that section, their information is updated by adding the next (it appears in bold on the *Code Listing 5*):

- When the signal has been sent.
- When it is expected to be effective (considering timestamp and the Full Activation Time of the asset).
- Its current consumption just before receiving the signal.
- Its expected consumption after the appliance of that signal.
- Once an asset has been selected for providing some flexibility, it must accomplish what is expected from it. If at some point it fails, it must be marked so for the next iterations of the *Monitoring* process that asset is ignored (but it will be taken into account during the remuneration phase).

This information will be used by *Monitoring* sub-process. Also, which has already been the last executed step is also stored, once again for *Monitoring* purposes:

```
"timestamp": "date",
"type_of_campagin": "reduce_consumption"| "increase_consumption",
"last_executed_step": integer,
"planning": [
   {
      "step": "date",
      "requested_amount": "double",
      "assets": [
         {
            "id": "string",
            "location": "string",
            "amount": "double",
            "type": "Light" | "HVAC" | "DHW"
         },…
      ],
      "backup_assets": [
         {
            "id": "string",
            "location": "string",
            "amount": "double",
            "type": "Light" | "HVAC" | "DHW"
         },…
      ]
   },…
],
"result": [
   {
      "timestamp": "date",
      "requested_amount": "double"
      "assets": [
         {
            "id": "string",
            "amount_expected": "double",
            "amount_provided": "double",
            "ack[13]": "true" | "false"
         },
         …
      ],
   }
],
"assets": [
   {
      "id": "string",
      "location": "string",
      "type" : "Light" | "HVAC" | "DHW",
```

[13] True if the signal is correctly applied

```
      “contract_details”:
         {
            “contract_start_date”: “date”,
            “contract_end_date”: “date”,
            “availability_price”:
               {
                  “value”: “double”,
                  “unit”: “€/MW”
               },…
         },
      “DR_attributes”:
         {
            “activation_frequency”: “double”,
            “delivery_period”: “double”,
            “full_activation_time”: “double”
         },
      “weight”: “double”,
      “flexibility”:
         {
            “timestamp”: “date”,
            “value”: “double”,
         },…
     },…
],
“used_assets”: [
   {
      “id”: “string”,
      “last_received_signal”: “date”,
      “signal_appliance”: “date”,
      “before_signal_consumption”: “double”,
      “after_signal_expected_consumption”: “double”,
      “failed”: “true” | “false”,
      “location”: “string”,
      “type” : “Light” | “HVAC” | “DHW”,
      “contract_details”:
         {
            “contract_start_date”: “date”,
            “contract_end_date”: “date”,
            “availability_price”:
               {
                  “value”: “double”,
                  “unit”: “€/MW”
               },…
         },
      “DR_attributes”:
         {
            “activation_frequency”: “double”,
            “delivery_period”: “double”,
            “full_activation_time”: “double”
         },
      “weight”: “double”,
      “flexibility”:
         {
            “timestamp”: “date”,
            “value”: “double”,
         },…
     },…

]
```
Code Listing 5: Optimization update after sending the 1st batch of signals

6.2.4. Monitoring

If there is a DR Campaign ongoing, then this Monitor sub-process must be running to ensure that everything goes as expected at every moment.

This sub-module will interact with the “used_assets” part of the plan that is currently running. It will check for every asset that should have already modified its consumption according with its “signal_appliance” parameter if their actual consumption (by requesting it from the **Demand**

Flexibility Profiling) matches with the “after_signal_expected_consumption”. If those values doesn’t match, then this module must trigger another asset from the “backup” ones on the last executed step and, once again, ensure that the sent signal is properly applied. Once an asset has failed, it is marked

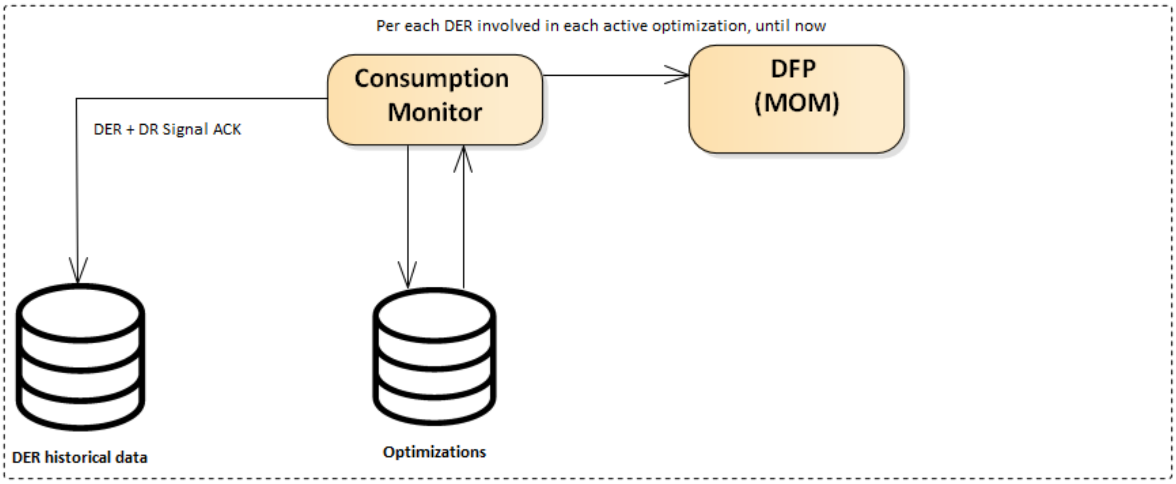


Figure 20: Monitoring components

7. CONCLUSION

This deliverable presents the whole DR flexibility value chain and, concretely, in detail one of the modules involved on that process: the Local Demand Manager. For achieving that goal, the USEF framework is used, and an introduction to it is presented in Chapter Introduction1.

The Local Demand Manager will be continuously gathering the potential flexibility that each device under its control can offer for the next 24 hours. That updated information is needed once a DR Event is received, so it can respond immediately to that signal and dispatch the proper signals to the involved devices to provide the needed amount of flexibility on that DR signal.

One of the goals of FLEXCoop's project is to offer and automatic and immediate mechanism for providing flexibility. For that reason so some kind of automatized system for controlling the users' devices is needed. This final task will be performed by the OSB, which will receive the increase/decrease consumption signals and will dispatch them to the indicated devices.

In addition to this, it must be ensured for the duration of the DR event that every device involved on the campaign doesn't modifies its behaviour once a signal has been sent to it, so all the involved devices must be monitored during the campaign to ensure that everything goes as expected.

The rest of this DR value chain process is explained in the Deliverables corresponding to the Global Demand Manager and DR Settlement an Remuneration phase. The GDEM will be the one beginning a DR Campaign as soon as they receive a signal from the DSO, and expanding that to some of the LDEM under its control (the selected ones). At the end of the campaign, all the involved assets must be remunerated (or penalized). Although this is out of the scope of this Deliverable, it is important to highlight that the entire process also involves those modules.

APPENDIX A: LITERATURE

[1] "USEF: THE FRAMEWORK EXPLAINED," [Online]. Available: https://www.usef.energy/download-the-framework/. [Accessed 25 Mar 2019].

[2] "EUROPEAN NETWORK OF TRANSMISSION SYSTEM OPERATORS FOR ELECTRICITY," *ENTSO-E Network Code on Demand Connection,* no. May, p. 63, 2012.

[3] Entso-E Aisbl, "Proposal for mFRR and RR Standard Products – supporting document - draft 7," 2016.

[4] Entso-E Aisbl, "performing the reserve replacement for the implementation framework for the exchange of balancing energy from Replacement Reserves in accordance with Article 19 of Commission Regulation (EU) 2017/2195 of 23 November 2017 establishing a guideline on electr".

[5] "Explanatory Document to All TSOs' proposal for the implementation framework for a European platform for the exchange of balancing energy from frequency restoration reserves with automatic activation in accordance with establishing a guideline on electrici," 2018.

[6] "Market," [Online]. Available: https://www.entsoe.eu/about/market/. [Accessed 5 Mar 2019].

[7] SEDC, "Explicit Demand Response in Europe," 2017.

[8] M. Pipattanasomporn, M. Kuzlu, S. Rahman and Y. Teklu, "Load Profiles of Selected Major Household Appliances and Their Demand Response Opportunities," *IEEE Trans. Smart Grid,* vol. 5, no. 2, pp. 742-750, Mar. 2014.

[9] S. Barker, S. Kalra, D. Irwin and P. Shenoy, "Empirical characterization and modeling of electrical loads in smart homes," *2013 International Green Computing Conference Proceedings,* pp. 1-10, 2013.

[10] D. Olsen, S. Kiliccote, M. Sohn, L. Dunn and M. A. Piette, "Taxonomy for Modeling Demand Response Resources," 2014.

[11] "Frequency Restoration Reserve (FRR)," [Online]. Available: https://www.emissions-euets.com/internal-electricity-market-glossary/794-frequency-restoration-reserve-frr. [Accessed 25 Mar 2019].

[12] "D10.2 WiseGRID Flexibility-based DR Optimization Framework Specification".

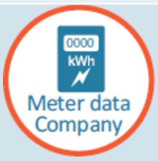
[13] "D10.1 DR Technologies Outlook and Flexibility Sources Clustering and Classification".

APPENDIX B: THE USEF ROLES MODEL

The following description for each USEF role is contained in [1]:

	A Prosumer can be regarded as an end user that no longer only consumes energy, but also produces energy. USEF does not distinguish between residential end users, small and medium-sized enterprises, or industrial users; they are all referred to as Prosumers.
	Active Demand & Supply (ADS) represents all types of systems that either demand energy or supply energy and which can be actively controlled. This enables the ADS device to respond to price and other signals from the Aggregator and to provide flexibility to the energy markets via the Aggregator. The Prosumer owns the device and defers responsibility for controlling its flexibility to the Aggregator. The Prosumer has final control over its assets, which means the Aggregator's control space is limited by the Prosumer's comfort settings. Hence the Prosumer is always in control of its comfort level; if the associated remuneration is high enough, however, the Prosumer might be willing to compromise on its comfort levels.
	The role of the Aggregator is to accumulate flexibility from Prosumers and their Active Demand & Supply and sell it to the BRP, the DSO, or (through the BRP) to the TSO. The Aggregator's goal is to maximize the value of that flexibility by providing it to the service defined in the USEF flexibility value chain that has the most urgent need for it. The Aggregator must cancel out the uncertainties of non-delivery from a single Prosumer so that the flexibility provided to the market can be guaranteed. This prevents Prosumers from being exposed to the risks involved in participating in the flexibility markets. The Aggregator is also responsible for the invoicing process associated with the delivery of flexibility. The Aggregator and its Prosumers agree on commercial terms and conditions for the procurement and control of flexibility.
	The role of the Supplier is to source, supply, and invoice energy to its customers. The Supplier and its customers agree on commercial terms for the supply and procurement of energy. Although the Aggregator is formally responsible for invoicing flexibility to the Prosumer, depending on the business model (see section 6.5) this flexibility might be invoiced through the Supplier.
	A Balance Responsible Party (BRP) is responsible for actively balancing supply and demand for its portfolio of Producers, Aggregators, and Prosumers. A BRP is contracted by the Supplier. In principle, everyone connected to the grid is responsible for his individual balance position and hence must ensure that at each PTU the exact amount of energy consumed is somehow sourced in the system, or vice versa in case of energy production. The Prosumer's balance responsibility is generally transferred to the BRP, which is contracted by the

	Supplier. Hence the BRP holds the imbalance risk on each connection in its portfolio of Prosumers.
	The DSO is responsible for the active management of the distribution grid and introduces the system operation services defined in the USEF flexibility value chain in section 3.4. UFLEX obtained from the Aggregators on its network is purchased to execute its system operations tasks. The DSO is responsible for the cost-effective distribution of energy while maintaining grid stability in a given region. Potentially, the DSO role could supersede the classical role of the DNO (distribution network operator) to cost-effectively maintain the distribution network, but this does not necessarily have to be the case; one could think of business models where these roles are separate legal entities. USEF only provides a roles model; such decisions are subject to market regulations and outside the scope of USEF.
	The role of the Transmission System Operator (TSO) is to transport energy in a given region from centralized Producers to dispersed industrial Prosumers and Distribution System Operators over its high-voltage grid. The TSO safeguards the system's long-term ability to meet electricity transmission demands. The TSO is responsible for keeping the system in balance by deploying regulating capacity, reserve capacity, and incidental emergency capacity. The role of the TSO remains unchanged in USEF, but UFLEX provides a new source of flexibility to the TSO as input for its system operation services as defined in the USEF flexibility value chain in section 3.5. The TSO can purchase UFLEX indirectly via the BRP from the Aggregators active on its network.
	The role of the Producer is to feed energy into the energy grid. In doing so, the Producer plays an important role in the security of the energy supply. The Producer's primary objective is to operate its assets at maximum efficiency. Though its responsibility remains unchanged, the introduction of demand response and changes to the merit order can alter its operating conditions quite drastically, since renewable energy sources such as wind and solar power have a relatively low operating expense and compete with existing power generation units.
	The ESCo offers auxiliary energy-related services to Prosumers. These services include insight services, energy optimization services, and services such as the remote maintenance of ADS assets. If the Supplier or DSO is applying implicit demand response through (for example) time-of-use or kWmax tariffs, the ESCo can provide energy optimization services based on these tariffs.

	The Common Reference Operator (CRO) is responsible for operating the Common Reference, which contains information about connections and Congestion Points in the network.
	The Meter Data Company (MDC) is responsible for acquiring and validating meter data. The MDC plays a role in USEF’s flexibility settlement process and the wholesale settlement process.
	The Allocation Responsible Party (ARP) is responsible, within a metering grid area, for establishing and communicating the realized consumption and production volumes per PTU, either on the consumer level or on the aggregated level. The realized volumes are primarily based on actual measurements, but can also be based on estimates. The allocation volumes are input for the USEF flexibility settlement process and the wholesale settlement process.

APPENDIX C: LOCAL DATA BASES

Assets Ranked Forecast

This Data Base will contain only two different results, one for the "reduce consumption" type of campaign and another one for the "increase consumption". Both results will be updated each 15 minutes.

It will contain the next information:

- Timestamp: The last time this information was updated;
- Type of campaign: The type of campaign this information is for;
- Timeline: There will be an element per each 15 minutes for the next 24 hours, which means 24 * 4 = 96 values. Each element will contain a list of ordered assets and how many flexibility could be obtained from them. The concrete information on each element is:
  - Timestamp: The step this element is related with. There will be a difference of 15 minutes between each element. The first timestamp will be now, and last now + 24 hours;
  - Total amount: The total amount of flexibility that could be obtained from all the elements available during this time slot;
  - Total price: The total price of the flexibility that could be obtained from all the elements available during this time slot;
  - Assets: The available assets for that slot of time. It will contain the basic information about the asset:
    - Id: Unique identifier of the asset
    - Weight: The importance of the asset according with the combination of all the ranking criteria;
    - Location: Where the asset is located;
    - Flexibility: The amount of flexibility it can offer during that time slot
    - Type: The type of device.
- Assets: Due to the same asset may appear multiple times during the timeline, the information that is not needed for sending the signal to it is saved here, just for avoiding redundancy on this kind information. There will be as many assets as involved in the timeline, containing each one the following information:
  - Id, Location, Type, Weight: They are the same information as depicted above;
  - Contract details: The terms and conditions on the contract between the owner of this asset and the Aggregator. The main information that is needed are the date range where this asset will be available, and the price for using it. Also some other information can appear here;
  - DR attributes: Each device will have different parameters when responding to a DR Event:
    - Activation frequency: It concerns the frequency of control signals to which a DR resource can respond;
    - Delivery period: It concerns the length of a load shed or shift before returning to normal operation;
    - Full activation time: This is the time between issuing a request for load modification and the full response of the DR resources;

- Flexibility: The entire time series of this asset and how many flexibility it can provide at each step of time.

```
"timestamp": "date"
"type_of_campaign": "reduce_consumption" | "increase_consumption"
"timeline": [
   {
      "timestamp": "date",
      "total_amount": "double",
      "total_price": "double",
      "assets": [
         {
            "id": "string",
            "weight"":"double",
            "location": "string",
            "flexibility": "double",
            "type" : "Light" | "HVAC" | "DHW"
         },…
      ],…
   },…
],
"assets": [
   {
      "id":"string",
      "location": "string",
      "type" : "Light" | "HVAC" | "DHW",
      "contract_details":
         {
            "contract_start_date": "date",
            "contract_end_date": "date",
            "availability_price":
               {
                  "value": "double",
                  "unit": "€/MW"
               },…
         },
      "DR_attributes":
         {
            "activation_frequency": "double",
            "delivery_period": "double",
            "full_activation_time": "double"
         },
      "weight": "double",
      "flexibility":
         {
            "timestamp": "date",
            "value": "double",
         },…
     },…
]
```

Code Listing 6: Assets Ranked Forecast local Data Base content

DER Historical Data

On this Data Base it will be stored all the historical information of all the assets involved in the DR Campaigns.

It will store the next information per each asset:

- Id: Unique identifier of the asset;
- Location: Where the asset is located;
- Type: The type of device;
- Decrease campaigns: The total amount of consumption to be reduced that has been requested to this device in all this kind of campaign where it has, or should have,

participated (total amount expected), and the total amount that it provided (total amount provided);

- Increase campaigns: The total amount of consumption to be increased that has been requested to this device in all this kind of campaign where it has, or should have, participated (total amount expected), and the total amount that it provided (total amount provided);
- Historical: All the historical information about every DR Event where this device has, or should have, participated:
    - Timestamp: When the signals have been sent;
    - Type of campaign: The type of campaign this information is for;
    - Amount expected: How many consumption that asset has to decrease/increase;
    - Amount provided: How many consumption that asset has decreased/increased;
    - ACK: If the asset responded as expected to the signal.

```
"id": "string",
"location": "string",
"type" : "Light" | "HVAC" | "DHW",
"decrease_campaigns"{
   "total_amount_expected": "double",
   "total_amount_provided": "double",
},
"increase_campaigns"{
   "total_amount_expected": "double",
   "total_amount_provided": "double",
},
"historical": {
   "timestamp": "date",
   "type_of_campaign": "reduce_consumption" | "increase_consumption",
   "amount_expected": "double",
   "amount_provided": "double",
   "ack": "true" | "false"
}
```

Code Listing 7: DER Historical Data local Data Base content

Optimizations

This Data Base will contain the entire planning for the duration of the DR Campaign once it has been triggered. The information contained on it will be updated at each step, every time a signal has been sent.

It will contain the next information:

- Timestamp: The last time this information was updated;
- Type of campaign: The type of campaign this information is for;
- Last executed step: This information will be used by the *Monitoring* sub-process if at some point any asset modifies its behaviour, and the flexibility it was providing must be covered by some other device(s). The *Monitoring* sub-process must trigger another asset from the "backup" list on the last executed step;
- Planning: According with the DR Signal received, the elaborated planning for covering the requested flexibility during its duration is stored. That planning will contain:
    - Step: The timestamps of this step, which will be obtained from the DR Event;
    - Requested amount: The amount of flexibility needed at this step, which will be obtained from the DR Event;
    - Assets: The list of selected assets for delivering the requested flexibility during this step. The details of the information contained inside this element are

explained in the "assets" element of the "timeline" *Assets Ranked Forecast* Local Data Base;
    - Backup assets: The ordered list of assets where the flexibility could be obtained just in case some sent signal is rejected during the *Signalling* sub-process, or if the *Monitoring* sub-process detects that the promised flexibility is not being covered. The details of the information contained inside this element are explained in the "assets" element of the "timeline" on the *Assets Ranked Forecast* Local Data Base.
- Results: After each step is executed and the signals have been sent, the results of applying those signals are stored here, and if the devices have failed then the “backup” ones that have been used (also considering if they have failed or not). Per each step of the planning, the next information is stored:
    - Timestamp: When the signals have been sent;
    - Requested amount: How many flexibility has been requested;
    - Assets: Assets involved during that step for retrieving the expected flexibility. Per each involved asset it will be stored:
        - Id: Unique identifier of the asset;
        - Amount expected: How many consumption that asset has to decrease/increase;
        - Amount provided: How many consumption that asset has decreased/increased;
        - ACK: If the asset responded as expected to the signal.
- Assets: Due to the status of the devices and the properties of their contracts can change over time, it is needed to know the actual status of them at the beginning of the optimization process for using those values at the end of this process when the remuneration phase takes place. This means that it must be kept the complete information about all the assets that are selected to take part on the campaign. The details of the information contained inside this element are explained in the "assets" element on the *Assets Ranked Forecast* Local Data Base;
- Used assets: Each time an asset is selected to participate in the DR Campaign, it is moved from the "assets" section to this one. The *Monitoring* sub-process will use the information contained here to ensure that everything goes as expected. All the assets on this section will be taken into account during the remuneration phase. The details of the information contained inside this element are explained in the "assets" element on the *Assets Ranked Forecast* Local Data Base, and adding to the moved asset the next information:
    - Last received signal: The last time a signal was sent to this device;
    - Signal appliance: When that signal is expected to be effective (considering timestamp and the Full Activation Time of the asset);
    - Before signal consumption: Its current consumption just before receiving the signal;
    - After signal expected consumption: Its expected consumption after the appliance of that signal;
    - Failed: Once an asset has been selected for providing some flexibility, it must accomplish what is expected from it. If at some point it fails, it must be marked so for the next iterations of the *Monitoring* process that asset is ignored (but it will be taken into account during the remuneration phase).

```
"type_of_campagin": "reduce_consumption"| "increase_consumption",
```

```
"last_executed_step": integer,
"planning": [
   {
      "step": "date",
      "requested_amount": "double",
      "assets": [
         {
            "id": "string",
            "location": "string",
            "amount": "double",
            "type": "Light" | "HVAC" | "DHW"
         },…
      ],
      "backup_assets": [
         {
            "id": "string",
            "location": "string",
            "amount": "double",
            "type": "Light" | "HVAC" | "DHW"
         },…
      ]
   },…
],
"result": [
   {
      "timestamp": "date",
      "requested_amount": "double"
      "assets": [
         {
            "id": "string",
            "amount_expected": "double",
            "amount_provided": "double",
            "ack": "true" | "false"
         },
         …
      ],
   }
],
"assets": [
   {
      "id": "string",
      "location": "string",
      "type" : "Light" | "HVAC" | "DHW",
      "contract_details":
         {
            "contract_start_date": "date",
            "contract_end_date": "date",
            "availability_price":
               {
                  "value": "double",
                  "unit": "€/MW"
               },…
         },
      "DR_attributes":
         {
            "activation_frequency": "double",
            "delivery_period": "double",
            "full_activation_time": "double"
         },
      "weight": "double",
      "flexibility":
         {
            "timestamp": "date",
            "value": "double",
         },…
     },…
],
"used_assets": [
   {
      "id": "string",
      "last_received_signal": "date",
      "signal_appliance": "date",
      "before_signal_consumption": "double",
      "after_signal_expected_consumption":"double",
```

```
      “failed”: “true” | “false”,
      “location”: “string”,
      “type” : “Light” | “HVAC” | “DHW”,
      “contract_details”:
         {
            “contract_start_date”: “date”,
            “contract_end_date”: “date”,
            “availability_price”:
               {
                  “value”: “double”,
                  “unit”: “€/MW”
               },…
         },
      “DR_attributes”:
         {
            “activation_frequency”: “double”,
            “delivery_period”: “double”,
            “full_activation_time”: “double”
         },
      “weight”: “double”,
      “flexibility”:
         {
            “timestamp”: “date”,
            “value”: “double”,
         },…
   },…
]
```

APPENDIX D: LOCAL DEMAND MANAGER OPTIMIZATION PROCESS

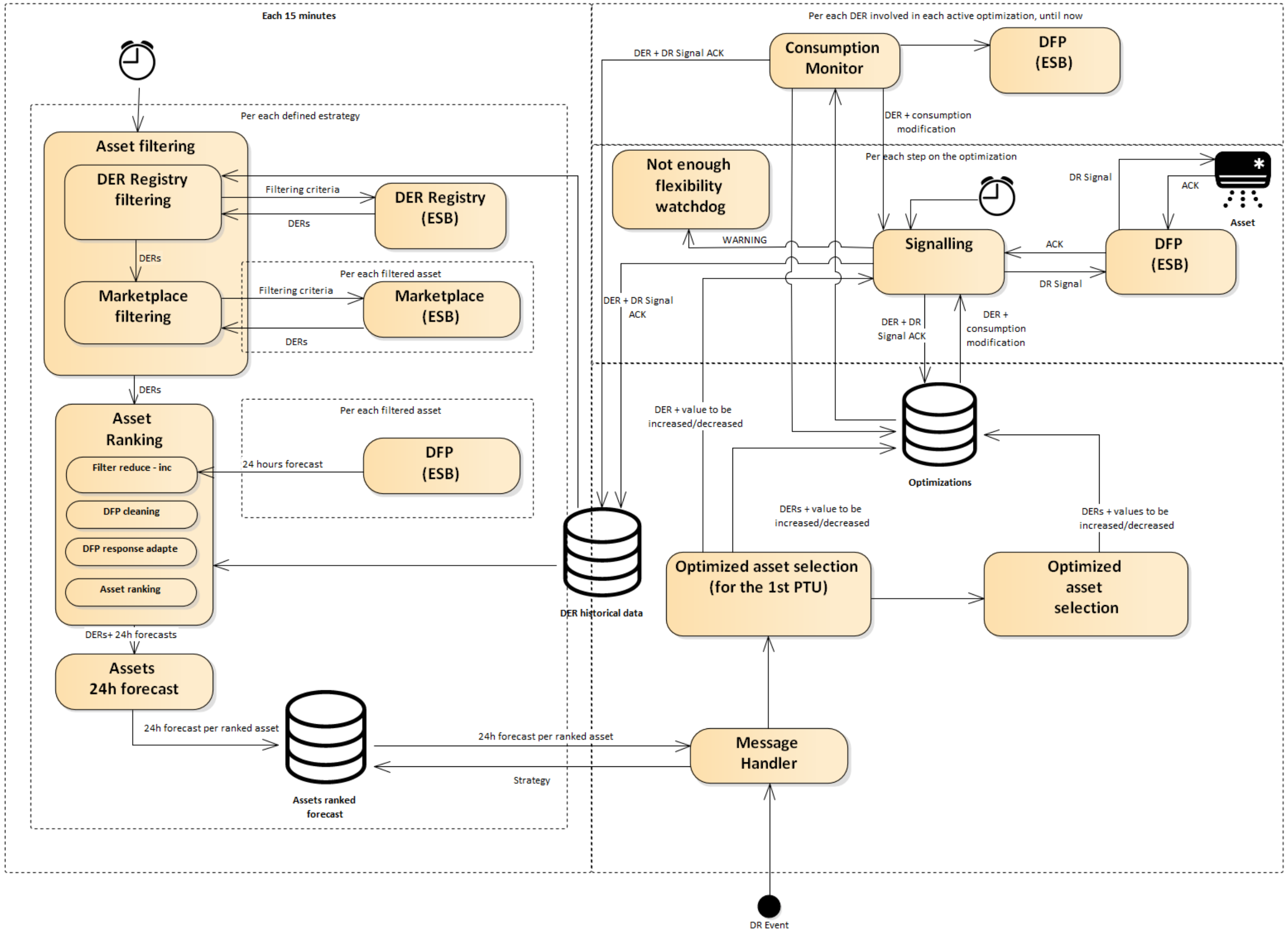


Figure 21: Detailed full optimization process at LDEM level