D1.2

Definition of use cases and specification of technical, market and social requirements for electric flexibility and grid resilience

DATE : 28.02.2020

AUTHORS:	KRZYSZTOF PIOTROWSKI	IHP
	MOHSEN BANAEI	DTU
	IGNACIO BENÍTEZ	AMP
	MARÍA DEL CARMEN BOCANEGRA	CEM
	ZBIGNIEW BOHDANOWICZ	IPI
	RAZGAR EBRAHIMY	DTU
	JAIME CHEN GALLARDO	SOF
	DANIEL GARRIDO MÁRQUEZ	UMA
	IGNACIO GUERRERO	AMP
	LIUDAS KARALIUS	AMP
	JUAN JACOBO PERALTA ESCALANTE	CEM
	PILAR RODRÍGUEZ	UMA
	CHRISTOPHE SAUDEMONT	JUN
	GEORGIOS STRAVOPODIS	EMT
	MARA VAN WELIE	ESC

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grand agreement N°864283

Technical References

Project Acronym	ebalance-plus
Project Title	Energy balancing and resilience solutions to unlock the flexibility and increase market options for distribution grid
Project Coordinator	CEMOSA
Project Duration	42 months

Deliverable No.	D1.2
Dissemination level [1]	PU
Work Package	WP1
Tasks	T1.2, T1.3, T1.4
Lead beneficiary	IHP
Contributing beneficiary(ies)	CEM, EMT, DTU, ESC, SOF, UMA, IPI, AMP, REE, TPS, MGC, UNC, JUN, ENF
Due date of deliverable	31.01.2021
Actual submission date	

[1] PU = Public
PP = Restricted to other programme participants (including the Commission Services)
RE = Restricted to a group specified by the consortium (including the Commission Services)
CO = Confidential, only for members of the consortium (including the Commission Services)

Document history

V	Date	Beneficiary	Author
1	28.02.2021	IHP	Krzysztof Piotrowski

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°864283

Summary

1.1 Summary of Deliverable

This deliverable presents the use cases chosen for the ebalance-plus project. They define the scenarios of interest the project shall address and demonstrate. For each use case there are defined objectives and involved actors that need to interact in a specific way, in order to achieve the goals of these objectives. We identified eleven technical and four business cases. The description of the use cases is followed by an analysis of requirements – only if these are satisfied there is a condition for successful implementation of the use cases.

Section 1 defines the context of the use cases, both technical and conceptual. It describes the ebalance-plus platform that is the base for our implementation. Further, it also explains the methodology we followed while defining the use cases, the structure used to describe each use case and that they are described following the SGAM model.

Section 2 describes the business cases/scenarios. First the stakeholders are listed and then the business cases that involve these are presented.

Section 3 presents the first two identified use cases. These belong to the architecture class. The UC.01 covers the data exchange platform, while the UC.02 defines the interactions of the main platform with external platforms and solutions for interoperability purposes. UC.02 focuses on BEMS solutions, but the approach is not limited to that.

Section 4 presents five more use cases. These belong to the resilience and reliability class. The use cases in this class address voltage quality (UC.03), fault detection, isolation and recovery (UC.04), Volt-VAr optimization (UC.05), intentional islanding after cascading failures (UC.06) and LV transformer monitoring (UC.07).

Section 5 presents the last four use cases. These belong to the energy flexibility class and include virtual power plant use cases, based on district solutions (UC.08) and on building solutions (UC.09), as well as use cases on CO2/Price based demand response optimizations (UC.10) and on acillary services and market mechanisms based on residential power-to-heat control (UC.11).

Based on the analysis of the use cases several requirements were identified. The technical ones are presented in the Section 6 and the social ones in Section 7. The latter were also defined based on our social study. The results of a social survey carried out in the 4 countries where ebalance-plus interventions are planned (France, Denmark, Spain and Italy) gave some general indications on how to design technological solutions from the point of view of electricity consumers.

Section 8 concludes the document.

Disclaimer

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°864283

Table of Contents

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°864283

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°864283

Table of tables

Table of figures

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°864283

Abbreviations

AMI	Advanced Metering Infrastructure
BRP	Balance Responsible Party
cVPP	Commercial Virtual Power Plant
DER	Distributed Energy Resource
DERMS	Distributed Energy Resources Management System
DERMU	Distributed Energy Resources Management Unit
DR	Demand Response
DSO	Distribution System Operator
EC	European Commission
EMS	Energy Management System
ESCO	Energy Service Company
EU	European Union
EV	Electric Vehicle
IoT	Internet of Things
LVGMU	Low Voltage Grid Management Unit
MU	Management Unit
MVGMU	Medium Voltage Grid Management Unit
OMS	Outage Management System
SGAM	Smart Grid Architecture Model
TLGMU	Top Level Grid Management Unit
ToU	Time of Use
TSO	Transmission System Operator
USEF	Universal Smart Energy Framework
VPP	Virtual Power Plant
V2G	Vehicle to Grid

1 Introduction

1.1 The ebalance-plus ecosystem

The solutions to be developed within the ebalance-plus project are built around the major component of the project – the ebalance-plus energy management platform. The hierarchical approach followed in the project allows to involve these different smart-grid innovations (smart production, storage and consumption technologies, etc.) and to realize distributed and scalable energy control. The approach exploits the actual topology of the energy grid and makes use of computational elements (management units - MUs) that are located on the joints of the grid topology branches, to be closer to the monitored and controlled assets, enabling the decision-making process to be local (see Figure 1). These MUs are located on different levels of the grid and manage all the lower-level management units, but also additional elements, like sensors and actuators, located in their branch (see Figure 2). Similar to a fractal, depending on the level of the considered MU, the monitored parameters and control tasks are the same, but they differ in the scale. This allows developing generic algorithms that can be deployed on the MUs in the smart grid in order to realize many different tasks. The project aim is aligned with a variety of EU strategies and roadmaps promoted in the last years, like reducing CO2 emissions, increasing the energy efficiency at different levels and engaging the customers in this kind of innovative solutions, beingthe main goal of the project to increase the flexibility and resilience of electric grids, or power system.

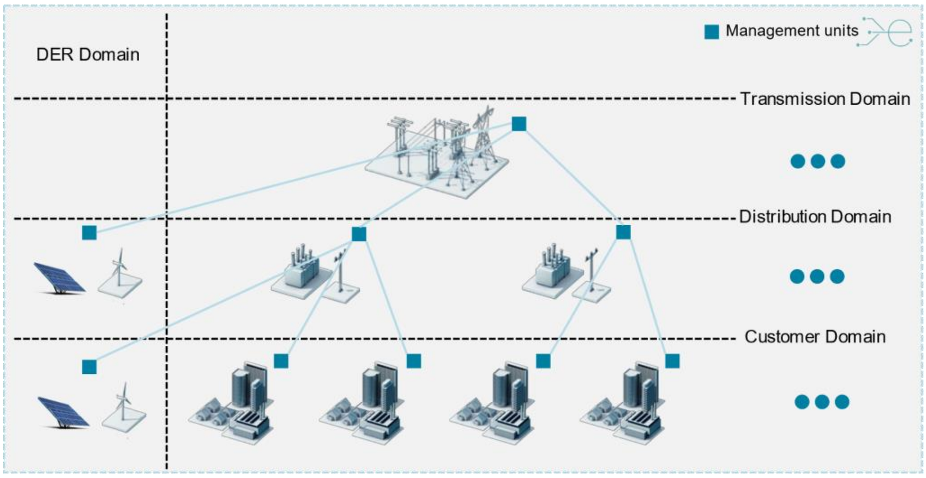


Figure 1 Fractal-like hierarchical ebalance-plus architecture

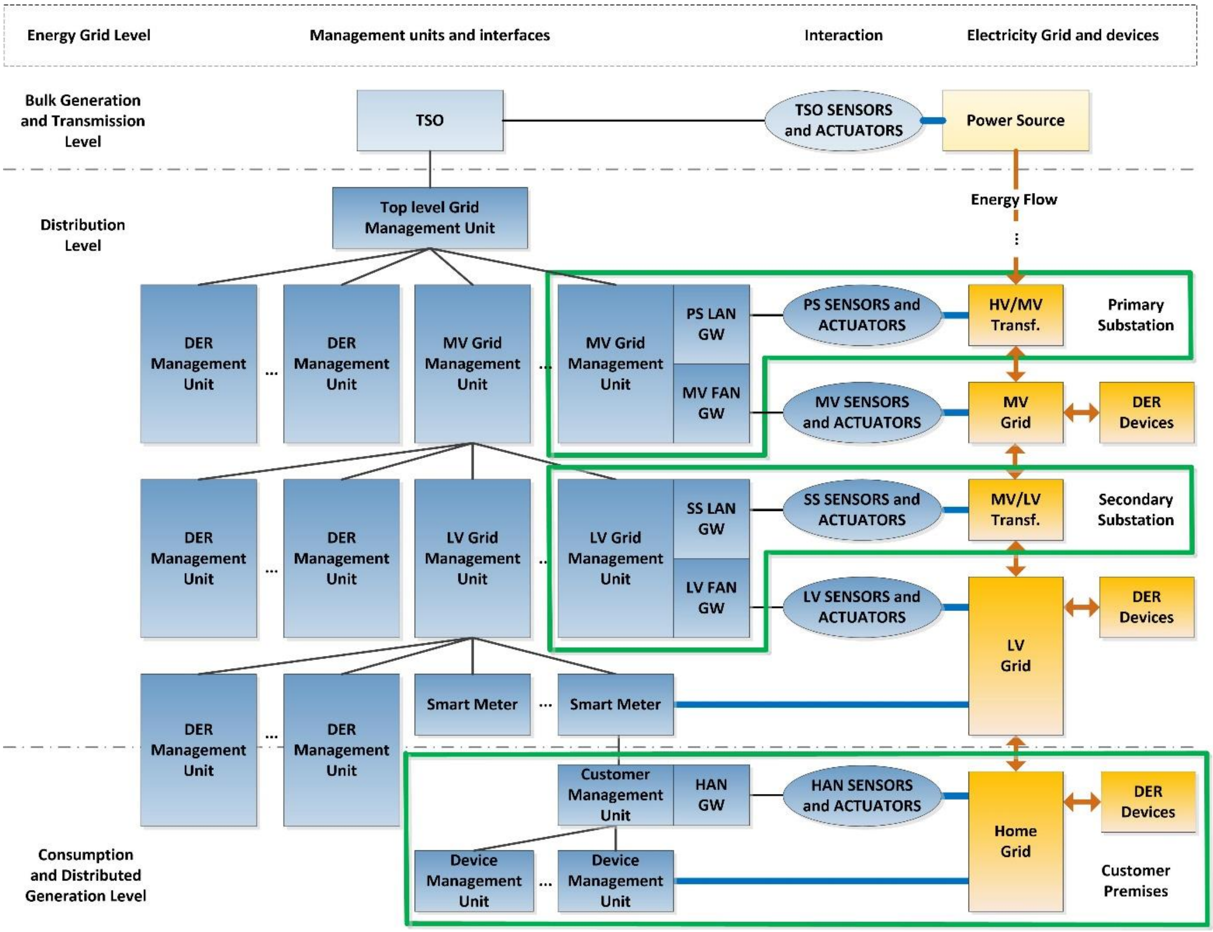


Figure 2 Example of naming and distribution of management units within the energy grid

1.2 Business relevance

The European electricity markets are changing as part of the energy transition to accommodate Europe's goals to reduce CO_2 emissions and reach its climate targets. The Clean Energy Package [1] plays a key role in this transition and steers towards the realisation of a European energy market in which demand side flexibility plays an important role. It has become necessary to ensure the balance of distribution grids that have to cope with an increasing share of Distributed Energy Resources (DERs), Electrical Vehicles (EVs) and storage connected. The ebalance-plus platform facilitates these changes and leads to new business opportunities based on demand side flexibility mechanisms at distribution level (with the possibility to scale-up the platform to the TSO level). The platform can support business cases such as commercial Virtual Power Plant (cVPP), Distributed energy resources management system (DERMS), energy/flexibility management platform, or a combination of the three. In the different cases, value is created for Prosumers (flexibility services, access to energy market); Aggregators (business opportunity trading flexibility in the energy market); Energy retailers (use the platform to fulfil an aggregator role and provide flexibility services to their customers); DER managers (optimising schedules of assets); Building facility managers (integrate BEMS in ebalance-platform and participating in local energy markets); ESCOs (business opportunity optimising behind-the-meter flexibility assets of prosumers). Additionally, ebalance-plus solutions create value for DSOs contributing to reach the required reliability standards that, as is well known, are extremely high and depend on the levels of adequacy, safety and resilience they can achieve. Lastly, as the platform allows integrating multiple flexible technologies such as smart batteries, V2G, etc., it provides an opportunity for technology providers too.

There are still large differences regarding the allowance of demand response and independent aggregators in electricity markets in different EU Member States. Currently, the TSO-run balancing markets are the main electricity markets that allow for the participation of aggregated demand side flexibility. Most EU wholesale markets are not (yet) open for demand side flexibility, and also local or regional flexibility market mechanisms do not exist yet. If wholesale markets and local flexibility mechanisms would be available for demand side flexibility trading, this would enlarge the set of possible ebalance-plus-based business cases. However, at this point of the project the main market to trade demand side flexibility is the balancing market. However, with the implementation of the Clean Energy Package in the Member States in the coming years, more markets might become available. As a reference to explain the preliminary business scenarios of the project, we will adopt the (terminology of) the Universal Smart Energy Framework [2], which is a market model that proposes roles, tools, and rules for flexibility trading. USEF`s market model fits *on top of* most European electricity markets.

1.3 Use cases methodology

This section explains the methodology followed while defining the use cases for the ebalance-plus project. It presents the existing approaches and how the relevant scenarios have been described in a way that the description is compatible with other approaches.

1.3.1 Existing methodologies and standards to create smart-grid use cases

The definition of use cases is the cornerstone of smart grid projects to specify requirements and design the necessary tests to verify the suitability, interoperability and performance of new technologies and solutions in specific contexts. The use case concept was born in the Intelligrid project [3] by the Electric Power Research Institute (USA), evolving with several modifications by the CEN/CENELEC/ETSI to the current use case standard template IEC 62559-2:2015. This template is structured as shown in Figure 3, providing a structured way to identify requirements.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°864283

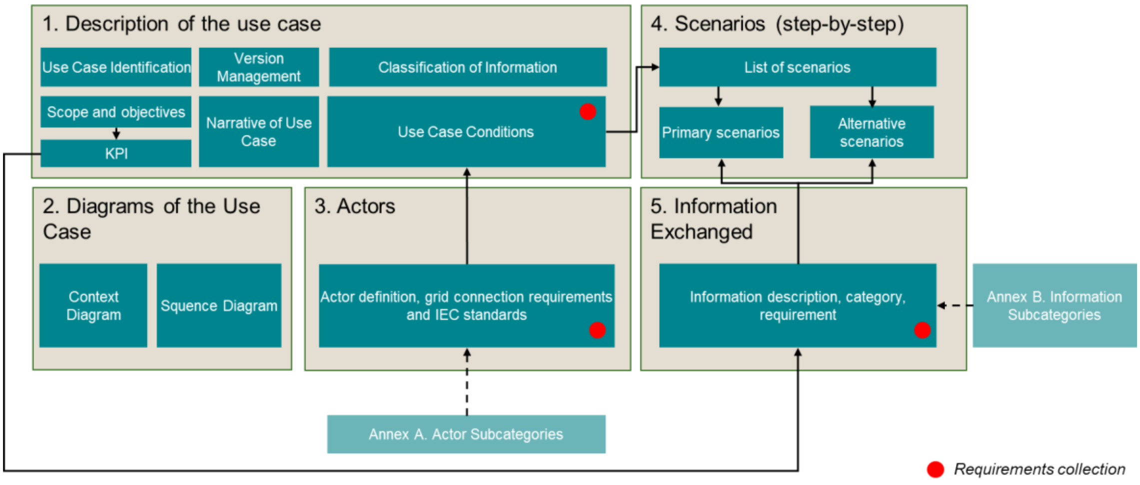


Figure 3 Use Case Structure according to the IEC 62259 template

However, the smart grid research community may generate a broad variety of different use cases that can be interlinked and thus some kind of coordination and categorization was required. For this reason, in 2014 as a result of a Smart Grid Coordination Group, the Smart Grid Architecture Model (SGAM) appeared and became the first reference model to analyse and visualise Smart Grid use cases in a technology neutral manner. Named as *Smart Grid Plane* a 3D representation (see Figure 4) of the entire energy conversion chain was created and partitioned into 5 domains (generation, transmission, distribution, DER and customer premises), 6 zones (process, field, station, operation, enterprise and market) and 5 interoperability layers (component, communication, information, function and business).

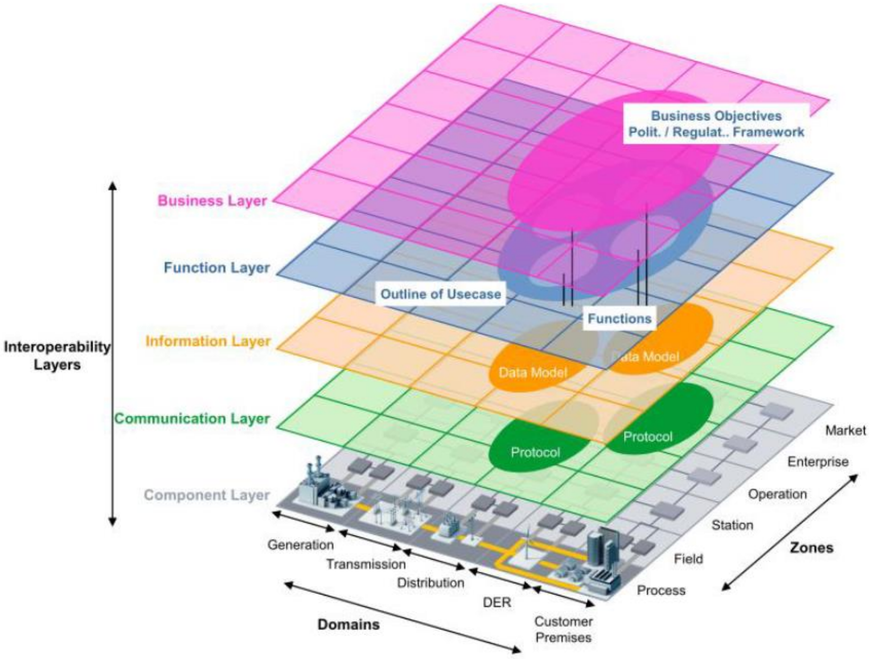


Figure 4 Smart Grid Plane proposed by CEN-CENELEC-ETSI Smart Grid Coordination Group 2014 [4]

In 2019, this methodology was refined by IEC 62913-1 and represented by Figure 5.

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement N°864283

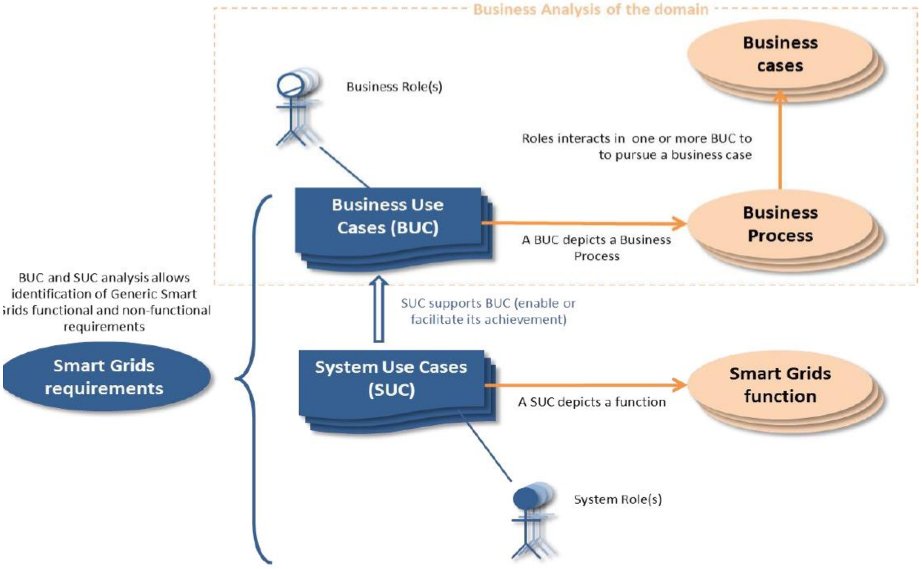


Figure 5 Methodology to propose business and system use cases IEC 62913-1

This methodology defines 2 types of Use Cases: Business Use Cases (BUC) and the system Use Cases (SUC). Whilst BUC are only using Business Roles (Person, or Organisation), SUC can use System Roles (information systems, devices). The following picture describes where BUC and SUC stands on the SGAM layers:

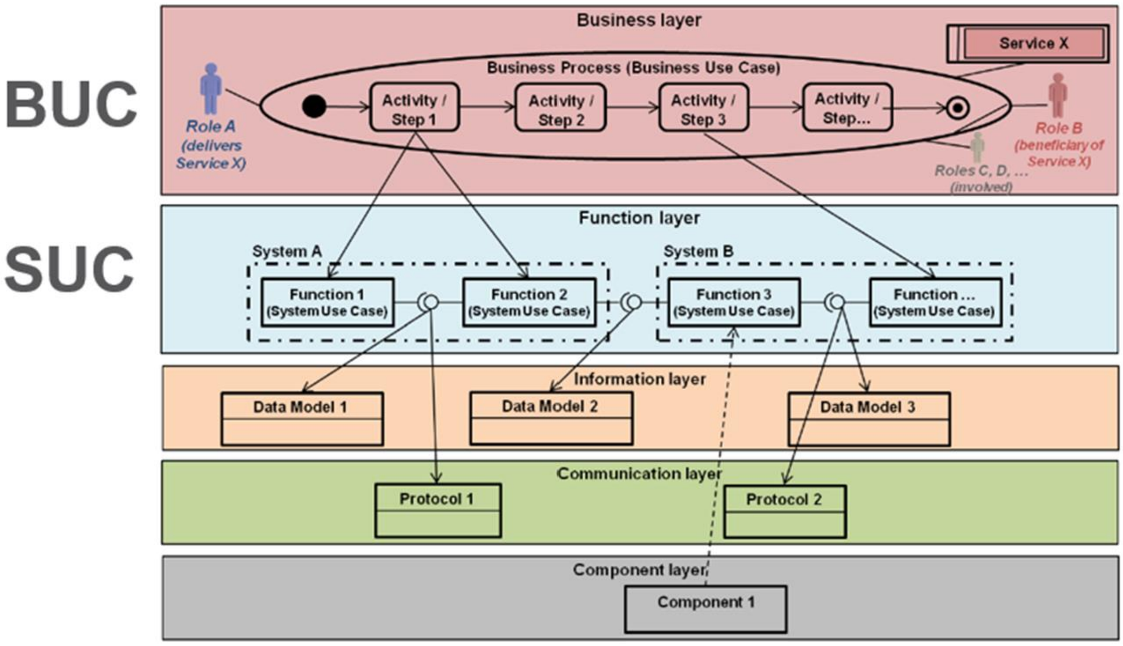


Figure 6 Methodology to propose business and system use cases IEC 62913-1: Procedure

Therefore, the definition sequence for SUC must start from a preliminary definition of the BUC and its context (services and activities). However, given that the description of use cases in ebalance-plus is before than business model design, the consortium has carried out an alternative sequence of this methodology to create the SUC and combining the SGAM within the IEC 62559 template.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°864283

1.3.2 Use case methodology in ebalance-plus

The project, since the very beginning of conceptual design, proposed a set of technologies and approaches that can improve different aspects of grid flexibility, reliability and resilience. These technologies can provide different functionalities depending on the system objectives and the environments where they are deployed. On the other hand, the project objectives allowed defining a set of preliminary use cases based on the demo site ambition and characteristics that were used as baseline. For this reason, the natural thinking process was based on the following approach:

1) Functionalities definition: potential functionalities (mainly supported by technology developers/providers) based on the preliminary use cases and demo site conditions.
2) Identification of users (business layer), devices (component and communication layer) and data (e.g. KPI) necessary in the different project environments.
3) Check that all the preliminary use cases and project objectives are covered by system functionalities. Otherwise, new functionalities must be defined.
4) Clustering system functionalities into SUC.
5) Define BUC based on available SUC and market research feedback (state of the art (SoA)). BUC diagrams are defined using SGAM.
6) Validation: every BUC must be linked at least with one SUC. Otherwise, restate proposed BUC or SUC.
7) Whole description using SGAM and IEC 62559 template: use case diagrams are designed based on the Smart Grid Pane (Domains-Zones).

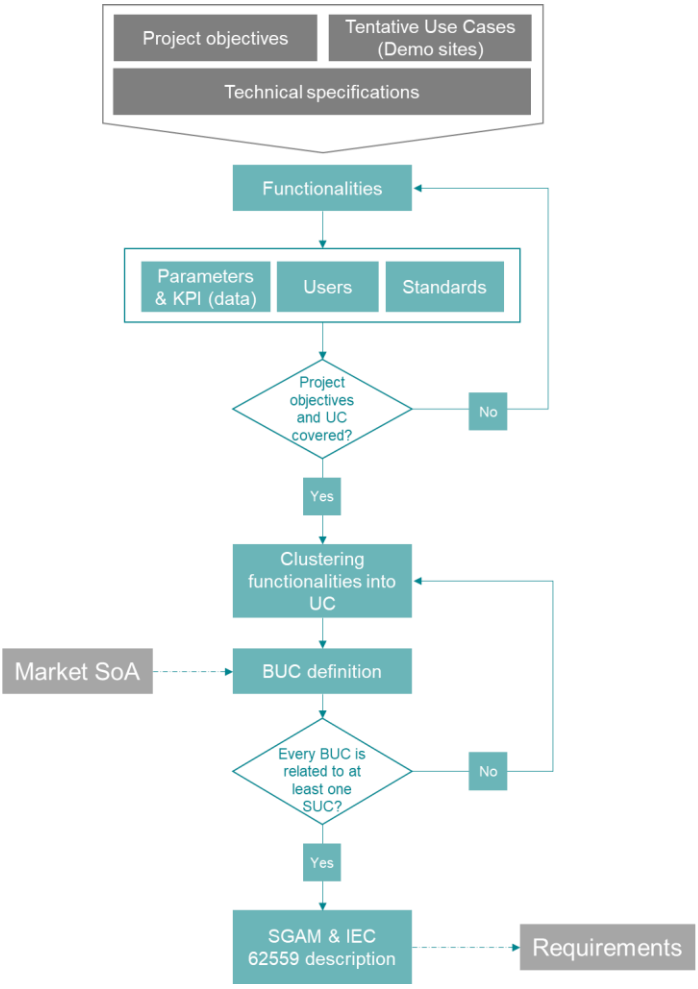


Figure 7 Use Case definition methodology in ebalance-plus

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°864283

Using this methodology, the ebalance-plus consortium has defined **11 use cases**, clustered in three groups, and **4 business cases,** which are explained in the following paragraphs and detailed in the following sections.

ICT architecture: use cases related to communication infrastructure, interoperability with existing systems and energy management systems (EMS), privacy and security, distributed control and management units.

- **UC.01** ebalance-plus hierarchical energy communication platform
- **UC.02** Interoperability solutions to integrate existing BEMS within demand response markets

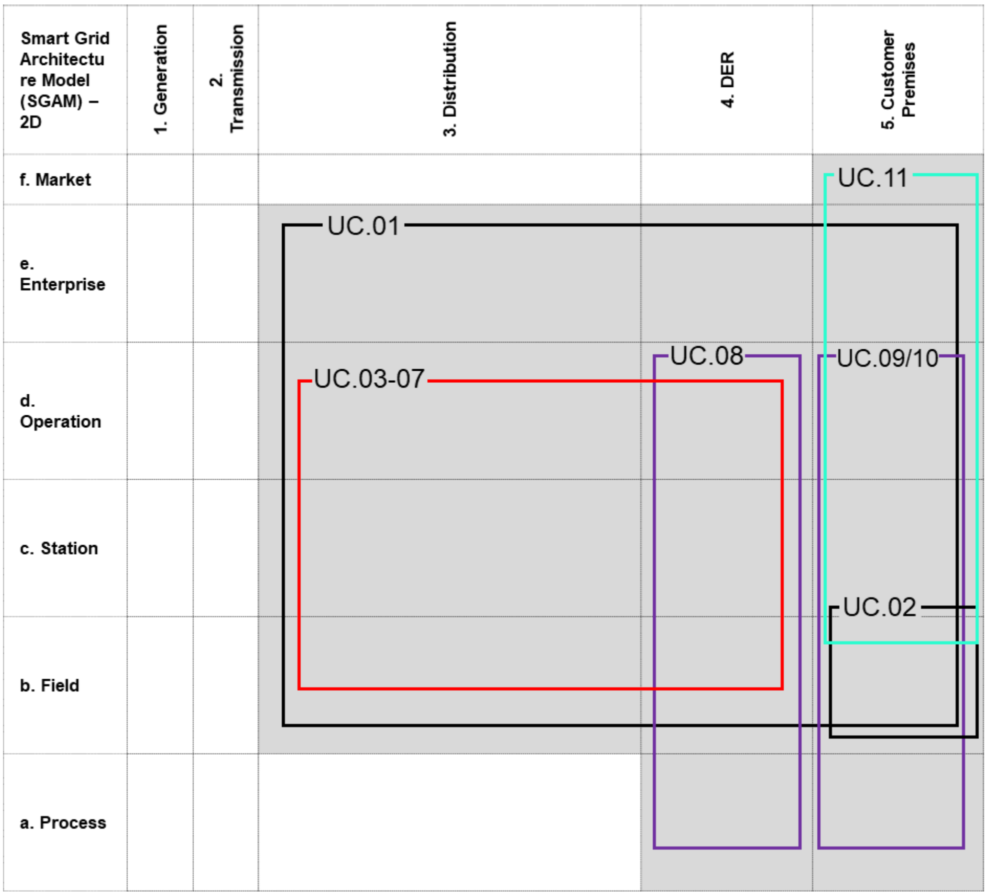
Grid reliability and resilience: all the mechanisms, technologies and algorithms to increase the grid observability and restore the power system quickly against unexpected events (resilience).

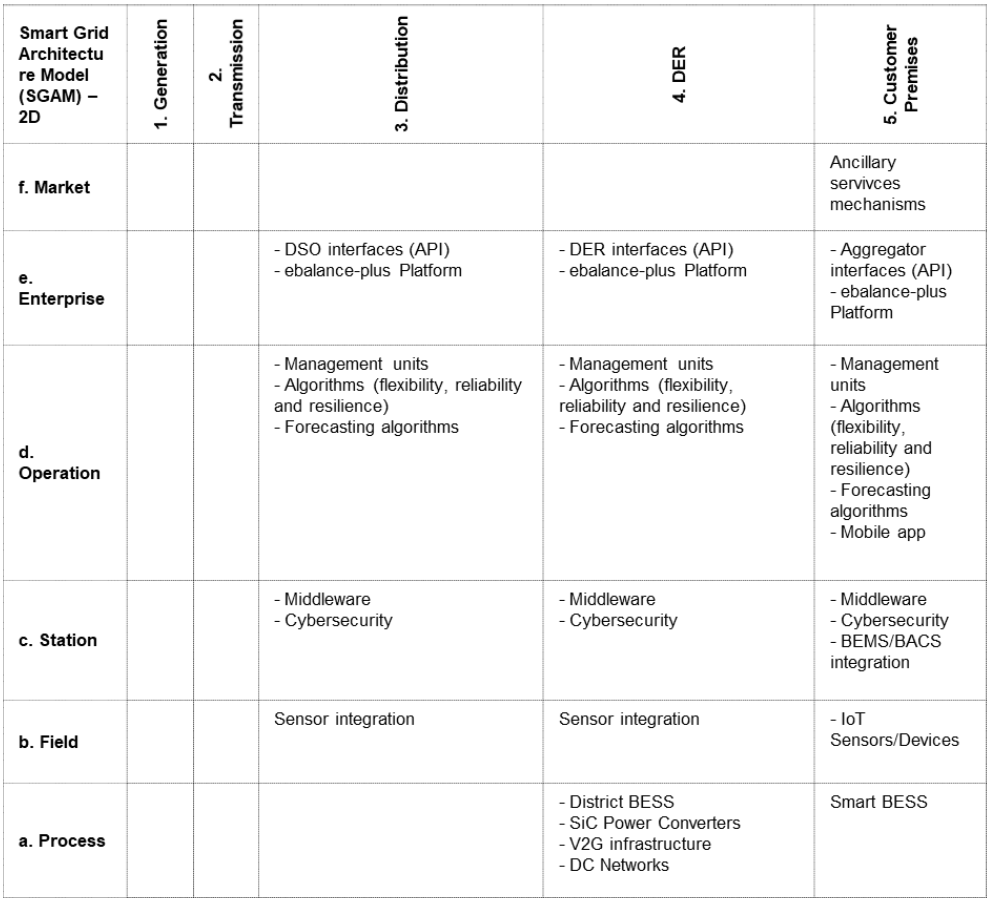
- **UC.03** Application of IEN 50160 for voltage quality
- **UC.04** Fault Detection, Isolation & Restoration (FDIR) services
- **UC.05** Volt/VAr optimization with increasing RES generation
- **UC.06** Intentional islanding after cascading failures
- **UC.07** Secondary substation transformer monitoring (health and voltage quality)

Flexibility mechanisms: use case related to unlock the energy flexibility at customer premises, district or neighbourhood level (DER facilities), ancillary services (frequency and non-frequency), energy demand optimization and market mechanisms.

- **UC.08** Flexibility measures I: Virtual Power Plant (VPP) services based on district solutions (variable PV generation, storage and V2G)
- **UC.09** Flexibility measures II: Virtual Power Plant (VPP) services based on building solutions (IoT devices, PV and storage)
- **UC.10** Flexibility measures III: Price/CO2 based optimization (demand response)
- **UC.11** Ancillary services and market mechanisms based on residential power-to-heat-control (Denmark)

As mentioned above, the use cases have been mapped in the SGAM according to current standards. In the Figure 8, use cases scope are shown, together with the whole ebalance-plus technologies and solutions by domain-zone.





Smart Grid Architecture Model (SGAM) – 2D	1. Generation	2. Transmission	3. Distribution	4. DER	5. Customer Premises
f. Market					Ancillary servivces mechanisms
e. Enterprise			- DSO interfaces (API) - ebalance-plus Platform	- DER interfaces (API) - ebalance-plus Platform	- Aggregator interfaces (API) - ebalance-plus Platform
d. Operation			- Management units - Algorithms (flexibility, reliability and resilience) - Forecasting algorithms	- Management units - Algorithms (flexibility, reliability and resilience) - Forecasting algorithms	- Management units - Algorithms (flexibility, reliability and resilience) - Forecasting algorithms - Mobile app
c. Station			- Middleware - Cybersecurity	- Middleware - Cybersecurity	- Middleware - Cybersecurity - BEMS/BACS integration
b. Field			Sensor integration	Sensor integration	- IoT Sensors/Devices
a. Process				- District BESS - SiC Power Converters - V2G infrastructure - DC Networks	Smart BESS

Figure 8 Mapping of ebalance-plus use cases and technologies/solutions in the SGAM 2D Plane

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°864283

2 Supported business cases/scenarios

This section describes the supported business cases in detail. It describes the involved stakeholders, the data exchanged among them and the business/market meaning. The descriptions presented must be considered tentative. The ebalance-plus project started in February 2020 and one of the results is the configuration of business models to exploit the project results in different environments and European markets. Hence, the following definitions are provided for a better understanding of the use cases' objectives described below.

2.1 Stakeholders

This section describes the involved stakeholders, their interests (economic, social, etc.).

Stakeholder	Value ebalance-plus
Prosumers: Households	Household prosumers can profit from services that can be facilitated by the ebalance-plus platform. The platform can help to optimize the use of the flexibility hidden in the prosumer's household's assets. The ebalance-plus platform, for example run by aggregators or ESCOs, can automatically and remotely control some of these assets. The prosumer's flexibility can then be used by grid operators or other players in energy markets to balance the grid. Such flexibility services provided through the ebalance-plus platform can help the prosumer to reduce their energy expenses and gives them an opportunity to actively contribute to the energy transition. Moreover, ebalance-plus provides households insights in their own energy usage and supply.
Prosumers: Small-scale (tertiary) industry **(e.g. universities, holiday parks, small industrial sites, airports, commercial buildings)**	Small-scale industry prosumers can profit from the services that can be facilitated by the ebalance-plus platform. Similar to household prosumers, the platform can optimize the use of the flexibility that is hidden in the prosumer's building/district assets. Additionally, ebalance-plus helps small-scale industry to gain insights in their own energy usage and supply. Thereby saving energy costs and reducing CO_2 emissions. Moreover, the small-scale industry could obtain economic benefit through the ebalance-plus platform offering flexibility services.
Building owners and facility managers	Facility managers that integrate their BEMS in the ebalance-plus platform profit from further optimisation of the efficient use of their building assets (e.g. IoT devices PV, storage). The ebalance-plus platform provides precise predictions on weather, energy use, and costs. Moreover, the platform enables interaction with energy aggregators and thereby unlocks the possibility to participate in local energy markets. All-in-all, this leads to saving energy costs and reducing CO_2 emissions.
DER managers at district level (type of ESCO)	The ebalance-plus platform can help DER managers to enhance the exploitation of their facilities, optimising schedules of assets (e.g. storage, V2G, PV generation) through precise predictions on distributed generation, energy use, and energy costs.
Aggregators	Aggregators may use the ebalance-plus platform as a Virtual Power Plant (VPP), which provides a business opportunity to trade energy flexibility from prosumers with market players. The ebalance-plus platform can help aggregators to participate with fitting aggregated loads to flex products on the energy market.
ESCO	ESCOs may use the ebalance-plus platform to provide services to prosumers / consumers. For example, optimising the scheduling of

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°864283

	behind-the-meter flexibility assets of prosumers based on market prices and precise forecasts from data providers, thereby reducing energy bills for their customers.
System operator: DSO / TSO	System operators may take advantage of the ebalance-plus platform as a DERMS for local services (e.g., congestion management) as well as ancillary services (frequency and voltage control). This leads to increased resilience and reliability of the grid as well as minimisation of RES curtailment. This might lead to reduced costs for grid maintenance and infrastructure expansion as promoted by the EC.
Energy retailers	Energy retailers might be good candidates to fulfil the role of aggregators, as they have a strong connection to the electricity market and consumers [5]. They can use the ebalance-plus platform to perform this role (see “Aggregator”). In a future scenario, energy retailer’s connection to customers might become even more intense when real-time data is being used. They might be increasingly linked to end-users to inform them about changes in prices, energy purchasing and bill optimisation. The ebalance-plus platform can be used by energy retailers to provide new demand side flexibility services to their customers.
Data providers	The ebalance-plus platform provides a business opportunity to provide data (e.g., energy predictions, weather information for DER generation) as inputs to the platform. This is a service to the operator(s) of the platform, such as aggregators, ESCOs, energy retailers or DSOs. Customers can also be data providers, they can offer their own measurement data for some profit. It is here extremely important to work along with the GDPR. Also to protect the privacy of the users / customers. In any case, since the data is the marketed product, it needs to be protected by security means.
Technology providers (e.g., Software developers, intelligent energy devices providers, power electronic suppliers, grid equipment suppliers, smart storage providers, etc.)	Business opportunity to provide smart storage, production or consumption technologies (software and/or hardware) that can be integrated in the ebalance-plus platform.
Ebalance-plus manager / / technician developer	Person or institution in charge of setting up an ebalance-plus platform instance and/or physically deploying the ebalance-plus solution (IT service provider/flexibility service provider). These stakeholders exploit the business opportunity to offer ebalance-plus as a commercial product. The developer can be part of the same institution as the ebalance-plus manager and technicians or an external stakeholder.

2.2 Business cases

The ebalance-plus`s use cases UC.03 to UC.07 support business cases related to resilience & reliability services for system operators. The distributed set-up of the ebalance-plus platform provides DSOs with sophisticated approaches to increase the grid resilience and grid reliability. More specifically, the platform provides better observability and contributes to flexible, reliable, and cost-effective management of the distribution grid, considering the scenario where energy aggregators, DER managers, and prosumers support grid operation with relevant available energy flexibility.

Furthermore, ebalance-plus` use cases UC.02 & UC.08-UC.11 support business cases related to flexibility. Generally, business cases based on demand side flexibility mechanisms can be categorised as explicit demand side flexibility or implicit demand side flexibility [6]. *Explicit demand side flexibility,* or incentive-driven demand side flexibility, is the one traded on the different energy markets (wholesale, balancing, system support and reserves markets). This is usually facilitated and managed by an aggregator that can be an independent service provider or a supplier [7], [8]. Renumeration for the prosumer can be in the form of a direct payment or savings on the electricity bill. *Implicit demand side flexibility,* or price-based demand side flexibility, is the prosumer's reaction to electricity or network price signals. When prosumers have the possibility to choose ToU or dynamic tariffs that reflect the variability on the market or network, they can adapt their behaviour (through automation or personal choices) to reduce energy expenses [7], [8]. Renumeration for the prosumer is mostly in the form of savings on the electricity bill. We take up this distinction of demand side flexibility in the description of the business cases that can be supported with the ebalance-plus platform.

At this point in the project based on the use cases, the following business cases that can be supported by the ebalance-plus platform (UC.01) have been identified:

1. Increased grid resilience and reliability for DSOs (UC.03-07)
2. Flex based on explicit demand flexibility
    a. VPP based on district solutions (UC.08)
    b. VPP based on building solutions (UC.09)
    c. Flex based on residential power-to-heat-control in local flex markets (UC.11)

3. Flex based on implicit demand flexibility (UC.10)
4. Flex based on combined energy efficiency and explicit demand-side flexibility (Integrate existing BEMS within DR markets) (UC.02)

These business cases are preliminary and are open to be adapted during the project based on knowledge gained from the demonstration pilots, market requirements analysis, innovation obstacles and market analysis.

2.2.1 Increased grid resilience and reliability for DSOs

Because of the increasing share of DER generation in distribution grids, DSOs will need more sophisticated approaches to ensure grid resilience and grid reliability, which can be improved using the distributed set-up of the ebalance-plus platform (management units and respective algorithms).

The ebalance-plus platform provides better observability and contributes to flexible, reliable and cost-effective management of the distribution grid. Specifically, it provides better information about primary and secondary substation status for operational control purposes taking into account the increasing DER penetration, avoiding grid failures. The platform will help DSOs reduce voltage violations and improve overall quality of service (Figure 9). Lastly, the platform contributes to better reactions to failures and unexpected events, minimizing the interruption time. The specific advantages derived are:

- DSOs: defer costs for grid reinforcements and increase grid resilience and reliability.
- DER owners: minimisation of RES curtailment
- Ebalance-plus technician / developer: deploying the ebalance-plus solution (hardware / service provider).

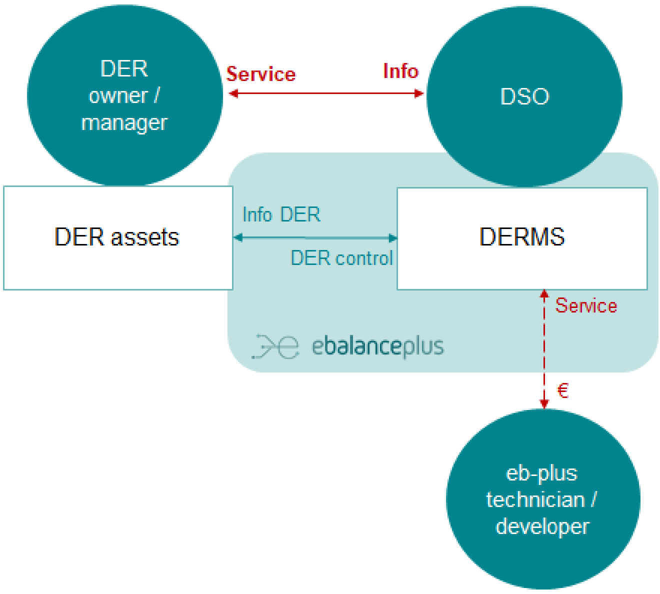


Figure 9 Business case 1: Increase resilience and reliability for DSOs

2.2.2 Flex based on explicit demand flexibility

The ebalance-plus platform can unlock the energy flexibility of building assets (e.g. IoT devices, PV, storage, HVAC) or district assets (e.g. V2G, PV, district BESS), and this flexibility can support the operations of DSO/TSO/BRPs. A set of building facilities or DER manager offers its flexibility assets to a VPP run by an aggregator, which pools the prosumer's loads to provide flexibility to TSOs (and in the future also other players e.g. BRPs and DSOs) on the market. This business case supports prosumers with small loads to enter the market (Figure 10). The benefits derived are the following:

- Prosumers: Improve the use of their flexibility assets, reduce their energy costs, and participates (indirectly) with their flexibility assets in the market.
- Building facility or DER manager: optimises the scheduling of flexibility resources (V2G, BESS and PV) and gains revenues through its contract with an aggregator.
- Aggregator (VPP operator): providing flexibility services based on precise prediction and optimal schedules of IoT devices, PV, storage or V2G.
- DSO / TSO: Using flexibility to optimise grid management (e.g. reduce power peaks and congestions).
- BRP: Optimises the balance of its portfolio, reduced costs for penalties.
- Data provider: Provides data services to ebalance-plus platform operator, in this case an aggregator.
- Ebalance-plus technician / developer: deploying the ebalance-plus solution (hardware / service provider) for the VPP, prosumer and/or facility manager.

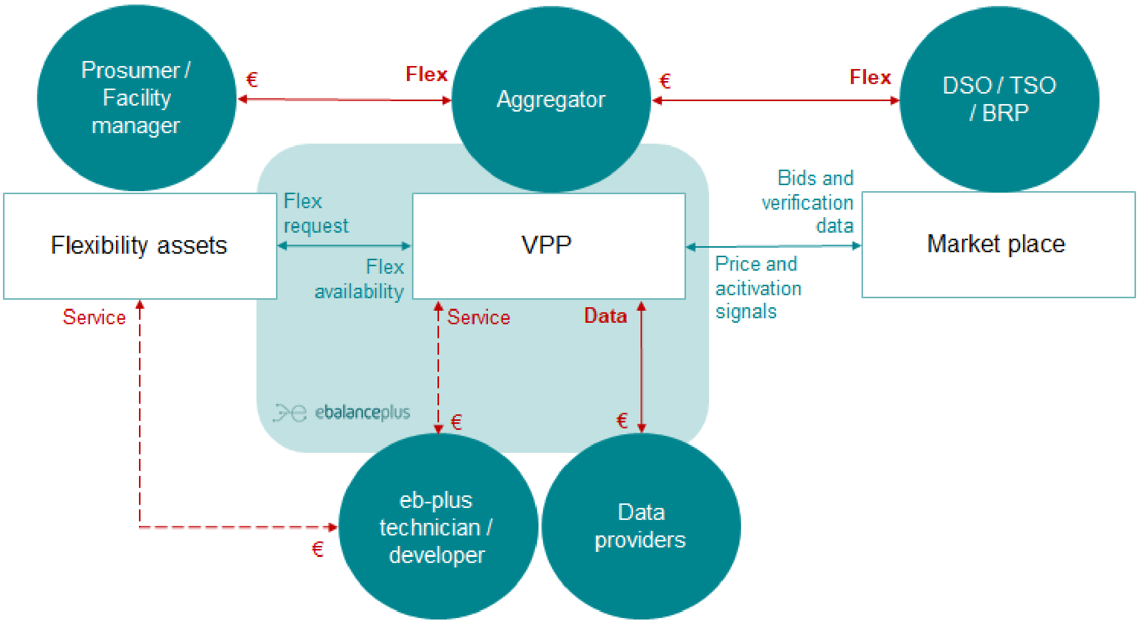


Figure 10 Business case 2a & 2b: Flex based on explicit demand flexibility: VPP based on district solutions

2.2.3 Flex based on implicit demand flexibility

The ebalance-plus platform can unlock the energy flexibility of buildings (e.g. heat pumps coupled with thermal energy storage) to optimise the costs / CO_2 emissions through implicit demand response (Figure 11). The ebalance-plus platform might be operated by an ESCO who offers its services to prosumers, alternatively the platform provides flexibility optimisation services automated and remotely directly to the prosumer. The benefits obtained are the following:

- Prosumer: Improves the use of its flexibility assets and reduces energy costs through dynamic or ToU electricity and/or network tariffs.
- Energy retailer (BRP): Offers ToU or dynamic tariffs to prosumer, thereby optimizes its portfolio and reduces costs for penalites
- Data provider: Provides data services to ebalance-plus platform (operator).
- ESCO: optimises the scheduling of behind-the-meter assets of prosumers to reduce their energy costs, based on local conditions, weather forecasts and ToU or dynamic prices.
- Ebalance-plus technician / developer: deploying the ebalance-plus solution (hardware / service provider) for the ESCO and / or prosumer.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°864283

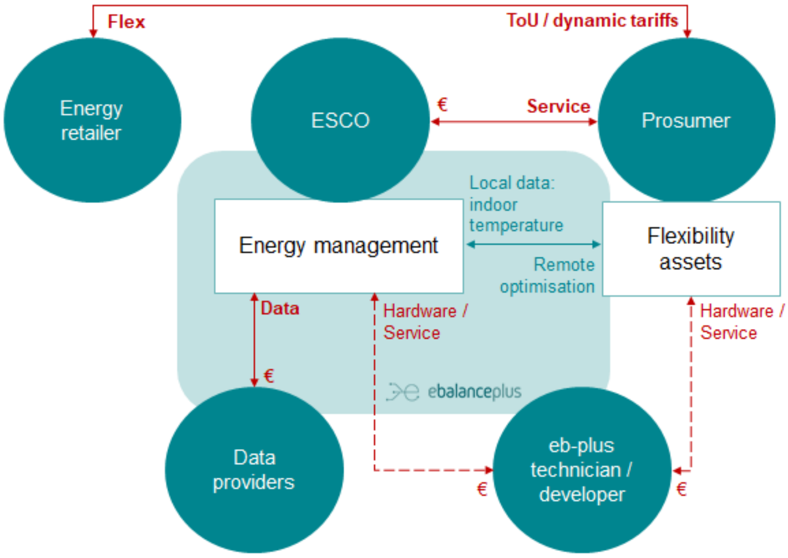


Figure 11 Business case 3: Flex based on implicit demand flexibility: using ToU or dynamic tariffs

2.2.4 Flex based on combined Energy Efficiency and explicit demand flexibility

Existing BEMS can be integrated in the ebalance-plus platform, thereby BEMS can participate in demand response programmes. The business case of energy efficiency (EE) and demand flexibility can strengthen each other, but combining EE and demand flexibility also leads to trade-offs that need to be managed. An ESCO manages both flexibility and other energy resources at building level and optimizes the scheduling of assets of prosumers / facility manager and offers the flexibility assets to a VPP run by an aggregator, which pools the prosumer's loads to provide flexibility to BRPs, DSOs or TSOs on the market (Figure 12). The advantages of the individual stakeholders are similar to business case 2 and there will be additional advantages for ESCOs that provide their services; additionally prosumers will benefit from optimizing both energy efficiency and demand flexibility.

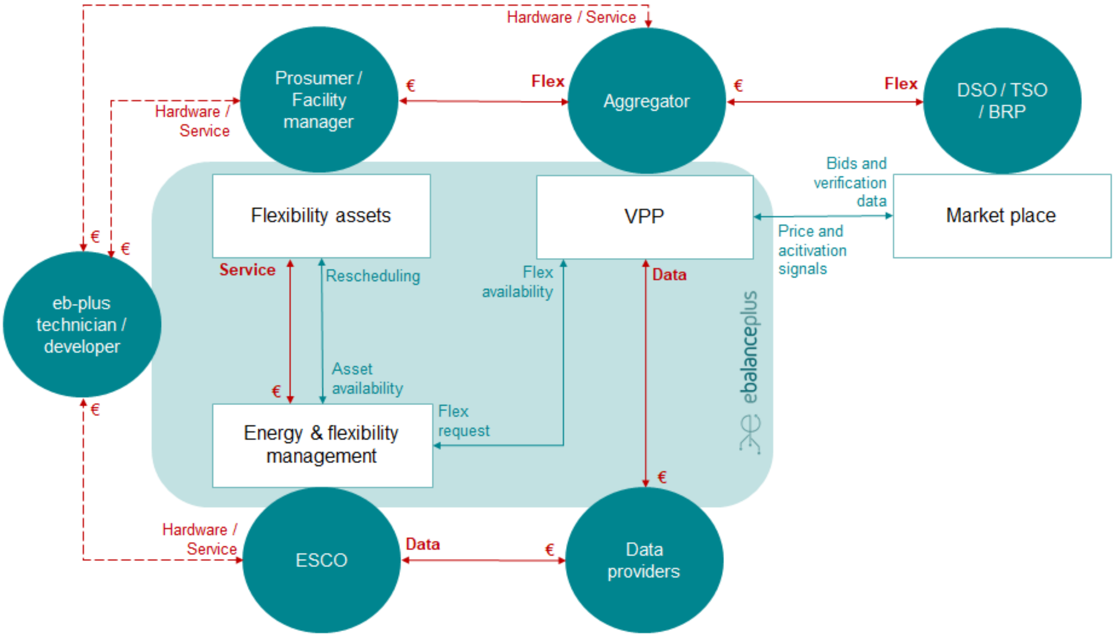


Figure 12 Business case 4: Flex based on combined EE and explicit DR

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°864283

Finally, the integration of existing BEMS in the ebalance-plus platform, provides a business opportunity for technology providers (e.g. BEMS and controls manufacturers), who can extend their existing capabilities of monitoring, analysing and recommending energy efficiency measures, and providing customers a service to participate in DR and monetise flexibility [9].

3 The Architecture use case cluster

This section introduces the use cases related to the architecture of the system. There are two examples here, the UC.01 and UC.02. The first one provides the infrastructure for the data exchange and is the basis for implementing distributed energy management algorithms. It also defines the rules for the data access, providing the security for the approach. The second use case defines the interconnection between the main ebalance-plus data infrastructure and other existing approaches (here mainly BEMS, but the concept works for almost any other subsystem) that can already in use and shall be integrated with our approach to increase interoperability.

3.1 UC.01 – ebalance-plus hierarchical energy communication platform

Table 1 Brief description of UC.01

Title	Ebalance-plus Hierarchical Energy Communication Platform
Narrative short	This Use Case aims at demonstrating the functionality provided by the hierarchical energy-related communication platform. It abstracts the data exchange from the main energy management algorithms and by that simplifies the implementation of distributed energy management algorithms. The Use Case presents all the steps and procedures related to the platform, needed for its proper configuration and executed during its run-time.
SGAM domains-zones	1b-f Generation/Field-Market 2b-f Transmission/Field-Market 3b-f Distribution/Field-Market 4b-f DER/Field-Market 5b-f Customer/Field-Market
Actors	Any stakeholder (via a service running in the platform)
Scope	The scope of this Use Case is to describe the platform as a means to exchange data between the distributed energy management algorithms that are installed and executed on spatially distributed machines within the energy grid – management units. The scope covers the data exchange, but also other procedures needed to be done on the infrastructure management side, like registering stakeholders and their services, registering management units and defining their hierarchy.
Objectives	**UC01.1**. Platform initialization (preparation phase) a. Registration of a stakeholder

	b. Registration of a Management Unit and identification of its responsible stakeholder c. Defining relations between Management Units (hierarchy relations parent-child) d. Registration of services that shall run on the behalf of a stakeholder e. Defining stakeholder policies to define allowed data access **UC01.2**. Performing a data exchange within the platform (run-time phase)

The Use Case aims at demonstrating the following main steps:

a. Preparing the platform infrastructure
b. Performing data exchange between distributed processes (services) executed on distributed management units (MUs)

These two steps can be further split into procedures that need to be applied to achieve the goal of the step, but these procedures can be applied in different combinations and sequences, depending on the given deployment. But in any case, the infrastructure needs to be prepared first, before the data exchange can take place.

A deployment starts with the top-level units (ebplus discovery and authority). These units are responsible for the organizational procedures related to the platform, like registration, certification, revocation.

First, each stakeholder needs to be registered in the system. A stakeholder is any actor that participates in the energy grid, being either a customer or (any service) provider. A stakeholder is relevant for the platform if there is data acquired or generated by that stakeholder or related to that stakeholder. After being registered the stakeholder obtains a unique identity in the system that she can prove to others with a certificate.

In order to create the physical infrastructure for the platform it is necessary to install the management units (hardware and software) and to register each of them within the platform. Here, similar to the stakeholder registration, each management unit obtains a unique identity and a digital certificate based on PKI to prove the identity to others. The management unit is additionally linked to a specific stakeholder that is in charge of the management unit and has physical access to it. This stakeholder and management unit relation can be, for instance, defined by the premises the unit is installed within. After a management unit is registered in the system, it can be attached to the existing topology of units by defining its place in the hierarchy within the platform. This definition is done by creating a parent-child link between two management units. This relation is 1-to-n, meaning that one parent can have many children, but one child can have only one parent (at a time). To define this link, it is necessary to configure both the management units properly, i.e., the child is added to the children configuration set on the parent MU and the parent is added to the parent (one element) configuration set on the child MU. This setting is local to this two MUs, it is not forced or configured by the top units, as it can be dynamic if the deployment allows topology/hierarchy changes, for instance, to improve the reliability.

In order to create data sources and exchange points it is necessary to register services that use the platform. A service is an implementation that accesses the data in the platform and executes a local algorithm processing the data and triggering actions or generating new data. These local services cooperate and together they implement a distributed algorithm. The locally installed piece of software (service) is executed on a management unit on behalf of a given stakeholder. It means that the same piece of software may be executed on the same management unit but for different stakeholders. By that we have two different instances of the algorithm, but performing their tasks for different stakeholders. Thus, within the platform not the piece of software or service is registered, but its specific instance to be run by a specific stakeholder. Such registered services to be run by specific stakeholders also get their certificates to prove their identity. This approach allows to specify data access policy that allows restricting the data accesses for specific algorithms by specific stakeholders only.

Data stored by a service onto the platform is labelled as data belonging to the stakeholder the service runs on behalf of. By default, each service run for a given stakeholder can access the data by that stakeholder without restrictions. But in order to access data of other stakeholders it is necessary that a proper access control policy is defined. Such policy specifies the allowed access patterns for given stakeholder/service configurations. And as the data access policy is handled by the MU where the data was written by a service of a stakeholder, it is also necessary to define the policy at that management unit. The best way to do that is to set it up while the service first starts. The access policy is then available on other MUs in the platform as well.

Finally, the data exchange between the running services may happen. The data exchange ways include reading, writing data, but reading can also be extended to subscribing to specific events, resulting in periodic data delivery or delivery of each newly available value. To exploit the hierarchical feature of the energy grid it is advised to perform data exchange according to the parent-children hierarchy, but indeed any other data exchange is possible as well. It is only necessary to know the identity of the target management unit, where the desired data origins from. Additionally, it is of course also necessary to have the right to access the desired data (policy definition by the data owner).

3.2 UC.02 - Interoperability solutions to integrate existing BEMS within demand response markets

Table 2 Brief description of UC.02

Title	Interoperate with devices from existing BEMS to integrate them within demand response markets
Narrative short	Existing BEMS are integrated in the ebalance-plus system, at a communication and control level, in order to allow them to participate in demand response programmes.
SGAM domains-zones	5a-e Customer premises/enterprise, operation, station, field, process
Actors	Ebalance-plus manager, BEMS manager, Ebalance-plus technician,

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°864283

	Developer
Scope	Existing BEMS must be interoperable with the ebalance-plus middleware. The BEMS is already installed within customer premises, possibly relying on cloud technologies to control/monitor the devices. Interoperability solutions proposed here only apply to the communication between a BEMS and the ebalance-plus middleware. It is assumed that once the BEMS is interoperable with ebalance-plus the former is able to participate in demand-response services.
Objectives	An existing BEMS, and therefore all the devices it is composed of, must be interoperable with the ebalance-plus middleware in order to integrate the system within demand response markets. In order to do that several objectives need to be achieved: **UC02.1**. Analyze signal communication requirements and design interoperability strategy **UC02.2**. Modify the existing control algorithms in the BEMs by either: a. Extending the existing algorithms to allow external control, b. Replacing them with the new ebalance-plus logic. **UC02.3**. Interconnect the resulting systems a. Deploy and configure interconnection hardware, b. Develop interoperability services and connect ebalance-plus algorithms to the BEMS algorithms.

This use case aims at demonstrating that BEMS can be integrated to participate in demand response programmes (markets) and operate based on steering signals, allowing building facility managers to set their own preferences (thresholds). In order to do that, interoperability between these already existing BEMS and the ebalance-plus platform must be guaranteed, not only at the communication protocol level but also at a control level. It is possible and in fact likely that the existing BEMS already has some intelligent algorithms that control the devices connected to the system. In this case, it is essential to make sure that the BEMS algorithms can coexist with the ebalance-plus algorithms and that they are able to coordinate their behaviour to produce a coherent result. In order to meet these requirements, the use case contemplates three main steps:

1. Analyse signals communication requirements and design an interoperability strategy in order to assess the modifications needed to be done in the BEMS
2. Modify the BEMS based on the conclusions drawn in step 1. This typically involves extending and/or replacing the existing control logic in the BEMS
3. Interconnect the resulting systems and algorithms, that is, the ebalance-plus platform and the BEMS. By means of new services, the required subset of the BEMS data will be accessible.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°864283

4 Resilience and reliability use case cluster

Electric power grid resilience (hence **grid resilience**) implies the recovery rate from service disruption. Essential properties of a resilient system are avoiding service disruption through **anticipation / prevention**, minimizing damages caused by hazardous events (**absorption / degradation**), restarting / rebuilding its functionalities (**recovery / restoration**) and learning from past such events (**adaptation**) in order to deal with future ones. The aforementioned resilience properties are visualized for a functioning grid over time (see Figure 13) as an *event* on the grid takes place at time t_E and the transition to the states of degradation and restoration form a **resilience triangle**.

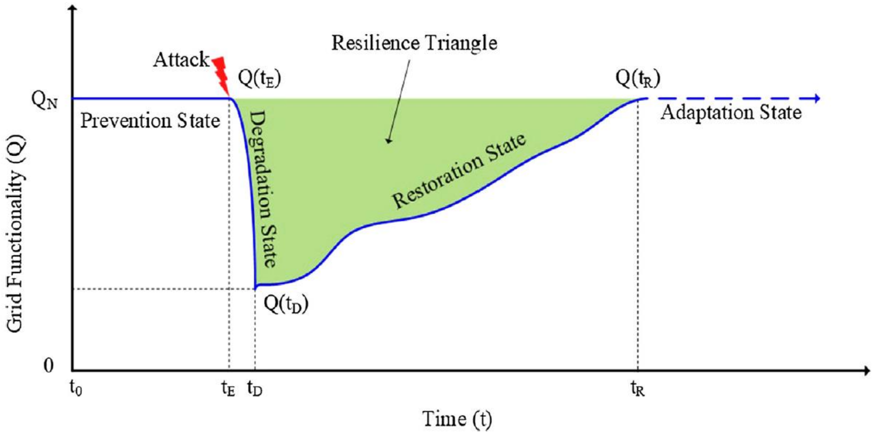


Figure 13 Grid resilience states associated with a hazardous event (source: [17])

An important element of the grid resilience aspect is its **infrastructure,** which is considered critical as it enables core societal, economic and technological functions. Infrastructure level malfunctions can either happen at transmission or distribution level with the later presenting the highest possibility of causing customer service disruption.

In the EU, according to the DSO Observatory Project (DSO-OP) 2018 edition, 80% of service interruptions are due to failures that take place at the distribution level [10]. From ENTSO-E monthly statistics (2010-2016, 22 Member States), the majority of electricity supply disruption events were attributed to failure of equipment or material damage (40%) and severe weather conditions and natural hazards (33%), while the top-20 events account for the 67% of non-supplied electricity [11].

A notion related to grid resilience is **grid reliability**: IEEE defines it as the grid's required performance for given conditions and time interval [12]. An overview of the differences in aspects of grid resilience and reliability can be observed in Table 3 and a conclusion drawn is that a reliable grid is not necessarily evaluated as resilient.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°864283

Table 3 Differences in aspects of grid resilience and reliability (author's table based on [13][14])

Grid notion	Hazardous event probability	Hazardous event impact	System focus	Concern
Resilience	Low	High	Transition time between states	Infrastructure recovery time
Reliability	High	Low	State	Customer interruption time

A correlation of the grid resilience properties with main solution clusters has been proposed in [15] and can be observed in Table 4. While smart-grid solutions are the largest cluster, they correlate mainly to the restoration property – holistic approaches in solutions should be comprised from all clusters.

Table 4 Correlation of grid resilience states to solution clusters (source: author's adaption of [15])

Grid resilience state	Relevant solution clusters
1. Prevention	• Prevention and management • Monitoring and fault detection • Modeling and simulation
2. Degradation	• Monitoring and fault detection
3. Restoration	• Smart grid-based
4. Adaptation	• Prevention and management • Modeling and simulation

As the distribution level of the electric power grid presents the highest frequency of service disruptions, smart-grid resilience options for this level include [16]:

a. Use of distributed generation and storage to reduce dependence on particularly vulnerable lines and protect critical customers and loads;
b. Grid modernization, substation & distribution automation and smart meters to collect grid condition quickly and analyze and act on it more quickly, precisely and effectively;
c. Use of demand response, automated load-shedding and interruptible rates for fast frequency response and capacity provision.

In [18] the impact of RES penetration (mainly wind and solar) on distribution networks was analysed for different scenarios seen in Table 5. The economic impact of this penetration in the rural network for different onsite PV sizes was assessed by means of a penalty cost function for voltage and overload costs per day. As it can be observed from the charts in Figure 14, in worst case scenarios (2030 x 2) the aforementioned costs can reach 20k and 100k euro per day respectively. The DSO Observatory Project 2018 report showed that at the MV level about 42% of the distributed generation is wind and 22% is photovoltaics (which are 84% at LV level).

Table 5 PV penetration levels (4 scenarios)

Sc.1 2020	Sc.2 2030	Sc.3 2030 x 2	Sc.0 No RES
7,5%	15%	30%	0%

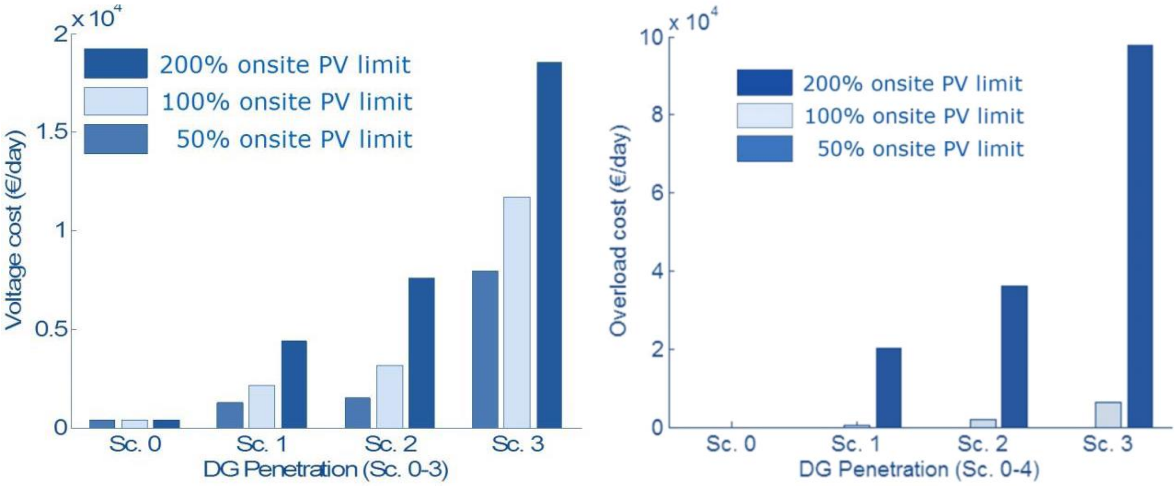


Figure 14 Voltage and overload costs (€/day) for different onsite PV limits and different penetration scenarios (source: [18])

As distribution grids are penetrated by an increasing share of DER (mainly RES) generation, the whole grid operation requires more sophisticated approaches that can be implemented only by the combination of intelligent electronic devices with advanced communication and functional features in a more distributed setup (such as in the ebalance-plus approach). Furthermore, network visibility at low voltage levels is required with real-time monitoring of assets like transformers and connected DER in order to increase resilience and reliability in cases of faults.

The cluster use case for resilience and reliability services to DSOs has 5 major use cases that are presented in the following paragraphs.

4.1 UC.03 - Application of IEN 50160 for voltage quality

Table 6 Brief description of UC.03

Title	Application of IEN 50160 for Voltage Quality
Narrative short	The Use Case refers to the application of the IEN 50160 Voltage Quality Standard in (VQA) in a distributed manner for a Power Distribution Grid, aiming to apply and demonstrate concepts and technologies of the ebalance-plus project. The Use Case shall evaluate a specific distribution grid topology. One core scenario will be presented in the use case.

SGAM domains-zones	3b-d Distribution / Field, Station, Operation 4b-d DER / Field, Station, Operation
Actors	Service Provider, DSO, MVGMU, LVGMU, DERMU, Power quality meter, SCADA, DER Owner
Scope	The scope of the proposed Use Case is to implement an approach for detecting and partially preventing violations of the IEC EN 50160 Voltage Quality Standard using complex event analysis on the underlying electricity grid by leveraging the ebalance-plus middleware, management units (MVGMUs, LVGMUs and DERMUs) and the FIWARE tools
Objectives	**UC03.1**. Increase the reliability of voltage supply to end users by means of understanding the sources of non-compliances and thus enabling the DSO to apply small or large corrective measures. **UC03.2**. Demonstrate that complex event analysis can help in conforming with the standard by mitigating the DER effects on voltage quality

The EN-50160 standard defines the supply voltage characteristics for Power Grids under normal operation. To achieve its goals the standard sets forth a series of compliance and statistical thresholds that need to be observed. To apply the standard and especially its statistical thresholds, it is necessary to assess a series of metrics (most notably V, P, Q, f) in a historical context. However, by leveraging the current framework it is possible to prevent violations by analysing events on the power grid as they occur. These events include but are not limited to, set-point modification of DER and capacitor and TAP state changes. By analysing these primary events it is possible to determine correlations that can lead to loss of power quality. Specifically, the events are correlated both among themselves (one event leads to another) and versus the available metrics (an event leads to voltage drop/rise or frequency change).

Such events can be assessed macroscopically in time and provide useful insights to operators to help them understand how different actions or series of actions can lead to disruption of voltage quality according to the standard. This creates the opportunity of creating a proactive approach in the application of the standard thus ensuring a larger degree of compliance.

Based on the above the application of the standard can have two forms. A reactive approach where monitoring and historical data are used for measuring compliance and a proactive approach where complex event analysis is used to avoid violations in the first place. In any case, event and metric monitoring will occur on all levels of the grid with the use of the appropriate units (DERMU, MVGMU, LVGMU) and power quality analysis while the assessment of the information will take place on the MVGMU level. To perform its goal the algorithm of the MVGMU component will be responsible for the synthesis of primary events with metrics based on both real time and historic data.

While interaction will be based on the ebalance-plus Framework, events emission and analysis will be based on the FIWARE technology which specifically provides a Complex Event Analysis meta-model definition. FIWARE is an open-source European initiative (https://www.fiware.org/) and provides open-source tools for the next generation internet. The Complex Event Processor (CEP) toolbox for FIWARE (https://fimac.m-iti.org/3e.php) can track a series of events and based on preset conditions trigger actions. CEP in this case will be used for its exhaustive meta-model definition for event classification, an aspect that is believed to elevate the ebalance-plus platform with a common European Standard.

Overall, this use case aims to demonstrate the following:

- Constant monitoring at primary and secondary substations via management units equipped with power analysers
- Use of historic and real time data to monitor compliance and statistical limits for IEC EN 50160
- Fusion of events and metrics in order to determine violations of the IEC EN 50160 standard to enable correlation with grid elements behaviour (e.g., DER)
- Perform Volt-VAr Optimisation (VVO) as a partially reactive measure

Methodology:

- Define the grid topology to be used
- Deploy MVGMUs, LVGMUs and DERMUs
- Define the standard's quantities to be monitored
- Store and fuse data and events with CEP
- Perform correlation analysis of events
- Report violations and react via VVO if possible

4.2 UC.04 – Fault, Detection, Isolation & Recovery (FDIR)

Table 7 Brief description of UC.04

Title	Fault Detection, Isolation and Recovery
Narrative short	The Use Case refers to Fault Detection, Isolation and Restoration in a distributed manner for a Power Distribution Grid, aiming to apply and demonstrate concepts and technologies of the ebalance-plus project. The Use Case shall evaluate a specific distribution grid topology in three different setups: 1. Laboratory Numerical Simulation, 2. Laboratory Simulation with Hardware-in-the-Loop (of ebalance-plus management units), 3. Actual performance in project's demo site(s). Regarding setup 3 (demo site) certain modifications in the distribution grid topology are anticipated, mainly due to the limitations of access to grid assets, as well as the limitations to intervene in the present control schemes. Two core scenarios will be presented: 1. Nominal, 2. Interrupted. In the Nominal Scenario all the units can communicate efficiently with each other thus allowing optimal monitoring and problem distribution, i.e. instead of a single management unit addressing the problem as a whole, several units can participate, each solving part of the problem. The information is exchanged via the ebalance-plus middleware and the LVGMU devices (management units) are mainly used for communication interfacing and as remote terminal points (RTUs). In the Interrupted scenario, some of the management units are considered offline and as such the FDIR algorithm must compensate by performing state

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°864283

	estimations to approximate the conditions on the missing nodes. As in the Centralized scenario, the LVGMUs are used for communication interfacing, again following ebalance-plus middleware information routes.
SGAM domains-zones	3b-d Distribution / Field, Station, Operation
Actors	Service Provider, OMS, DSO, LVGMU
Scope	The scope of the proposed Use Case is to implement an approach for FDIR in the context of ebalance-plus, by means on intelligent management units and optimization algorithms in the application field (i.e., Distribution Substations).
Objectives	**UC04.1**. To increase grid resilience and reliability using an FDIR methodology (minimize average number of customers with service interruption). **UC04.2**. To demonstrate the impact of FDIR algorithms for a distributed approach.

Overall this use case aims to demonstrate the following:

- Constant monitoring of complete topology for relay faults by leveraging underlying middleware
- Constant monitoring of voltage range violations by leveraging underlying middleware
- Automatic triggering of FDIR for selected triggers
- Distributed / cooperative execution of optimization algorithms (such as optimal power flow) for FDIR by relying on an information/communication middleware (ebalance-plus)
- Hierarchical communication relay to avoid communication bottlenecks
- Use of redundancies in management units to allow for increased resilience, i.e. If a unit fails then another takes its place in the “tree”
- Control of assets from central nodes
- Application of state estimation with more than one MU in cases of communication loss

4.3 UC.05 – Volt/VAr optimisation with increasing RES generation

Table 8 Brief description of UC.05

Title	Volt-VAr optimization with increasing RES generation
Narrative short	The proposed Use Case refers to Volt-VAr optimization in a Power Distribution Grid incorporating DER (mainly RES), aiming to apply and demonstrate concepts and technologies of the ebalance-plus project. The Use Case shall evaluate a specific distribution grid topology (TBD) in three different setups: 1. Laboratory Numerical Simulation, 2. Laboratory Simulation with Hardware-in-the-Loop (of ebalance-plus management units), 3. Actual performance in project’s demo site(s). Regarding setup 3 (demo site) certain modifications in the distribution grid topology are anticipated, mainly due to the limitations of access to grid assets, as well as the limitations

	to intervene in the present control schemes. Two core scenarios will be presented: 1. Centralized, 2. Distributed. In the Centralized Scenario the Volt-VAr control is arbitrated and executed in the (A)DMS system (assumed to exist). The information is exchanged via the ebalance-plus middleware and the MVGMU, LVGMU and DERMU devices (management units) are mainly used for communication interfacing and as remote terminal points (RTUs). In the Distributed scenario, the Volt-Var control is performed in the MVGMU device as an alternate scenario in case of central systems failures. As in the Centralized scenario, the LVGMU and DERMU are used for communication interfacing, again following ebalance-plus middleware information routes.
SGAM domains-zones	3b-d Distribution / Field, Station, Operation 4b-d DER / Field, Station, Operation
Actors	Service Provider, DER Owner, DSO, LVGMU, MVGMU, DMS/SCADA
Scope	The scope of the proposed Use Case is to implement Volt-VAr optimization approaches in the context of the ebalance-plus project, by means of intelligent management units and optimization algorithms in the application field (i.e., Distribution Substations, RES, etc.).
Objectives	**UC05.1**. To demonstrate the impact of Volt/VAr optimization on voltage stability **UC05.2**. To demonstrate the impact of Volt/VAr optimization on technical power losses **UC05.3**. To demonstrate the impact of Volt/VAr optimization on RES curtailment **UC05.4**. To demonstrate the performance of Volt/VAr optimization both with a centralized and a distributed implementation with respect to possible failures in both approaches.

Volt/VAR Optimization (VVO) is an application to optimally manage system-wide voltage levels and reactive power flow for efficient distribution grid operation. VVO is achieved by determining the best set of control actions for all voltage regulating devices and reactive power (VAr) control devices to achieve one or more objectives without violating any of the fundamental operating constraints (voltage & load limits, etc.) This use case applies to a power distribution grid incorporating DER (mainly RES), aiming to apply and demonstrate Volt-VAr optimization approaches in the concept of the ebalance-plus project. The Use Case evaluates a specific distribution grid topology in three different setups: 1) Laboratory Numerical Simulation, 2) Laboratory Simulation with Hardware-in-the-Loop (of ebalance-plus management units) and 3) Actual performance in project's demo site(s). Regarding setup 3 (demo site) certain modifications in the distribution grid topology are anticipated, mainly due to the limitations of access to grid assets, as well as the limitations to intervene in the present control schemes.

Overall, this use case aims to demonstrate the following:

- Increased RES penetration in power distribution grids causes congestion and effective VVO can intelligently manage RES to alleviate the problem;
- An information/communication middleware (ebalance-plus) adopted by intelligent management units installed in the Operation, Station, and Field domains (following SGAM notation) can increase overall system resilience by means of automatic re-configuration and continuity of Volt-VAr service;
- Intelligent management units in the Station and Field domains (e.g. MVGMU) are able to provide optimized Volt-VAr service;

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°864283

- Distributed intelligence could support VVO approaches
- Simulate respective VVO approaches;
- Apply Hardware-in-the-Loop of the ebalance-plus intelligent devices in the above simulations;
- Apply selected VVO scenarios in the ebalance-plus demo sites;
- Measure and analyse performance in the demo sites.

4.4 UC.06 – Intentional islanding after cascading failures

Table 9 Brief description of UC.06

Title	Intentional Islanding after cascading failures
Narrative short	The Use Case refers to Intentional Islanding after Cascading Failures (IISL) in a distributed manner for a Power Distribution Grid, aiming to apply and demonstrate concepts and technologies of the ebalance-plus project. The Use Case shall evaluate a specific distribution grid topology (TBD) in two different setups: 1. Laboratory Numerical Simulation, 2. Laboratory Simulation with Hardware-in-the-Loop (of ebalance-plus management units). The operational scenario to be simulated includes a black box of simultaneous grid failures resulting also to interrupted operation of some management units (considered “offline”) and as such the IISL algorithm must compensate by applying state estimation to approximate the conditions on the missing nodes. In the scenario, the LVGMUs are used for communication interfacing, again following ebalance-plus middleware information routes.
SGAM domains-zones	3b-d Distribution / Field, Station, Operation 4b-d DER / Field, Station, Operation
Actors	Service Provider, OMS, DSO, AMI, MVGMU, LVGMU, DER Owner, DERMU
Scope	The scope of the proposed Use Case is to implement an approach for intentional Islanding after cascading failures in the context of ebalance-plus, by means on intelligent management units and optimization algorithms in the application field (i.e., Distribution Substations).
Objectives	**UC06.1**. To continuously serve as much customers as possible after cascading failures **UC06.2**. To demonstrate resilience of the grid when applying Intentional Islanding (IISL) approaches

Cascading failures refer to a series of failures that can occur over a large area of the grid where each failure is the result of a previous one. Capturing the root causes of cascading failures is difficult and is dependent on many variables. However, their effect can be simulated by periodically failing a number of grid elements. This will allow the Intentional islanding to work around the problem in every iteration and create islands with the criterion of serving as many clients as possible. In this context, a large enough topology will be used to simulate the effect. Also due to the configurable nature of the simulation, the IISL algorithm can be tested in a diverse set of starting conditions. This approach handles the cascading failures as a “black-box”, i.e., no knowledge is provided as to what exactly happened. Also, for simplicity purposes, the failures are assumed to happen one after another quickly enough to be considered cascading. To handle the cascading failures, the grid can compensate and adjust either by load shedding or by intentional islanding. Since the target is to lose as few clients as possible, focus is given on the islanding approach.

An island can be determined by the following characteristics; it can be completely isolated from the rest of the grid if it has one or more DER so as to supply power independently and can balance between supply and demand to avoid collapse. The islands can be determined either by having a previous analysis of power grid (islands are known in advance and used when a cascading failure is detected) or by a dynamic simulation during operation (islands are determined using simulations of power flows). The first solution gives a concrete plan, known in advance, while the second leads to an increased computational load but can lead to island definition in an ad-hoc manner. In the context of this use case, the islands shall be pre-calculated and their knowledge allows to also determine the isolation points (points of common coupling).

The grid is continuously monitored and when cascading failures occur that may result into loss of operation, islands are isolated. At this point the DERMUs of the island start their balancing (EMS) algorithms to maintain voltage and frequency at the required levels and avoid collapsing. For the areas that are not islanded, a load shedding approach is followed in an effort to maintain supply to the rest of the network.

Methodology:

- Define the grid topology to be used
- Define the potential islands in the topology
- Define a cascading failure black box approach
- Define a simplified EMS process for the islands
- Monitoring of the system for failures and formation of islands or load shedding.

4.5 UC.07 – LV transformer monitoring with PMUs and sensors

Table 10 Brief description of UC.07

Title	LV Transformer Status Monitoring with PMUs and Sensors
Narrative short	The Use Case refers to the status monitoring of LV Transformers in a power grid with the use of sensors and high accuracy and GPS synchronized PMUs (TRM), aiming to apply and demonstrate concepts and technologies of the ebalance-plus project. The Use Case shall evaluate a specific distribution grid topology (TBD) for one of the project’s demo site(s). One scenario will be presented which represents a nominal power grid with no communication interruptions. In the scenario, the LVGMUs are the core of the facility since they interact with the defined sensors and PMUs but the DSO’s SCADA will be used as the main collection point for all the data points.
SGAM domains-zones	3b-d Distribution / Field, Station, Operation

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N°864283

Actors	Service Provider, AMI, DSO, LVGMU, MVGMU
Scope	The scope of the proposed Use Case is to implement an analytical approach for enabling predictive maintenance for LV transformers and state estimation with the use of PMUs and sensors in the context of ebalance-plus.
Objectives	**UC07.1**. Enable Predictive Maintenance with the use of sensors **UC07.2**. Enable State Estimation with accurate GPS timing on PMUs

This use case concerns the definition of an algorithmic approach to enable the prevention of failures on low voltage transformers as well as state estimation with the use of advanced sensors, PMUs and event analysis.

A transformer faces many different failures. These failures are the result of its operating conditions and its aging and are classified by severity and rate of occurrence. In this context, transformers typically have a maintenance schedule. Most HV and MV transformers, since they are expensive assets, are already monitored and maintained consistently but LV transformers are not, so operators do not have visibility in this part of their network for both asset health and network status. In order to enhance asset management, the LVGMU shall firstly be enhanced with additional sensors to monitor its conditions. These sensors will monitor temperature, vibrations and magnetic field. Furthermore, measurements of high accuracy for Voltage, Current and their angle will be provided from a PMU device. As the LVGMU installations take place across multiple LV transformers, synchronization of the measurements will rely on the common time source of a GPS radio clock.

All the information from the LVGMUs will be collected at a centralized location so that a systematic record can be created from which meaningful metrics can be extracted. The collection and analysis of readings occurs at the MVGMU level and communication among all the LVGMUs is based on the ebalance-plus framework. The MVGMU is also connected to a SCADA and an OMS service. The aforementioned collection focuses on enabling predictive maintenance for LV transformers as it will be communicated to the DSO, that can then determine potential actions to be incorporated in the maintenance planning.

Moreover, via the PMUs (accurate timing of the GPS) state estimation can be enabled in case of communication loss with grid elements. Finally, with this approach and the presence of an Advanced Metering Infrastructure, it is also possible to enable fraud detection in the topology.

5 Flexibility mechanisms use case cluster

The ebalance-plus project aims at unlocking the hidden flexibility of the electricity grid using as communication and managing technology the hierarchical ebalance-plus energy balancing platform described in the **UC.01,** and following a bottom-up approach, from the customer premises and DER facilities until the TSO-DSO coordination needs and using the aggregator as central player of flexibility dispatching.

At customer (buildings) level (**UC.09**), the available flexibility is managed from the Customer Management Unit (CMU) in different ways: coupling ebalance-plus platform with existing building energy management system (BEMS) that control building flexible loads (**UC.02**);

integrating the energy management system (EMS) of existing flexible loads (e.g. electric batteries or thermal storage) or, in the absence of flexible loads, deploying smart-storage solutions, local controllable RES and/or IoT devices to control main consumption sources like HVAC (ventilation speed, heat-pump operation, thermal storage control) and smart apliances. In this case, it is assumed that flexible loads are every energy consumption, generation or storage facilities that allows dynamic control settings, i.e. shifting energy profile. As an example, single phase and three-phase smart storage solutions will be deployed in two demo sites (residential and non-residential environments) and IoT devices/networks will be deployed to operate building facilities or making home appliances smart. This approach is also considered at DER level using the DERMU (**UC.08**).

A preliminary methodology to enhance building and district flexibility is shown in Figure 15.

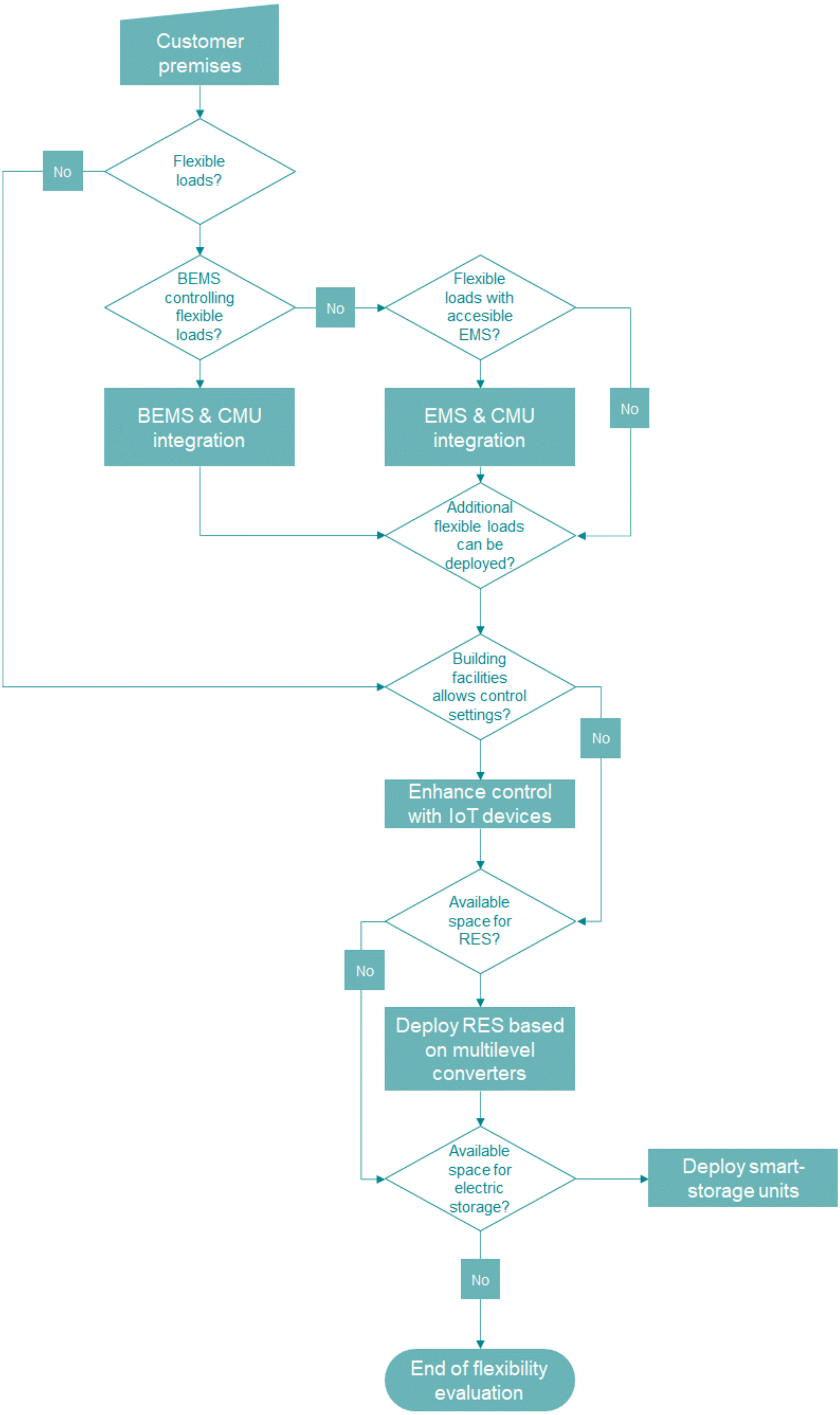
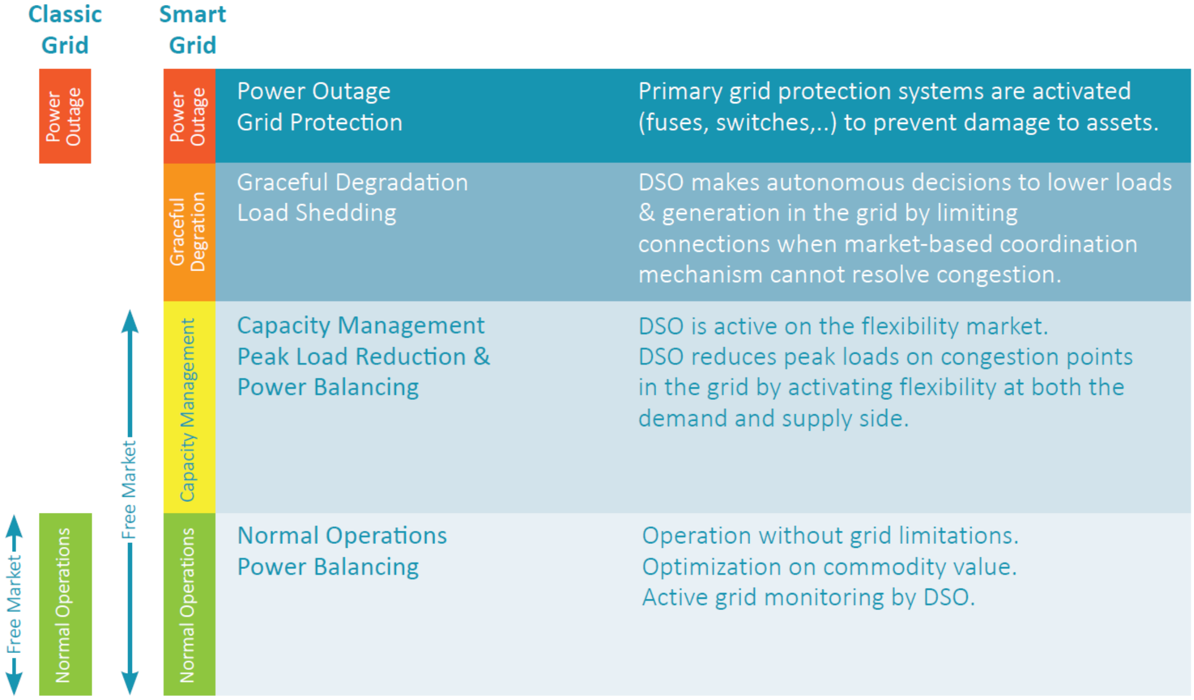


Figure 15 Evaluation methodology to enhance building premises flexibility

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°864283

At grid level, the flexibility services allow DSO to setup the capacity management thresholds (see Figure 15) in the corresponding units (LVGMU or MVGMU) to request energy flexibility when necessary. Desigining specific user interfaces (API), DSO in cooperation with TSO can establish dynamically active and reactive power capacity thresholds to the electricity substations (primary and secondary) in order to activate automatically the available flexibility of the entire system and to keep grid conditions in normal operation. In addition, the ebalance-plus project will research on ancilliary services at residential level using heat-pump control with thermal storage (UC.11).



Power Outage	Power Outage Grid Protection	Primary grid protection systems are activated (fuses, switches,..) to prevent damage to assets.
Graceful Degration	Graceful Degradation Load Shedding	DSO makes autonomous decisions to lower loads & generation in the grid by limiting connections when market-based coordination mechanism cannot resolve congestion.
Capacity Management	Capacity Management Peak Load Reduction & Power Balancing	DSO is active on the flexibility market. DSO reduces peak loads on congestion points in the grid by activating flexibility at both the demand and supply side.
Normal Operations	Normal Operations Power Balancing	Operation without grid limitations. Optimization on commodity value. Active grid monitoring by DSO.

Figure 16. USEF Smart Grid Regimes [6]

Under this approach and in accordance with the USEF [6] emerging flexibility platforms description, the ebalance-plus platform corresponds to three specific solutions identified in future markets:

1. "TSO-DSO coordination platform": electric network operators can establish dynamically electrical thresholds to operate the grid with the support of the downwards energy flexibility.
2. "Technology platform / VPP / MicroGrid Controller": that is the ebalance-plus platform, i.e. hardware and software solutions making the flexibility available for energy aggregators and grid management.
3. "Energy management platform": using the project data-centric middleware, building and district facilities can be integrated and operated by the energy aggregator to offer the different grid services described. In addition, to complement the flexibility services and considering normal operation scenarios, the ebalance-plus platform will optimise the CO2 emissions and energy costs operating the flexible loads and according to the end-user preferences (**UC.10**).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°864283

5.1 UC.08 - Flexibility measures I

Table 11 Brief description of UC.08

Title	Virtual Power Plant (VPP) services based on district solutions (variable PV generation, storage and V2G)
Narrative short	Optimised control of DER (including PV generation, BESS and V2G) can help to release flexibility according to grid constraints to enhance its operation. This would lead to lower operational costs, grid congestion and generation curtailment, while maximising revenue through VPP services.
SGAM domains-zones	4a-d DER/Process, Field, Station, Operation 3c-d Distribution/Station, Operation
Actors	DERMU, LVGMU, MVGMU, Energy aggregator flexibility management system, DSO energy management system, EV-V2G user, DER Manager, V2G charging points EMS, District BESS, Local RES Power Converter EMS (e.g., PV)
Scope	To enhance grid operation at district level by allowing flexibility mechanisms from Distributed Energy Resources (DER), specifically managing at district level Battery Energy Storage System (BESS), PV generation and V2G charging point infrastructure working on a DC voltage network.
Objectives	**UC08.1**. Balancing energy flows to support distribution grid operation (targets: charge/discharge electric vehicles, controlling local BESS and modulating PV production with power converters) **UC08.2**. Optimise electric car charging costs by local RES, local energy store or provided by the distribution grid (pool-based information) **UC08.3**. Reduce electric car charging CO2 emissions by using local RES, local energy store or provided by the distribution grid (pool-based information). **UC08.4**. Demonstrate high-efficient operation of DC networks with silicon carbide-based power converters.

This use case aims (a) to define technical solutions to manage the energy flexibility of distributed energy resources (DER) that are exploited potentially by a DER manager (e.g., facility manager, ESCO, etc.), and (b) to define market steps to exploit such energy flexibility through energy aggregators, balance responsible parties (BRP) or similar stakeholders.

The technical context of this use case is a DC voltage network that integrates generation, storage and consumption units at district/neighbourhood level. As example, this use case is tested in the ebalance-plus project creating a DC voltage network with SiC-based power converters, PV canopies, external BESS and V2G infrastructure. In the operation level, the energy flow is managed mainly by two energy management units: the DERMU (distributed energy resources management unit) and the LVGMU (low voltage grid management unit). The former monitors the operation of all the DER components and receive the grid status and steering signals from the latter located in the secondary substation that supplies electricity to the DC network. As tentative market context, it is assumed that the DER manager has a deal with an energy retailer or energy aggregator to buy/sell the energy according to specific contract conditions (tariffs, daily prices, carbon emissions…) and with specific bonus by supporting grid operation.

The DERMU optimises energy flows considering the DC network components, energy forecasting (e.g., PV generation, charging vehicles, BESS status), energy contract conditions or requests on demand from the energy aggregator as primary scenario and it will balance energy flows when the LVGMU requests flexibility from the DSO/TSO level as alternative scenario.

In the primary scenario, the energy aggregator/ESCO enterprise system sends a specific flexibility request. The DERMU receives the steering signals, balances the network elements, and calculates the degree of compliance with the original requests and sends it back to the aggregator/ESCO enterprise system, which validates if finally accepts the energy flexibility according to contractual conditions. In case of validation, the DERMU executes the optimized plan.

In the alternative scenario, the energy management system of DSO/TSO will request flexibility to the ebalance-plus platform. The MVGMUs identify the most suitable LVGMUs and generate specific steering signals. These in turn identify the most suitable DERMU and generate specific steering signals to support the request in a cost-efficient manner. The DERMU receives the steering signals, balances the network elements, and calculates the degree of compliance with the original requests and sends it back to the LVGMU. Finally, the energy retailer or energy aggregator accounting system monitors the flexibility released and calculates the bonus.

5.2 UC.09 – Flexibility Measures II

Table 12 Brief description of UC.09

Title	Virtual Power Plant (VPP) services based on building solutions (IoT devices, PV and storage)
Narrative short	Buildings accounts for 40% of the final energy consumption in Europe and its flexibility is seen as one of the most relevant means to manage future grids and enhance their operation. This would lead to lower operational costs, grid congestion and generation curtailment, while maximising revenue through VPP services.
SGAM domains-zones	5a-d Customer premises/Process, Field, Station, Operation 3c-d Distribution/Station, Operation
Actors	ebalance-plus platform, CMU (Customer Management Unit), LVGMU (Low Voltage Grid Management Unit), MVGMU (Medium Voltage Grid Management Unit), Energy aggregator flexibility management system, DSO energy management system, Facility Manager, BEMS, Building facility component, customer/prosumers.
Scope	To enhance grid operation at the distribution level by allowing flexibility mechanisms from Building Energy Management, including Battery Energy Storage System (BESS), PV generation and IoT devices.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°864283

Objectives	**UC09.1**. Balancing energy flows to support distribution grid operation (lower operational costs, reducing grid congestion and minimizing generation curtailment). **UC09.2**. Optimising BEM operation including control of smart devices (IoT), roof-PV generation and batteries. **UC09.3**. Reducing energy consumption costs and/or CO2 emissions at building level. **UC09.4.** Encouraging different actors (facility managers, DSOs/TSOs or energy aggregators) to request/release flexibility through the ebalance-plus platform.

This use case aims (a) to define technical solutions to manage the energy flexibility of building facilities managed by a facility manager, and (b) to define market steps to exploit such energy flexibility through energy aggregators, balance responsible parties (BRP) or similar stakeholders.

The technical context of this use case is a building facility that integrates generation (i.e., roof-PV), smart storage and consumption units. In the operation level, the energy flow is managed mainly by two energy management units: the CMU (customer management unit) and the LVGMU (low voltage grid management unit). The former monitors the operation of all the smart devices (IoT), batteries and PV facilities in the building, and receives the grid status and steering signals from the latter.

The CMU optimises energy flows considering the building facility components, energy forecasting (e.g., PV generation, smart devices operation, BESS status), energy contract conditions or flexibility requests when the LVGMU requests flexibility from the DSO/TSO as primary scenario and from the energy aggregator level as alternative scenario.

In the primary scenario, the energy management system of DSO/TSO will request flexibility to the ebalance-plus platform. The MVGMUs identify the most suitable LVGMUs and generate specific steering signals. These in turn identify the most suitable CMUs and generate specific steering signals to support the request in a cost-efficient manner. The CMU receives the steering signals, balances its generation and consumption elements, calculates the degree of compliance with the original requests and sends it back to the LVGMU. Finally, the energy retailer or energy aggregator accounting system monitors the flexibility released and calculates the bonus.

In the alternative scenario, the energy aggregator system sends a specific flexibility request. The CMU receives the steering signals, balances its generation and consumption elements, calculates the degree of compliance with the original request and sends it back to the aggregator system, which eventually validates and accepts the energy flexibility according to contractual conditions. In case of validation, the CMU executes the optimized plan.

5.3 UC.10 - Flexibility measures III: Price/CO2 based optimization (demand response)

Table 13 Brief description of UC.10

Title	Price/CO2 based optimization (demand response)

Narrative short	Price/CO2-based control is an indirect control mechanism that can be used to drive end-users' power consumption on the basis of signals representative of market or grid (e.g., TSO/DSO) requirements. Indeed, end-users exposed to time-varying electricity or network tariffs and equipped with smart controllers can react to changes in the price of electricity over time by shifting their consumption from peak to low-tariff hours, thus reducing their energy costs on the one hand and the overall demand, during peak-hours, on the other.
SGAM domains-zones	5a-f Customer premises/Process, Field, Station, Operation, Enterprise, Market
Actors	Market operator, Aggregator, CMU
Scope	This use case is aimed at unlocking the energy flexibility potential of end-users using smart energy management system, i.e., price-based or CO2-based optimal control, to enabling their participation in demand-response programs.
Objectives	**UC10.1**. Reduce end-users' electricity costs **UC10.2**. Reduce CO2 emissions **UC10.3**. Enabling end-users' participation in price-based demand response programs **UC10.4**. Exploit the energy flexibility of a pool of heat pumps coupled with sensible thermal energy storage (i.e., swimming pools) **UC10.5**. Develop quantification methodologies to assess end-users' flexibility

UC.10 aims to develop and implement advanced control strategies to unlock the energy flexibility potential of summerhouse swimming pools coupled with heat pump technologies. Thanks to their high thermal energy storage capacity, swimming pools heated through power-to-heat technologies, like heat pumps, offer several demand-side management opportunities. In this framework, the Use Case analyses and develops indirect price/CO2-based control mechanisms that can be used to drive end users' power consumption on the basis of signals representative of market or grid (e.g., TSO/DSO) requirements, according to an implicit demand response (DR) paradigm. Among DR programs, price-based programs (also known as implicit DR programs) are recognized as the most suited for engaging low-voltage end-users, like households, in grid operations. Indeed, heating/cooling technologies equipped with controllers capable to react to external signals, like time-varying electricity prices, can exploit storage capacities (e.g., water of swimming pools) to implement load-shifting strategies that, on the one hand, reduce their energy cost and, on the other end, provide a service to the grid (e.g., peak-shaving, congestion relief, etc.). The present Use Case is structured as follows:

1. Each day, the market operators upload the market clearing prices (spot prices) for the next 24 hours to the Cloud platform, where they will be accessible to all the authorized end-users;
2. Before real-time operations, the Control Management Unit (CMU) acquires the electricity tariffs from the Cloud platform, and all the information (e.g., sensors data, weather forecasting, etc.) needed to optimize the end-user energy consumption over the considered control horizon (e.g., 24 hours);
3. The CMU optimizes the end user's consumption on the basis of the data gathered and implements the optimal control action.

The main Use Case's goals can be summarized as follows:

- Unlocking the energy flexibility potential of heat pump coupled with thermal energy storage (i.e., swimming pools);
- Identifying the steering signal best suited to indirectly control the heat pump by overriding the internal control logic;
- Cost-optimizing the energy management of the heating system, while fulfilling the occupant comfort requirements and reducing environmental impact (e.g., CO2 emissions);
- Assessing the end users engagement and acceptance of the proposed DR control strategies;
- Identifying KPI and methodologies to assess and measure the provided energy flexibility;
- Aggregating the flexibility of individual summerhouse.

5.4 UC.11 - Ancillary services and market mechanisms based on residential power-to-heat control (Denmark)

Table 14 Brief description of UC.11

Title	Ancillary services and market mechanisms based on residential power-to-heat control (Denmark)
Narrative short	Nowadays, ancillary services of the power systems are mostly provided by the generators. However, demand side of the system is attracting an increasing attention in providing these services due to their flexibility and fast response ability to the system needs. This project aims at defining market mechanisms for procurement of ancillary services from end-user electricity consumers such that both system operators and consumer benefit from trading ancillary services in the system.
SGAM domains-zones	2b-f Transmission/Process-Market 3b-f Distribution/Process -Market 4b-f DER/Process-Market 5b-f Customer/Process-Market
Actors	TSO, DSO, Aggregators, Customers
Scope	The scope of this use case is proposing a market place to release the energy flexibility in the distribution grid level for proving the ancillary services in the power systems.
Objectives	**UC11.1**. Design and describe a market place for procuring ancillary services from demand side of the power system which in this case are the heat pumps. **UC11.2**. Reducing the congestion and providing stable operation condition for the distribution grids using the flexibility provided by the end-user consumers.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°864283

	UC11.3. Providing incentives for end-user consumers, aggregators, and DSOs to participate in the ancillary service markets. **UC11.4**. Design and implement optimization algorithms to help end-user consumers, aggregators, and DSOS to participate in the ancillary services market.

Nowadays, ancillary services of the power systems are mostly provided by the generators. However, there is growing attention for procuring these services from the demand side of the system. This is mostly because of the increase in penetration of renewable energy sources (RESs). Some countries like Denmark are moving toward 100% RESs by 2050. Increase in the installation of renewable energy-based power plants reduces the share of conventional power generations that can provide frequency control ancillary services. Moreover, since many RESs like wind turbines and photovoltaic cells have an intermittent nature, the more renewable energy-based power plants mean more uncertainty and power imbalance, and consequently more requests for frequency control ancillary services. In this situation, demand side of the system is identified as a useful resource for providing these services.

Another point is variations in the structure of power system, like increasing investment in distributed generation and changes in the consumption patterns of consumers due to introducing new technologies, like electric vehicles, facing the distribution girds with challenges like congestion issues. These challenges cannot be solved by existing ancillary services and new flexibility resources in the distribution grid level should be used as a solution. This leads to utilizing the flexibility of demand side of the system for solving distribution grid operation problems.

UC.11 aims at defining market mechanisms for procurement of ancillary services from end-user electricity consumers such that both system operators and consumer benefit from trading ancillary services in the system. To this end, a local flexibility market is introduced that allows the aggregators to trade the flexibility of their under-contract end-users with the DSO or other aggregators. DSO can use the offered flexibility of aggregators to solve the operation issues of the distribution grid. DSO or the local flexibility market operator can also trade the net flexibility of this market in upper-level ancillary service markets like the regulating power market. The ability of peer-to-peer flexibility trading with neighboring distribution grid can also be considered in this structure.

The main goals of the use case are as follows:

- Design and describe a flexibility market for procuring ancillary services from demand side of the power system which in this case are the end users heat pumps.
- Defining new roles and duties for the electricity market players to adapt with the new framework.
- Reducing the congestion in the distribution grids using the flexibility provided by the end-user consumers.
- Providing incentives for end-user consumers, aggregators, and DSOs to participate in the new ancillary service market.
- Design and implement optimization algorithms to help end-user consumers, aggregators, DSOs and TSO to participate in the new ancillary services market.
- Quantify and manage the available energy flexibility at building and LV grid level in real time

6 Technical Requirements

There are several requirements that need to be satisfied in order to allow an efficient implementation of the defined use cases. These requirements are of different nature; some are strictly technical, and others are rather higher level, i.e., requiring some functionality to be present. In any case, the higher the number of the satisfied requirements, the better the effects of the use case implementations. This simply means that for a specific deployment only a given efficiency of the use cases implementation is achievable, without increasing the number of satisfied requirements, i.e., without additional investments.

Most of the use cases involve energy management algorithms that interact with the energy grid infrastructure and assets. The better the interactions are, the more the algorithms can achieve. As shown in Figure 17 and depending on the use case, the energy management algorithms need to have controllable energy production, energy consumption and storage available, in order to operate. Additionally, in order to have a good base for their decisions, they need sensors providing the values of the needed parameters and, in order to perform their actions, they need actuators executing the needed procedures. These interactions define the requirements from the first set – requirements related to the interactions between energy management and the energy grid (see Table 15).

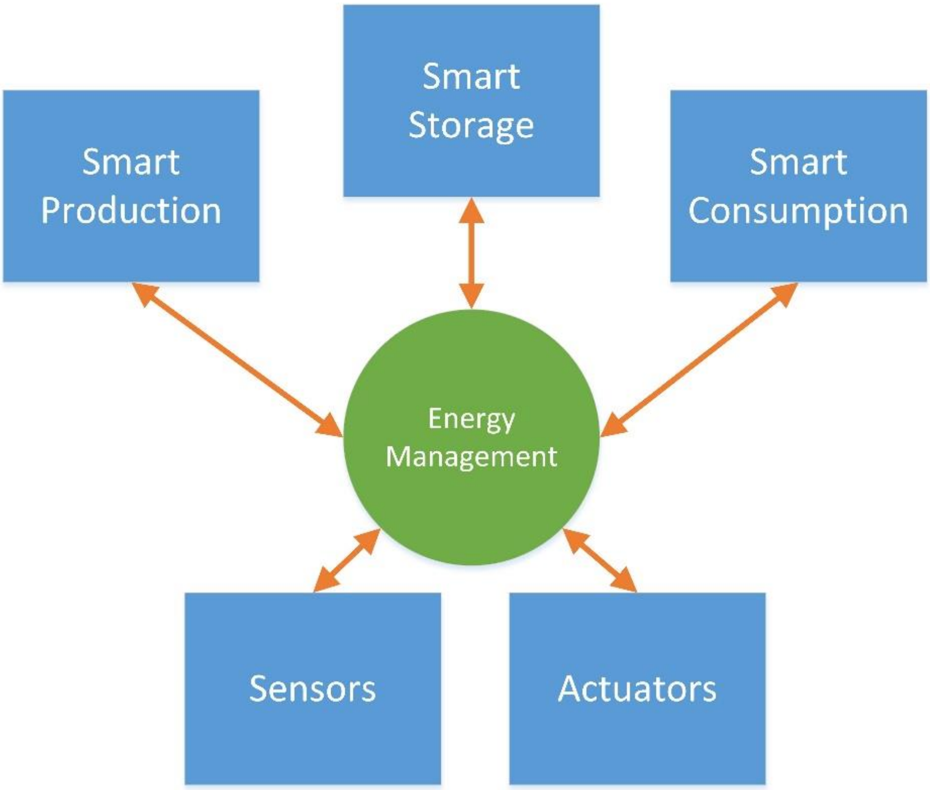


Figure 17 Energy management algorithms interacting with the energy grid

Additionally, as shown in Figure 18, there are interactions involving different instances of the energy management (algorithms). These energy management instances can belong to a single stakeholder, representing a single, distributed energy management algorithm. But they can also belong to different stakeholders, realizing possibly different tasks, but for instance, exchanging data. These interactions define the second set of requirements – requirements related to the interactions between energy management instances (see Table 16). These requirements include strictly technical ones, but also requirements related to the market aspects.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°864283

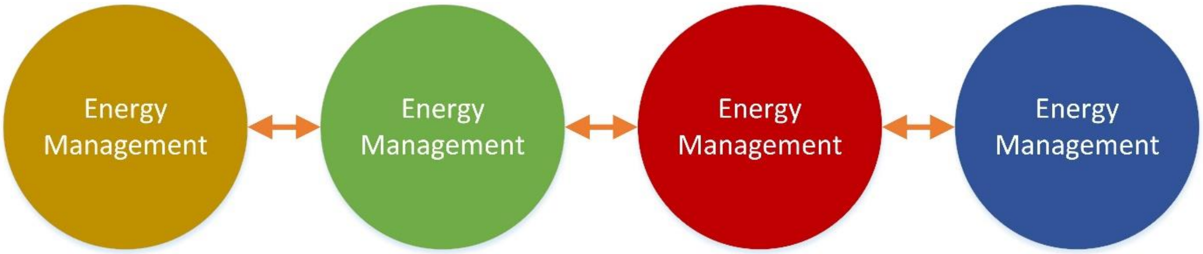


Figure 18 Different energy management instances interacting with each other

The third and last set of requirements include those related to the implementation of the energy management platform (see Table 17). These include requirements covering the low level implementation issues, as well as those related to the interaction with the users, like the (graphical) user interface, making them sometimes very close to the social requirements covered in the Section 7.

Table 15 Requirements related to the interaction between the energy management and the grid elements

Req. no	Requirement description
a1	Energy balancing algorithms require energy status of flexible electric loads at least every 15 minutes
a2	Building loads must allow some kind of energy management system with a standard communication to change the energy profile
a3	There is a need to support interoperability, the ebalance-plus platform shall be able to communicate with the grid devices installed in the deployment. A set of adapters is required to translate the commands/requests on both sides to enable data exchange.
a4	The management units need a proper set of communication modules/interfaces to be able to communicate with the grid assets and devices the algorithms need to interact with.
a5	To participate in the ancillary market, it would be necessary to include a small device to measure the grid frequency so the prosumers can response to these deviations.
a6	For the energy management algorithms it is often necessary to have a prediction of the behaviour of the grid devices and energy users.
a7	In order to ensure the forecasts reliability, it is necessary to define the principles of the users behavior to reduce uncertainty. An example could be the working schedules, the charge of electric vehicles, etc.
a8	The energy management algorithms require measurements of the system state (e.g., energy consumption/production in a building or household).
a9	The measurements and interaction between the energy management algorithms and the grid devices may have specific real-time requirements (e.g., maximum delay).
a10	Topology definitions shall include at least the following information: - Line Specification (length & conductance) - Load Specification - Number and location of smart meters and switches (depends on use case)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°864283

a11	The inputs of the Voltage Qualiy Assurance (VQA) algorithm shall be: - Voltage (V) - Active Power (MW) - Reactive Power (MVAr) - Frequency (Hz) - Power Quality Metrics (List of absolute values) - Events (List based on FIWARE definition)
a12	The outputs of the VQA algorithm shall contain the found correlation between metrics and events along with their expected impact to voltage quality according to the VQA standard
a13	The inputs of the FDIR algorithm shall be: - Voltage (V) - Active Power (MW) - Reactive Power (MVAr) - Relay Fault Flag (On/Off)
a14	The output of the FDIR algorithm shall be: - State of switches (On/Off)
a15	The inputs of the VVC shall be: - Voltage (V) (from distribution grid and RES) - Active Power (MW) (from distribution grid and RES) - Reactive Power (MVAr) (from distribution grid and RES) - Tap position (number) - Capacitor Bank status (on/off per capacitor)
a16	The outputs of the VVC algorithm shall be: - Capacitor bank new status (on/off per capacitor) - TAP Position (number) - Line Capacitor Status (on/off) - RES Set-Point (desired power factor)
a17	The inputs of the IISL shall be: - Voltage (V) - Active Power (MW) - Reactive Power (MVAr) - Frequency (Hz) - Switches State (On/Off)
a18	The outputs of the IISL algorithm shall be: - Switch State (On/Off) - DER Scheduling & Dispatching
a19	The Inputs of the TRM algorithm shall be: - Voltage - Current - Phase - Temperature - Vibrations - Magnetic Field
a20	The output of the TRM algorithm shall include only KPI values.

Table 16 Requirements related to the interaction between energy management instances

Req. no	Requirement description
b1	Energy balancing algorithms require upwards steering signals (demand response, contingency, etc.) and energy profile forecasting (demand/generation) at least every 15 minutes.
b2	Energy aggregator should have access to the flexibilty status of their customers anytime.
b3	CMU and DERMU must publish the flexibility profile (predicted consumption plus max/min power) in the ebalance-plus platform with a granularity of 15 minutes and every 15 minutes.
b4	DSO must include/indicate voltage/power thresholds for primary and secondary substations in the ebalance-plus system.
b5	It is necessary to provide interoperability between the ebalance-plus platform and other EMS. Specific adapters that translate the APIs of both sides should allow including and manipulating information dynamically, e.g, by the DSO's EMS.
b6	It is necessary to have a Local / Regional market that supports trading flexibility.
b7	To be able to involve aggregators there is a need for wholesale market open for DR and independent aggregators.
b8	The energy management algorithms need parameters from external sources, like energy tariff details, weather parameters and forecasts, and the like, to realize their tasks.
b9	For all the interacting components and systems there is a need to have a common way to represent the temporal data and state changes. For instance, as a time series with compatible intervals, i.e., intervals that can be adapted for each other by means of aggregation (e.g., 5-minute interval vs. 15-minutes interval).
b10	For the interaction between the different energy management systems, it is necessary to consider and implement their respective security measures and protocols, in order to keep the composed system secure.
b11	The internal avaluation results by the energy management algorithms (KPI) need to be shared and available in the platform.
b12	The KPIs of the Voltage Qualiy Assurance (VQA) algorithm shall be: - The standard's measures non-compliance - DER impact on voltage quality
b13	The KPIs of the FDIR algorithm shall be: - Customer service interruption - Total reconfiguration time
b14	The KPIs of the VVC algorithm shall be: - Voltage violations - Technical losses - RES Energy Injenction
b15	The KPIs of the IISL algorithm shall be: - Number of distinct customers with service interruption
b16	The KPIs of the TRM algorithm shall be: - Asset Health Awareness - Low-voltage network status visibility

Table 17 Requirements related to the implementation of the energy management

Req. no	Requirement description
c1	Energy balancing algorithms require prosumer's preferences regarding optimization type (cost-, CO2- basis)
c2	The connectivity between the management units within the platform needs to be reliable to enable data exchange. It can be based on Internet, but also on other approaches, like PLC and others.
c3	The ebalance-plus platform needs a stakeholder to be responsible for its administration - at least to manage the main top level units
c4	The ebalance-plus platform needs to be configured for the deployment - the management units need to be installed within the grid and properly configured. The top level units (discovery, proxy, certification authority) need to be configured as well.
c5	Each participant in the ebalance-plus platform needs to be registered and her services need to be registered as well.
c6	There is a need for a technical means for the stakeholders to be able to install their services on the management units - according to a defined access policy of the other stakeholders that manage the management units.
c7	Each instance of the middleware requires a globally unique Id within the deployment.
c8	The ebalance-plus platform requires the correct environment on the MUs to run (e.g., JVM 8.0 and higher and Linux OS)
c9	grid assets and controllable devices that are accessed via cloud services require Internet access at the place of installation.
c10	For the installation of the energy storage an appropriate place must be sought indoor, with enough space and with the following requirements: • Temperatures between -5 ºC to +40 ºC and relative humidity between 5% - 85%. • Appropriate clearance from any object or surface. • Easy access to the electrical distribution board.
c11	The mobile application the users will use to monitor their equipment shall also be able to access the necessary data it shall display. The data includes, for instance, the results of the operations by the energy management algorithms. A proper adapter may be necessary.
c12	The (graphical) user interface options shall offer the presentation of a relevant set of data (configurable) to present the user the most interesting aspects of the performed actions (by the algorithms).
c13	The implemented algorithms need a means to monitor themselves and evaluate their functioning based on some KPIs defined for them.
c14	The implementation of the energy management system requires extendability of the current deployment. These include room for necessary equipment (smart meters, sensors and actuators) that fulfil safety requirements.
c15	To support the Voltage Qualiy Assurance (VQA) algorithm, an event list shall be provided and the specification shall be based on FIWARE meta-model definition
c16	To support the Fault Detection, Isolation and Restoration (FDIR) algorithm, an interaction and processing hierarchy shall be defined to allow efficient resource management and problem distribution.

c17	To support the Volt/Var Optimization (VVC) algorithm, the topology shall additionally define: - Generator and RES Generator specifications (Rated Power, Inverter Specification) - Transformer Specification (Voltage Step, Losses) - Capacitor Specification (capacitance) - TAP Specification (voltage step)
c18	To support the Intentional Islanding after Cascading Failures (IISL) algorithm the topology shall additionally provide: - Load Estimation - Generation Estimation - Some predetermined islands
c19	To support the LV Status Monitoring with PMUs and Sensors (TRM) algorithm a GPS server shall be available and accessible.
c20	For procuring ancillary services from distribution grid level it is necessary to provide communication infrastructures between consumers and DERs and aggregators, aggregators and local flexibility market and DSO and TSO.
c21	For procuring ancillary services from distribution grid level it is necessary to design hardware and software platforms for interacting with local flexibility markets.
c22	For procuring ancillary services from distribution grid level it is necessary to Implement smart metering devices throughout the distribution grid with the ability of data communication with the DSO.
c23	For procuring ancillary services from distribution grid level it is necessary to create data hubs that allow the data providers to share the required information for effective participation of market players in the ancillary service markets.

7 Social Requirements

Effective implementation of smart grid solutions increasing electric flexibility and grid resilience requires understanding and acceptance of these solutions by the end user. Therefore, when designing smart grid systems, it is advisable to rely on the knowledge of success factors and barriers for end user engagement, derived from social research and experience from other smart grid projects.

The results of a social survey carried out in the 4 countries where ebalance-plus interventions are planned (France, Denmark, Spain and Italy) gave some general indications on how to design technological solutions from the point of view of electricity consumers. The study collected information from electricity consumers in households (a total of N=3200, n=800 in each of the countries surveyed) and professional smart grid operators at the university campuses (5 interviews of 120 minutes each at YNCREA, University of Malaga and University of Calabria).

Some of the smart grid solutions in the ebalance-plus project are intended to support the flexibility of the energy system at the level of the entire building or group of buildings (as is the case at the university campus), and some are addressed to individual electricity consumers. Therefore, recommendations for smart grid solution design & implementation are presented broken down into applications for university campuses (Section 7.1) and end users in households (Section 7.2). The last section presents a summary and general recommendations for the successful implementation of smart grid solutions (Section 7.3).

7.1 Good practices and recommendations for the introduction of an energy management system in campuses

The success of the solutions designed within the framework of ebalance-plus depends not only on their technical efficiency but also on a number of characteristics of the organisations in which the solutions will be implemented. Based on the social study results drivers and barriers for adaptation of smart grid solutions at university campuses have been identified. Below the key take-outs for smart grid solution designers and managers are described, based on information from the social survey.

7.1.1 Smart grid intervention affects all aspects of the organization.

Interviews with facility managers have shown that when introducing a technological innovation on campus, one has to be aware that this is a change that potentially affects many aspects concerning work and study organization. The introduction of technical innovation on campus has special characteristics because universities and campuses are complex institutions with many actors. There are many user groups (with their own specificity) in institutions of this type. Furthermore, each group has its own assumptions about how the system works, its own mental maps and habits. Therefore, it is important to take into account the needs and habits of all campus users, i.e., researchers, office workers and students.

7.1.2 New solutions should be verified by end users

The success of the solutions designed within the framework of ebalance-plus depends not only on their technical efficiency but also on a number of characteristics of the organisations in which the solutions will be implemented and the way of introduction of the solution to the social actors. In order to minimize the risk of misuse of the technological solution by the end users, it is advisable to test it at subsequent stages of its development - concept, prototype and implementation of the finished product. Since the social factors are very important for the success of the introduction of technology, the following issues should be taken into account:

- When implementing innovations of this type, it is extremely important to take into account the needs and the points of view of end users, and to map potential barriers. This should take place at various stages of project development (idea, creation of use-cases, interface projects, prototype). The designed solutions should be tested and confronted with end users as soon as possible (even at the stage of concept-tests or mock-ups).
- The assumption that designers know how end users think and act should be avoided. Mental maps of end users and their way of thinking about the system's operation are very often different from those of the designers.
- Clear and understandable information and a contact person available in case of problems are very helpful.
- It is advisable to prepare simple, legible information about the new solutions and provide technical support in case of problems.

7.1.3 Smart grid solutions can not interfere with the primary objective of the organisation

It should be remembered that the primary objective of facility managers at campuses is to guarantee energy supply and security for the campus so that it can function properly.

Therefore, solutions that save energy or increase the flexibility of demand must not be associated with difficulties for people using the campus facilities, because in practice it will make them impossible to implement.

According to facility managers' opinions, one of the perceived barriers to the functioning of the energy management system on campuses is an imaginable conflict of interest. This may be the case, for example, when the energy operator requires power reduction (Demand Side Management use case). In such a situation, the facility manager has the dilemma of which goal to pursue first, which is more important - campus operation and user comfort, or reduction of consumption!

7.1.4 Each organisation is at a different stage of transformation

Campuses may differ in their approach to energy-saving innovative solutions. This is influenced by many different factors, i.e.: organisational culture, technological sophistication of the facility management solutions used on campus, skills held internally within the institution, available budget and resources, status of facility manager as institutional actor, scopes of tasks and responsibilities. The energy transformation at universities is not a one-off event, but rather a long, gradual process. Individual universities participating in the study were at different stages of this process and differed in organizational culture, technological competence, budget allocated for energy-saving solutions, etc. Therefore, when preparing smart energy solutions for such institutions, it is advisable to take into account their specific needs and prepare solutions that will be easy to implement in most entities, including those less technologically advanced, and devoting a smaller part of their financial and human resources to improve the energy efficiency of their buildings.

The functionalities implemented within the framework of ebalance-plus should not be thought of as a technical solution implemented on a one-off basis, but more as a new system feature implemented in technical-social process. This process takes time and should be conducted in dialogue with end users. They need time to know and understand the changes, change habits and mental maps. This is particularly important for new technological solutions.

7.1.5 New solution should fit into the current habits and daily routine of end users

Innovations are better adapted, when they are in line with current habits and mental maps of end users. Ideally, the system's performance and characteristics should be rooted in the end-user's values and motivations. The analysis carried out showed that some of the designed features of the smart grid system may seem hard to understand to users, or may not work in accordance with rooted mental maps. It is important to communicate well with the end user through a friendly-user interface, design an effective way of engagement and to embed functionality in values. Such a way will enable to motivate the end user to give up part of his own comfort up to benefits for society (better use of resources, low-carbon economy, environmentally friendly system). It also helps, when there is a direct and evident link between the end user action and the result (e.g. the savings in power consumption in the dormitory are shown on the display).

7.1.6 Advice for engineers and designers

It is recommended to consider the following points while designing new smart grid solutions:

	Potential Issue	Recommended Action
1	Organizations vary greatly in terms of their technological solutions, experience and limitations (eg. budget or staff)	Prepare solutions that are applicable also for less technologically advanced organisations

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°864283

2	At the solution design stage, evaluate the design from the user's point of view	Create models/ prototypes of systems and interfaces and test them with end users
3	Different actors have different needs and goals	Take into account the complexity of the system and all involved actors with their own goals and interests
4	Systems can be more difficult to understand and operate than expected	Do not assume that the system will be self-explanatory – create touch points where you can explain something to the end user
5	There are instances where available user knowledge is not incorporated at an early stage of solution design	Ensure that designers are familiar with the available knowledge about end users, their behaviors, habits, needs.

7.1.7 Advice for smart grid systems managers

Finally, based on the study findings, we can formulate some advice for the smart grid managers who are responsible for implementation and maintenance of the innovative smart grid solutions at the university campuses:

	Potential Issue	Recommended Action
1	Adaptation of all campus members to the new energy management system is usually slower than expected, it is a process when people's mental maps change and end users learn new habits	Schedule a realistic time for users to become familiar with the new system and to implement it
2	Understanding how the system works for the average user may be more difficult than its designers assume	Use various communication tools to communicate how the new system works: posters, e-mails, video, use simulation, training for change leaders' minds who may actively pass on knowledge to others
3	If something does not work, end users tend to think that there is a failure	At the first stage of implementation, it is recommended to introduce a contact person who will be the first point of contact. Often it is enough when a real person explains the logic of the system to the users.
4	A system is difficult to understand if its performance changes over time or is different in different parts of the building.	Avoid dividing the space into separate sectors where the logic of the system is different (e.g., when in some rooms you can regulate the heating yourself and in some rooms you cannot).
5	Do not assume that information or data alone means energy control. True control is when information is used to do real improvements.	Monitor system operation. Check if it works as intended, if it achieves its goals, if end users use it correctly. Improve the observed imperfections and check the effects of changes.
6	Sometimes complaints about the performance of a system are not due to faults in the system, but to a lack of understanding of how it works	There should be a clear and understandable information available for each end user and a designated contact person responsible for technical support.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°864283

7.2 Openness of households to smart grid interventions

The main implications of the study regarding individual electricity end users, from the perspective of their households, are summarized in the points below:

- More than 80% of energy consumers in the countries surveyed (France, Spain, Italy, Denmark) declare that they want to save electricity and choose energy-efficient devices when buying new electronic equipment for their homes.
- The main factor influencing the willingness to save energy is financial, and ecological considerations are mentioned in second place.
- In the opinion of the respondents, the barrier to effective energy saving is the lack of effective and easy to apply solutions that give a noticeable reduction in energy consumption.
- Larger installations for energy production and storage are currently chosen by a small percentage of households with high income. The challenge is to develop new solutions that would increase energy independence of smaller households (both houses and blocks of flats), with more limited financial resources. It would be advisable to prepare new solutions dedicated not only to individual consumers, but also to groups of houses or entire blocks of flats, available in financial plans adapted to the capabilities of less affluent people.
- For a majority of people, environmental considerations are an important motivator to change the way they use electricity. Therefore, in a situation where the financial savings resulting from the introduction of solutions limiting and making the demand for energy more flexible are small, it is advisable to focus on environmental benefits in communication.

Main points regarding intention to buy and use electric cars in the future:

- In all the countries surveyed, environmental considerations are the main factor in choosing the next car to buy. About half of the people surveyed declare that the next car they buy will be hybrid or electric.
- The cost of electricity at a level equal to the price of fuel for a car with an internal combustion engine is unacceptable to half of those who own or are interested in buying an electric car. Currently, most of these people expect that the cost of electricity to charge the car will be significantly lower than the cost of fuel for a traditional internal combustion engine.

Individual electricity end users' opinions about smart energy systems:

- Concepts of systems for smart management of electricity are understandable to about 80% of the respondents, and more than half of the respondents are interested in using such solutions.
- The respondents want to have control over energy management systems; they expect that the end user interface would give them a sense of control over the system.
- The intention to use systems for smart management of electricity consumptions is motivated by financial benefits, simple operation, trouble-free (preferably free of charge) installation and positive environmental impact.
- General attitudes towards technological solutions are positive. Technology is perceived as something that makes life easier, helps, gives access to new information.

- The people surveyed are generally aware of climate change and consider it a serious problem, both for their country and for them personally. Therefore, the ecological aspect of more efficient energy use is important to most of them.

7.3 Social requirements summary

The interviews carried out have shown that a successful adoption of new functionalities will be fostered by treating innovation not only as a technological tool, but also as a system which has an important economical-social dimension. Therefore, the proposed new solutions be designed with the following advices in mind:

- Facilitate the use of existing mental maps of end users. This will significantly shorten the process of adopting the system and learning how it works.
- Take advantage of the possibilities offered by mobile technology – many functionalities can be available through smartphone applications.
- Provide an opportunity for future expansion. Plan an open structure, offering not only the possibility to connect to existing systems in technical terms, but also to take advantage of possible information synergies. Combine new data and information with the data that already is in the system, and present it in the form of clear dashboards, charts, analyses.
- While designing, take into account everything you know about end users (their needs, habits, mental maps) and test the resulting solution, if possible, at several stages (concept, prototype, finished solution).
- Monitor the effects of the introduced innovation - both on the level of impact on energy consumption and end user behaviour (do end users understand the system operation, do they use it correctly, is the system convenient and useful). Correct the observed imperfections and again - monitor the effect of changes.
- Consider goals of different end user groups. Ideally, a facility manager combines technical mastery and the ability to interact with end users in order to understand their needs.

8 Conclusion

This document presents the use cases defined for the ebalance-plus project. With these defined use cases and their requirements, the project consortium will go ahead with the implementation of the energy management algorithms to be applied in the pilot sites in the demonstration phase of the project. The identified requirements will also help to control the deployment of the solutions. During the demonstration phase the KPIs will be used to evaluate the deployed solutions.

During the preparation of this document additional information on the use cases described here were collected. It extends the description provided here and is maintained as a living document that is adapted and modified as needed. The plan is also to integrate the ebalance-plus use cases in the database approach of the BRIDGE initiative.

References

[1] European Commission, ENERGY UNION PACKAGE, COM(2015) 80 final.
[2] USEF Foundation. (2018). *Flexibility Platform White Paper.*
[3] IntelliGrid Project homepage, http://intelligrid.sdsu.edu/, (accessed 27.02.2021).
[4] Smart Grid Coordination Group. (2014). *Methodology and New Applications- SG-CG/M490/F.* CEN-CENELEC-ETSI.
[5] Xiaoxing Lu, Kangping Li, Hanchen Xu, Fei Wang, Zhenyu Zhou, Yagang Zhang, “Fundamentals and business model for resource aggregator of demand response in electricity markets,” Energy, Volume 204, 2020, ISSN 0360-5442.
[6] USEF Foundation. (2020). *USEF Flex Trading Protocol.*
[7] Smart Grids Task Force: Expert Group 1 – Standards and Interoperability. (2019). *Towards Interoperability within the EU for Electricity and Gas Data Access & Exchange.*
[8] SEDC Report 2017: Explicit Demand Response in Europe – Mapping the Markets
[9] The Delta-ee European Heat Summit *Exploring disruption, change and opportunity in European heating markets,* Edinburgh, 7-8 June 2017.
[10] Prettico, G., Flammini, M. G., Andreadou, N., Vitiello, S., Fulli, G., Masera, M., *Overview of the electricity distribution system in Europe*, Distribution System Operators observatory 2018.
[11] European Commission, Final Report on Study on the quality of electricity market data of transmission system operators, electricity supply disruptions, and their impact on the European electricity markets, March 2018.
[12] International Electrotechnical Commission (IEC). IEC glossary; http://std.iec.ch/terms/terms.nsf/0/1036BB0DDCDB80CDC1257E36004BC268?OpenDocument, (accessed 27.02.2021).
[13] M. Panteli and P. Mancarella, The Grid: Stronger, Bigger, Smarter?: Presenting a Conceptual Framework of Power System Resilience, in IEEE Power and Energy Magazine, vol. 13, no. 3, pp. 58-66, May-June 2015.
[14] J.P. Watson, R. Guttromson, C. Silva-Monroy, et al., Conceptual Framework for Developing Resilience Metrics for the Electricity, Oil, and Gas Sectors in the United States, Technical Report SAND2014-18019, Sandia National Laboratories, http://energy.gov/sites/prod/files/2015/09/f26/EnergyResilienceReport_Final_SAND2014-18019.pdf, (accessed 27.02.2021).
[15] Mar, A., Pereira, P., Martins, J.: A Survey on Power Grid Faults and Their Origins: A Contribution to Improving Power Grid Resilience. Energies. 12. 2019.
[16] Silverstein, A., Gramlich, R., Gogglin, M.: A Customer-focused Framework for Electric *System Resilience*, May 2018.
[17] Fauzan Hanif Jufri, Victor Widiputra, Jaesung Jung, State-of-the-art review on power grid resilience to extreme weather events: Definitions, frameworks, quantitative assessment methodologies, and enhancement strategies, Applied Energy, Volume 239, 2019, Pages 1049-1065, ISSN 0306-2619.
[18] Prettico, G., Gangale, F., Mengolini, A., Lucas, A., Fulli, G.: From European Electricity Distribution Systems to Representative Distribution Networks, Distribution System Operators observatory 2016.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N°864283