Sensible – Deliverable

Building and Network Storage Aggregator Managers (methods)

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Executive Summary

This deliverable describes the two concepts tested in SENSIBLE for the management of aggregated storage, which are:

- Flexibility analytics
- eBroker

The first is a cloud based solution developed by ARMINES. Its objective is to minimise the operation cost of the flexibility portfolio with a global optimisation of all the flexibility resources such as batteries, thermal storage or curtailable renewables.

The second is a distributed agent based solution developed by GPTech. In this case each battery takes its own decisions but is connected to a network of other similar intelligent storages, with the aim to solve several objectives such as: 1) Savings in electric infrastructures, 2) Improve the integration of renewable energy sources to the electric grid, 3) Increase economic user's benefits, 4) optimize the usage of batteries and 5) To solve the problems of Distribution Network Operators (DSO) caused by distributed in-feed.

The flexibility analytics is tested in the Évora demonstrator in Use Case 2 (UC2) whilst the eBroker is tested in the Meadows demonstrator in Use Case 7 (UC7). For each solution a description of the concept is provided along with information on how forecasts are taken into account and how conflicts between different stakeholders or devices are managed.

Both solutions involve integration to the markets realised by Empower through the Energy Market Service Platform (EMSP). This platform is divided into three different components: The Customer Information System (CIS), the Energy Data Management System (EDM) and the Energy Management System (EMS).

1 Introduction

1.1 Purpose and Scope of the Deliverable

This deliverable describes the two concepts tested in SENSIBLE for the management of aggregated storage. The two storage aggregation approaches tested in SENSIBLE are:

- Flexibility analytics
- eBroker

The first is a cloud based solution developed by ARMINES. Its objective is to minimise the operation cost of the flexibility portfolio with a global optimisation of all the flexibility resources such as batteries, thermal storage or curtailable renewables.

The second is a distributed agent based solution developed by GPTech. In this case each battery takes its own decisions but is connected to a network of other similar intelligent storages, with the aim to solve several objectives such as: 1) Savings in electric infrastructures, 2) Improve the integration of renewable energy sources to the electric grid, 3) Increase economic user's benefits, 4) optimize the usage of batteries and 5) To solve the problem of distributed source to Distribution Network Operators (DSO).

The flexibility analytics is tested in the Évora demonstrator in Use Case 2 (UC2) whilst the eBroker is tested in the Meadows demonstrator in UC 7. For each solution a description of the concept is provided along with information on how forecasts are taken into account and how conflicts with other actors or between the devices are managed.

Both solutions in both demonstrators involve integration to the markets realised by Empower through the Energy Market Service Platform (EMSP). This platform is divided into three different components: The Customer Information System (CIS), the Energy Data Management System (EDM) and the Energy Management System (EMS).

1.2 References

1.2.1 Internal documents

[1] Project SENSIBLE D1.1 "Energy storage domain roles & classification", 2015

[2] Project SENSIBLE D1.3 "Use Cases and Requirements", 2015

1.2.2 External documents

[3] *Business Requirement Specification for a Harmonised Nordic Retail Market*, 2014. http://www.nordicenergyregulators.org/wp-content/uploads/2014/06/BRS-Report.pdf

[4] *Fingrid – Taseselvitys (Balance settlement)*, http://www.fingrid.fi/fi/asiakkaat/tasepalvelut/taseselvitys/Sivut/default.aspx, Accessed on May 2016.

[5] *SVK – Balance Responsibility*, http://www.svk.se/en/stakeholder-portal/Electricity-market/Balance-responsibility/, Accessed on May 2016

1.3 Acronyms

AMI	Advanced Metering Infrastructure
BRP	Balance Responsible Party
BEMS	Building Energy Management System
BAU	Business as usual
CD	Controllable Device
CIS	Customer Information System
DSM	Demand Side Management
DSO	Distribution System operator
EDM	Energy Data Management System
EMS	Energy management system
EMSP	Energy Market Service Platform
EFET	European Federation of Energy Traders
ebIX®	European forum for energy Business Information eXchange
ENTSO-E	European Network of Transmission System Operators
GHG	Greenhouse gases
HA	Home Analytics
EMSHEMS	Home Energy Management System
LV	Low voltage
MV	Medium Voltage
MP	Metering Point
PV	Photovoltaic
PCC	Point of common coupling
RM	Resource Manager
SOC	State of Charge
TSO	Transmission System Operator
UC	Use Case

2 Flexibility analytics

2.1 General approach

The flexibility analytics tool has the objective of managing a portfolio of distributed residential flexibility resources. The resources controlled are: batteries, controllable loads and controllable renewable generation. The availability of this last resource in the Évora demonstrator is still under discussion, depending on the capability of the Home Energy Management System (HEMS) and of the inverters deployed. The tool is conceived with two time frames: day ahead and intraday, where it performs the tasks of unit commitment and dispatch.

The general approach here described won't be applied fully in the Évora demonstrator since the UC2 involves several partners and the flexibility optimisation problem has been split in more parts. This will be described in Section 5.1.

Both tasks are approached as an optimisation problem as reported in Equation (1) where, for each flexibility resource F_i, the optimal schedule $\mathrm{P_{F_i}}$ defined for all the time steps $t \in T$ is calculated, by taking into account an objective function $\mathrm{f_{obj}(P)}$ and constraints for the energy storage capacity (via the State of Charge, (SOC)) and the power constraints at each location L_j.

$$\begin{aligned} &\underset{\mathrm{P}}{\text{minimise}} \quad \mathrm{f_{obj}(P)} \\ &\text{subject to} \quad \begin{cases} \mathrm{P_{F_i}^{min}(t) \le P_{F_i}(t) \le P_{F_i}^{max}(t)} \\ \mathrm{SOC_{F_i}^{min}(t) \le SOC_{F_i}(t) \le SOC_{F_i}^{max}(t)} \ \forall \ \mathrm{F_i} \\ \mathrm{P_{L_j}^{min}(t) \le \sum_i P_{B_i}(t) \cdot T}_{i,j} \le \mathrm{P_{L_j}^{max}(t)} \end{cases} \end{aligned} \tag{1}$$

Where $\mathrm{T}_{i,j}$ represent a topology matrix defined as follows:

$$\left\{ T_{i,j} = \begin{matrix} 1 \ if \ \mathrm{F_i} \ is \ in \ \mathrm{L_j} \\ 0 \ otherwise \end{matrix} \right.$$

The objective function to minimise represents the operational costs of the flexibility and is made of the sum of several components. In particular it is considered: i) the cost associated to the aging of the batteries and of the equipment C_i^{aging}, ii) the cost associated to the self-discharge C_i^{sd}, iii) the cost (or profit) associated to charge C_i^{ch} and discharge C_i^{disch} and finally iv) the cost associated to the electricity lost by the inverter and by the electrochemical conversion process C_i^{loss}. These costs depend on the equipment; the electricity cost and the schedule P defined over the time interval T are as described in Equation 2.

$$\mathrm{f_{obj}(P)} = \sum_i \left(C_i^{aging}(\mathrm{P_{F_i}}) + C_i^{sd}(\mathrm{P_{F_i}}) + C_i^{ch}(\mathrm{P_{F_i}}) + C_i^{disch}(\mathrm{P_{F_i}}) + C_i^{loss}(\mathrm{P_{F_i}}) \right) \tag{2}$$

Where each term is defined as follows:

- C^{aging} is calculated considering the loss of life associated to a cycle multiplied by the cost of the battery. If the energy displaced by the cycle is $e = \Sigma_t(P_t)$, the battery capacity is E, The cycling life is N cycles and the battery cost is $C^{battery}$, then $C^{aging} = e/(E \cdot N) \cdot C^{battery}$
- C^{sd}: if the storage has a self-discharge SD, a state of charge SOCt, a capacity E and the electricity has an average price EP, then $C^{sd} = SD \cdot \Sigma_t(SOC_t) \cdot E \cdot EP$
- C^{ch}: if P_t is the power charged into the battery and EP_t is the cost of electricity, both at time t, then $C^{ch} = \Sigma_t(P_t \cdot EP_t)$
- C^{disch}: if P_t is the power discharged from the battery and EP_t is the cost of electricity, both at time t, then $C^{disch} = \Sigma_t(P_t \cdot EP_t)$
- C^{loss}: if the storage as a roundtrip efficiency of L^2, the cost of electricity at time t is EP_t and the power charged or discharged is EP_t, then $C^{loss} = L \cdot \Sigma_t(P_t \cdot EP_t)$
- P_{Fi} is the power flow at the i-th flexibility source

The methods proposed above can be improved when the datasheets of the flexibility devices will be available. This is true in particular for the aging cost, since often for batteries this is not a linear function.

Each cost must be defined by a function taking into account the nature of the flexibility source (battery, thermal storage, PV curtailment)..

The first constraint in Equation 1 represents the power limits of the flexibility source, with $P_{F_i}^{min}$ and $P_{F_i}^{max}$ representing the maximum value of the power that can be absorbed or injected into the network. The convention used here is that power is positive if it is absorbed from the network (such as when a battery is charging) and negative if it is injected into the network (such as when a battery is discharging). In general these two values are not symmetrical and equal in absolute value. For example batteries in general have a charge speed lower than the discharge speed, resulting in $|P_{F_i}^{max}| < |P_{F_i}^{min}|$. In the case of thermal loads or curtailable renewables generators $P_{F_i}^{max}$ and $P_{F_i}^{min}$ are respectively null. This aspect is discussed more in detail in Section 2.3.4.

The second constraint in Equation 1 limits the amount of energy displaced by the flexibility. This is referred to storage flexibilities such as batteries or thermal storage, but can be extended to load and renewable curtailment when this should be limited for contractual reasons. This constraint can also be used to force storage units to reach a specific state of charge at one hour of the day, in order to be able to provide the expected flexibility.

Finally the third constraint in Equation 1 limits the collective power consumption or injection on the network for a group of batteries. This is necessary when the tool is called in intraday when targets for aggregated flexibilities have been set at the aggregated level but the individual schedule for each device can be modified following individual actions from the users or observed loads and weather different from the forecasted ones.

2.2 Main user

The tool is conceived to facilitate the management of large parks of flexible resources by several actors such as DSOs, retailers, or aggregators, but in SENSIBLE it will be operated by the retailer.

2.3 Individual and aggregated storages

2.3.1 How storages are modelled and managed?

Flexibility resources are all modelled as storages. Each storage is modelled considering the parameters specified in Table 1.

Table 1: Modelling of flexibility sources

		Typical values		
Parameter	**Unit**	**Li-ion batteries**	**Controllable water heaters**	**Controllable renewables**
Expected availability	%	100	100	100
Rated discharge	kW	3	0	3
Rated charge	kW	1	3	0
Rated capacity	kWh	3	2	tbc
Round trip Efficiency	%	95	99	100
Self-discharge	%/hour	0	0	0
Charge electricity cost	€/kWh	0.05-0.3	0.05-0.3	0.05-0.3
Discharge electricity cost	€/kWh	0.05-0.3	0.05-0.3	0.05-0.3

2.3.2 What are the objectives?

As mentioned in 2.1the objective of the tool is to minimise the operation cost of the flexibility portfolio in order to allow the retailer to optimise its procurement on the electricity market and to minimise grid congestion penalties. .

2.3.3 How potential conflicts are managed?

The tool is conceived as an operational tool for the management of portfolios of flexibilities. This can be used by existing actors such as retailers, as in the Evora demonstrator or DSOs, TSOs or producers. Therefore conflicts are not expected and the tool can be operational without amendments to the existing regulation. The tool can be used also by new actors such as communities or storage aggregators, provided that their actions are feasible in the regulatory framework.

2.3.4 How forecasts are taken into account

The flexibility analytics tool takes into account forecasts for the electricity production from renewables and for the electricity consumption of the household. These are used for determining the constraints of the optimisation problem described in (1).

As an example, a PV plant will be able to offer zero flexibility during the night. During each hour of the day will be able to offer a positive flexibility (a reduction of the production is equivalent to an increase of a load) lower or equal to its actual production. The forecast of this production for each hour *t* is equivalent to the term $P_{F_i}^{max}(t)$ in (1), whilst $P_{F_i}^{min}(t)$ is constantly equal to zero in the case of PV. Since forecasts are associated to a degree of uncertainty, probabilistic forecasts are used and the value $P_{F_i}^{max}(t)$ used is relative to a determined quantile. As an example, it will be a value which has the 90% probability of being achieved at time *t*.

The example above on the use of forecast for PV flexibility can be applied for load flexibility.

3 Energy broker

3.1 General approach

The way in which the electric power systems have been developed has led to different problems such as:

- A centralized energy system which has a strongly dependency on fossil fuels, implying greenhouse gases (GHG) generation.
- The scalability of the existing infrastructure is limited and the distance between power generation and consumers are very high.
- Previous point could result on the saturation of the distribution network.
- Finally, a lack of energy storage systems forces to keep power plants being active in an inefficient way.

The result of all these problems means an unsustainable growth of the electric power system and an increasingly energy cost. Therefore, the need for a paradigm shift in order to get a model that makes an efficient and smart use of energy is more than justified. Based on this idea, the eBroker manager development was established as an essential component in this new electric model.

eBroker propose a radically new model of growth adding interconnected Cyber-Batteries (commercial storage systems with eBroker implementation) by means of an “on cloud” architecture which lets them to collaborate by artificial intelligence tools. eBroker technology implies:

- Matches energy supply and demand in real time taking into account batteries' state of charge, charge/discharge forecasts, distributed power generation as well as other parameters, including network energy cost and power quality.
- In this way, eBroker will allow to integrate storage systems in an optimal way, in both terms of economy and energy management.
- It will also open new energy transport channels having the possibility to carry batteries to the points where its operation is maximized.
- Moreover, the user earns benefits from energy trade, using energy storage management in micro-grids with distributed generation.
- The application of the eBroker in the electric power systems implies savings in electric infrastructures.
- Furthermore, it aims to solve energy efficiency problem for both users and system operators.

What makes eBroker to be a really smart manager is the combination of:

- Genetic algorithms to get the best energy strategy regarding technical and economic factors.
- A predictive manager, which is adapted and customized according to user behaviour, including the chance to include different forecast tools.
- Self-control and automatic operation without the need of user attention, improving prosumer integration into the new energy model.

- Power management and energy trading for cost reduction.
- Extend battery lifetime taking into account the consequences of battery usage and SOC.
- Home automation controllability, allowing direct demand management.

3.2 Main user

One of the most important drawback of buying batteries, or any other technology of energy storage, and connect it in low voltage network, is the difficulty of recovering investments and monetize them. eBroker introduces a new management method that ensures the maximum profit for the owner at the same time that improves the network performance by providing energy storage points with controllability features to DSO. Thus, it goes a step further of the current strategies, buy energy when its cost is low and sell energy when its cost is high.

It's expected that a new tool for energy optimization, like eBroker, encourages consumers and distributed energy resources' producers the use and the integration of energy storage devices to electric power systems. With that, the so called prosumer concept makes sense and the active participation of consumers into the electric grid is viable and organized.

Among the improvements that can be found in the management energy system it is highlighted:

- Reduction of maximum power for electric connection of micro-grids as well as for infrastructures in point of common coupling (PCC) for both consumers and producers.
- Increase network capacity. It means reduce the amount of extra reserve that the operator should hire to ensure the supply.
- Better match between power demand and supply, also favouring the use of electricity generators whose production is more efficient with respect to fossil fuel consumption.
- Facilitate the penetration of renewable energy systems and the use of micro-grids by improving supply continuity. Thus promoting the incorporation of distributed energy resources.
- Provide a micro-grid the following capabilities:
  - Islanding mode operation.
  - Energy management system (EMS).
  - Interoperability with the current energy model.
- Scalable solution.
- Using storage systems as a distributed energy resource's generator (concept of energy vector)

In first place, regarding economic aspects and energy usage, the development of eBroker tool is focused to industrial customers. Despite that, eBroker is programmed with genetic algorithms and it is capable to work as a predictive manager. Both characteristics let it be adapted and customized according to user's behaviour and apply the best energy strategy to get the best results in each node in which it can negotiate. Moreover, the system is interconnected by mean of an “on cloud” architecture so it will make possible to manage a complete microgrid.

For the reasons explained above, it is understood that the use of this tool will be useful for industrial consumer and DSOs, however its adaptability features make eBroker to be adaptable to small users.

3.3 Individual and aggregated storages

3.3.1 How storages are modelled and managed?

As a first approach, storage systems are considered as a dual tool, with consumption and power source features. Several conditions are taken into consideration such as operation historical, type of storage system or operation characteristics. Additional details will be disclosed with eBroker implementation progress.

3.3.2 What are the objectives?

The main objective of eBroker is to improve the performance of the electric power systems as well as maximizing user’s benefits.

The use of interconnected intelligent Cyber-batteries by means of an “on cloud” architecture makes possible split the objective in different sub-objectives:

1. **Savings in electric infrastructures**. Most elements of that kind of infrastructures are designed according to maximum value of power that only flows during short periods of time. The fact of having a source of electric power close of consumers reduces the maximum power flows on the grid which relaxes peak values.
2. **Improve the integration of renewable energy sources to the electric grid**. The use of storage elements with artificial intelligence tools in parallel to renewable energy source allows delivering power when it is necessary instead of when it is produced and providing grid backup services during regular operation of the grid.
3. **Increase economic user’s benefits** storing energy when it has low cost and selling it when the cost is higher.
4. In relation with 3, **optimize the usage of batteries** taking into account not only economic criteria but also their state of charge and energy consumption and generation forecast in order to extend the batteries lifetime.
5. **To solve the problem of distributed source to DSO**. eBroker is a solution to the challenges regarding controllability of a huge amount of distributed source without direct control or access to system operators. With this system, DSO will understand every user as a whole, more powerful than a single part of the system or an aggregation of consumption and power sources variables.

3.3.3 How potential conflicts are managed?

The main drawback facing the eBroker implementation is the fact that an innovative model for electric energy systems' growth means a change in the role of the consumer, taking part in the system as an active element. Some of the features that eBroker pretends to develop (such as the possibility that users can offer energy stored as a backup to the network) require certain changes in current legislation and in some grid design concept where protection would prevent the presence of bi-directional power flows.

3.3.4 How forecasts are taken into account

eBroker tool is developed to deal with weather and energy consumption forecasts. The fact that weather is a known variable allows the system to make a more accurate approximation of the power generation.

Before the power estimation is used by the system, it is compared to data history in order to evaluate its reliability. Once it is done, eBroker has a forecast about the availability of the power in the battery, as well as the consumption of electric power required by the loads.

The predictive control method is programmed with a sliding horizon for the following 24 hours and it takes into account the consequences that the control action will have on the state of the battery.

Due to the fact that the tool works with forecast data, adaptability in deviations of parameters is an issue to deal with. For this reason, the results generated by the test of the tool will be compared to those obtained from a strategy based on the blind application of charge and discharge times. Doing that, it will be possible to compare the improvements made on the storage system's performance.

4 Connection to the markets

4.1 Market roles and responsibilities

The energy markets connect producers with consumers and manage the balance between demand and supply at all times. The markets are operated both at contractual and physical levels and in the liberalized energy markets these operations are separated. This means that the delivery of electricity (transmission and distribution) has been divided from the supply of electricity. Furthermore, generation is also a separate function on the markets. This market model has created various stakeholders on the markets which have been described below in the Table 2.

Table 2 Energy market stakeholders [3]

Role	Definition
Energy Producer	A party that operates large scale generation capacity.
Transmission System Operator (TSO)	A party that operates electrical power (or natural gas) grids on a national or regional level. TSOs are responsible for managing the grid frequency i.e. the balance between demand and supply. For this purpose the operator facilitates balancing power and reserve markets.
Distribution System Operator (DSO)	A party responsible for providing access to the grid through an Accounting Point and its use for energy consumption or production to the Party Connected to the Grid.
Energy Retailer/ Supplier	A party that operates the contractual agreement with the end customers and procures the required energy to the Point Connected to Grid.
Customer	A party that contracts for the right to consume or produce electricity at an Accounting Point. In the ebIX®, EFET and ENTSO-E Harmonised Electricity Role Model the *Customer* is called *Party Connected To Grid*
Balance Responsible Partner (BRP)	A party that has a contract proving financial security and identifying balance responsibility with the Imbalance Settlement Responsible of the Market Balance Area entitling the party to operate in the market. This is the only role allowing a party to nominate energy on a wholesale level. Additional information: The meaning of the word “balance” in this context signifies that the quantity contracted to provide or to consume must be equal to the quantity really provided or consumed.
Balance Supplier	A party that markets the difference between actual metered energy consumption and the energy bought with firm energy contracts by the Party Connected to the Grid. In addition the Balance Supplier markets any difference with the firm energy contract (of the Party Connected to the Grid) and the metered production.

	Additional information: There is only one Balance Supplier for each Accounting/Metering Point. The business term for "Balance Supplier" is normally "Electricity Supplier" or just "Supplier"
Aggregator	A party that aggregates small scale end customers or industrial sites in larger pools to build up flexible capacity that can be offered at different levels of the wholesale energy markets. The entities may be utilized to optimize energy procurement or demand response activities.
Power Exchange	A party responsible for operating the power spot markets for short-term trading at day-ahead and intraday levels.
Service Providers	Parties that may offer services for operating e.g. demand response, electric vehicle charging, smart meter measurement and trading activities. One example of a service provider is an aggregator.

A key function on the energy markets is that the production and consumption is measured accurately on each metering point connected to the markets. The information is used to settle the energy balances after the delivery hour. Table 3 below illustrates the different responsibilities regarding energy measurement.

Table 3 Meter data management roles [1]

Meter Administrator	A party responsible for keeping a database of meters. Usually the DSO.
Meter Data Aggregator	A party responsible for the establishment and qualification of metered data from the Metered Data Responsible. This data is aggregated according to a defined set of market rules. Usually the TSO.
Meter Data Collector	A party responsible for meter reading and quality control of the reading. Usually the DSO.
Meter Data Responsible	A party responsible for the establishment and validation of metered data based on the collected data received from the Metered Data Collector. The party is responsible for the history of metered data for a Metering Point. Usually the DSO.
Metering Point Administrator	A party responsible for registering the parties linked to the Metering Points in a Metering Grid Area. He is also responsible for maintaining the Metering Point technical specifications. He is responsible for creating and terminating Metering Points. Usually the DSO.

4.2 Market structures supporting aggregator models

The amount of renewables is increasing rapidly in the energy markets. Because of the intermittent nature of the renewables it's necessary that both consumption and generation capacity is managed dynamically and actively. For this purpose the role of aggregators is vital since individual customers can't participate in the markets directly. To promote the operation of aggregators the market structures need to evolve. To enable efficient demand response schemes various market stakeholders need to provide new type of information, the markets need new information exchange solutions and the utilized devices need to be connected efficiently to the markets. For this purpose the old solutions that were designed for centralized utility driven environments are obsolete.

It is possible to consider a very high level conceptual model that facilitates the use of flexibility for different purposes. Key component in the model is the service for flexibility operation that provides open structures for every market stakeholder to utilize the controllable resources. For aggregators this enables the utilization of resources and the collection of necessary data to be used at the markets. The structure secures that i.e. the DSOs and BRPs will have an overview regarding the aggregator's actions. This way all the stakeholders can optimize their own operations based on common and open market information.

The aggregators', and also every other market stakeholders', actions should take into account the balance responsibilities. Balance responsibility is a key function of the energy markets which ensures that as much electricity is supplied as the customers consume. To fulfil this obligation there must be someone who undertakes this responsibility for the electricity supply in every metering point connected to the grid. The electricity supplier can acquire the role of a balance responsible or it can be contracted from a third party that already is such an actor. In every case the agreement is established with the TSO. [5]

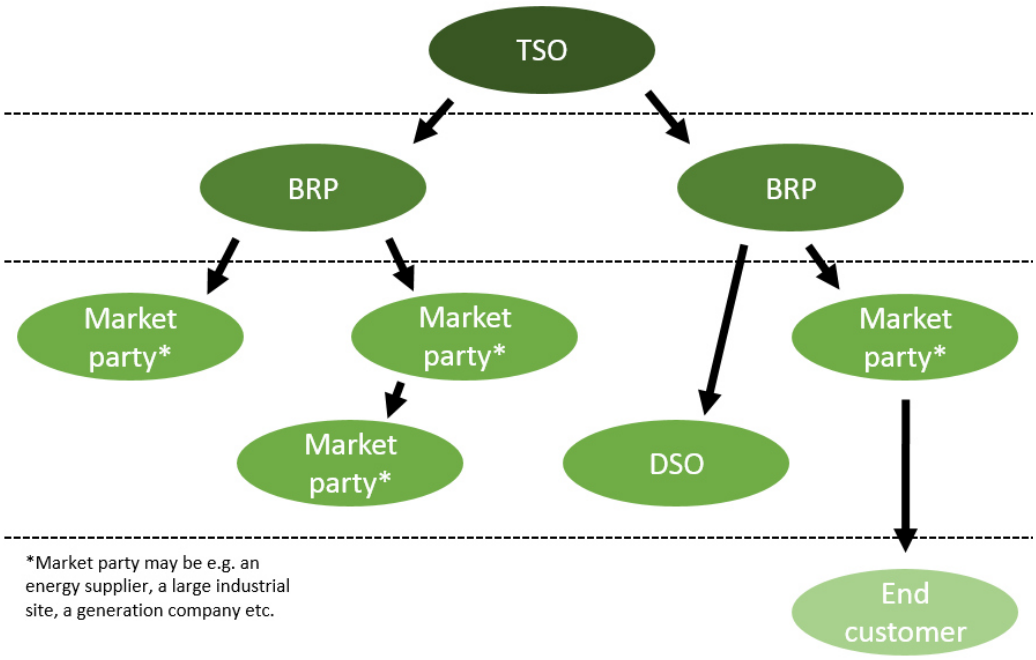

Figure 1 Balance responsibility chain [4].

Balance responsibility is important for demand side management activities in general because they cause a deviation in the energy balance. Balance responsible plan and report both consumption and production portfolios before the delivery hour. If the demand response actions or other flexibility services change the planned levels, the BRP has to pay the TSO who intervenes to restore the balance. Therefore the imbalance causes extra costs to BRPs. If the scale of imbalance is large enough it could jeopardize the whole markets. This possible conflict has to be managed with new market structures that for example support the role of aggregators. [5]

4.3 Energy market service platform

In the SENSIBLE project the different aggregator models are connected to the energy markets through the Energy Market Service Platform (EMSP). The EMSP enables the management of customer information, energy measurement data and portfolio information through common market interfaces. The EMSP collects necessary data from the connected systems, transforms that in standard market formats and delivers the information to all relevant stakeholders. This way the resources may be managed without creating conflicts or shadow markets which might jeopardize the entire position of the new services.

The Energy Market Service Platform is divided into three different components. The Customer Information System (CIS), the Energy Data Management System (EDM) and the Energy Management System (EMS). Below a description of how these systems are used to provide required services for the aggregator’s connection to the markets.

Customer information management

Aggregator services require the collection of customer data to be used for different purposes. Billing, remuneration and end customer compensation just to name few. Therefore customer identification is necessary and it’s usually tied into metering point identification. This way the official energy market measurements can be merged with a particular customer. In the future also the customer information management will get more complex as new types of dynamic and autonomous resources could enter the markets. The managed customer information includes:

- Metering point identification
- Customer information

In the SENSIBLE project the demonstrations provide different customer information to the EMSP. What is at least available is the smart meter identification and customer ID.

Balance management

Balance management means that the BRPs optimize the consumption and production at portfolio level to achieve equilibrium. This is established on hourly basis. While connecting the demonstrations with the energy markets, the EMSP will also provide balance management functionalities. This will include the collection of forecasts, portfolio planning and the utilization of various marketplaces. The marketplaces that could be utilized through the EMSP include the following:

- Bilateral transactions
- Spot markets
- Balancing power markets
- Ancillary markets

Balance settlement

Balance settlement is required since the BRPs rarely manage to achieve an optimal energy balance. In balance settlement the deviations or imbalances are determined after the delivery date. Possible imbalances are settled with the TSOs and compensated in money. The EMSP will also provide balance settlement functionalities for the SENSIBLE demonstrations. In general balance settlement includes the following activities:

- Measurement data collection
- DSO balance settlement
    - Supplier specific total consumption and production amounts calculated
- BRP balance settlement
    - Total portfolio amounts calculated
- TSO balance settlement
    - Total amounts of an entire balance area calculated

5 Applications in Sensible

5.1 Évora

The Évora Demonstrator is focused on validation of the benefits of using storage for both distribution grid and customers. Thus five use cases where designed to support this investigation [2]. Their implementation depends on the development of several tools described in chapters above.

Regarding the Use Case 2 – Flexibility and Demand Side Management DSM in the market participation – two core tools are essential:

- Flexibility analytics – On the one hand this tool will aggregate the flexibility from a portfolio of clients that will be used to optimize the market participation of a retailer. On the other hand, when the amount of flexibility that each retailer needs for market's purposes is calculated, the Flexibility analytics has the capability to disaggregate it down to single homes or devices and communicate the plan for each home.
- Energy Market – The Energy Market Service Platform will be responsible to simulate the market where the retailer will optimize its participation using the aggregated flexibility provided by Flexibility Analytics. Moreover, from the DSO point of view, the Energy Market tool will be also responsible to calculate the grid access tariff. Notice that, in a real implementation, the DSO is the entity that is responsible for establish the grid access tariffs but for the simulation of this UC and since the final result is not compromised, this approach is more convenient and easier to implement.

Having said that, Flexibility Analytics and Energy Market tools will be complementary key pieces for the functioning of the UC 2 since they are used in a logical sequence in order to provide the set points for each home that minimise their energy bills while contributing simultaneously for grid management.

The remaining four use cases are focused on grid operation supported by storage. The Use Cases 8 and 9 aim at optimizing the MV and LV storage systems to solve technical problems of respectively MV and LV distribution grid, whereas Use Cases 10 and 11 will demonstrate the importance of storage devices to supporting the islanding mode. Therefore, these use cases are strongly dependent on the Grid Storage Management tool since it will be is responsible for deciding the optimal plan for storage devices that keeps the distribution grid within the technical limits.

Furthermore, since these tools, namely the Flexibility Analytics and the Grid Storage Management, are based on optimization algorithms, they will enhance the KPI results because systems/ equipment and their flexibility will be exploited in such a way that maximise their potential.

5.1.1 Home analytics and EMSP in Évora's UC2

The interaction between the Home Analytics (HA) and the energy market service platform is described. A detailed description of the sequence of actions performed by the different actors in UC2 can be found in Figure 2 and Figure 3. The steps relevant to the HA and the EMSP are 5, 10-12 and 13 for the day ahead and 5, 11-13 and 14 for the intraday. In the following text it should be remembered that 'Resource ID' is a label that can be applied to individual devices, homes or groups of flexibilities.

Flexibility Forecast

This action is performed by the HA both in day ahead and in intraday, which corresponds to the step 5. In this step the tool will forecast the technical constraints of the optimisation problem mentioned in Section 2.1 and the technical costs of the objective function shown in Equation 2. An example of the outputs of the tool is shown in Table 4 where the fields are respectively:

- Power charge max: The maximum value of the flexibility in the direction of the consumption from the grid. It is calculated by taking into account the load and PV forecast, the rated contract for the homes and the availability from the flexibility sources
- Power discharge max: The maximum value of the flexibility in the direction of injection into the grid. It is calculated by taking into account the load and PV forecast, the rated contract for the homes and the availability from the flexibility sources
- Energy max: The maximum value of the energy that can be stored
- Energy min: The minimum value of the energy to be consumed, it represents the energy that is demanded by the consumers for the thermal storage. For example: at least 5kWh must be consumed by 23:00 and another 2 kWh must be consumed before 23:15
- Cost function v1 - Cost -100% - -60% to Cost function v1 - Cost 60% - 100%: The technical cost for using the flexibility (due to losses and battery aging) is represented here for different ranges (0% - 20%, …, 80% - 100%) of the available flexibility interval [between the maximum charge and the maximum discharge]. This is a linear approximation of the cost, and the intervals ranges are fixed, introducing two sources of errors.
- Cost function v2 - Power 1 to Cost function v2 - Power 6: The power flexibility interval is split in sections. Power 1 corresponds to P Discharge max, Power 6 corresponds to P Charge max. The other values are intermediate and can be different from time step to time step.
- Cost function v2 - Cost P 1-2 to Cost function v2 - Cost P 5-6: The technical cost for using the flexibility (due to losses and battery aging) in the range of each power interval (Power 1 and Power 2, Power 2 and Power 3 … etc…)

The parameters relative to 'Cost function v2' will be used only if the approximation introduced in 'Cost function v1' will be considered too large.

Table 4: Flexibility forecast output, example

Resource ID	Flexibility forecast type	00:00	00:15	00:30	…	23:30	23:45
A	Power charge max	50	50	50	…	70	70
A	Power discharge max	-35	-35	-35	…	-25	-25
A	Energy max	100	100	100	…	100	100
A	Energy min	0	0	0	…	0	0
A	Cost function v1 - Cost -100% - -60%	2	2	2	…	2	2
A	Cost function v1 - Cost -60% - -20%	1	1	1	…	1	1
A	Cost function v1 - Cost -20% - 20%	0,7	0,7	0,7	…	0,7	0,7
A	Cost function v1 - Cost 20% - 60%	2	2	2	…	2	2
A	Cost function v1 - Cost 60% - 100%	5	5	5	…	5	5
A	Cost function v2 - Power 1	-35	-35	-35	…	-35	-35
A	Cost function v2 - Power 2	-18	-18	-18	…	-18	-18
A	Cost function v2 - Power 3	-1	-1	-1	…	-1	-1
A	Cost function v2 - Power 4	16	16	16	…	16	16
A	Cost function v2 - Power 5	33	33	33	…	33	33
A	Cost function v2 - Power 6	50	50	50	…	50	50
A	Cost function v2 - Cost P 1-2	5	5	5	…	5	5
A	Cost function v2 - Cost P 2-3	2	2	2	…	2	2
A	Cost function v2 - Cost P 3-4	0,5	0,5	0,5	…	0,5	0,5
A	Cost function v2 - Cost P 4-5	3	3	3	…	3	3
A	Cost function v2 - Cost P 5-6	7	7	7	…	7	7

Optimal allocation

This action is performed by the EMSP both in day ahead and in intraday, where it corresponds to the steps 10-12 and 11-13 respectively.

In this step it is performed the optimal allocation of flexibility (the actual solution of the optimisation problem) taking into account the wholesale electricity price and the variable grid access tariff. An example of the output of this tool is presented in Table 5.

Table 5: Retained flexibility at the portfolio level

Resource ID	Type	00:00	00:15	00:30	…	23:30	23:45
A	Retained flexibility	0	0	20	…	0	0
A	Power charge max	50	0	50	…	0	0
A	Power discharge max	-35	0	0	…	0	0

Disaggregation

This action is performed by the HA both in day ahead and in intraday, where it corresponds to the step 13 and 14 respectively. Here the retained flexibility for a portfolio is disaggregated in order to be sent to each individual flexibility source. The tool takes into account the cost, the capacity and the availability of each device in order to allocate optimally the flexibility associated to the portfolio. An example of the output of this step is shown in Table 6.

Table 6: Disaggegated plans, example

Resource ID	Type	00:00	00:15	00:30	…	23:30	23:45
A_1	Power [kW]	0	0	10	…	0	0
A_2	Power [kW]	0	0	5	…	0	0
A_3	Power [kW]	0	0	5	…	0	0

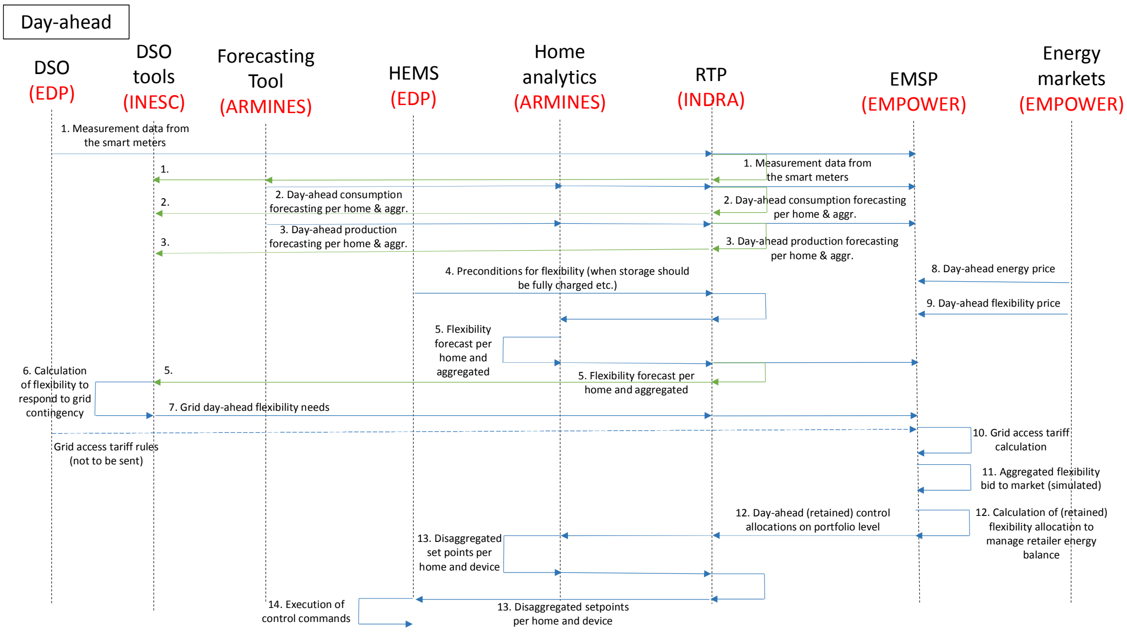

Figure 2: Evora's UC2, day ahead sequence diagram

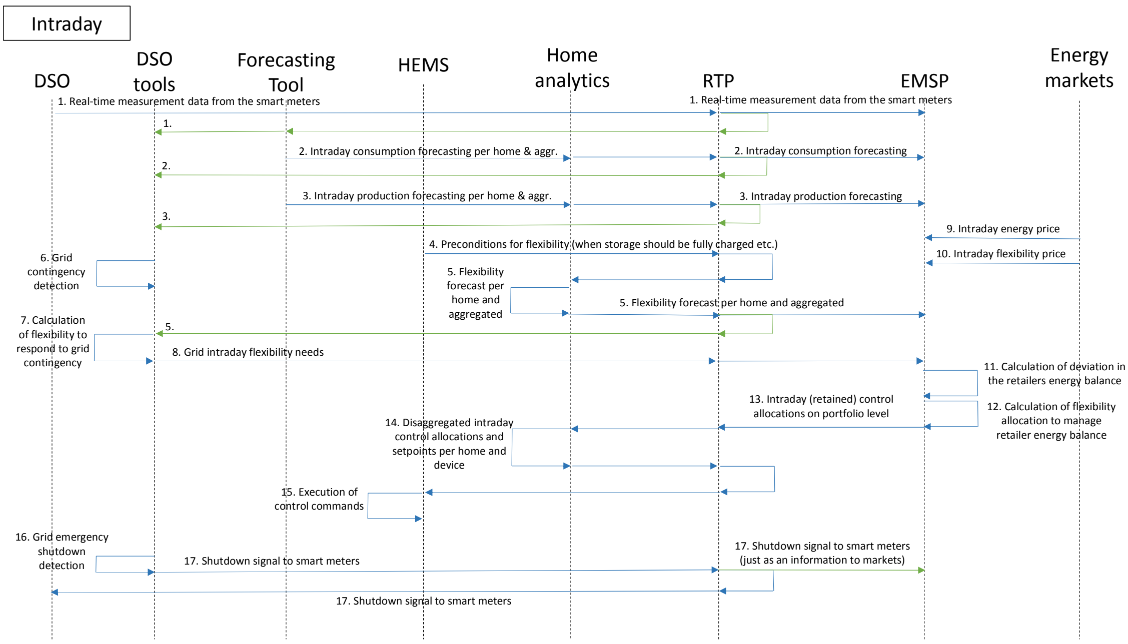

Figure 3: Evora's UC2, intraday sequence diagram

5.1.2 Low level KPI

A low level KPI is defined for the storage aggregation developed for UC2. This KPI, directly linked with KPI 4 “Increased flexibility from energy players” is KPI 4.1 “reduction of flexibility cost”. The idea behind this KPI is that due to the use of forecast, optimal allocation at the market level and optimal dispatch it is possible to reduce the average cost of the flexibility provided, in relation to the base case in which the flexibility resources would be used without aggregation.

BASIC KPI INFORMATION			
KPI Name	Reduced cost of flexibility	**KPI ID**	#4.1
Demo Site	Évora, PT x	Nuremberg, DE ☐	Nottingham, UK ☐
Main Objective & Domain	This KPI will demonstrate that the aggregation of flexibility sources will reduce the average cost of the flexibility provided		
KPI Description	The KPI is calculated as a percentage reduction of the cost paid for the flexibility in the SENSIBLE's UC2 scenario and the base case. Only variable costs are taken into account, since it is considered that the fixed costs relative to the installation of the devices are the same in both scenarios. The parameter C_{BAU} is calculated as the average cost per kW of flexibility provided by the installed base of controllable devices in the demonstrator. The parameter C is calculated as the average of the measured cost paid during the demonstration phase for the amount of flexibility effectively used.		
KPI Formula	$\Delta C = (C_{SENSIBLE}-C_{BAU})/C_{BAU}\cdot 100$		
Unit of Measurement	Both $C_{SENSIBLE}$ and C_{BAU} are expressed in €/kW.		
Explanation of the Link with High-level KPI	The high level KPI 4 accounts only for the amount of flexibility provided. Although important this value is strictly linked with the installed flexibility capacity, which can be increased simply with investments in infrastructures. The low level KPI 4.1 shed light on another aspect of the problem, by quantifying the impact on the cost of flexibility of the business chain developed.		

5.2 Nottingham

The Nottingham Demonstrator is linked to three use cases. Here the use of energy storage will allow the management of energy throughout the community and with that provide the opportunity to manage energy according to technical or economical constraints, dwelling or community priority and also according to energy market influence.

Storage aggregation realised by the eBroker will be used mainly in "Use case 7: microgrid energy market". In this use case the energy management system will manage the microgrid power and energy according to the internal energy market. The system will always look for the best economical solution while assuring that the technical requirements are met.

The eBrokers will use the data communicated about the various systems in the community and will decide among themselves on the energy transfers to be performed by the devices under their control. The decision by the eBroker will consider PV production, energy storage state-of-charge, community conditions and the economic (energy buy and sell price) benefit. The outcome of the eBroker decision will see the energy being moved, stored, bought or sold, depending on the various technical and economic constraints.

As such, the eBrokers will perform the energy management controls scheme for this use case.

5.2.1 Low level KPI

Previous objectives are further detailed on the two low level KPI defined for the eBroker in Table 7 and Table 8, taking as reference the high level KPI presented in [1]. These KPIs will be quantified by means of the KPI formula during the demonstration phase and comparing it with the BAU (Business as usual) scenario. BAU is still on development, once the final users involved in the demo are specified, the BAU will be analysed and defined.

The two KPIs are specific applications to the eBroker of the High Level KPI 1 and KPI 6 described in [1].

<table>
<tr><th colspan="6">BASIC KPI INFORMATION</th></tr>
<tr><td>KPI Name</td><td colspan="3">Photovoltaic power panels/plants integration</td><td>KPI ID</td><td>#1.1</td></tr>
<tr><td>Demo Site</td><td>Évora, PT
☐</td><td>Nuremberg, DE
☐</td><td colspan="3">Nottingham, UK
×</td></tr>
<tr><td>Main Objective & Domain</td><td colspan="5">This KPI is aimed to demonstrate that the management tool is able to maintain reliability and security grid levels with larger amount of PV generators than conventional solutions.</td></tr>
<tr><td>KPI Description</td><td colspan="5">The integration of storage devices in the LV and MV networks can potentially be increased maintaining its reliability and security levels due to local and global control. This way of control of power flow from the grid reduce electrical line stress, as well as, the drop voltage along it.
The KPI result is the percentage of additional PV power that can be connected to the grid</td></tr>
<tr><td>KPI Formula</td><td colspan="5">$EHC_{\%} = \frac{HC_{e-Broker} - HC_{BAU}}{HC_{BAU}} \cdot 100\%$</td></tr>
<tr><td>Unit of Measurement</td><td colspan="5">$EHC_{\%}$: enhanced hosting capacity of PV when e-Broker solutions are applied with respect to BAU scenario.
$HC_{e\text{-}Broker}$: additional hosting capacity of PV when e-Broker solutions are applied with respect to currently connected generation (kW or MW).
HC_{BAU}: additional hosting capacity of PV in BAU scenario applied with respect to currently connected generation (kW or MW).</td></tr>
<tr><td>Explanation of the Link with High-level KPI</td><td colspan="5">This Low-level KPI is directly linked with High-level KPI 1: Increased RES and DER hosting capacity. It determines the amount of hosting capacity of PV that the solution e-Broker can coordinate against which the conventional solution does.</td></tr>
</table>

Table 7: Low level KPI #1, eBroker

<table>
<tr><th colspan="5">BASIC KPI INFORMATION</th></tr>
<tr><td>KPI Name</td><td colspan="2">Increased percentage of self-consumption</td><td>KPI ID</td><td>#6.2</td></tr>
<tr><td>Demo Site</td><td>Évora, PT
☐</td><td>Nuremberg, DE
☐</td><td colspan="2">Nottingham, UK
×</td></tr>
<tr><td>Main Objective & Domain</td><td colspan="4">The objective is to determinate the increased level of self-consumption that one user can get adopting e-Broker solution.</td></tr>
<tr><td>KPI Description</td><td colspan="4">This KPI is focused on the amount of energy generated by one user and how the energy management system deals with it. The algorithm programmed to manage the power is the key element to make an efficient and profitable use of PV panels and storage systems.
The KPI compares the amount of energy consumed by loads with the energy consumed from the grid during a period of time.</td></tr>
<tr><td>KPI Formula</td><td colspan="4">$$SC_{\%} = \left(1 - \frac{E_{net}}{C_{total}}\right) \cdot 100\%$$</td></tr>
<tr><td>Unit of Measurement</td><td colspan="4">$SC_{\%}$: percentage of self-consumption. (%).
E_{net}: energy consumed from the grid during a period of time when e-Broker solutions are applied (kWh or MWh).
C_{total}: energy consumed by loads during a period of time (kWh or MWh).</td></tr>
<tr><td>Explanation of the Link with High-level KPI</td><td colspan="4">KPI6.1 is based on the High-level KPI 6 that has the same name: “Increased percentage of self-consumption “.</td></tr>
</table>

Table 8: Low level KPI #2, eBroker