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FLEXCoop

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

WP7 - System Validation and Impact Assessment

D7.2 – FLEXCoop Evaluation Framework and Respective Validation Scenarios

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FLEXCoop Key Facts

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Consortium:	13 organizations from nine EU member states

FLEXCOOP Consortium Partners

Fraunhofer	Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V.
ETRa	ETRA INVESTIGACION Y DESARROLLO SA
HYPERTECH	HYPERTECH (CHAIPERTEK) ANONYMOS VIOMICHANIKI
DTU	DANMARKS TEKNISKE UNIVERSITET
GRINDROP	GRINDROP LIMITED
CIRCE	FUNDACION CIRCE CENTRO DE INVESTIGACION DE RECURSOS Y CONSUMOS ENERGETICOS
KONCAR	KONCAR - INZENJERING ZA ENERGETIKUI TRANSPORT DD
SUITE5	SUITE5 DATA INTELLIGENCE SOLUTIONS Limited
S5	SUITE5 DATA INTELLIGENCE SOLUTIONS Limited
CIMNE	CENTRE INTERNACIONAL DE METODES NUMERICS EN ENGINYERIA
RESCOOP.EU	RESCOOP EU ASBL
SomEnergia	SOM ENERGIA SCCL
ODE	ORGANISATIE VOOR HERNIEUWBARE ENERGIE DECENTRAAL
Escozon	ESCOZON COOPERATIE UA - affiliated or linked to ODE
MERIT	MERIT CONSULTING HOUSE SPRL

Executive Summary

The main objective of the FLEXCoop project is to employ modern tools for massive deployment of Distribution Energy Resources (DER) and innovative business models for energy cooperatives to democratize the energy market. FLEXCoop project aims at bringing together different type of DER technologies to construct Demand Response (DR) optimization framework for energy cooperatives (also known as aggregators) and prosumers. The optimization framework should take into account the economic behavior of underlying business entities and therefore, detailed evaluation through Key Performance Indicator (KPIs) and cost-benefit analysis (CBA) is of utmost importance. Thus, this deliverable provides a solid evaluation framework for validation activities.

DER units, located at distribution level, bring forth an additional opportunity for provision of local services for Distributed System Operator (DSO) and Ancillary Services (AS) for the Transmission System Operator (TSO) counting on their flexibility potential. Single DER cannot enter to an electricity market to trade their energy for the following two reasons: 1) the available flexibility potential of an individual DER is below the threshold to participate in AS markets and 2) the participation of an individual DER will increase the number of market actors.

Hence, a new market entity, an aggregator, will be required in order to enable smooth cooperation between DER owners and System Operator (SO). The aggregator, through the development of novel DR tools, makes it possible for small DERs to participate in AS markets and obtain additional revenue streams meanwhile, reducing the amount of data passed onto the AS markets.

Two pilots (business cases) have been launched, in the Netherlands and in Spain, aiming to demonstrate the aggregated flexibility potential using the DER units, and its capability to provide ancillary services.

In the Dutch pilot, the cooperative playing the role of the aggregator is already involved in a pilot project related to the provision of automatic Frequency Restoration Reserve (aFRR) services, since AS market in Netherlands allows service provision from DER units. Therefore, the aggregator needs to accurately estimate the flexibility of its entire portfolio and bid to the aFRR market respecting the existing market rules and regulations.

In contrast, ancillary service provision using DR is not acknowledged yet in the Spanish AS market. Thus, this use case is centered in optimizing the participation of an aggregator in the day-ahead electricity market while increasing self-consumption of the energy generated by PV rooftop systems.

Wide range of KPIs, for measuring the forecasts and flexibility, are introduced for the performance evaluation. First, these KPIs are defined. Then, it is outlined how the KPIs can be specified on individual and aggregated levels. Finally, different examples of application are provided. The calculation of the KPIs occurs after the delivery period using the observations from the Spanish and Dutch use cases.

At the end, a guidance on how to carry out micro-level CBA is presented, which aims at estimating the impact of DER unit integration in the power system, in particular, the performance of the Demand Response tool on involved economic parties. In the scope of the FLEXCoop project, the involved economic entities are aggregators and end users. The analysis is carried out considering observations obtained from Dutch and Spanish pilots.

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Abbreviations

ACE	Area Control Error
ACF	Auto-Correlation Function
aFRR	Automatic Frequency Restoration Reserve
AS	Ancillary Market
BRP	Balance Responsible Party
BSP	Balance Service Provider
BTP	Balance Transported Power
CAPEX	Capital Expenditure
CBA	Cost-Benefit Analysis
CE	Continental Europe
CCF	Cross-Correlation Function
CRPS	Continuous Ranked Probability Score
D	Deliverable
DA	Day-Ahead Market
DER	Distributed Energy Resources
DHW	Domestic Hot Water
DR	Demand-Response
DRF	DEmand Response and Flexibility
DRMS	Demand - Response Management System
DSO	Distribution System Operator
EV	Electric Vehicle
FCR	Frequency Containment Reserve
FRR	Frequency Restoration Reserve
GDEM	Global Demand Manager for Aggregators
HVAC	Heating, Ventilation, & Air Conditioning
ICT	Information and communication technology
IGCC	International Grid Control Cooperation
ISP	Imbalance Settlement Period
KPI	Key Performance Indicator
LDEM	Local demand energy manager
LFC	Load Frequency Control
mFRR	Manual Frequency Restoration Reserve

mFRRsa	Manual Frequency Restoration Reserves scheduled activated
OPEX	Operational Expenditure
OSB	Open Smart Box
PPA	Power Purchase Agreement
PV	Photovoltaic
RES	Renewable Energy System
SO	System Operator
TSO	Transport System Operator
VPP	Virtual Power Plant
WP	Work Package

Nomenclature

Some short clarifications on the use of prosumers and assets: In the Dutch use case where it is described how the FLEXCoop system will work when applied to operate with the Tennet aFFR market the following must be noted: In the documents from Tennet one “asset” is specifically a system with a grid connection point, e.g. a power plant. Hence in the FLEXCoop setup, where the aggregator interacts with prosumers, who each have a grid connection point, the prosumers should then be referred to as the assets. However, in the FLEXCoop deliverables the term “asset” has been used for a device, which is behind the connection point of the prosumer and controllable at the local level, e.g. a heat pump. This meaning of prosumer and asset is kept in this document.

Further, it must be noted that in FLEXCoop the flexibility (or balancing power) is on the demand side. Historically balancing power has been delivered on the generation side which is reflected in the terminology used. Therefore the following should be kept in mind:

- “Up-regulation” means that there is a lack of generation, hence the demand must be decreased. Thus when the prosumers deliver “up-regulation flexibility” it means that they are decreasing their demand.
- “Down-regulation” means that the generation is too high, hence the demand must be increased. Thus when the prosumers deliver “down-regulation flexibility” it means that they are increasing their demand.

Variables KPIs and use case sections (sections 2 to 4):

Symbol	Name	Unit
t	Time (normalized time unit $t_2 - t_1 = 1$)	$[\Delta t]$
Δt	Sampling period such that $\Delta t = t_{i+1} - t_i$	time (s,h,day, etc.)
i	Index variable indicating the i’th consumer	
j, k	Index variables	
If not particularly specified in the context, a variable will be denoted with i if its for the i’th prosumer, if without then its the aggregated value, e.g.: $P_{i,t}$is the power of the i’th prosumer and $P_t$is the aggregated power of many consumers.		
A hat indicates a forecast, e.g.: $\hat{P}_t$is the power forecast at time t which was issued at some earlier time. If there is a need to specify when the forecast was issued, then it’s done by $\hat{P}_{t\mid t-k}$(the forecast power at time$t$issued at $t-k$) or similar $\hat{P}_{t+k\mid t}$(the forecast power at time $t+k$issued at time t)		
$\hat{P}_t$	Forecast of baseline demand of i’th prosumer at time t	W
$\hat{P}_t^{max}$	Forecast of maximum demand level (i.e. max demand which can be delivered under down-regulation)	W

$\hat{P}_t^{min}$	Forecast of minimum demand level (under up-regulation)	W
$\hat{P}_t^{down}$	Forecast of available flexibility for down-regulation (i.e. possible increase in demand)	W
$\hat{P}_t^{up}$	Forecast of up-regulation flexibility (i.e. possible decrease in demand)	W
$\hat{P}_t^{PV}$	Forecasting of PV generation	W
$a_t^{down} = \{0,1\}$	Down-regulation activation	
$a_t^{up} = \{0,1\}$	Up-regulation activation	
P_t	Observed demand of i^{th} prosumer	W
P_t^{up}	Delivered up-regulation flexibility	W
P_t^{down}	Delivered down-regulation flexibility	W
P_t^{downND}	Not delivered activated down-regulation flexibility	W
P_t^{upND}	Not delivered activated up-regulation flexibility	W
P_t^{downAD}	Additional delivered activated down-regulation flexibility	W
P_t^{upAD}	Additional delivered activated up-regulation flexibility	W
$\hat{c}_t^{name}$	Forecast of cost at time *t* of “name”	Monetary
c_t^{name}	Cost at time *t* of “name”	Monetary

1 INTRODUCTION

The scope of the document

This document results from Task 7.1, offering a *global framework for validation activities* of the FLEXCoop project. This deliverable describes the evaluation methodology by defining specific validation pilot scenarios (also addressed as use cases or business cases), associating them to suitable key performance indicators (KPIs) capable to address specifications of each pilot case and finally identifying a cost-benefit analysis (CBA) framework to assess the project results. The outcomes of the deliverable D7.2 will be implemented and integrated in further tasks of the WP7 environment.

Validation activities through KPIs and CBA are based on the observations obtained from the developed **Demand Response framework and tool suite** for DER units for the two countries where FLEXCoop focuses on, the Netherlands and Spain (Dutch and Spanish use cases). The focus is on these two selected cases as an indicative part of the complete list of the business models described in deliverables of WP2 (D2.4). These two use cases have different objectives depending on the existing electricity market regulation in Spain and in the Netherlands.

Ancillary service market in the Netherlands allows flexibility provision from both generation and demand side. Therefore, Dutch pilot aims at addressing ancillary service provision from demand side by aggregating DER units and entering the aFRR market. It focuses on investigating flexibility potential - mainly from heat pumps.

In contrast, the Spanish market does not grant permission for demand side to provide ancillary services. Thus, the Spanish use case aims at maximising self-consumption of roof-top PV generation and improving the bidding process to day-ahead market.

The business cases are elaborated through the mathematical aggregation models of DERs, namely demand response (DR), in order to assess their flexibility potential to provide ancillary services to the system. The aggregation of small DERs enables the inclusion of their bids in the electricity market. These offers address physical and dynamic characteristics of underlying DER technology. Figure 1.1 illustrates the information flow between the individual DERs, the aggregator and the electricity market.

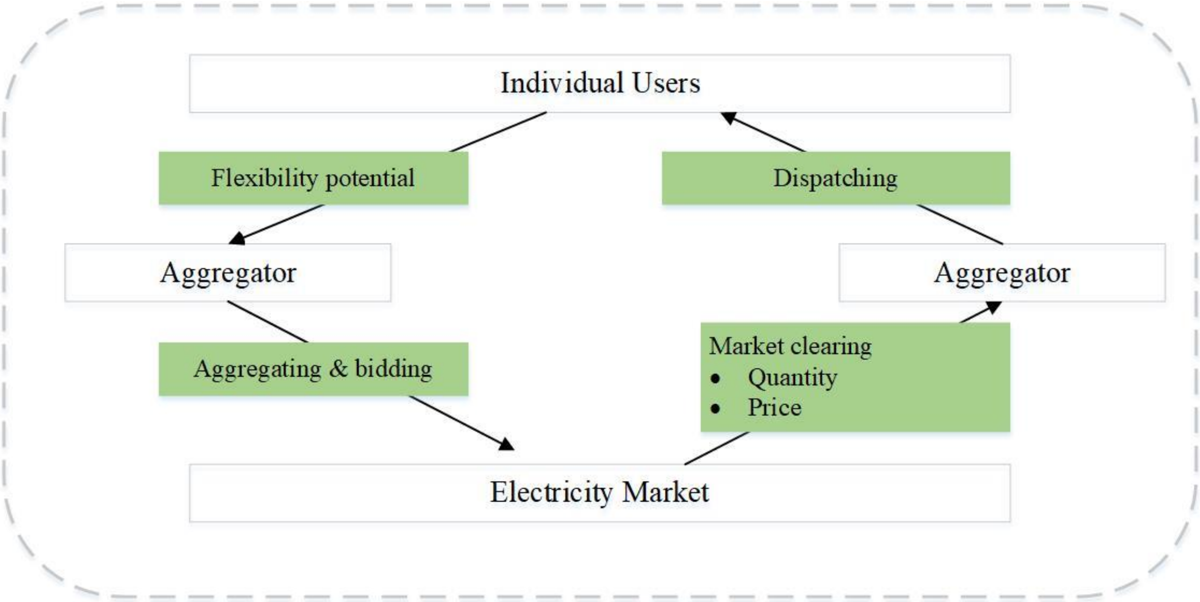

Figure1.1: The illustration of aggregation, bidding and dispatching procedure.

The results/observations obtained from pilots' environment are the core input for the corresponding KPIs and CBA described in this report.

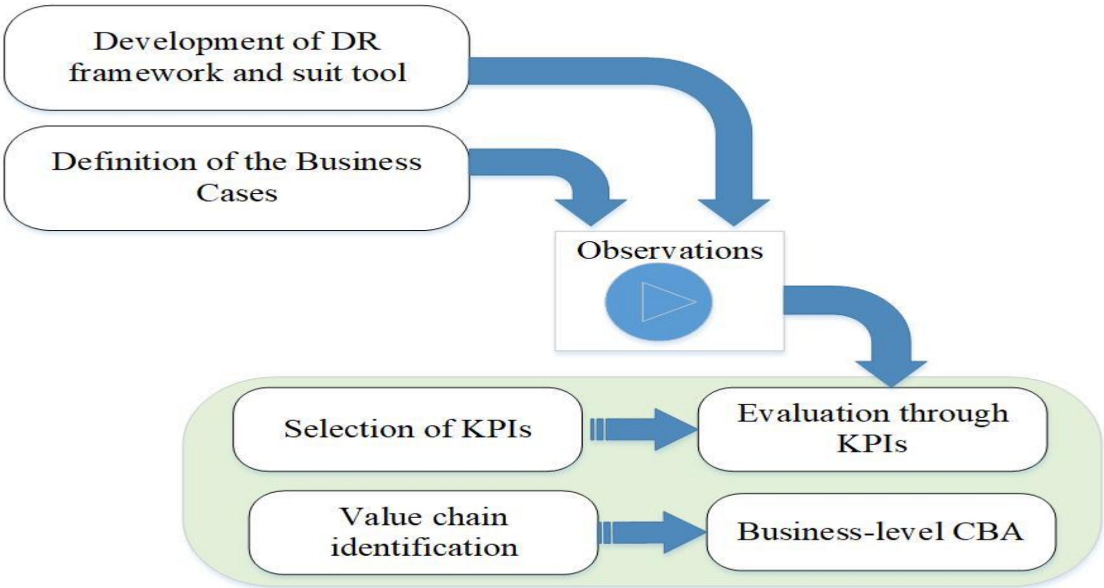

Figure1.2: Evaluation approach for FLEXCoop project.

It is possible to observe from Figure 1.2, that the evaluation methodology, which is highlighted in light green, is an integral part of the long-term process performed for the two business cases considered at this stage within the FLEXCoop project. Together with the development of the DR framework and suit tool and the definition of the two business cases, the most suitable KPIs and CBA methodology are selected. Then, based on the results of observations, evaluations through selected KPIs are provided. After the identification of the value chain guidelines on how to perform a business-level CBA could be extracted.

Format presentation

The deliverable has four core sections and is structured in the following way.

In Section 2, the KPIs and evaluation measures for performance and remuneration are presented. In Section 3, the Dutch (NL) use case of delivering regulating power is described, and in Section 4, the Spanish use case of self-optimization and day-ahead participation. In Section 5, the economic cost benefit analysis (CBA) methodology is outlined, and in Section 6, the social and environmental CBA. Finally, conclusions are presented in Section 7.

2 EVALUATION METHODOLOGIES

In this section, the KPIs and evaluation measures which will be applied to the use cases are described. First, a part is devoted to forecast evaluation and then the measures of flexibility are defined - followed by a description of how they can be applied to form a methodology for the aggregator to remunerate between prosumers. Finally, some KPIs are given, which can be applied as performance and monitoring indicators, technical aspects of the response of assets to activation, etc.

One important point is to notice that the prosumers delivering regulation are delivering loads variations (i.e. on the demand side), in most other settings the assets delivering regulation are generating power, e.g. power plants. It simply means that when there is a lack of generation then there is a need to up-regulate the generation assets, hence the prosumers (load assets), then need to decrease the load - this will be referred to as a “up-regulation activation” and that the prosumers are delivering “up-regulation flexibility”. The same holds for the down-regulation case, where the prosumers must increase their loads (demand) and this will be referred to as an “down-regulation activation” and as they are delivering “down-regulation flexibility” by increasing their demand.

2.1 Forecast KPIs

In order to measure the performance of forecasts, several measures can be applied depending on the setting. First, some clarifications on concepts are given:

- In this section, the notation $\hat{P}_{t+k|t}$ is used, it refers to the forecast of the power for time $t + k$ issued at time $\boldsymbol{t}$. Hence, no information available later than t is used, and the forecast is k steps ahead. Naturally, P could represent any type of variable, i.e. different from power.

- A point forecast is a forecast of the conditional mean value for each $t + k$ horizon with the interdependencies to other time periods neglected.

- A probabilistic forecast is a forecast of the probability density function (pdf) of the random variable.

- A quantile forecast is a forecast of quantiles in the pdf.

- A spatio-temporal forecast is a forecast of the multivariate pdf of a multiple output model, taking into account both spatial and temporal dependencies. This type of forecast is describing the full possible information about the development of model outputs and can be used for generating scenarios as the samples of the multivariate pdf. Most often such samples are the output from a spatio-temporal forecast, which can be used in other applications.

Depending on the type of application, the forecasts can include more or less effects according to the above mentioned points. Dealing especially with thermal and weather dependent systems it can be profitable to take interdependencies into account, like space and time, however in most applications today point forecasts are used in practice - but that could change in the future as more fluctuating renewables enter the energy system.

Most of the times it can be useful to calculate the KPIs on normalized values in order to be able to compare the performance between systems of different capacity.

Note that it is important to evaluate the forecasts out-of-sample, also called cross-validation, which is usually done in two ways:

- Division of the data set in a training and a test set, possibly in an m-fold setting [1]
- Recursively iterating causal through the data set using only past data to train and then for each time t calculate the forecast, hence essentially an$n$-fold cross-validation (where n is the number of observations in the period).

It is noted that calculation of the KPIs can only be carried out on a past period and they are rarely used in a real time setting, but rather as tools for analysis for model development, and performance and fault diagnostics.

2.1.1 Evaluating point forecast performance

The two most used KPIs for evaluating the forecast performance of the k^{th} horizon are the bias measured by the mean absolute error

$$MAE_k = \frac{1}{n}\sum_{t=1}^{n} \hat{P}_{t+k|t} - P_{t+k}$$

and the accuracy or variance measured by the root mean square error

$$RMSE_k = \sqrt{\frac{1}{n}\sum_{t=1}^{n} (\hat{P}_{t+k|t} - P_{t+k})^2}$$

For both it holds: the smaller the value the better the performance.

Useful measures for analysis of forecast quality are the auto-correlation function (ACF) and cross-correlation function (CCF), which can be used for investigation of usually one-step forecast residuals. Further, useful and insightful plots should be generated to learn if the forecast model applied is fulfilling. For more details on point forecast evaluation methodologies see [2].

2.1.2 Evaluating probabilistic and spatio-temporal forecast performance

The Continuous Ranked Probability Score (CRPS) is the most widespread KPI for measuring probabilistic forecast performance. The predicted conditional cumulative density function (cdf), $F(x)$,is described by the predicted quantiles

$$q^{\tau}_{t+k|t} = F^{-1}_{t+k|t}(\tau)$$

where $\tau \in [0,1]$and the $^{-1}$indicates the inverse function, i.e. $F_{t+k|t}(q^{\tau}_{t+k|t}) = (\tau)$. The CRPS for horizon k is calculated by

$$CRPS_k = \frac{1}{n}\sum_{t=1}^{n}\int_{-\infty}^{\infty}(\hat{F}_{t+k|t}(x) - 1_{x\geq P_{t+k}})^2 dx$$

where $1_{x\geq P_{t+k}}$ is the indicator function which is zero if the subscript expression is false and one if it is true.

Finally, if spatio-temporal forecast performance should be evaluated, then variogram scores can be applied. They can measure how well the dependence structures of generated scenarios are matching the dependence structures in data. The two most useful variogram scores measures, respectively, spatial and temporal dependence. So if scenario generating forecasts, both for single and for multiple systems with potential spatial dependencies must be evaluated, then the two variogram scores below can be applied.

The spatial variogram score is defined by

$$V_{i_1,i_2,k}^{spatial} = \sum_{(i_1,i_2)\in\Omega}\sum_{t=1}^{n} w_{i_1,i_2}(|P_{i_1,t+k} - P_{i_2,t+k}|^p - E|\hat{P}_{i_1,t+k|t} - \hat{P}_{i_2,t+k|t}|^p)^2$$

where i_1 and i_2 are indexing through all the systems included in the evaluation set Ω.The $E|\cdot|^p$is the expectation operator of the p'th order moment - most used is $p = 2$ called the variogram, for further details see [3]. The weights w_{i_1,i_2} are calculated as recommended by

$$w_{i_1,i_2} = 0.5^{(dist(i_1,i_2))}$$

where $dist(i_1, i_2)$ is the Euclidean distance between the location of the two assets.

Finally, how well the temporal correlations are captured forward in prediction horizon, can be measured by the temporal variogram score. The temporal variogram score is defined by

$$V_i^{tempo} = \sum_{(k_1,k_2)\in\Omega} w_{k_1,k_2}(|P_{i,t+k_1} - P_{i,t+k_2}|^p - E|\hat{P}_{i,t+k_1|t} - \hat{P}_{t+k_2|t}|^p)^2$$

where k_1 and k_2 are indexing through all the horizons included in the evaluation set Ω and

$$w_{k,k_2} = 0.5^{(dist(k_1,k_2))}$$

where the distance is $dist(k_1, k_2) = |k_1 - k_2|$.

2.2 KPIs for measuring load flexibility

In this section, the KPIs applied for measuring different aspects of flexibility are presented. The KPIs are first defined and then it is outlined how they can be specified on individual and aggregated levels, and finally different examples of application are given. Calculation of the KPIs will occur after the delivery period.

The KPIs for measuring flexibility are presented in this section. The calculation of the KPIs is carried out on historical data, hence when all observations for the evaluated period are available. The period of evaluation is between t_{beg} and t_{end}.

In the FLEXCoop setdown, the following three time series are available as forecasts for decision making:

- $\hat{P}_t$: The forecasted baseline power, which is the load of the prosumer given no activation is requested.
- $\hat{P}_t^{min}$: The forecasted minimum power level, which is the reference load of the prosumer if up-regulation activation is activated.
- $\hat{P}_t^{max}$: The forecasted maximum power level, which is the reference load of the prosumer if down-regulation is activated.

These three series are all forecasts generated before (or potentially during) the evaluation period. They represent the flexibility which was "promised" in the period and afterwards in the evaluation period they are the reference power which the observed power must be compared to, in order to measure how much flexibility was actually delivered.

In the Figure 2.1 a generated example of the three references are shown.

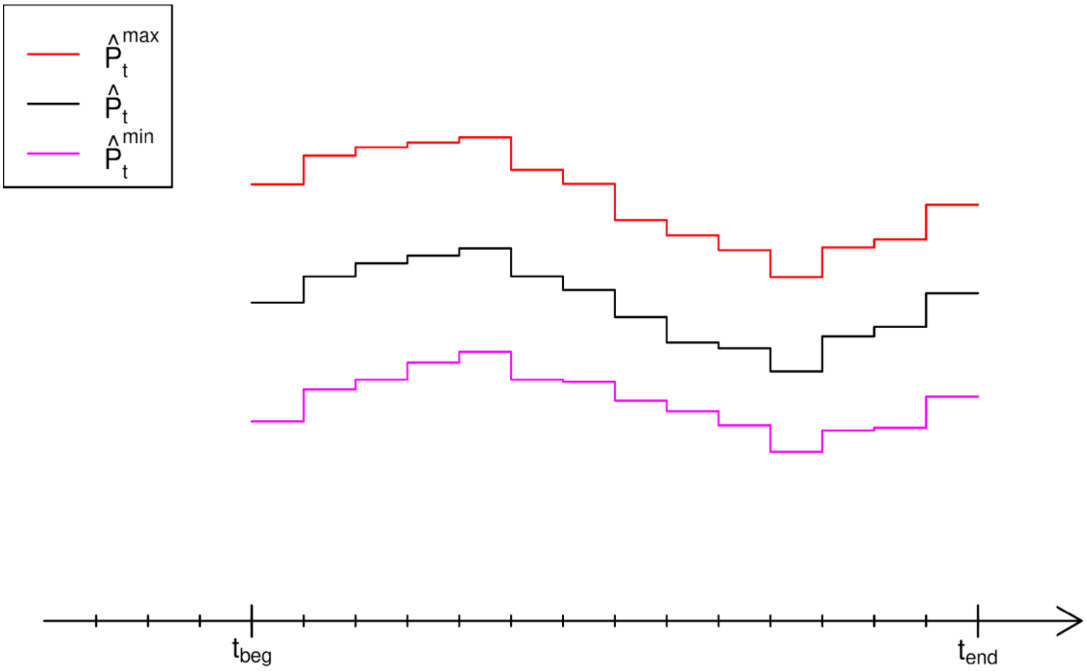

Figure 2. 1: A generated example of the three power references.

In order to define the requested activation the following two signals are defined:

- $a_t^{up} = [0,1]$: The signal which represent the requested up-regulation activation, i.e. load reduction. From 0 indicating no activation to 1 indicating full up-regulation activation.

- $a_t^{down} = [0,1]$: The signal which represent the requested down-regulation activation. From 0 indicating no activation to 1 indicating full down-regulation activation.
- at most one activation to one side can be carried out at any time t, thus $a_t^{down} > 0 \Rightarrow a_t^{up} = 0 \wedge a_t^{up} > 0 \Rightarrow a_t^{down} = 0$always hold.

Using these the requested power reference can be calculated by

$$P_t^{ref} = (1 - a_t^{down} - a_t^{up})\hat{P}_t + a_t^{up}\hat{P}_t^{min} + a_t^{down}\hat{P}_t^{max}$$

The flexibility measures are defined separately for up-regulation and down-regulation flexibility. First the up-regulation flexibility.

The delivered up-regulation flexibility at time t is

$$P_t^{up} = a_t^{up}(\hat{P}_t - max(P_t, \hat{P}_t^{min}))$$

the promised, but not delivered up-regulation flexibility at time t is

$$P_t^{upND} = 0 \text{ for } P_t \leq \hat{P}_t^{min}$$

$$P_t^{upND} = a_t^{up}(P_t - \hat{P}_t^{min}) \text{ for } P_t > \hat{P}_t^{min}$$

and finally, the additionally delivered up-regulation flexibility at time t is

$$P_t^{upAD} = a_t^{up}(\hat{P}_t^{min} - P_t) \text{ for } P_t \leq \hat{P}_t^{min}$$

$$P_t^{upAD} = 0 \text{ for } P_t > \hat{P}_t^{min}$$

Similar KPIs for down-regulation flexibility are defined in the following.

The delivered down-regulation flexibility at time t

$$P_t^{down} = a_t^{down}(min(P_t, \hat{P}_t^{max}) - \hat{P}_t)$$

the promised, but not delivered down-regulation flexibility at time t

$$P_t^{downND} = 0 \text{ for } P_t \geq \hat{P}_t^{max}$$

$$P_t^{downND} = a_t^{down}(\hat{P}_t^{max} - P_t) \text{ for } P_t < \hat{P}_t^{max}$$

and the additional delivered down-regulation flexibility at time t

$$P_t^{downAD} = \{a_t^{down}(P_t - \hat{P}_t^{max}) \text{ for} P_t \geq \hat{P}_t^{max}$$

$$P_t^{downAD} = 0 \text{ for } P_t < \hat{P}_t^{max}$$

In order to calculate these measured in the period they are simply summed, e.g.

$$P^{down}_{t_{beg}:t_{end}} = \sum_{t=t_{beg}+1}^{t_{end}} P^{down}_t$$

All the KPI series and sums are included in Figure 2.2.

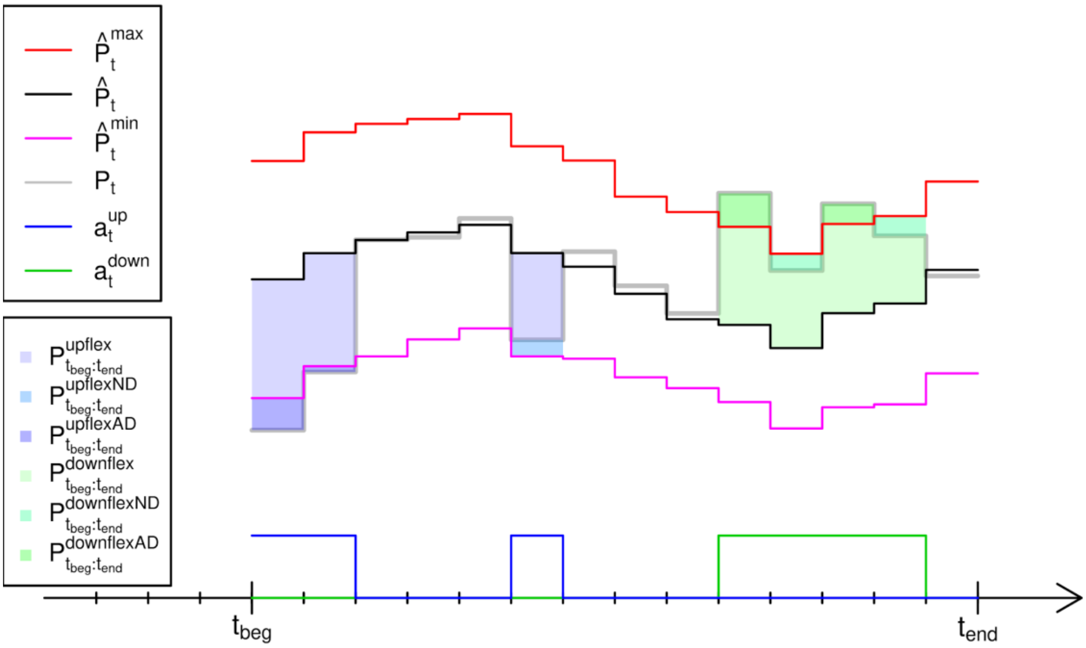

Figure 2.2: KPI series and related sums.

2.3 Specification on individual and on aggregated level

The measures can specified for the i'th prosumer e.g. delivered down-regulation flexibility

$$P^{down}_{i,t} = a^{down}_{i,t}(min(P_{i,t}, \hat{P}^{max}_{i,t}) - \hat{P}_{i,t})$$

which can then be summed up for the activated prosumers in the campaign. E.g. for some set of activated prosumers

$$i_{act} = \{1,2,7,19,23,24\}$$

the aggregated delivered down-regulation flexibility is

$$P^{down}_t = \sum_{i \in i_{act}} a^{down}_{i,t}(min(P_{i,t}, \hat{P}^{max}_{i,t}) - \hat{P}_{i,t})$$

To calculate the measures for the period between t_{beg} and t_{end} simple summing is applied. E.g. for the delivered down-regulation flexibility for the i'th prosumer

$$P_{i,t_{beg}:t_{end}}^{down} = \sum_{t=t_{beg}+1}^{t_{end}} P_{i,t}^{down}$$

and aggregated

$$P_{t_{beg}:t_{end}}^{down} = \sum_{i \in i_{act}} \sum_{t=t_{beg}+1}^{t_{end}} P_{i,t}^{down}$$

2.4 Remuneration to prosumers for delivered flexibility

In order to carry out remuneration to the prosumers for their delivered flexibility the aggregator must have some model for calculating a fair remuneration to its prosumers based on their promised and delivered flexibility. The remuneration should be understood as a KPI which can be used by the aggregator to "share" revenue fairly between its prosumers, hence remunerate them for the flexibility they have provided during a specified period.

The remuneration can be divided into the following remuneration components (the c symbol is used as remuneration "component"). They are all defined here in the units of currency per. power, e.g. EUR/W:

- $c_t^{up} > 0$: The remuneration for delivered up-regulation flexibility.
- c_t^{upND}: The remuneration of up-regulation flexibility not delivered, which in most settings would be a negative value, since the prosumer didn't live up to the promised delivery.
- c_t^{upAD}: The remuneration of additional up-regulation flexibility delivered, hence if the prosumer delivers more flexibility than promised - might be rewarded or fined.

The equivalent remuneration components for down-regulation are c_t^{down}, $c_t^{downND}$and c_t^{downAD}. How these values are settled must be defined in the particular setting based on the revenue and costs obtained by the aggregator from delivering the flexibility to the market, and by taking into account the contractual setup between the aggregator and the prosumers. For more details on this see Section 5 on CBA.

A remuneration model for the i'th prosumer in the period from t_{beg} to t_{end} can then be set up as

$$c_{i,t_{beg}:t_{end}}^{flex} = \sum_{t=t_{beg}+1}^{t_{end}} [a_{i,t}^{up}(c_t^{up} P_{i,t}^{up} + c_t^{upND} P_{i,t}^{upND} + c_t^{upAD} P_{i,t}^{upAD}) +$$

$$a_{i,t}^{down}(c_t^{down} P_{i,t}^{down} + c_t^{downAD} P_{i,t}^{downAD} + c_t^{downND} P_{i,t}^{downND})]$$

One note to make is that the remuneration costs are defined as equal for all prosumers above, however this might be too simple (e.g. due different contracts, offers etc. to the individual prosumers) in which case individual terms should be included in the model - other refinements might also be necessary at a later stage.

2.5 Intra ISP KPIs

Whereas intra ISP KPIs have limited relevance for wholesale market purchase optimisation (Spanish case) where the performance of retailers are measured from one ISP to the other, the performance of demand-side flexibility for the provision of ancillary services (Dutch case) is key, as these services is monitored close to real-time by the TSO [4].

In order to quantify how a given asset delivers flexibility within the ISP and how it responds to an activation signal, some operational KPIs are defined. They should be applied on time series with a sampling frequency higher than the ISP period. They are suited for measuring useful information with regards to operational performance.

It should be noted that the KPIs for flexibility and remuneration presented in the previous section are suited also for intra ISP evaluation, in which case they will provide more detailed information.

In this section t_{beg} is at the beginning and t_{end} at the end of the ISP, as shown in Figure 2.3, where a generated example of an up-regulation activation is presented. The KPIs presented here are formulated for up-regulation activation and a similar KPI for down-regulation activation can easily be defined. Note well that the measures presented are presented in absolute form, hence directly applied to the demand observations, but could as well be calculated relatively, e.g. relative to the mean power of the prosumer or relative to the predicted flexibility or similar, this would allow a relative comparison between prosumers with respect to their performance.

At t_{beg} the up-regulation activation starts. An important aspect of the response to an activation is the time it takes before the prosumers power is decreased to the reference

$$t_{response} = \left(\min_t t \; w.r.t. P_t \leq (\hat{P}_t^{min} + P_t^{tol}) \wedge t_{beg} \leq t \right) - t_{beg}$$

where the reference is $\hat{P}_t^{min}$ and some chosen tolerance P_t^{tol} has been added. Further details about the shape of this ramp could also be measured, but left as out of scope for now.

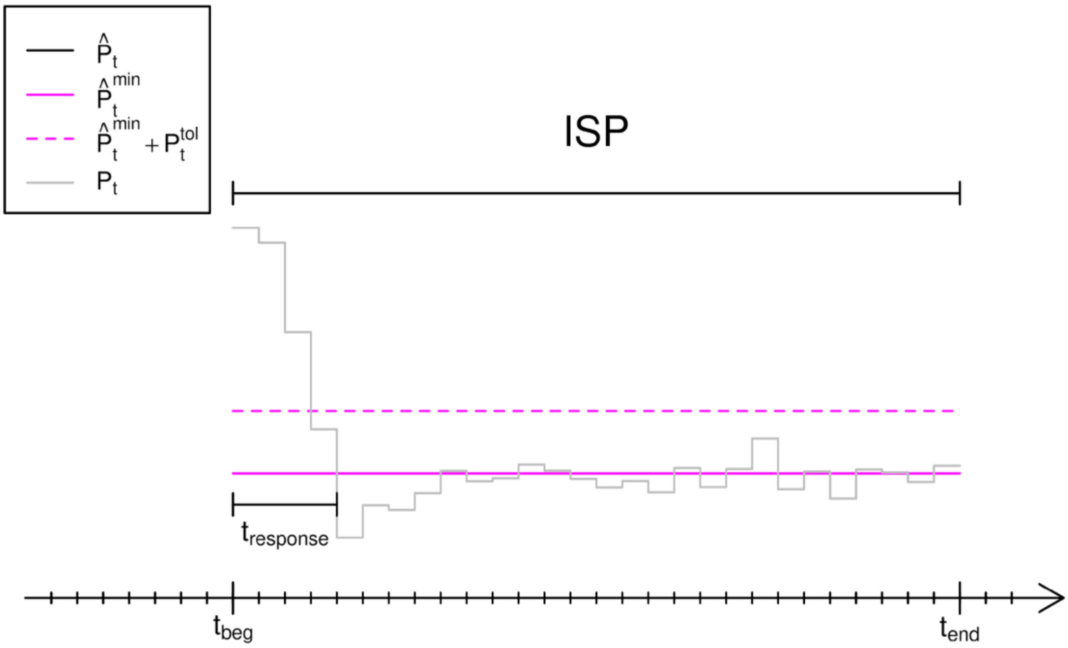

Figure 2.3: A generated example of a up-regulation activation.

Another important aspect is how stable the delivered flexibility from the prosumer is. The following KPIs measures the bias and variability in the period after the reference power has been reached. The bias

$$MAE_{ISP} = \frac{1}{n_p} \sum_{t=t_{beg}+1}^{t_{end}} (P_t - \hat{P}_t^{min})$$

and variance

$$RMSE_{ISP} = \sqrt{\frac{1}{n_p} \sum_{t=t_{beg}+1}^{t_{end}} (P_t - \hat{P}_t^{min})^2}$$

For both the case is: the smaller the better performance, and both are directly related to the flexibility KPIs presented in the last section.

Finally, KPIs are presented which can be used for revealing systematic patterns in ISPs. These can be useful for more in-depth analysis and understanding of the behaviour of prosumers, for example if a prosumer has a systematic patterns in the response to activation, an aggregator must take this into account when aggregating prosumers to achieve accurate and unbiased delivery of flexibility within the ISP and getting smooth ramp ramping. If there is a systematic intra ISP pattern it can be detected with

$$f_{step}(k) = \frac{1}{n_{ISP}} \sum_{j=1}^{n_{ISP}} P_{t_{beg}+k}^{min} - P_{t_{beg}+k}$$

which should be calculated as a kind of step response function of the activation. It can be tweaked in several, calculated on absolute values or relative, and applied in different settings, hence this is a general definition from which it can be refined for each particular use case.

2.6 General evaluation KPIs

The KPIs, which, in addition to the already presented KPIs, will be applied for evaluation of the performance of within the FLEXCoop system, are all defined in deliverable D2.5 Appendix A. They can be applied in different settings throughout the evaluation and validation of individual and aggregated values, both for technical (power and temperatures etc.) and financial purposes. The different KPIS to be used are:

- **Self-consumption**. For evaluation of individual prosumers the self-consumption ratio (ENE1) is a metric used for quantifying the amount of electricity produced and consumed locally relative to the total production that is locally available from on-site generation units. It is calculated as the ratio of self-consumption divided by the self-generated energy.

- **Buildings final energy consumption** (ENE3). This KPI aims to show the total amount of energy consumed in a building (or part of it) in a time period

- R**enewable total energy consumption** (ENE4). This KPI aims to show the total amount of renewable energy (electricity) consumed in a building (or in a part of it) in a time period. It will also show its proportion concerning the total energy consumed.
- **Demand response and flexibility KPIs** such as “DR participation analysis” (DRF1), offered aggregated flexibility (“flexibility on offer”, DR2) or “Peak load reduction” (DRF3)
- **Comfort** KPIs such as Predicted Percentage of Dissatisfied (COM1), System Average Interruption Duration Index (COM2) or Thermal Discomfort Factor (COM3)

An additional indicator related to the environmental impact will be used to calculate **CO_2 emissions**, which can be defined by

$$E_{i,t_{beg}:t_{end}}^{CO_2} = \sum_{t=t_{beg}+1}^{t_{end}} I_t^{CO_2} P_t$$

where $I_t^{CO_2}$ is the carbon intensity in CO_2 equivalents per generated power unit at time t. The carbon intensity is available in many countries via [5].

3 Use Case 1 (NL's case, Pilot 1; aFRR market)

3.1 Introduction to ancillary services

At every power system, balance between production and consumption of electricity must be ensured at any moment. Disturbances at production or changes in consumption have a direct impact on the system balance and cause grid frequency deviations. Ancillary services ensure access at all times to the needed resources to ensure the reliable and stable electricity system operation [6].

The ancillary services are procured from electricity generators and consumers and are used for different purposes, and various requirements therefore apply to the supply of the different services.

In the case of the Netherlands, four different ancillary services are offered:

- <u>FCR:</u> Frequency Containment Reserve (primary reserve). Those are the reserves used for a constant containment of frequency deviations from nominal value in order to constantly keep the power balance in the entire system. It includes operating reserves with the activation time up to 30 seconds [7].
- <u>FRR:</u> Frequency Restoration Reserves. Reserves available to restore the frequency of the system to the nominal frequency and to restore power balance to the scheduled value. It replaces FCR if the frequency deviation lasts longer than 30 seconds. On the Dutch market it can be distinguished between [8]:
    - <u>aFRR:</u> automated Frequency Restoration Reserves
    - <u>mFRRda:</u> manual Frequency Restoration Reserves directly activated
    - <u>mFRRsa:</u> manual Frequency Restoration Reserves scheduled activated

3.2 General description of the pilot

As it was detailed in the Business Scenario 3 in D2.1 [9], it is focused on the participation into balancing and ancillary services. For achieving this, cooperatives use their flexibility for providing services to other actors of the system such as Transmission System Operator (TSO), Distribution System Operators (DSO), retailer or other cooperatives.

Within the FLEXCoop project, this scenario is taking place on the Dutch pilot site, with ODE acting as an independent aggregator in the role of BSP and interacting with the TSO (TenneT) for participating in the automatic Frequency Restoration Reserve (aFRR) market.

With the aim of maintaining the real-time power balance of the country, TenneT uses Frequency Restoration Reserves (FRR) [4]. Within this FRR two different products can be distinguished:

- automatic Frequency Restoration Reserve (aFRR), activated on schedule
- manual Frequency Restoration Reserve (mFRR), directly activated

For becoming an active actor of this aFRR market, the Aggregator has to analyse the flexibility of its entire portfolio and placing a bid on this market, but taking into account the requirements it imposes [10]. And if the bid is finally activated by TenneT, then it must be ensured that everything goes as planned.

3.2.1 General description of Dutch aFRR market

In most European countries, there are three different roles in the balancing system [11]:

- Transmission System Operator (TSO): The role of the TSO in the Netherlands is played by the high-voltage grid operator, which is TenneT TSO B.V. The TSO in the synchronous frequency area of Europe is responsible for a stable frequency of 50 Hz. To fulfil this task, each TSO is in charge of monitoring, maintaining and restoring the imbalance between demand and supply of electrical power in its area once market operations are over (after "gate closure").

  It is TenneT's responsibility to maintain the power balance in the country. Power imbalance is the instantaneous mismatch between injections and withdrawals at the overall grid level. This imbalance on the system as a whole is mainly the sum of all deviations of Balance Responsible Parties (BRPs) from their commercial scheduled trade. When these deviations occur, the imbalance situation does not appear immediately for the BRPs due to the adjustment of those imbalances happen each Imbalance Settlement Period (ISP), which has a duration of 15 minutes.

- Balance Responsible Party (BRP): Each connection to the electricity grid must be allocated to a BRP accredited by TenneT. For each BRP it is mandatory (obliged by law) to send a commercial trade schedule to TenneT for each day. The BRP is financially responsible for its own imbalance and pays or receives the imbalance price of the relevant ISP. The positive or negative imbalance will be notified by, TenneT who sends an imbalance invoice to the BRPs.

- Balancing Service Provider (BSP): This is the market party from which TenneT activates power for its balancing tasks. For the aFRR and mFRRsa products, bids can be submitted directly to TenneT. It is possible to sign a contract with TenneT obliging the BSP to send aFRR bids of a certain amount during the duration of the contract. Within the FLEXCoop solution, for the Dutch pilot this role is being played by ODE.

At EU level, the system for the balancing of the grid are the so called Load Frequency Control (LFC) processes [12], and in the Netherlands their main goal is to respond to detected imbalances in the Netherlands and restore it within 15 minutes. The LFC area is a part of the synchronous interconnected area demarcated by points of measurements at the interconnectors to other LFC areas. In most cases the LFC area corresponds to the national area under the control of a national TSO[13]. Additionally, the TSO acts through LFC processes in case of smaller imbalances in order to limit unplanned energy exchange with the electricity network in the synchronous area of Continental Europe (CE). It is necessary a continuous monitoring of this energy exchange and interference by the TSOto provide a proper system balancing quality.

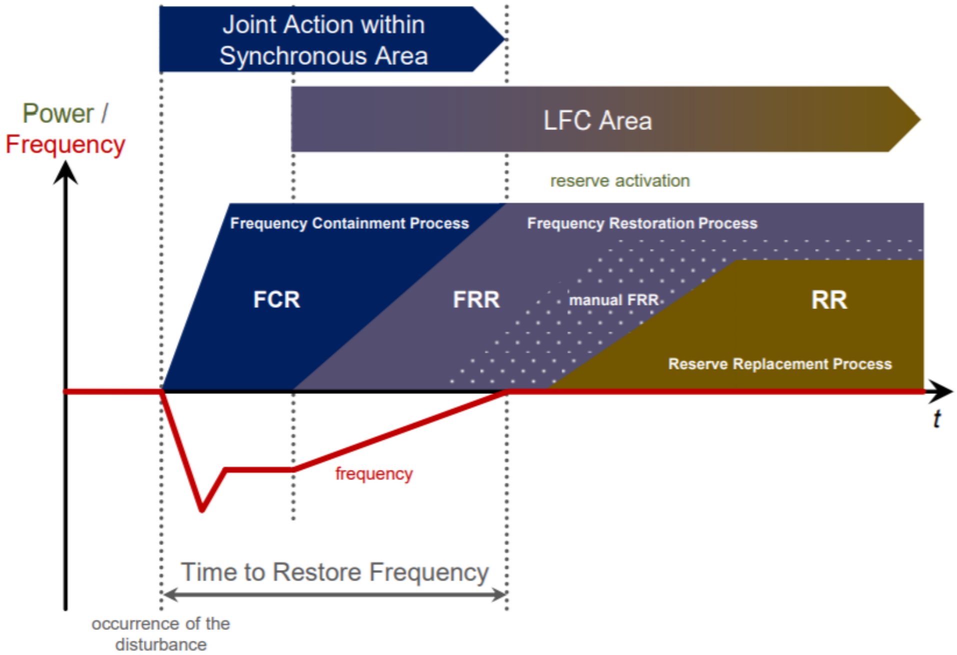

Figure 3.1: Dynamic hierarchy of Load-Frequency Control processes according to ENTSO-E

The TSO, through LFC processes, continuously determines the Area Control Error (ACE) a.k.a. Frequency Control Errors of the area. It is mostly dependent on the difference between the total cross-area-border electricity exchange versus the total measured exchange on the interconnector with the remainder of the Continental European synchronous electricity system. This difference is corrected for the expected Dutch frequency support by activating the FCR. The expected FCR-delivery is determined by multiplying the measured frequency deviation with the internationally agreed frequency constant for the Netherlands. According to the results of those calculations, the TSO determines the amount of aFRR to be activated in order to maintain the power balance.

Market parties sometimes work with their own controller to adhere to their planned obligations and to reduce imbalance in their role of BRP. In this balancing process, the parallel controllers interact with each other, that means that the TSO responds to a balance disturbance. In addition to this, the TSO will take corrective action when a local controller introduces a national power imbalance that may have the positive but uncoordinated goal of achieving an individual desired level of energy production [4].

In collaboration with other TSOs in the CE region, TenneT participates in the International Grid Control Cooperation (IGCC), that addresses the market imbalances of individual TSOs in a coordinated supranational way. To this end IGCC converts market imbalances from different countries with opposite direction into mutual support. The details about this IGCC and the Dutch market can be read at [14].

3.2.2 Load Frequency Control and the aFRR bids

The activation of the aFRR bids for balancing is a real-time process used for correcting power imbalance in the network. Bids for aFRR are sorted by taking into account their price, and they are placed on the so-called "bid-ladder".

Considering that the bids on this market have to be placed before 14.45 of the day before, after that Gate Closure Time they are nominated per ISP for the TSO. During each ISP the LFC processes can activate automatically the bids, and the price of activating them will define the price for which delivered aFRR energy is settled, being this also the basic element for the determination of the imbalance price.

At the beginning of each ISP the LFC determines the bids that are being activated based on the new aforementioned "bid-ladder". The bids that have been already activated may no longer be available. Their price does not affect the price of the activation of the ISP, but the delivered aFRR energy will be remunerated at this activation price. aFRR bids that have not been nominated for the LFC for a certain ISP are kept on the "bid-ladder".

During the activation of the bids, the LFC sends so-called "setpoints" to the BSPs of aFRR in order to activate their bids. The total amount aFRR bids that is activated by the LFC depends on the balance situation:

3.2.3 Which way we choose to enter and why

The Dutch TSO TenneT is investigating the options for offering local (sustainable) electricity generation capacity on the market for balance maintenance in the Dutch high-voltage grid ('balance maintenance' refers to achieving a balance between the supply of and the demand for electricity). This concerns the so-called automatic Frequency Restoration Reserve (aFRR), also referred to as 'regulating capacity'.

The pilot project is a follow-up to a previous collaboration with Dutch energy supplier Vandebron. The scope of the study has now been extended and six new partners have joined the project. The sources that the project partners are planning to use include wind energy, solar energy, combined heat and power generation (CHP), heating grids, electric cars, electric boilers and electric heat pumps.

In the past, the balance on the high-voltage grid was maintained largely by deploying the capacity of conventional power plants. In the future, support from decentralized sources will become increasingly important. TenneT has set up this aFRR pilot project to prepare for such a future.

During the pilot project, new data communication technologies will be tested to enable TenneT and suppliers of flexible generating capacity to exchange the required information for balance maintenance purposes. TenneT and its partners will also investigate suitable methods for the verification of actual aFRR supplies from a pool of decentralized sources.

In selecting suitable partners for this project, TenneT paid particular attention to ensuring the widest possible range of technologies and assets.

TenneT is undertaking this pilot project in collaboration with seven market parties: Engie, Enova, Escozon & ODE Decentraal, Next Kraftwerke & Jedlix, Scholt Energy & Enervalis, Sympower and Vandebron.

Escozon & ODE Decentraal were selected by Tennet because as cooperatives they represented the citizens. Escozon and ODE Decentraal joined the pilot for two reasons. First, in the short term, the up-regulation flexibility of cooperative production capacity (generation curtailment), solar and wind, can be sold to the aFRR market. And second, in the longer term the cooperative can sell the flexibility of their members as electricity consumers also to the aFRR market. The FLEXCoop solution can make that possible.

In the Netherlands, in the coming 20 years there will be a heat transition. That means that heating of dwellings and buildings will not be done with gas anymore. As a result of this, there will be millions of heat pumps in the Netherlands installed in dwellings in the coming years.

In the Dutch use case we combine two elements the possibility for the Dutch pilot cooperatives (Escozon and ODE Decentraal) to access to the Dutch aFRR market, and the emerging trend related to the massive installation of heat pumps which use electricity and have potential flexibility.

3.3 Description of mathematical tool

TenneT offers the possibility to participate into the ancillary market with two types of bids: what it is called “contracted bids” and the “free bids”. In the case of the “contracted” ones, the process is more extensive and it is depicted on the following schema.

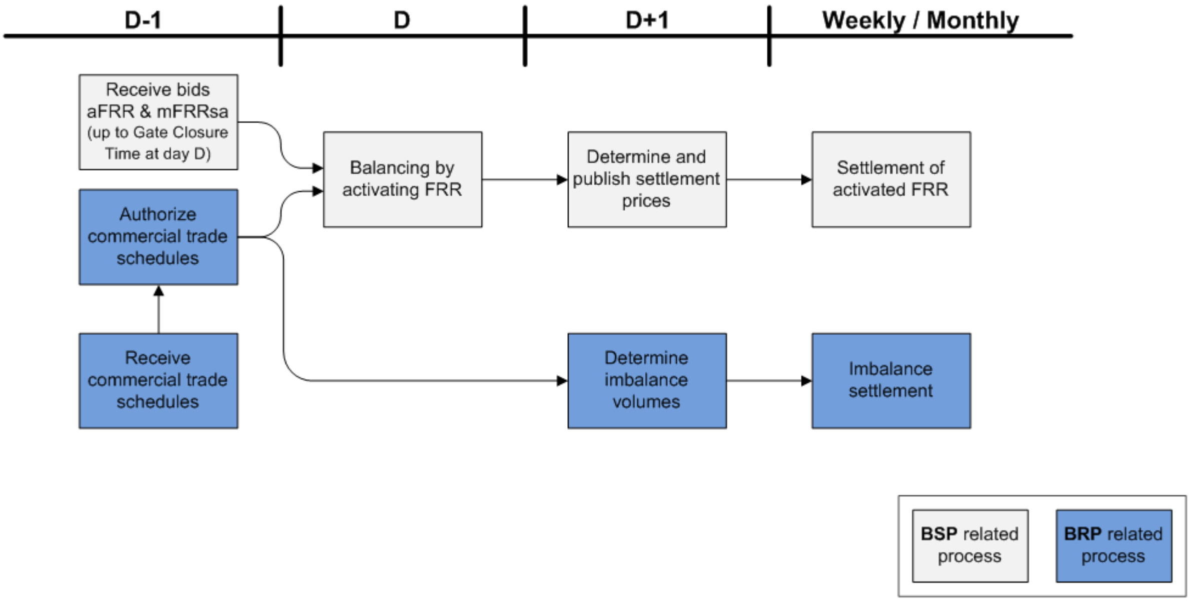

Figure 3.2: Process diagram: balancing process [11].

As it can be seen in Figure 3.2, the execution of this use case is mainly divided in three steps:

- Preparation day ahead: On the day before the delivery day (D-1), each BRP submits their bids for the delivery day. TenneT checks whether these commercial transactions add up to zero, so that the demand and supply of electricity is in balance for every ISP of the delivery day.
- Delivery day: The delivery day (D) is the day on which energy injections and withdrawal from the electricity grid take place. BSPs should act in accordance with their submitted bids. If a power imbalance happens at any point, the TenneT will take measures to restore it within 15 minutes.
- Settlement: After the delivery day (D+1), the process of financial settlement begins. During this step, the settlement prices are determined and published and the imbalance per BRP is then set and invoiced.

Although FLEXCoop will support both types of bids, we will initially focus on the free ones. The main difference between both of them are:

- Contacted bids means that you have to bid, which means that if you have made a bid and then you are activated, you have to deliver what you have promised in your bid. If you don't deliver, you have to pay the imbalance price. Also you have to pay an additional penalty because you get a fee for the obligation to bid, which is defined in a separate contract.
- Free bids means you don't have to make a bid, but if you have made a bid and you are activated, you have to deliver what you have promised in your bid. If you don't deliver, you have to pay the imbalance price (but in this case you don’t have to pay the aforementioned penalty).

Concerning the bids, there are some restrictions imposed by TenneT that must be fulfilled in order to being able to participate in the aFRR market [4]:

1. The ramp rate of the offered aFRR (up and/or up) volume should be at least 7% per minute of the bid volume.
2. An observable power change is expected within 30 seconds after a setpoint change.
3. Bids have to be placed before 14.45 of the day before

Within the FLEXCoop solution, the bidding process will take place mainly through the Global Demand Manager (GDEM) component, in collaboration with some other components of the architecture.

As shown in Figure 3.3, the Local Demand Manager (LDEM) will gather all the flexibility (the details about the calculation of this flexibility can be found at D3.1 [15], D3.2 [16], D3.3 [16], [17], D3.4 [18] and D3.5 [19]), and the price of activating it according to the contracts between the aggregator and the end-users on its portfolio, for the next 24 hours of all the available assets (HVAC, light, EV...) and it will aggregate them at dwelling level. But before that aggregation process at dwelling level, it has to be taken into account the 1st and 2nd restriction aforementioned; that means that not all the devices that can provide some flexibility can be considered, and the LDEM is responsible for identifying them and exclude them for participating in this market.

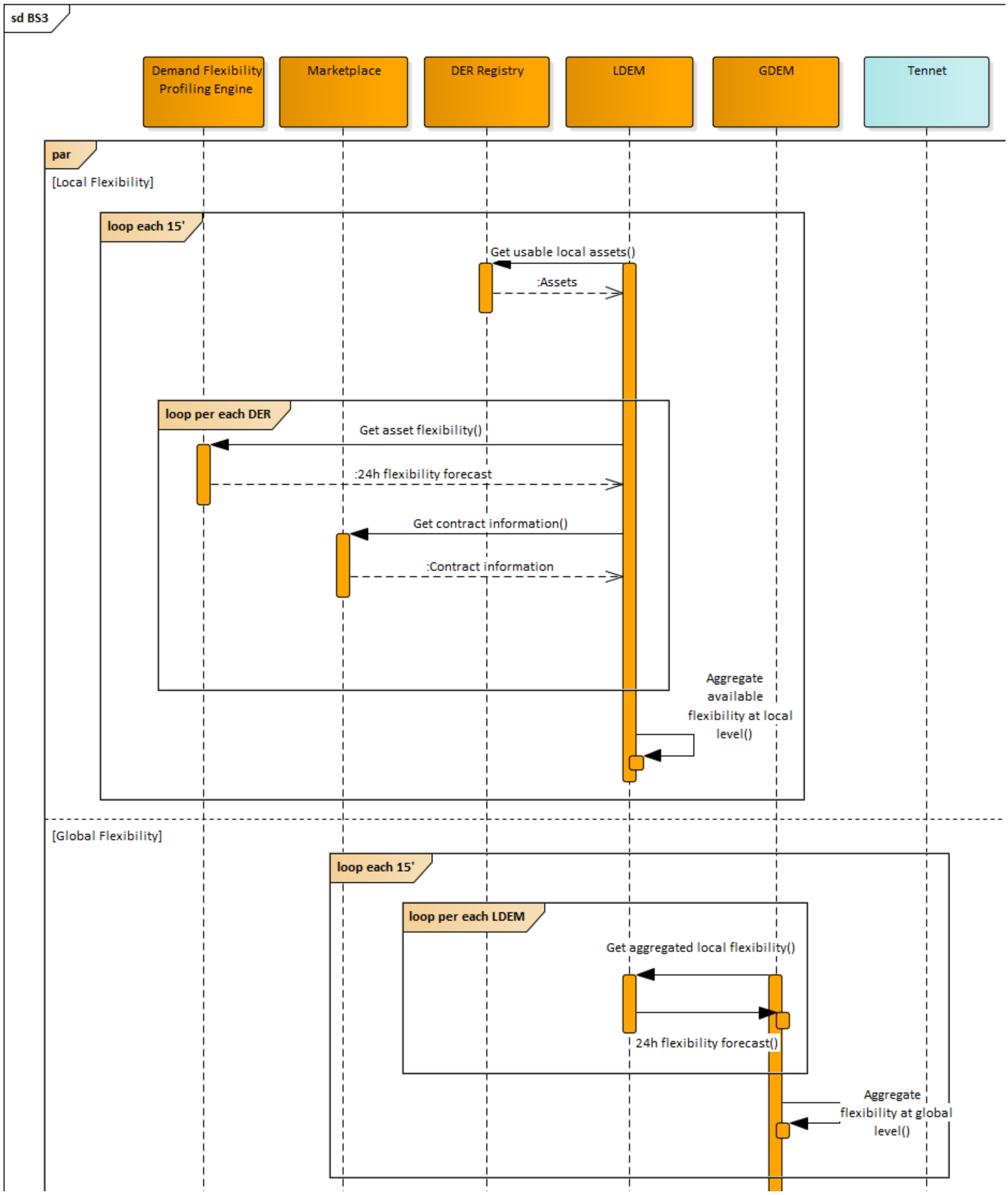

Figure 3.3: Aggregation of local flexibility.

Once the GDEM has received all this aggregated flexibility at dwelling level, it has enough information to elaborate the bids for the next day, creating the message that will be communicated to TenneT. This message is called "BTP message" (Balanced Transported Power message); its general structure can be seen at Figure 3.4, and its details can be read in [20].

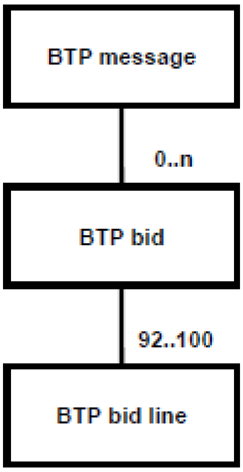

Figure 3.4: Format of the message containing the bids communicated to TenneT.

The BTP message contains a combination of BTP bids, whose number per BTP message is unlimited. On the other hand, each BTP bid is composed of bidding lines, one for each ISP. So any normal day will have 96 ISPs.

Before 14.45 of the previous day (Figure 3.5), the bid is communicated to TenneT. Once it has been placed, each ISP can be revised 30 minutes before its activation adjusting its price and volume (but it has to be taken into account that it is still considered deviation and will get a fine during the settlement period). That means that the GDEM will continue processing the flexibility coming from the LDEM to constantly tune the bid (all the details about this process will be depicted in the deliverables of this module, the D5.3 [21] and D5.7 [22]).

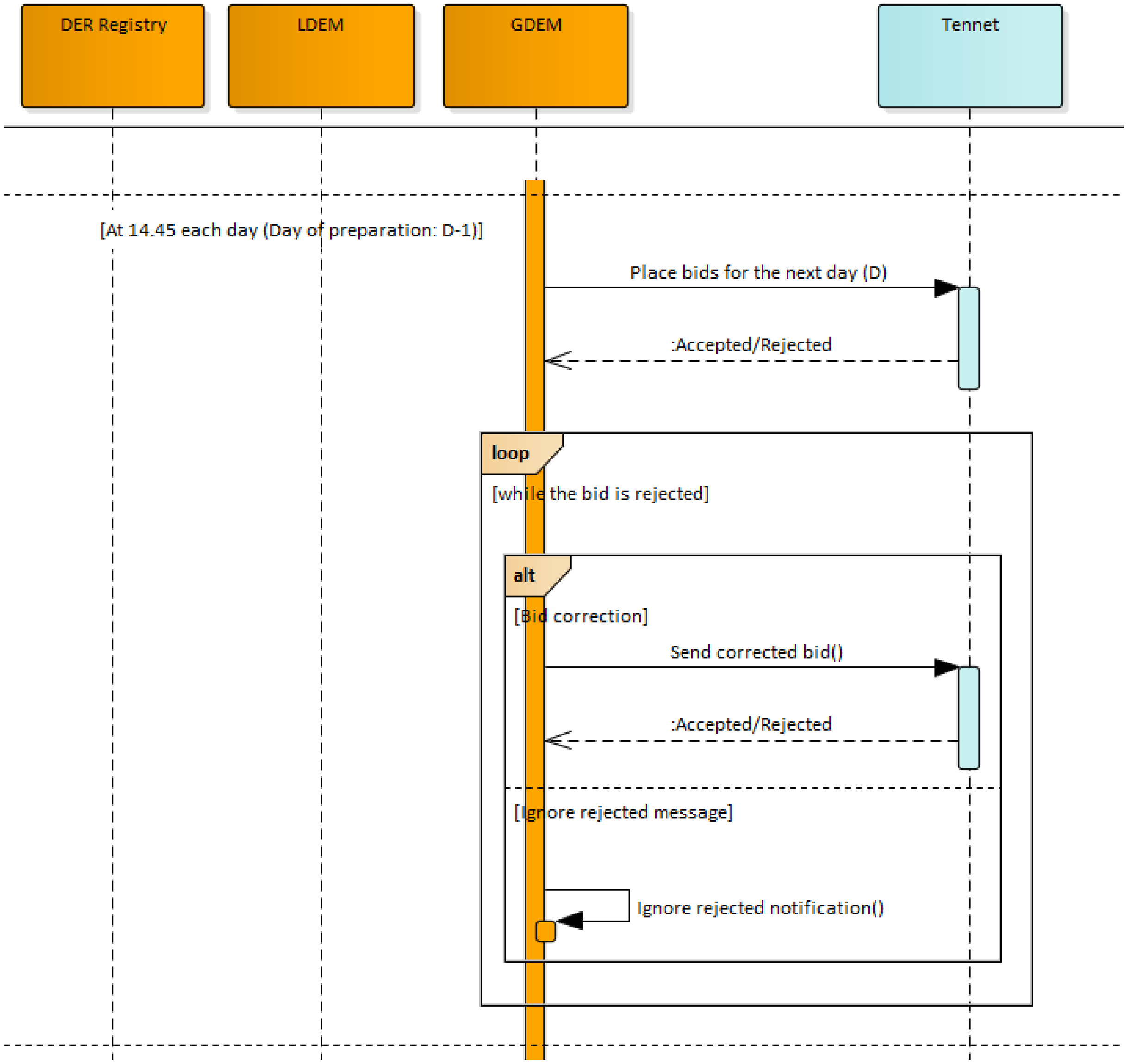

Figure 3.5: Bidding process.

During the delivery day (Figure 3.6), if TenneT decides to activate the bid then some signals are exchanged between the aggregator and them for ensuring that everything goes as stated in the bid.

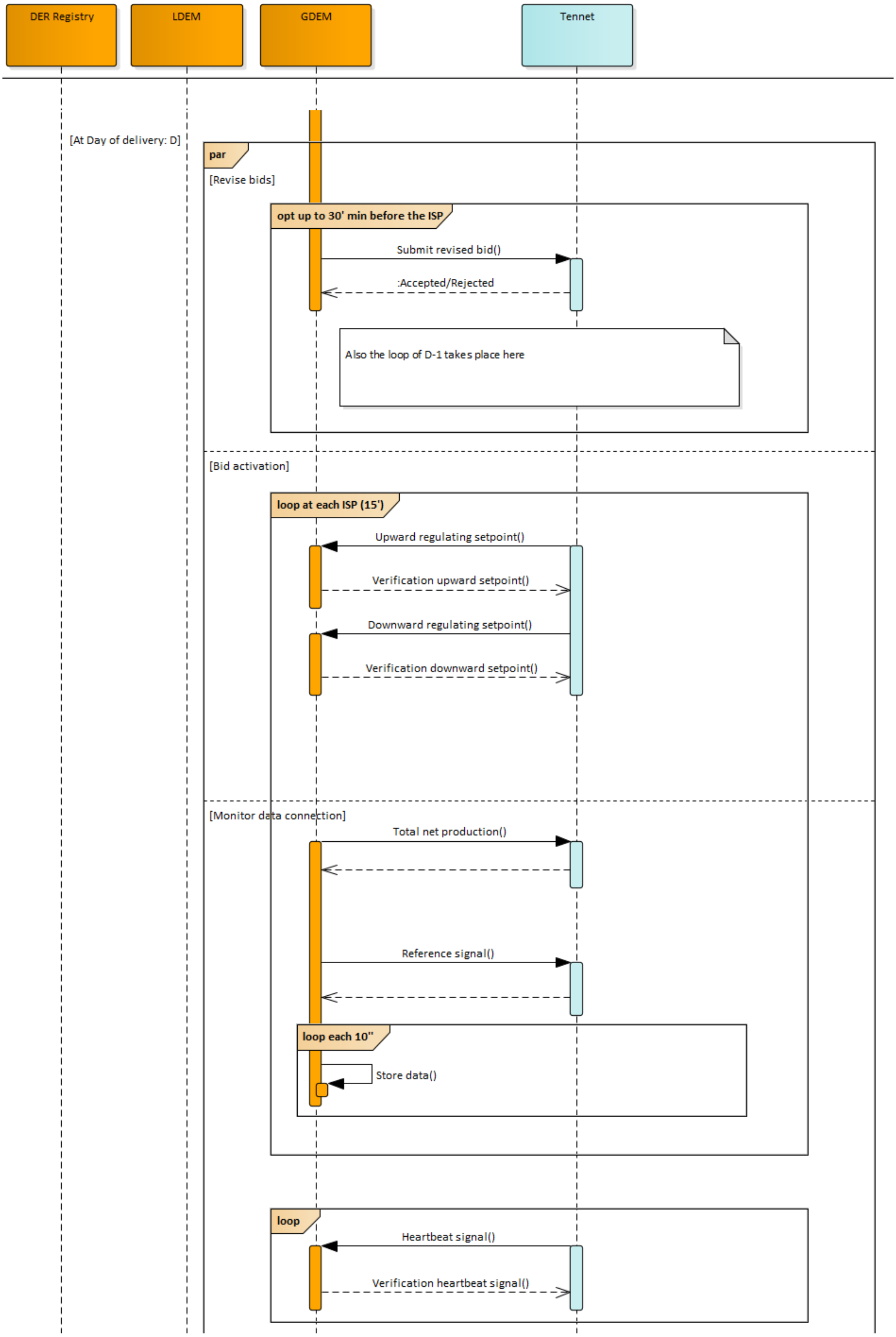

Figure 3.6: Delivery proces

4 USE CASE 2 (SPAIN'S CASE; PILOT 2)

4.1 General description of the pilot

This use case concerns cooperatives which are power producers and retailers and which will take the additional role of an aggregator in order to valorise consumers' flexibility to match prosumer's assets generation period, or in order to match low prices period on the wholesale market. In both situations, the cooperative retailer proposes the FLEXCoop solution to its customers in exchange for cheaper electricity (through increased self-consumption or cheaper retail prices).

The FLEXCoop solution will be triggered depending on the prosumer's on-site generation and the wholesale market prices. Depending on the business model, the flexibility may have different uses:

a) related to self-consumption, by maximizing consumption from local generation units at prosumer level to maximize energy consumption when high RES generation exists.

b) related to system efficiency by optimising energy purchase from wholesale market based on price, surpluses rewards and deviations prices.

Those flexibility uses are complementary and can be incorporated together depending on the sourcing strategy of the cooperative (own generation/Power Purchase Agreement (PPA) or wholesale market).

This use case is centered in optimizing the participation of Som Energia (aggregator) and of their clients (prosumers) into the day-ahead electricity market. The objective is to dynamically find an optimal balance between the self-consumption of the energy generated by PV rooftop systems, the reward of surplus energy delivered to the grid, the costs of deviations and the benefit (for the customer) of using electricity in the lower price hours.

The procedure to participate in the day-ahead market starts with a first purchase offer which Som Energia should undertake before 12 pm (noon) of the day before. This purchase contains the forecasting of the energy to be spent for the next 24 h of the following day (starting at midnight). Som Energia needs to perform the following actions to define this first purchase offer:

1) A forecasting, with a horizon of 24 h, of the: (i) individual and aggregated customers' electricity consumption baseline; (ii) individual prosumers' PV generation; (iii) the available flexibility (based on the user comfort requirements) of each device/consumer; (iv) the price of the day ahead market, (v) the costs of the deviations; (vi) the rewards for the exported PV generated energy.

2) A first optimization is performed, aiming at:

    a) matching the electricity consumption of each customer with the electricity generated by the PV rooftop systems. For the customers without PV systems only a minimization of the energy consumption is performed;

    b) In case the forecasting models of the day ahead prices, of the deviation costs and of the rewards for exported energy are available, Som Energia can also complement the optimization taking these elements into account (showed as optional optimization in Figure 4.1).

3) Som Energia makes the energy purchase offer (before the day ahead market prices are published) based on the optimized forecasted aggregated energy load profile for the next 24h.

After 1 PM, the day ahead market is closed and the prices for the next day, starting at midnight, the imbalance deviations costs and the rewards for the exported energy, are published and made available. The market operator (OMIE) closes the deal with Som Energia and applies the published prices over the energy purchase offer. The following actions can then be performed:

4) Som Energia can make a second optimization by considering the rewards for exported energy, the day ahead time varying price and the imbalances deviations costs.

5) Som Energia will have to trigger Demand Response events in the corresponding hour of the 24 hours schedule in order to follow the optimized load profile.

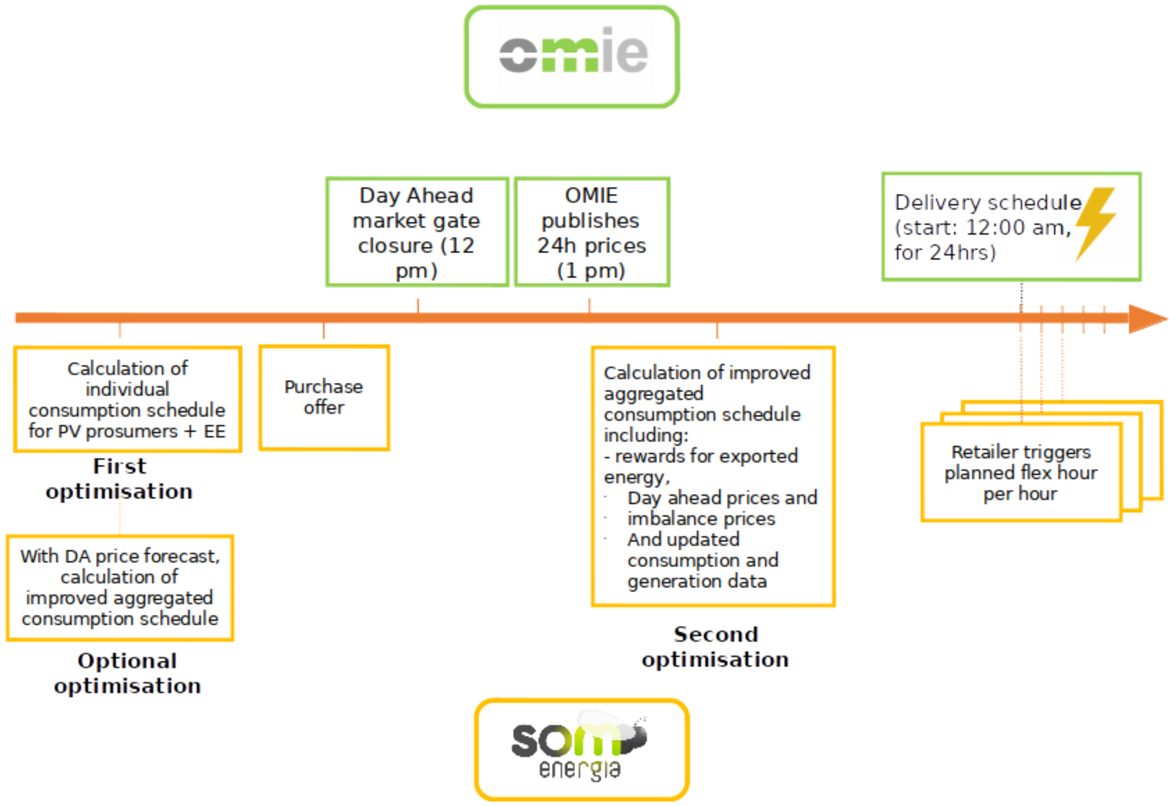

Figure 4.1: Timeline of retailer-aggregator and power exchange activities

4.2 General description of Spanish Day Ahead market

4.2.1 Time horizons and prices definition

The underlying market in Use Case 2 is the Spanish day-ahead market. Electricity prices in Spain are set on a daily basis (every day of the year) at 12 noon, for the twenty-four hours of the following day. The price and volume of energy over a specific hour are determined by the point at which the supply and demand curves meet, according to the marginal pricing model adopted by the EU in compliance with the Commission Regulation (EU) 2015/1222 of 24 July 2015 establishing a guideline on capacity allocation and congestion management. For that, it uses the algorithm approved for all European markets (EUPHEMIA).

The bids (purchase offer) need to be offered before 12 h in the noon of the day before. This offer is made without knowing the electricity price for the next day. The day-ahead market is then closed at 13:00 h and the price is cleared for the next 24 h (starting at midnight) and in time slots of 1 h.

Buying and selling agents will present their offers to the day-ahead market through OMIE (Operator of the Iberian Energy Market). Their purchase and sale bids are accepted according to their economic merit order and depending on the available interconnection capacity between the price zones. For instance in 2018, the price of electricity was the same in Spain and Portugal for 95% of the time, which shows a high convergence of prices between both bidding zones, however between Spain and France this figure only reached 27.5% of the hours.

4.2.2 Participation requirements and bid acceptance

The results of the day-ahead market, as determined by the free trade between buying and selling agents, are the most efficient solution from an economic perspective. Nonetheless, given the nature of electricity, this process also needs to be feasible in physical terms. Accordingly, once these results have been obtained, they are sent to the System Operator (REE – Red Eléctrica. Spanish TSO) for their validation from the standpoint of technical viability. This means that the day-ahead market results may be altered slightly, in response to an analysis of the technical limitations conducted by the System Operator, giving rise to a viable daily programme.

Sellers on the electricity power production market are obliged to comply with the Electricity Market Activity Rules by signing the corresponding contract of adherence. Bids made by these sellers are submitted to the market operators and will be included in a matching procedure that will affect the daily programming schedule corresponding to the day after the deadline date for the reception of bids for the session. All available production units that are not bound by physical bilateral contracts are obliged to submit bids for the day-ahead market.

Buyers on the electrical power market are mainly retailers and direct consumers. Buyers may submit bids to purchase electricity on the daily market. However, in order to do so they must abide by the Electricity Market Activity Rules.

4.2.3 New legal frame for self-consumption

Self-consumption has been recently regulated in Spain. The Royal Decree 244/2019 has established a fully new regulatory framework for self-consumption in Spain. In order to properly address the purposes of this use case, the simplified compensation should be taken into account. The simplified compensation mechanism consists of a kind of net balance. The electricity injected by a consumer is calculated on a monthly basis and the compensation cannot exceed the economic value of his/her own consumption from the grid during this period (a net zero electricity component on the bill is the maximum compensation).

4.2.4 Pilot's day-ahead market strategy

Ideally using flexibility in the Day Ahead market would require a reliable price forecast in order to anticipate the cheapest hours before market gate closure and being able schedule consumption during these hours. However such a forecast is not available in the context of the project. The optimisation could still be performed simulating the existence of such a forecast by simply waiting for prices publication and simulating market results if these had been taken into account with Som Energia's offer in the Day Ahead market.

If the forecast for the day-ahead prices, surpluses reward price and imbalance prices are not available for the first optimization, the second optimization may generate deviations from the initial energy purchase.

Currently, the imbalance costs for Som Energia are marginal. If the imbalance costs increased considerably, then Som Energia will have to participate in the intra-day market, in order to balance those deviations. Because of the Spanish intra-day market is currently under a readjusting process, at the moment the FLEXCoop solution can't take full advantage of the intra-day market. So, the participation into this market is out of the scope of the FLEXCoop project.

4.5 Description of the mathematical tool

4.5.1 Aggregated bids for the day-ahead market

'The definition of the parameters needed in this business scenario follows:

$$t_{bid} = 12{:}00 \text{ at } day_{-1}$$

$$t_{beg} = 00{:}00 \text{ at } day$$

$$t_{end} = 24{:}00 \text{ at } day$$

$$\Delta t = 1\ h$$

$$n_p = t_{end} - t_{beg} = 24$$

4.5.2 Time series of each variable

a) Forecasting of the PV generation

Some of the FLEXCoop customers have PV self-consumption in their rooftops. For these users, a forecasting of the PV generation ($\hat{P}_t^{PV}$) for a horizon of 24 hours in hourly steps $n_p = 24$ will be delivered by the DER forecasting modules :

$$\hat{P}_t^{PV} = \left[\hat{P}_{t_{beg}+1}^{PV}, \hat{P}_{t_{beg}+2}^{PV}, \dots, \hat{P}_{t_{beg}+j}^{PV}, \dots, \hat{P}_{t_{beg}+n_p}^{PV}\right] \text{[KW]}$$

Where j counts the forecasting time step. It is the $j'th$ element in the series and $j = \{1, \dots, n_p\}$.

b) Baseline demand forecast

The forecasted time series of the household electricity consumption under no activation (baseline) is expressed as:

$$\hat{P}_t = \left[\hat{P}_{t_{beg}+1}, \hat{P}_{t_{beg}+2}, \dots, \hat{P}_{t_{beg}+j}, \dots, \hat{P}_{t_{beg}+n_p}\right] \text{[KW]}$$

c) Day ahead electricity price

The day-ahead electricity prices for the next 24 h, starting at midnight, can be expressed as:

$$c_t^e = \left[c_{t_{beg}+1}^e, c_{t_{beg}+2}^e, \dots, c_{t_{beg}+j}^e, \dots, c_{t_{beg}+n_p}^e\right] \text{[EUR/MWh]}$$

d) Day ahead imbalances deviation costs

Once the day ahead market is closed, the Spanish market operator also publishes the time varying penalties of the imbalances deviations. In the Spanish day-ahead market, two categories of imbalances penalties are considered: (i) the deviations due to lowering the energy purchase offer of the *day-1*, because the real energy consumption, *day*, was lower $\left(c_t^{d,up}\right)$; (ii) and the deviations due to increasing the energy purchase offer of the *day-1*, because the real energy consumption was higher than predicted $\left(c_t^{d,down}\right)$.They can be expressed as:

$$c_t^{d,up} = \left[c_{t_{beg}+1}^{d,up}, c_{t_{beg}+2}^{d,up}, \dots, c_{t_{beg}+j}^{d,up}, \dots, c_{t_{beg}+n_p}^{d,up}\right] \text{[EUR/MWh]}$$

$$c_t^{d,down} = \left[c_{t_{beg}+1}^{d,down}, c_{t_{beg}+2}^{d,down}, \dots, c_{t_{beg}+j}^{d,down}, \dots, c_{t_{beg}+n_p}^{d,down}\right] \text{[EUR/MWh]}$$

e) Rewards for the exported energy

Once the day ahead market is closed, the Spanish market operator also publishes the rewards due to the surplus energy exported to the electricity grid. As in the case of deviations, they are highly correlated with the day ahead price, therefore, forecasting models may be obtained. They can be expressed as:

$$c_t^{r} = \left[c_{t_{beg}+1}^{r}, c_{t_{beg}+2}^{r}, \dots, c_{t_{beg}+j}^{r}, \dots, c_{t_{beg}+n_p}^{r}\right] \text{[EUR/MWh]}$$

4.5.3 First optimization: PV self-consumption and exported energy rewards

The optimization processes will be limited to the individual level since each customer has specific comfort-based flexibility profiles. The PV generation profiles are also different for each customer since they are placed in different climatic regions.

Once the load profiles are optimized at individual level, SOM Energia (aggregator), will aggregate them to interact with the day-ahead electricity market.

This first optimization has 2 objectives:

- The main objective is to help SOM Energia to define an energy offer to the day-ahead market, which is an optimal balance between the self-consumption and the energy to be exported, from the energy generated by the PV rooftop systems.
- A second objective, aiming at supporting the prosumers to synchronize their PV generation with their energy consumption, can be also derived from this first optimization. The purchase offer should be ready and delivered the day$_{-1}$ before 12 AM.

The cost function offer ($\hat{c}$) is carried out for each prosumer at time $t_{bid}$by the local demand manager and is expressed as:

$$\hat{c} = min(u) \sum_{t=t_{beg}}^{t_{end}} c^{buy}(\hat{P}_t, t) + c^{sell}(\hat{P}_t, t)$$

w.r.t.

$$\forall t \in \{t_{beg}, t_{beg}+1, \dots, t_{end}\}$$

$$c^{buy}(\widehat{P}_t, t) = c_t^e \widehat{P}_t \text{ for } \widehat{P}_t > 0$$

$$c^{buy}(\widehat{P}_t, t) = 0 \text{ for } \widehat{P}_t = 0$$

$$c^{sell}(\widehat{P}_t, t) = c_t^r \widehat{P}_t \text{ for } \widehat{P}_t < 0$$

$$c^{sell}(\widehat{P}_t, t) = 0 \text{ for } \widehat{P}_t = 0$$

$$\widehat{P}_t = \widehat{P}^{hp}(T_t^{set}, T_t) + \widehat{P}_t^{other} - \widehat{P}_t^{PV}$$

$$T_t^{min} \leq T_t \leq T_t^{max}$$

$$C \cdot \frac{dT_t}{dt} = \frac{1}{R}(T_t - T_t^{out}) + COP(T_t^{out}) \cdot \left[\hat{P}^{hp}(T_t^{set})\right]$$

where

- $u = \{T_{t_{beg}}^{set}, T_{t_{beg+1}}^{set}, \dots, T_{t_{end}}^{set}\}$is the set of control variables which minimize the cost.
- $c_t^e$is the price of buying from the grid.
- $c_t^r$is the reward of selling to the grid.
- $\hat{P}^{hp}(T_t^{set})$ is the electrical power consumed by the heat pump as a function of the temperature set point. It appears both in the cost function and in the model of the indoor temperature. The details of the model of the indoor temperature T_t can be found in D3.1 and D3.2, however some further work needs to be carried out to learn the function $\hat{P}^{hp}(T_t^{set})$.
- $\hat{P}_t^{other}$is the remaining demand. Some of this could also be added as controllable demand.
- $T_t^{min}$and T_t^{max} are calculated using the comfort profiling engine as described in D3.2.
- $C$is the overall thermal capacitance of the household
- R is the overall thermal resistance of the household
- $COP$is the coefficient of performance of the heat pump

Since $c_t^e$and $c_t^r$are not known at the time t_{bid} they have to be forecasted, which can be in a very simple way e.g. as average value of the day before.

After carrying out this optimization the baseline forecast can then be communicated by the LDM as

$$[\hat{P}_{t_{beg}}, \hat{P}_{t_{beg}+1}, \dots, \hat{P}_{t_{end}}]$$

together with the forecasted power given up-regulation activation

$$[\hat{P}_{t_{beg}}^{min}, \hat{P}_{t_{beg}+1}^{min}, \dots, \hat{P}_{t_{end}}^{min}]$$

and down-regulation activation

$$[\hat{P}_{t_{beg}}^{max}, \hat{P}_{t_{beg}+1}^{max}, \dots, \hat{P}_{t_{end}}^{max}]$$

The bid submitted is now the sum of all the baseline forecasts from the prosumers in the portfolio

$$P_t^{bid} = \sum_{i=1}^{n} \hat{P}_{i,t}$$

where $\hat{P}_{i,t}$is the baseline forecast for prosumer $i$of $n$prosumers in total (note that the subscript i was not added in the description of the optimization above in order to simplify the notation).

4.5.4 Second optimization: 24 h electricity price and imbalance deviations

A second optimization, aiming at finding the optimal balance between the day ahead market price, the rewards and penalties due to deviations from imbalances, is then performed. This optimization will be a multi-purpose optimization. This optimization is carried carried out during the period between $t_{j-1}$and $t_j$by the global demand manager to optimize the total costs for the aggregator

$$c^{agg} = min(u_i, i \in \{1,2,\dots,n\}) \sum_{t=t_j}^{t_{end}} (\sum_{i=1}^{n} c^{buy}(\hat{P}^*_{i,t}, t) + \sum_{i=1}^{n} c^{sell}(\hat{P}^*_{i,t}, t) +$$

$$+c^{d,up}(\sum_{i=1}^{n}(\hat{P}^*_{i,t}, t) + c^{d,down}(\sum_{i=1}^{n}(\hat{P}^*_{i,t}, t))$$

w.r.t.

$$\forall t \in \{t_j, t_{j+1}, \dots, t_{end}\}$$

$$\hat{P}^*_{i,t} = \left(\hat{P}_{i,t} + a^{down}_{i,t}(\hat{P}^{max}_{i,t} - \hat{P}_{i,t}) - a^{up}_{i,t}(\hat{P}_{i,t} - \hat{P}^{min}_{i,t}) - \hat{P}^{PV}_{i,t}\right)$$

$$c^{buy}(\hat{P}^*_{i,t}, t) = c^e_t \hat{P}^*_{i,t} \text{ for } \hat{P}^*_{i,t} > 0$$

$$c^{sell}(\hat{P}^*_{i,t}, t) = c^r_t \hat{P}^*_{i,t} \text{ for } \hat{P}^*_{i,t} \leq 0$$

$$c^{d,up}(\textstyle\sum_{i=1}^{n} \hat{P}^*_{i,t}, t) = c^{d,up}_t(P^{bid}_t - \textstyle\sum_{i=1}^{n} \hat{P}^*_{i,t}) \text{ for } \textstyle\sum_{i=1}^{n} \hat{P}^*_{i,t} < P^{bid}_t$$

$$c^{d,down}(\textstyle\sum_{i=1}^{n} \hat{P}^*_{i,t}, t) = c^{d,down}_t(\textstyle\sum_{i=1}^{n} \hat{P}^*_{i,t} - P^{bid}_t) \text{ for } P^{bid}_t \leq \textstyle\sum_{i=1}^{n} \hat{P}^*_{i,t}$$

where

- $u_i = \{a^{up}_{i,t_j}, a^{up}_{i,t_j+1}, \dots, a^{up}_{i,t_{end}}, a^{down}_{i,t_j}, a^{down}_{i,t_j+1}, \dots, a^{down}_{i,t_{end}}\}$
- $a^{up}_{i,t} = [0,1]$: The signal which represents the requested up-regulation activation, i.e. load reduction. From 0 indicating no activation to 1 indicating full up-regulation activation.
- $a^{down}_t = [0,1]$: The signal which represents the requested down-regulation activation, i.e. load increase. From 0 indicating no activation to 1 indicating full down-regulation activation.
- At most one activation to one side can be carried out at any time t, thus $a^{down}_t > 0 \Rightarrow a^{up}_t = 0 \wedge a^{up}_t > 0 \Rightarrow a^{down}_t = 0$always hold.

- $\hat{P}_{i,t}$ is the forecasted baseline power level.
- $\hat{P}_{i,t}^{min}$ is the forecasted minimum power level, which is the reference load of prosumer i if up-regulation activation is activated.
- $\hat{P}_{i,t}^{max}$ is the forecasted maximum power level, which is the reference load of prosumer i if down-regulation activation is activated.

Please note that here we introduced the first version of the optimization models which will be further adjusted (as appropriate) in the relevant tasks that will deal with the FLEXCoop optimisation framework.

5 Cost and Benefit Analysis (CBA)

This section describes the approach of the cost-benefit analysis (CBA) to be applied within the Horizon 2020 FLEXCoop project to investigate potential costs and benefits for involved economic entities, namely aggregators and prosumers. In this deliverable, the analysis will be carried out considering the Dutch and the Spanish pilots.

The demand response tool to be developed in the FLEXCoop project aims to facilitate the deployment of DER integration in the power system to provide flexibility. The demand response tool must allow a profitable business case for the involved stakeholders; resulting an appropriate allocation of costs and benefits. Thus, a micro-level analysis, in other words a business level analysis, is necessary to estimate the impact of DER unit integration in the power system as well as the performance of the Demand Response tool on involved economic parties. In addition, micro-level analysis are important when making regulatory decisions. So this chapter aims at providing guidance on how to carry out this type of analysis.

In general, the development of micro-level analysis requires the identification of relationships among the involved parties and the potential formulas to be used.

This chapter is structured in the following way: Section 5.1 states the CBA general description. The CBA framework for prosumers and aggregators within the FLEXCoop project is presented in Section 5.2 and in sections 5.3 and 5.4 is presented the CBA for the prosumer and the aggregator in more details, respectively.

5.1 CBA general description

5.1.1 Micro-level CBA

When a business idea is distinguished and specific analyses are required for its profitability the e^3 value methodology can be used, which is described in [23]. The micro-level analysis follows several main steps to determine, at the end of the process, whether business scenarios are economically attractive for all actors. In the two examined business cases (Dutch and Spanish case) as well as in the whole FLEXCoop framework, the concerned actors are aggregators and prosumers. The main steps to analyse each business case are: 1) identify the relationships among involved parties, 2) define the principles for the CBA analysis.

5.1.2 CBA for FLEXCoop prosumer and aggregator

As a rule of thumb, every single entity involved in a business scenario must be able to make a profit. This should be clear for anyone building a new business idea, since no Stakeholder is interested in a new product or service if its benefit is not evident.

Any business scenario/case can be represented by a value model. A value model represents several players exchanging objects of economic value among them, that all of them benefit.

As already mentioned, two are the concerned stakeholders in FLEXCoop, namely, aggregators and prosumers. The benefits can be different for each one of them. Especially for prosumers the benefits can be of various types and not necessarily expressed in monetary terms (e.g. increase comfort, contribute in a more "eco-friendly" use of electricity etc)

The specific value chains for all the business scenarios examined in FLEXCoop project have already been provided in [24] and will be further updated accordingly - if necessary - in the next and final version of the same deliverable.

5.2 CBA for prosumer and aggregator

As it was stated above, in the FLEXCoop project we conduct micro level - CBA, specifically - for prosumers and aggregators (in our case, cooperatives take the role of an aggregator). The macro-level CBA, or in other words CBA for the whole system performance, is out of the scope of the FLEXCoop project because for evaluating the whole system performance in monetary terms many parameters should be taken into account that are beyond the scope and objectives of the FLEXCoop project (as for example costs and benefits for the TSO e.g. avoided capacity costs, benefits from increased number of BSP etc). In general, given the complexities and uncertainties associated with demand response program cost-effectiveness assessments, it is important that models, inputs and assumptions made are well-defined and – to the degree possible – known.

Moreover, to deploy each business scenario the involved actors need to make a specific investment. Thus, the investment profitability analysis should be performed for each actor. In the FLEXCoop project, for both business scenarios only specific ICT costs should be addressed for aggregators and prosumers, since those are expected to be the only new required investments.

Finally, for each involved player, the estimated annual cash flow and the annualization of the necessary investment must be compared. Results will indicate the attractiveness of FLEXCoops business scenarios for each player.

In the business cases examined in this document (Dutch and Spanish) an explicit demand response framework is applied. In general, explicit DR entails pre-contracted agreement with customer for a specified amount of load and compensation. To this end, in the following sections we present the basic costs/benefits in a more generic manner and the respective sections will be clearly defined after the contract templates have been concluded and finalised.

In order to make an assessment of a business case for a DR program, an estimation of the financial impact of the applied DR programs is required. For a given DR deployment, having detailed costs of all the components is important to define the CBA. Then, the business case should quantify the costs and benefits over the lifetime of the applied programs (e.g. 1 year) for the concerned actors.

Before providing the exact costs/ benefits for each actor per scenario, the principles that will evaluate cost effectiveness are:

- **The Prosumer Cost - Benefit**. This includes the costs and benefits experienced by the prosumer that participates in the demand-side program. The costs include all the direct expenses incurred by the customer to purchase, install and participate in a DR program. The benefits include the reduction in their electricity bills, as well as any financial or other incentive paid by the aggregator (cooperative).
- **The Aggregator (cooperative) Cost - Benefit**. This includes the energy costs and benefits that are experienced by the demand-side program administrator i.e. the aggregator. The costs include all expenditures by the aggregator to design, plan, administer, deliver, monitor and evaluate demand-side programs. The benefits include all the avoided costs, including for example avoided energy costs, and any other avoided costs (e.g., environmental compliance costs) that would otherwise be incurred by the aggregator to provide electric services plus any direct benefits for participating in DR programs.

These are summarised in the Table 5.1 below. The analysis has been based on [25] with the appropriate adjustments / modifications to serve FLEXCoop needs.

	Key Question Answered	Summary
Aggregator Cost - Benefit	Will the aggregator be able to make profit? i.e. are in total /average the benefits greater than the costs?	Includes the costs and benefits that are experienced by the aggregator. Identifies impacts on aggregator revenue requirements. Provides information on program delivery effectiveness, i.e. benefits per amount spent by the aggregator.
Prosumer Cost - Benefit	Will the prosumer be able to make profit? i.e. are in total /average the benefits greater than the costs?	Includes the costs and benefits that are experienced by the program participants. Provides useful information in program design to improve participation and engagement

Table 5.1: Principles of the consumer’s and aggregator’s cost-benefit

There are many different types of demand response program costs that must be accounted for when evaluating cost-effectiveness either on Aggregator Cost-Benefit or on prosumer Cost-Benefit. These are:

Costs

- **Operational Expenses**: This includes primarily ICT related operational costs for being able to provide DR services, like maintenance costs or software licenses. This is referred to the integrated FLEXCoop ICT tool suite. Further details on the actualisation of these costs are provided in the sections below.

- **Capital Expenses**: This includes primarily ICT related capital costs for being able to provide DR services, like the servers and complementary ICT material needed. Further details on the actualisation of these costs are provided in the sections below.

- **Financial Incentive to Participant**: This includes any financial incentive that is provided by the aggregator to the prosumer based on their signed contractual agreement for their participation in DR programs with their DER assets.

- **DR Measure Cost:** This includes any hardware device/ equipment that is necessary for the deployment and administration of DR implementation. In the FLEXCoop case, this is the OSB. Depending on the business scenario that will be adopted in the financial relationship between aggregator / prosumer, this could be a cost for the aggregator or the prosumer.

- **Non-performance cost:** This includes any financial penalty incurred due to non-delivery of the promised DR service.

- **Participant Transaction Costs**: This includes any education related activities that should be performed by the aggregator towards prosumer training / consulting and/ or marketing expenses, etc.

- **Participant Value of Lost Service:** This is a comfort- related cost. This represents a cost for the end-user in terms of possible impact on his/her comfort. Although, it is a challenge to quantify this cost, it should be incorporated in a cost benefit analysis because it can be used as a measure for increasing e.g. people participation. These costs can be significant to the participant, depending upon the type of DR program, the type of demand response measure, and the type of demand response event and the contractual agreements in place.

- **Overhead Cost:** This cost concerns only the aggregator. It refers to those expenses associated with running a business that can’t be linked to creating or producing a product or service. They are the expenses the business incurs to stay in business, regardless of its success level.

The Table 5.2 summarises the applicability of these costs in the cost-benefit analysis that will be performed per actor.

	Prosumer Costs	**Aggregator Costs**
Operational Expenses	√	√
Capital Expenses	√	√
Financial Incentive to Participant	--	√
DR Measure Cost	(√)	(√)
Non-performance cost	√	√
Participant Transaction Costs	--	√
Participant Value of Lost Service	√	--
Overhead Cost	--	√

Table 5.2: Inclusion of costs in a cost benefit analysis per FLEXCoop actor

On the other hand, there are many different types of demand response program benefits that must be accounted for when evaluating cost-effectiveness either on Aggregator Cost-Benefit or on prosumer Cost-Benefit.

Benefits

- **Avoided Energy Costs**: Automation services associated with DR can be used to perform energy efficiency which can result in reduced energy costs. DR programs can also reduce energy costs by shifting demand from high-priced hours to lower-priced hours (see FLEXCoop Spanish pilot case). Calculations of avoided energy costs should be based on analyses of hourly energy costs, because they can vary significantly throughout the day and throughout the year.

- **Ancillary Services Benefits:** In the case of participation to the balancing market (see FLEXCoop Dutch pilot case), this includes the financial benefits provided due to the offering and delivering flexibility towards providing ancillary services to the TSO. These benefits can be shared among the aggregator and prosumers or just by the aggregator when people are incentivised with another way.

- **Participant bill savings:** Bill savings concern only prosumers. They are calculated from the perspective of end-users who participate in demand response programs. It is possible that participation in a demand response program could increase participant bills, making this a cost category rather than a benefit category, but for simplicity it is listed here as a benefit on the assumption that most customers will not enrol in a program that increases their bills. This should be ensured through appropriately defined contracts.

- **Financial incentive to prosumer:** This is any financial incentive provided by aggregator for gaining access to their DERs. This should be defined in the respective contractual agreements. These payments should be accounted for as a benefit in the prosumer cost-benefit analysis.

- **Credits / Other non-financial incentives:** This includes any non-financial incentive (e.g. provision of a data analytics tool, personalised home automation services, etc.) that will be provided to the consumers for their engagement and participation in DR programs. This cannot be easily quantified but it should be counted for in a CBA analysis. It is very important in the FLEXCoop framework that focuses on providing comfort-based services to the prosumers involved in DR schemes.

- **Other benefits:** This includes other benefits that are not easily quantified like for example:
  - customer-perspective benefits (e.g., increased safety, improved health, improved aesthetics, customer control over their bills, etc.)
  - society-perspective benefits, more details can be found on the respective section of this report.

The Table 5.3 summarises the applicability of these benefits in the cost-benefit analysis that will be performed per actor.

	Prosumer Benefits	**Aggregator Benefits**
Avoided Energy Costs	√	√
Ancillary Service Benefits	(√)	√
Participant Bill Savings	√	--

Financial Incentive to Prosumer	√	--
Credits / Other non-financial incentives	√	--
Other Benefits (e.g., market competitiveness)	depends	depends

Table 5.3: Inclusion of benefits in a cost benefit analysis per FLEXCoop actor

To this end, in what follows we divide the CBA per player/actor depending on the examined scenario. Where there are no differences between the two examined business cases (Dutch and Spanish pilots as presented in this document), this is explicitly mentioned.

5.3 CBA of a prosumer

In the following sub-section, we provide in more detail the costs of prosumers based on the Table 2 presented. In particular, we present in detail the ICT and hardware related costs that are assumed to be common in both scenarios examined. Then, we present the non-performance costs based on some assumptions made on potential contractual agreements and finally we elaborate the prosumer cost for lost service. Environmental costs are not further detailed in this section because there is a comprehensive presentation in Section 6.

As mentioned before, in the business cases examined in this document (Dutch and Spanish) an explicit demand response framework is applied. This entails precontacted agreement with customer for a specified amount of load and compensation. To this end, in the following sections we present the basic costs/benefits in a more generic manner and the respective sections will be clearly defined after the contract templates have been concluded and finalised for each business scenario examined in the project.

5.3.1 Cost of prosumer

5.3.1.1 Operational and Capital expenses

The ICT costs for prosumers include the purchase of metering devices, sensors and actuators, gateways, smart lights, etc., as well as the operational costs. This equipment needs to be installed in the prosumers' dwellings in order to automatically control their HVAC, DHW, lights and heat pumps. Table 4 shows a general list of materials to purchase and other installation costs per end-user. The information for this list has been extracted from the bill of materials already provided to some end-users, in whose dwellings the FLEXCoop installation has begun; the detailed individual bill of materials from the friendly users can be found in D7.1 [26]. If there are any upgrade of this list, it may be included in the next versions of the task 7.1:

D7.5 (M30) and D7.7 (M36). As an important remark, not all prosumers need to buy necessarily all the equipment because some of them could have already part of it installed, just the equipment they need with the purpose to control the assets and promise a high-quality performance of their home automatization.

CAPEX related ICT costs per end-user
OSB hardware and software
Equipment Required (off-the-shelf sensors, total consumption, HVAC consumption), e.g. Clamp Power Meter
Multisensors, USB Adaptors, extenders,
Smart sockets for DHW heaters
Lighting devices (LED bulbs, dimmers, gateways, etc.)
WIFI remote controllers for the HVAC Systems and Heat Pumps, Thermostat
OPEX related to ICT costs per end-user
Installation costs (cost of installer + cost of installation)
Purchase, maintenance and upgrades of software licenses
Consumption of energy for running these ICT devices
Internet provider costs for internet connection (in case the end-user does not have one)

Table 5.4: ICT costs per prosumers: investment (CAPEX) and operational costs (OPEX)

5.3.1.2 DR measure cost

This cost can be accounted to the prosumer (or the aggregator in case we consider that this would be an incentive of prosumers' participation in the DR framework). In both cases, the starting point is the actual cost for OSB construction. Thus, we present in detail this information below. The hardware implementation of the OSB has been detailed in the [27] and [27], [28].

A detailed list of the hardware components required for an OSB to be constructed is provided in the table below. It should be noted, that in this cost we should't include the workforce costs required for the assembly and packaging of an OSB, as well as further business-related costs that should be considered for the commercialisation of an OSB (e.g. marketing, testing, maintenance, etc.).

Component	Description	Quantity
RPI 3B+	Main Processor Unit	1
DC Power	Power Supply	1
32GB MicroSD	Internal Memory	1
RPI Case	Gateway Casing	1
TSL25651	Luminance Sensor	1
CCS811	Air Quality Sensor	1
DHT22	Temperature Humidity Sensor	1
PaPIR	Motion Sensor	3
RPI Hat	Custom PCB	1
Zwave Antenna	Zwave Controller	1

Table 5.5: A detailed list of the hardware components

Furthermore, OSB includes also a software implementation as it is also described in detail in the D4.1 and D4.2. The estimation of this software development relevant costs should also be considered here.

5.3.1.3 Prosumer non-performance cost

The deviation cost represents the difference in revenues when the actual operation of prosumers devices differs from planned operation. The way it is attributed depends on contractual relationship between the aggregator and the consumer.

Taking into account the fact that FLEXCoop is entirely automated, prosumers counter-actions will be limited to situations where the end-users manually changes its set points.

- In the case of wholesale market purchase optimisation (Spanish case), this may impact the profile of a given end-user. However, the expected behaviour and related imbalances should be smoothen by the portfolio effect, and the bigger the pool is, the more predictable its aggregated behaviour should be.
- In the case of self-generation optimisation activity (Spanish case), changed consumption behaviour will lead to the consumption of more electricity from the grid at a higher price.
- In the case of balancing services provision (Dutch case), the aggregator needs to hold firm dispatchable resources. Any non-performance would be financially sanctioned by the TSO. The aggregator should anticipate individual deviations through hedging hits portfolio with additional resources. For the sharing of the cost, the following cases could be examined:
    - Any penalty / cost incurred to the aggregator is distributed to the prosumers that deviate from the FLEXCoop mechanism. In this case, the non-performance cost can be analogous to the non-delivered flexibility (energy deviation) by the concerned prosumers multiplied by a non-performance price.
    - No costs transferred to prosumers: their reliability can be reduced and based on a ranking process they can be entirely excluded from an aggregator's portfolio if they got a red flag on reliability due to frequent deviations.

5.3.1.4 Participant value of lost service

As mentioned above, this is a comfort- related cost. The idea behind FLEXCoop solution is that this cost should not be significant considering that the flexibility forecasting per prosumer is based on maintaining prosumer's comfort. However, it should be recorded and monitored because it can have a significant impact in the solution adoption by the prosumers. As mentioned before, this quantification is difficult to be translated to financial cost, thus, qualitative indicators can be used (e.g. percentage of deviation from comfort levels) especially considering that the FLEXCoop solution can identify the comfort levels / zones of the prosumers.

These costs are further discussed below in the section related to aggregators costs.

In the following, we provide in more detail the benefits of prosumers based on the Table 3 presented. This could be different in each business case examined in the document (namely Dutch and Spanish case). It should be noted that environmental benefits are not further detailed in this section because there is a comprehensive presentation in Section 6.

In general, to provide flexibility for a consumer means changing its consumption patterns according to external incentives.

- In the Dutch case (free bids in balancing market), this implies to consume less energy during up-regulation periods and to consume more energy during down-regulation periods according to TSO's requests.
- In the Spanish case, this implies to first consume the self-generated solar PV electricity (electricity at zero marginal cost) at the time of generation, and second to consume less energy during anticipated wholesale market peak-hours (high market prices) and to consume more energy during wholesale market valley-hours (low market prices).

Therefore, the prosumers benefits are reflected in the fact that, the changes in his/her consumption provides value to the energy system. These rewards would have to be shared between the aggregator and the end-user according to the terms of their contract. The aggregator needs to take this fact into consideration when preparing contracts with the consumers to incentify more customers. Hence, the aggregator's offered reward to end users should incentify the subscription to the DR contract.

5.3.2 Benefits of prosumer

5.3.2.1 Avoided Energy costs

In the Spanish case (ESCO and aggregator-retailer), this could imply for self-generating consumers to consume more of their self-generated electricity (at a zero marginal cost) while in this case also energy costs will be reduced by shifting demand from high-priced hours to lower-priced hours.

In the Dutch case, DR can reduce energy costs as it can result in load consumption reduction.

5.3.2.2 Ancillary Services Benefits

These benefits can only be considered in the Dutch case. In particular, in the **Dutch case** (independent aggregator), this could imply:

to share the payment of the TSO for balancing services. End-users would be paid when consumption change has been requested. This implies to be able to estimate the contribution of individual end-user to a DR campaign, and to have enough revenue to share with them. Any revenue of the aggregator is distributed to the prosumers that provided flexibility through the FLEXCoop mechanism. In this case, the revenue can be analogous to the delivered flexibility (energy modification) by the concerned prosumers multiplied by an agreed rewarding price.

However, the cases of Tiko in Switzerland and of Voltalis in France reveal that the revenue provided may not be enough to provide meaningful incentive together with a sustainable business model.

5.3.2.3 Participant bill savings

This can only be considered in the Spanish case. In the Spanish case (ESCO and aggregator-retailer), this could imply for all flexible consumers to get offered cheaper electricity than for non-flexible customers (through cheaper yearly retail tariff or more targeted dynamic pricing).

5.3.2.4 Financial Incentive to prosumers

This is any financial incentive provided by aggregator for gaining access to their flexible DERs. This should be defined in the respective contractual agreements. It could be implied for example by providing the OSB with the respective maintenance services for free.

5.3.2.5 Credits / Other non-financial incentives

In the **Spanish case** (ESCO and aggregator-retailer), this could imply:

- For self-generating consumers,
    - **self-generation monitoring** would be a valuable service for end-users with solar PV equipment.
- For all flexible end-users,
    - Additional **monitoring services and energy efficiency advice** may reinforce the offer.

In the **Dutch case** this could mean:

- **To provide additional services**. For example, in both Tiko [29] and Voltalis[29], [30] cases , rewards are not provided through additional revenues, but through customised energy monitoring, to which FLEXCoop could e.g. add the controls features and energy efficiency advices of the provided solution.

5.3.2.6 Other Benefits

The FLEXCoop solution promises to provide enhanced home automation services. This can be counted as an additional not quantifiable benefit that could, however, convince people to participate in DR programs, perhaps, even with no other financial incentive. To this end, this can be monitored to be able to evaluate in a qualitative manner the impact of such a service in the prosumers’ decisions to participate in DR schemes.

5.4 CBA for aggregator

5.4.1 Cost of aggregator

In the similar way, the main cost components for the aggregator are further detailed below. In particular, we present in detail the ICT and hardware related costs that are assumed to be common in both scenarios examined. Then, we present the non-performance costs related to each examined scenario and finally we elaborate on possible participant transaction costs. Environmental costs are not further detailed in this section because there is a comprehensive presentation in Section 6.

5.4.1.1 Operational and Capital expenses

ICT-related costs are investments and expenses associated with the FLEXCoop integrated solution that will be delivered to cooperatives to enable them to act as aggregators. This concerns infrastructure, software, administration, maintenance and resourcing costs and may also include processes associated with the planning, further design and development, change and incident management, training, etc.

ICT-related costs can be divided in capital costs and operating costs:

- **Capital** costs are the expenses required for the solution to be able to stand up as a product, or in other words, the total cost needed to bring FLEXCoop to a commercially operable status.
- **Operational** costs are the expenses associated with the maintenance and administration of the FLEXCoop solution within an aggregator's business on a day-to-day basis.

Capital costs categories related to FLEXCoop ICT solution include (see Table 5.7):

Hardware	Servers, storage, data centre, network infrastructure, computers, peripherals, A/V equipment, etc.
Support systems	Required licenses for commercial software use (pre-packaged software), firewalls, database management system, etc.
System integration/ development	Workforce expenses related to further development required, integration with other ICT systems / sub-systems, testing, maintenance, etc.
Physical infrastructure	Premises, HVAC, lighting, cleaning, furniture and fittings, etc.

Table 5. 6: Overview of FLEXCoop ICT capital cost for aggregators

Operating costs can be different depending on whether the cooperatives/ aggregators will obtain the solution as CapEx or as an OpEx [31]:

- FLEXCoop as CapEx: investment in the acquisition of the complete solution
- FLEXCoop as OpEx: regular payment to a service provider based on a hosting contract.

In particular, if the solution will be purchased as CapEx, the following costs should be considered (this is considered to be an up-front investment):

Personnel operating expenses	Personnel required to monitor/ support/ use the ICT system provided, training/ assistance personnel, system administrators, etc.

Supporting equipment	Redundant power supplies, UPS systems, generators, air conditioning, insurance, and maintenance of the physical infrastructure required
IT operations management expenses	Backups, operating system upgrades, and repairs
Supporting software and licensing	Other software applications/ tools and network licensing required

Table 5. 7: Overview of FLEXCoop operational costs for aggregators (solution as CapEx)

Procuring the same capability as an OpEx item under a hosting contract with a provider will usually include the following costs:

Personnel operating expense	Personnel required to monitor/ support/ use the ICT system provided, system administrators, etc.
FLEXCoop Software / Service licensing	Depending on contract, this can include all maintenance and IT operations management expenses so that the provider will handle them as part of the aggregator's monthly/ yearly service)
Supporting licenses	Other software application licenses that may be required

Table 5. 8: Overview of FLEXCoop operational costs for aggregators (solution as OpEx)

5.4.1.2 Financial Incentive to prosumers

This is any financial incentive provided by aggregator to the consumers for gaining access to their flexible DERs (other than the ones already described). This should be defined in the respective contractual agreements.

5.4.1.3 DR measure cost

As mentioned above, this cost can be accounted to the prosumer (or the aggregator in case we consider that this would be an incentive of prosumers' participation in the DR framework). In both cases, the starting point is the actual cost for OSB construction as this has been described in detail before.

5.4.1.4 Overhead Costs

This are the expenses of the cooperative towards being able to take over the role of aggregator and run the concerned everyday business. Typical such expenses include e.g. salaries that are not job specific (e.g. accountant), rent, utilities, insurance, external services, financing expenses, taxes, fees, fixed assets depreciation, other exploitation costs. etc.

5.4.1.5 The non-performance cost for the aggregator

Depending on the contract part of these costs can be transferred to the end-user in the case when non-performance is associated with consumers overriding FLEXCoop controls.

- In the case of participation to the balancing market (Dutch case), the non-performance cost consists in the absence of payments and possibly in fines from the TSO (if engaged in seasonal contracts). [It is important to note that the imbalance for the related BRP are tackled by the TSO in the Dutch regulation].
- In the case of self-consumption and wholesale market purchase optimisations (Spanish case), this would consist of the difference between the anticipated cheaper energy (self-generated or from valley hours in the market) and actual consumption, together with the associated imbalance costs.

5.4.1.6 Participant Transaction Costs

This includes any cost created due to education related activities that should be performed by the aggregator towards prosumer training / consulting and/ or marketing expenses, etc.

5.4.2 Benefits components

In the following, we provide in more detail the benefits of an aggregator based on the Table 3 presented. This could be different in each business case examined in the document (namely Dutch and Spanish case). It should be noted that environmental benefits are not further detailed in this section because there is a comprehensive presentation in Section 6.

5.4.2.1 Avoided Energy costs

In the Spanish case (ESCO and aggregator-retailer), this would imply that energy costs will be reduced by shifting demand from high-priced hours to lower-priced hours.

In particular, in the case of self-consumption and wholesale market purchase optimisations (Spanish case), the aggregator-retailer’s benefit corresponds to the difference of price between electricity purchase for flexible end-user (those equipped with FLEXCoop solution) and the non-flexible ones.

5.4.2.2 Ancillary Services Benefits

In the case of participation to the balancing market (Dutch case), the aggregator's potential benefit depending on the delivered flexibility. In particular, the aggregator's benefit will be:

- In case the aggregator does not share this revenue with the concerned prosumers of its portfolio, this would be just the cleared market price for each ISP multiplied by the flexibility delivered by the aggregator during this ISP
- In case the aggregator share this revenue with the concerned prosumers of its portfolio this would be the cleared market price for each ISP multiplied by the flexibility delivered by the aggregator during this ISP reduced by the ancillary services benefits of the prosumers.

If the aggregator has a contract with the TSO to participate in the market (contracted bids), the aggregator's benefit in this case consists of both payment for the capacity allocation and the payment from delivered flexibility volume. The payment for the capacity procurement is known beforehand while making the contract with TSO.

5.5 Profit and loss over the years

The CBA aims finally to estimate the Net Present Value (NPV) of the decision by discounting the investment and returns. Besides the NPV, the Internal Rate of Return (IRR) is the second procedure employed towards the financial evaluation of investment projects, which uses discounted cash flows and present values.

NPV is the difference between the present value of cash inflows and the present value of cash outflows over a period of time. NPV is determined by calculating the costs (negative cash flows) and benefits (positive cash flows) for each period of an investment. The period is typically one year, but could be measured in quarter-years, half-years or months. For calculating the NPV the following formula is used:

$$NPV = \sum_{y=1}^{Lifetime} \frac{NC_Y}{(1+IRR)^y} - C_0$$

Where *NC* is the net cash inflow the period *Y*, *IRR* is the internal rate of return, C_0 is the (single initial) investment outlay, *Y* is the time of the cash flow, *Lifetime* is the total time that the CBA concerns.

A positive net present value indicates that the projected earnings generated by a project or investment exceeds the anticipated costs. It is assumed that an investment with a positive *NPV* will be profitable, and an investment with a negative *NPV* will result in a net loss.

The IRR determines the discount rate for an investment where the sum of the present values of the expected future cash flows and the initial investment outlay equals zero. It basically means that the IRR is the discount rate that equates an investment project's NPV to zero. The equation estimation of IRR is considered as:

$$IRR = NPV = \sum_{y=1}^{Lifetime} \frac{NC_{\gamma}}{(1+IRR)^{y}} - C_0 = 0$$

In general, the higher a project's internal rate of return, the more desirable it is to undertake.

Furthermore, the payback period refers to the amount of time it takes to recover the cost of an investment, which is calculated as follows:

$$n_p = \frac{DR_{inv}}{\left(\frac{TB}{Lifetime}\right)}$$

Where DR_{inv} is the purchased and installation cost (i.e. the investment cost) of the DR equipment, *TB* is total benefit and *Lifetime* is the total time that the CBA concerns.

Finally, the Benefit-to-Cost ratio (BCR) is an indicator, used in cost-benefit analysis that attempts to summarize the overall value for money of a project or proposal and can be calculated as follows:

$$BCR = \frac{TB}{TC}$$

Where TC is the total cost.

Having all these indicators calculated, we may assess the financial feasibility of the cases examined in the project.

6 Cost Benefit Analysis: Social and environmental aspect

The analysis of social costs and benefits is here understood as the review of impacts at citizen level and at society level, without taking into account financial benefits already assessed in this report. The analysis of environmental costs and benefits is here related to the limits of Earth ecosystems. The methodology described below intends to consider these two aspects in a consistent manner. These costs and benefits are reviewed first for the solution as a generic case and then considering the specific Dutch use case related to the participation in secondary reserves and finally related to the Spanish use case related to the optimisation of solar consumption and to the purchase of electricity on the wholesale market.

6.1 Social and environmental costs and benefits in the general case

The famous "sustainability doughnut" created by the British economist Kate Raworth [32] proposed an exhaustive analysis of socio-environmental costs and benefits through a simple diagram. It details on the outer side the environmental boundaries of our ecosystem and on the inner side minimum social standards.

Figure 6.1: The Doughnut of social and planetary boundaries

This clear diagram was designed to highlight a safe path for human development between the safeguard of Earth's nine ecosystems and the promotion of social standards taken from the UN Sustainable Development Goals[1]. It also provides rather simple criteria to review the positive or negative contribution of a given company or product to this sustainable path. In the two tables

[1] The **Sustainable Development Goals** (**SDGs**) are a collection of 17 global goals set by the United Nations General Assembly in 2015 for the year 2030. The SDGs were developed to succeed the Millennium Development Goals (MDGs) which ended in 2015.(Wikipedia)

below, we have listed these environmental and social criteria, and included the positive impacts (benefits / in green) or negative (costs / in red) impacts.

Earth boundaries	FLEXCoop solution environmental costs and benefits
Land conversion	Promotion of domestic DER (saved land in comparison with centralised generation)
	Promotion of decentralised RES-E generation (increased land use through decentralised PV, wind turbines, etc.)
	Promotion of energy efficiency (decreased energy need and related land use)
	Promotion of data-driven solution · increased mining resources for hardware · increased digital infrastructure · related energy for software
Biodiversity loss	*Impact of wildlife habitat can compared with those related to "land conversion" above*
Freshwater withdrawals	-
Nitrogen & phosphorus loading	-
Chemical pollution	Saved raw materials · avoided generation facility (balancing and Ancillary Services) · avoided infrastructure (congestion management)
	Extraction impact of FLEXCoop materials (hardware and supporting data infrastructure, i.e. data centres)
	Limited re-use and recycling of FLEXCoop materials (circular economy)

Ocean acidification	Promotion of RES-E consumption (decrease of CO_2 emissions)
Climate change (GHGs)	idem
Air pollution	idem
Ozone layer depletion	-

Table 6.1: Overview of FLEXCoop environmental cost and benefits

Social needs	**FLEXCoop solution social costs and benefits**
Energy	Cheaper energy (customer level)
	Broader choice of energy services (customer level)
	More resilient energy system through multiplication of local level energy actors (prosumers, cooperative aggregators)
Water	-
Food	-
Health	Less air pollution (society) (decrease of SO_2, NOx, $PM_{2.5}$, and CO_2 emissions)
	Air quality control (customer level)
Education	-
Income and work	Additional income through DR activities (customer level)
	New set of non-relocatable jobs (society)

	Loss of jobs in conventional energy sector (society)
Peace and Justice	-
Political voice	Cooperatives acting as citizens intermediary in energy policies and markets
Social equity	Decentralisation of energy markets revenues
Gender equality	-
Housing	-
Networks (resilience)	Cooperatives connecting and empowering citizens (collective level)
	More resilient communities (society)

Table 6.2: Overview of FLEXCoop social cost and benefits

6.2 Social and environmental costs and benefits related to the participation in secondary reserves (Netherlands case)

The provision of secondary reserves through decentralised energy resources on the demand-side has a series of environmental and social impacts which have been reviewed in the two tables below.

Earth boundaries	**FLEXCoop solution environmental costs and benefits**
Land conversion	Promotion of domestic DER (saved land in comp. with centralised generation used as Balance Service Providers)
Biodiversity loss	*Idem* *(Impact of wildlife habitat can compared with those related to "land conversion" above)*
Freshwater withdrawals	-

Nitrogen & phosphorus loading	-
Chemical pollution	Saved raw materials (avoided generation facility for ancillary services, and related network capacity)
Ocean acidification	Use of Demand-side resources instead of fossil fuel generation (decrease of CO_2 emissions) *(CO_2 is the main factor of ocean acidification)*
Climate change (GHGs)	*Idem*
Air pollution	*idem*
Ozone layer depletion	-

Table 6.3: Overview of FLEXCoop solution environmental costs and benefits, in the secondary reserves participation case

The table below introduces the social cost and benefits related to the participation of cooperatives in the secondary reserves.

Social needs	**FLEXCoop solution social costs and benefits**
Energy	Cheaper energy through cheaper ancillary services resources (society)
Water	-
Food	-
Health	Decrease in air pollution through the use of demand-side resources in AS instead of fossil fuel resources
Education	-

Income and work	Increased income through participation in AS market (customers level)
	Increased need in qualified workforce at local level for installation and maintenance of DER participating in AS market (society)
	Decreased need in qualified workforce at for centralised power plants participating in AS market
Peace and Justice	-
Political voice	Engaged dialogue with TSOs
Social equity	Decentralisation of Ancillary Services market revenues
Gender equality	-
Housing	-
Networks (resilience)	Prosumers collaboration through cooperative independent aggregator (collective level)

Table 6.4: Overview of FLEXCoop solution social costs and benefits, in the secondary reserves participation case.

6.3 Social and environmental costs and benefits related to the day ahead market participation and self-consumption optimisation (Spanish case)

The optimisation of solar self-consumption and of electricity purchase on Day Ahead market has a series of environmental and social impacts which have been reviewed in the two tables below.

Earth boundaries	**FLEXCoop solution environmental costs and benefits**
Land conversion	Promotion of better system adequation (saved land in through avoided generation capacity)

	Promotion of rooftop PV generation (saved rural land for RES-E generation)
Biodiversity loss	*Idem* *Impact of wildlife habitat can compared with those related to "land conversion" above*
Freshwater withdrawals	-
Nitrogen & phosphorus loading	-
Chemical pollution	Promotion of better system adequation (saved raw materials through avoided generation capacity)
	Promotion of rooftop PV generation (saved rural land for RES-E generation)
	Limited recyclability and re-use of PV technology (insertion in circular economy)
Ocean acidification	Promotion of RES-E consumption through better system adequation and rooftop PV generation (decrease of CO_2 emissions)
Climate change (GHGs)	*idem*
Air pollution	*idem*
Ozone layer depletion	-

Table 6.5: Overview of FLEXCoop solution environmental costs and benefits, in the Day ahead market participation and self-consumption optimisation case

The table below introduces the social cost and benefits related to the participation of cooperatives in Day ahead market and self-consumption optimisation.

Social needs	FLEXCoop solution social costs and benefits
Energy	Cheaper energy through optimised self-consumption (prosumer level)
	Cheaper energy through better system adequation (prosumer and collective level)
Water	-
Food	-
Health	Decrease in air pollution through increased use of RES-E through self-consumption and better system adequation
Education	-
Income and work	Increased income through cheaper energy (customers level)
	Increased need in qualified workforce at local level for installation and maintenance of roof-top PV and DER as flexible market-resources (society)
	Decreased need in qualified workforce at for centralised power plants participating in wholesale market
Peace and Justice	-
Political voice	Cooperative promoting solar PV within community
Social equity	More accessible solar PV (prosumer level)
	Decentralisation of energy market revenue through better system adequacy for RES resources (society level)
Gender equality	-

Housing	-
Networks (resilience)	Prosumers collaboration through cooperative as rooftop PV promotor (collective level)

Table 6.6: Overview of FLEXCoop solution environmental costs and benefits, in the Day ahead market participation and self-consumption optimisation case

6.4 Conclusion on social and environmental CBA in the context of FLEXCoop

The review of FLEXCoop environmental costs and benefits let appear more positive aspects than negative. This review also poses fundamental questions especially related to the trade-off between increased integration of RES and extensive use of smart technology. This concerns life-cycle assessment of CO_2 emissions; ecological footprint of used materials and supporting infrastructure as well as insertion in a circular economy. This already represents an important learning and tells that any electricity even from renewable origin comes with an environmental cost.

However the exhaustive review of these aspects is too ambitious to be addressed within the scope of the project. The most relevant KPI, related to the main purpose of the project in terms of RES integration, would be the CO_2 impact of the FLEXCoop solution. The quantification of this aspect can be defined by

$$E_{i,t_{beg}:t_{end}}^{CO_2} = \sum_{t=t_{beg}+1}^{t_{end}} I_t^{CO_2} P_t$$

.

7 CONCLUSION

In this report a range of methodologies which can be applied to evaluate the performance of the FLEXCoop system have been presented - together with the use cases in which it will be tested applied.

In the first part, KPIs for measuring different aspects of performance and for use in remuneration between the prosumer and aggregator are described. They cover KPIs for both historical and online applications. KPIs are outlined for describing and evaluating forecast performance, both point and probabilistic forecasts as well a spatio-temporal are covered with a short description of when they are applicable and references to existing literature for detail are given. Then a new set of KPIs measuring delivered flexibility and deviations from promised flexibility is presented, as well as how they can be used for remuneration applications between the aggregator and prosumers - these will form the basis for the remuneration module which will be implemented in later stages of the project.

In the mid part, of the report the use cases which the FLEXCoop system will be designed to be applied in and thus realizing several business cases described in previous of the projects deliverables. The NL use case, in which it will be demonstrated how the FLEXCoop system can deliver regulating power via the Dutch aFFR market, is presented and the exact timing and functionalities needed has been described. The Spanish use case, in which the functionalities to carry out prosumer self-optimization with a focus on using the local HVAC system to shift demand to match optimally the locally generated PV-power, and then provide the aggregator with demand forecasts. Using these the aggregator can act as a retailer and bid to the day-ahead market. Further, during the course of the delivery day the prosumer flexibility can be used by the aggregator to optimize the aggregated demand to match the bids and avoid deviation costs. With these scenarios of applications of the FLEXCoop system the tests and demonstrations can be designed in detail and carried out to analyse and validate the performance of the system.

In the last part of the report, the CBA methodology which will be applied to evaluate the economical, social and environmental benefits of FLEXCoop system in the various use cases.

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