D2.1 - Initial Storage Scenarios and Use Cases

Deliverable ID	**D2.1**
Deliverable Title	**Initial Storage Scenarios and Use Cases**
Work Package	**WP2 – Business Models and Requirements Engineering**
Dissemination Level	**PUBLIC**
Version	**1.1**
Date	**2017-06-08**
Status	**Final**
Lead Editor	**EfNIIG**
Main Contributors	**ENiIG, UPB, EDYNA, FIT**

Published by the Storage4Grid Consortium

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731155.

Document History

Version	Date	Author(s)	Description
0.1	2017-01-16	EMIDT	First draft of TOC
0.2	2017-01-27	FIT	Suggests improvement to TOC
	2017-01-30	EMIDT	Second draft of TOC
0.21	2017-02-02	EMIDT	Introduction, Test site description, Scenario
0.22	2017-02-06	EMIDT	Usecases
0.23	2017-02-06	FIT	Inclusion of vision scenario (UPB) and scenario from EDYNA
0.24	2017-02-07	FIT	Inclusion of latest version of UPB's scenario example; Inclusion of list of figures and list of references
0.3	2017-02-14	FIT	Inclusion of Chapter 2, inclusion of current review state of EDYNA's scenario; inclusion of review of ENIIG's and UPB's use cases
0.4	2017-02-16	UPB	Integration of new use case structure for EDYNA, Filling of actors table for UPB
0.5	2017-02-16	EDYNA	Update of use cases for EDYNA, delivering test site description
0.6	2017-02-16	FIT	Use case table updates for UPB, ENIIG, EDYNA, introducing use case overview table, restructuring of TOC
0.7	2017-02-17	FIT	Updated table for Use Case overview (Chapter 1); Revision of EDYNA's Use cases, Integration of latest changes by EDYNA
0.8	2017-02-20	UPB	Improvement mainly in chapters 1-3
0.9	2017-02-20	EMIDT	Project goals added Updated Chapter 5 and 6.3
0.94	2017-02-21	FIT	Restructured chapters 4 and 5 to match the structure of chapter 3, closed many comments, proofreading
0.95	2017-02-21	FIT	Added some UML diagrams for EDYNA's and ENIIG's cases, text font and color correction for figures and tables
0.96	2017-02-23	EDYNA	Making further improvements
0.97	2017-02-24	EMIDT	Making further improvements in HLUC-3-PUC-2-3-4
0.98	2017-02-27	UPB	Making further improvements and internal review
0.99	2017-02-28	EMIDT	Final improvement, ready for submission
1.0	2017-02-28	FIT	Unification of all tables and figures as well as their references. Use cases and UML diagrams linked through reference to the figure.
1.0	2017-05-29	EDYNA	Changing Chapter 4.4. Cooperative charging in the parking lot of a commercial test site - HLUC-2-PUC-2 and Chapter 6.2. Testsite Bolzano
1.1	2017-06-03	UPB	Internal review of v1.1

Internal Review History

Review Date	Reviewer	Summary of Comments
2017-02-28	Mihaela Albu, UPB	• Approved
2017-02-28	Giovanni Paolucci, Apleria	• Approved
2017-06-06	Mihaela Albu, UPB	• Approved

Table of Contents

1 Introduction

The purpose of this deliverable is to present the initial Storage Scenarios and Use Cases identified at this early stage of the project. Final description will be described in D2.2 “Final Storage Scenarios and Use cases”, to be released in M18 and having updates on this initial version, based on the advancements in understanding, detailing and redefining different aspects related the initial proposal of use-cases. This deliverable is part of Task 2.1. Storage Scenario and Use Case definition.

The S4G project has identified three scenarios, which will be each addressed in a specific test site.

- Lower TRL solutions will be experimented and evaluated in a lab-scale test site by using MicroDERLab facilities in Bucharest, Romania (part of European DERLAB network)
- Higher TRL developments will be evaluated in two different real-life distribution grid infrastructures and energy use patterns:
  - in northern Europe (Island of Fur, Denmark) interacting with end-users;
  - in southern Europe (Bolzano, Italy), interacting with professional and end-users leveraging small-scale real-life test sites.

These test-sites will be used to test and improve a prototype control system and to compare different approaches in terms of:

- ease of deployment and maintenance;
- customer acceptance and behavior change;
- impact of self-consumption/uptake of renewables sources;
- economical cost/benefit ratio.

The generated experience will be used to pre-design a set of standards for distributed storage monitoring and controlling, aligned with the existing ecosystem, suitable to properly monitor and control available storage resources.

1.1 S4G in the context of the European Commission’s new Winter package

The new Winter package recently released by the European Commission brings major novelties which are much in line with S4G’s content.

The package specifically includes a binding energy efficiency target of 30% by 2030, with opening for high RES penetration and to what is called "community-owned and managed" renewable energy. Campaigners say that if "community energy" - the right to store and sell energy - is allowed to fulfil its potential, over half of European citizens could be producing their own renewable energy by 2050 [1].

The figure below gives high expectations on the amount of *energy citizens* in the perspective of 2050 horizon considering electric boilers and vehicles, solar and wind installations as well as large deployment of batteries. The boosting supportive technologies which enable these expectations are highly addressed in the S4G project. S4G is starting its activity at cornerstone moments where storage and PV technologies are getting more advanced and more attractive in price.

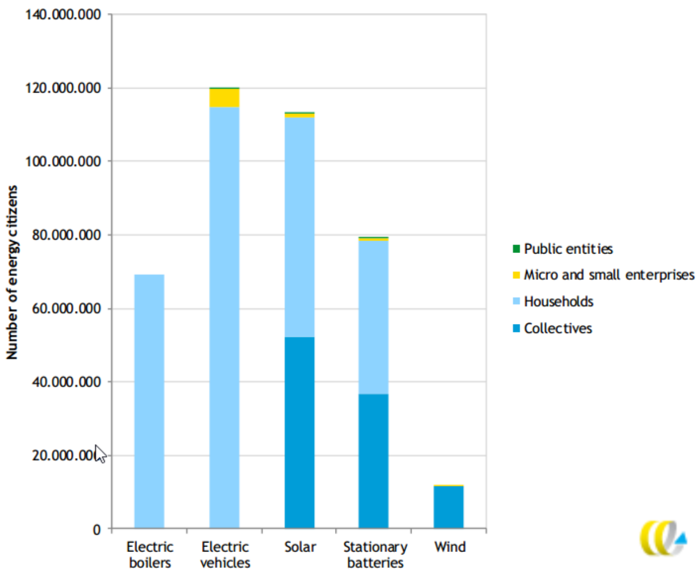

Figure 1 Number of energy citizens for the various technologies assessed, potential t0 2050 for the EU2 [1]

The study [1] estimates around 1800 GWh of energy storage to be considered only for stationary applications, which means an average of 3.6 kWh of storage per citizen (for a population of around 500 million for EU28) or and average of 7.2 kWh per household for an average of two persons per household.
The study considers around 80 million entities to use storage in 2050, thus increasing the average to 22.5 kWh of storage per entity.
Moreover, the same study predicts that for an estimated 120 million EVs in 2050 the total storage will be around 9000 GWh. This means around 75 kWh of battery for each EV, which is in line with the expectation of having EV driving autonomy similar or higher than today's ICE-based cars.

The legislative proposals of the Winter package cover energy efficiency, renewable energy, the design of the electricity market, security of supply and governance rules for the Energy Union.
The new EU package pursues three main goals:

- Placing energy efficiency first;
- Achieving global leadership in renewable energies;
- Providing a fair deal for consumers.

From this perspective, S4G is touching all three new pillars: it enables higher efficiency through more self-consumption and through enhanced control of EV charging and of PV production in existing grids, having as pivotal means the grid and local storage resources; it enables more RES production and give more power to the consumer for cope with profitable deals, enabled by extensive use of storage means.

Figure 2 shows an image about the "*time to research*" moment for the S4G project, as a prerequisite to speed-up the "*time to market*" also through our contributions in showing the potential or higher opportunities and market solutions at the end of the project.

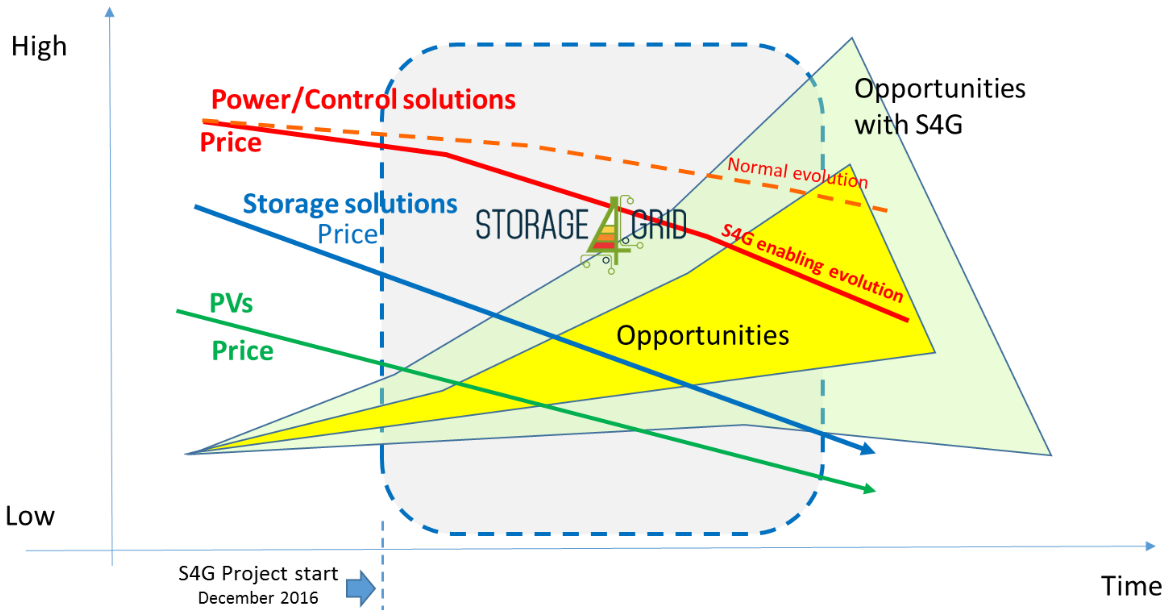

Figure 2 Storage4Grid – Time to research towards solutions for the market

Considering the S4G goals and also the new Winter package challenges, in order to detail the project scenarios and its corresponding use-cases, we are developing first the vision of each scenario.

1.2 Vision for the "Advanced Cooperative Storage Systems" scenario

Vision 1: The prosumer of the future is progressively increasing its resilience, by using advanced local hybrid AC/DC networks to accommodate its energy production, as well as by increasing local storage. This way the prosumer achieves a higher energy efficiency within a cooperative energy balancing with neighbours and cost-effective buyout of missing energy from the European single energy market.

In this respect, the end-user, either being consumer or prosumer, is progressively improving its survivability compared with today's 100% grid dependence, thus beginning to be a more resilient entity.

This target is realized through a new local architecture based on self-production, local storage and increased control of its demand (improved results based on self demand-response) in such a way that it is able to improve auto-consumption of up to 100% of its production. In particular cases, when there is excess of local energy or there is unused storage capacity, a cooperative exchange of energy is possible, with priority through an additional DC network belonging to the local community / neighbourhood. In order to achieve this, appropriate local storage is used, in a way that allows a self-resilient prosumer to be seen:

a) as bidirectional energy player, thus being able to provide various ancillary services, with full compliance with the network code for generation or
b) acting just as a consumer from the DSO grid side (no back generation), as its entire local production is controlled through an energy router, supporting advanced strategies for implementing an internal energy ecosystem, including EV charging and neighbourhood exchange for 100% consumption of its local production.

In the second approach, from grid side it is a self-resilient consumer who has connection to the traditional AC network for absorbing only energy, and essentially relying on its internal hybrid networks, with DC busses - to accommodate more efficient DC-consumption and DC-based production and storage, resilience for critical loads and neighbour "community energy" exchange. Resilient AC bus for legacy loads is also part of the ecosystem.

The prosumer transformed in a self-resilient consumer, as seen on the grid side, is labeled as *UniRCon* (Unidirectional Resilient Consumer).

1.3 Vision for the "Cooperative EV Charging" scenario

Vision 2: To use at higher limit the power grid, with minimal or no reinforcement, in order to accommodate as much as possible public and private EV chargers, by combining efficient cooperative charging with the support of high energy storage penetration.

Traditional network evolution, when consumption is increasing, is based on classic grid reinforcements such as installing bigger transformers and/or new or strengthened lines. These solutions do not need usually research, but use classic studies which propose developments of the network.

As an alternative, the S4G project starts with the vision of needing to serve the highest possible EV charging services in the current power network, i.e. without substantial reinforcements.

The project values the synergy between EV charging and storage solutions, in addition to cooperative charging based on correlated charging needs, such as e.g. the total EV load is well spread over the day (thus reducing temporary peak loads). Grid-based storage resources need to be used for the purpose of improving the impact on the grid, thus to allow grid acceptance and higher penetration of EVs.

The main goal of the project's Decision Support Framework (DSF) tool is to evaluate and estimate the technical and business feasibility and sustainability of MV and LV scenarios, where storage means are installed, to be used for EV charging.

The EV scenario will be evaluated for current grid situation and an evaluation will be made also in the situation of high penetration of EV charging stations.

As this situation is not yet attended, we are considering use cases which can be demonstrated at this stage, and in order to anticipate the near future higher penetration, we are also considering an appropriate scaling of existing EV related processes such that the grid can reach congestions and power quality (especially voltage level) problems. The scaling process will be simulated on existing grids and with amplified (overunity scaling) EV chargings, to simulate higher EV penetration. This scaling factor will be chosen based on power network calculation on appropriate scaled EV charging stations, so congestion and power quality may appear. For these situations it will be analyzed how the EV charging capability can be improved with the cooperative charging approach helped by storage means, in the condition of avoiding the network constraints.

With this approach, the fact that current network situations as well as current EV charging patterns do not stress so much the existing grid, the simulation is able to analyze the same patterns in a scaled EV charging situation, where proper storage (also scaled by simulation) can improve the capacity of serving charging services.

1.4 Vision for the "Storage Coordination" scenario

Vision 3: To use at highest grade the power grid, with minimal or no reinforcement, in order to accommodate the integration of highest RES production, to cover up to 100% of local consumption, by using storage coordination of combined energy storage means at end-user and grid level.

The main goal of this scenario is to analyze how distributed and grid-connected storage can bring the following benefits:

- Increase the DER penetration with existing network, thus avoiding grid reinforcement in condition of up to 100% renewables in the LV grid, compared with average consumption in the local grid, by using storage coordination from DSO perspective
- Improve end-user efficiency and resilience as a stand-alone entity coping with existing network.

In this respect, the vision of this scenario (particularly focused on the Fur demonstrator), is that in the medium- to long-term future the grid needs to be able to support highest renewable energy sources (production) without reaching network constraints. This is not an issue today since todays' existing renewables production is being low compared to consumption and the current grid has enough strength due to reserve in its capacity.

For this, the today situation will be analyzed and strategies of control will be developed in the project use-cases. To assess also the expected higher penetration of RES, additional scaling of RES will be made to such degree that consumption in certain periods of time is entirely covered by RES production, e.g. 80 to 100%. RES scaling will be simulated based on existing patterns of evolution and within the existing grid. In such moments the grid is expected to face congestions and voltage related problems, thus asking for traditional limitations such as RES curtailment. Through simulation of the high RES penetration situation, the limitations will be overpassed by the storage coordination (additional storage resources will be also scaled by simulation).

The project intends to show improvements in network operation in both todays' situations and in the projected future simulated through appropriate scaling by using coordination of storage means placed at end-user level, on grid level or as a combination of both. The end-user storage solution will be analyzed also in combination with the outputs of vision 1 which is related to a self-resilient consumer approach.

1.5 Overview on key facts about the three Storage4Grid scenarios

This section presents key facts about all three S4G scenarios at a glance. It shows the scenario's goal, its means of achievement, as well as the context in which the scenario is applied. At last, the pilot environment is listed for each scenario.
The presentation of these facts allows a comparison between the three scenarios.

Table 1 Overview on key facts about the three Storage4Grid scenarios

	Advanced Cooperative Storage System	**Cooperative EV Charging**	**Storage Coordination**
Goal	• Increase prosumer's energy resilience • Increase energy efficiency • Empower the citizen through more flexible options in purchasing energy from the AC network • Increase the resilience of a local smart community by enabling a hybrid neighbour energy ecosystem	• Increase the grid services following improved grid operation up to the secure limit situation, by serving as much as possible public and private EV charging with minimal or no classic grid reinforcements	• Increase the grid services following improved grid operation up to the secure limit, by accomodating up to 100% renewable based generation (relative to average energy consumption) connected in the LV grid
Means of achievement	• Local hybrid AC/DC networks and extended use	• Cooperative energy EV charging coordination	• Local storage owned by prosumer/household as

	of DC internal network • Local storage and production based on appropriate design dimensioning and on intelligent operation • Cooperative energy balancing / exchange with neighbours through a DC network • From the DSO's perspective, a net-metered prosumer changes into a unidirectional resilient consumer	• High power capacity electricity storage owned and operated by a prosumer (household and commercial) as well as by DSO • Upscale of existing situation through simulation, up to a maximum number of EV charging stations with minimal or no classic grid reinforcement	well as by DSO • Grid-, i.e. substation-based storage • Upscale of existing situation through simulation, to accommodate up to 100% renewables (compared with average local consumption)
Applied context	• Need for energy-resilient and empowered citizen, both as a stand-alone user and as a user integrated in a local smart community	• EV high penetration context, combined with high penetration of renewables in the same grid	• Renewables high penetration context (up to 100% of average consumption of the LV area)
Pilot environment	Lab	Field trial and supportive simulation	Field trial and supportive simulation

1.6 Project goals

S4G aims at boosting the uptake of storage technologies between the distribution grid level and the end-user level, by developing a novel, holistic methodology for modeling, planning, integrating, operating and evaluating distributed Energy Storage Systems (ESS) - including storage at user premises and storage at substation level, Electrical Vehicles (EVs), innovative energy metering and energy-routing technologies.

S4G will deliver: (i) a **Decision Support Framework** allowing utilities to evaluate costs and benefits of existing and hypothetical storage installations, for various energy use patterns and regulatory landscapes; (ii) a **Distributed Control methodology** for ESS; (iii) an **innovative Unbundled Smart Meter** to enable ESS control in real-life settings; (iv) an **Energy Router** for provision of future grid services by ESS.

These deliverables are broken down into 6 Technical Objectives (TO) and 5 Strategic Objectives (SO), which have success criteria as shown in Table 2.

Table 2 Overview on Storage4Grid's project goals

Obj. #	Indicator	Success criteria		
		End of Y1	End of Y2	End of Y3
TO1	Prototypes supporting S4G interfaces and models for storage coordination	4	9	9
TO2	Sets of distributed and centralized storage control algorithms prototypes developed	2	4	9
	Systems embedding S4G predictive control algorithms	1	3	3
	Systems considered by the S4G	Residential	Residential storage	Residential

	predictive control algorithms	storage	DSO-side storage	storage DSO-side storage EV charging stations
TO3	Test deployment of Unbundled Smart Meter prototypes	Bucharest	Bucharest Bolzano Fur	Bucharest Bolzano Fur
	Systems fully integrated with the prototyoes of unbundled smartmeter adapted for the S4G purposes	Laboratory (production and consumption) meters	Y1 systems + Energy router Residential storage	Y2 systems + EV home charging Stations
TO4	Test deployments of Energy Router prototypes	0	1	2
TO5	Availability of DSF components	20% of related specifications implemented	50% of related specifications implemented	100% of related specifications implemented
	DSF Features supported	Analysis by simulation	Y1 goals + Optimization	Y2 goals + Planning
TO6	Number of different cases evaluated in test sites Bucharest/Bolzano/Fur	1	3	6
SO1	Number of residential/professional users engaged in test sites	5 residential 2 professional	6 residential 5 professional	6 residential 10 professional
SO2	Number of Business cases proposed/ evaluated	1	2	4
SO3	Number of complete techno-economic planning cases analysed using the DSF	(early proof of concept using DSF)	2	4
SO4	Number of inputs proposed to EU or regional policyrelated, traditional or open standardization initiatives	Early gap analysis internally available	2	4
SO5	Number of inputs, lessons learned and recommendations published towards security- and privacy-related initiatives	Early inputs internally available	2	2

2 From Scenarios to Requirements – Methodology

In the past 30 years, the electricity sector slowly changed from a centralized system with huge power plants to a market based system where former consumers grew into the role of producing their own energy using private renewable generators. This created the need to switch from a solely engineer and technology driven view towards a more consumer and prosumer-friendly approach when it comes to developing the future electricity network [2]. Smart grid concepts range "from the development of a European Super grid to the construction of local, loosely-linked micro grids" [2]; even though the concepts differ, the most important idea from all of the modern approaches is to actively involve the end users and thus to increase the acceptance of renewable energy sources. The importance of early user involvement in the design process of smart grid solutions is depicted by various projects and reports (e.g. [3], [4]).

Resulting from that, a user-centered design (UCD) approach was chosen which can be combined with technology-driven methods. This ensures that the project's outcomes will be able to address future potential of storage in the context of peak load shaving and the integration of electric vehicles (EVs) in the smart grid as well as to solve current issues such as voltage peaks caused by renewable energy generators. Additionally, this approach reduces the risk of user rejection in later stages of the technology deployment. The UCD approach focuses mainly on user needs and problems. Besides the involvement of end-users such as prosumers and consumers, also the perspective of the DSO is taken into account to guarantee a fitting solution for electricity providers. Technical issues and constraints will be modelled with the help of the external stakeholder group (ESG) and addressed to ensure a coherent and flexible handling of storage applications in future smart grid solutions. The ESG delivers objective insights from external, independent specialists with different kinds of expertise. This ensures that the project's requirements and outcomes are aligned with a vast pool of knowledge from diverse fields, such as standards as well as market and technology trends.

2.1 Involving users and stakeholders

UCD is a framework of processes and methods which is not limited by the use of specific interfaces and technologies. This allows for flexible adaption to different end-user needs and demands. As depicted in Figure 3, the UCD process uses iterations to adapt to changing user needs and requirements as well as to limitations and problems which may occur during the project development at any stage. It is composed of four different phases:

1) *Understand:* Understand and specify the context of use; this phase also identifies user groups and their needs
2) *Specify*: Specify requirements based on previous analysis; This phase requires filtering the gathered requirements according to priority and feasibility
3) *Prototype*: Produce minimal feasible design solutions to meet requirements; this phase is used to portray and prototype knowledge which was gained from the previous phases
4) *Evaluate*: Evaluate design against requirements; this stage usually involves gathering direct user feedback

Iterations can happen between any phases in the process, but are usually triggered after evaluation.

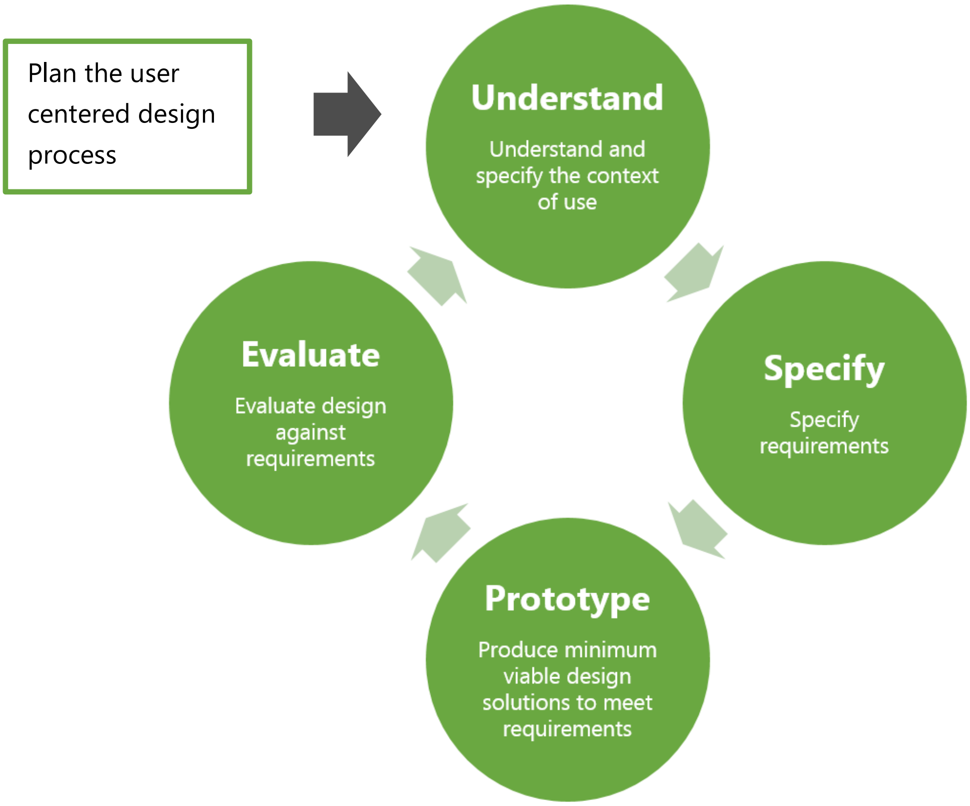

Figure 3 The UCD process adapted from the standard ISO 9241-210:2010 [5]

The UCD process offers multiple methods which are built on close interaction and discussion with users. This ensures the best possible information and feedback gathering from a human perspective. Hereby, the application of specific methods depends on the level of (already gathered) knowledge as well as on available resources.

In Storage4Grid, end-users (prosumers and consumers as well as owners of EVs) are especially involved in the test site of Fur (Denmark) and in Bolzano (Italy). Besides end-users, several stakeholders were identified who are represented by project partners and the ESG. Those two test sites will provide input for user-centered needs and requirements analysis using different methods, such as interviews and observations. The analysis phase will be executed with respect to projects and reports from the smart grid domain to aim for the best possible results in specifying needs and concerns in the application field of smart grids (see [3], [4], [6], [7]).
S4G's test site in Bucharest, Romania can be seen as a technical demonstrator that focuses on the potential capabilities and boundaries of specific low TRL hardware and software solutions.

For the initial scenario and use case development, information was gathered from the local DSOs (EDYNA; ENIIG) as well as technology researching facilities (UPB, UNINOVA) to ensure a goal-oriented project development. The ESG as well as the end-users will play a more important role in future iterations of the requirements gathering and specification process.

2.2 Technical aspects and conformities

Being conformant with already existing standards is one of the goals of Storage4Grid. Therefore, the documentation of use cases as one basis for requirements derivation will be conformant to the EIC62259-2-2015 [8] standard and to the mandate SG-CG/M490/E:2012-12 [9].
The mandate structures use cases into several levels of detail. The following use case types are of special interest for Storage4Grid:

1) High level use case (HLUC): "describe a general requirement, idea or concept independently from a specific technical realization like an architectural solution" [9]
2) Primary use case (PUC): "describe in detail the functionality of (a part of) a business process" [9]
3) Secondary use case (SUC): "elementary use case which may be used by several other primary use cases" [9]
4) Scenarios (S): "a possible sequence of interactions" [9]

This structure will be used to organize the identified use cases for Storage4Grid based on UCD and technical analysis. Use cases will be documented in both textual and tabular form. The latter will be based on tabular use case templates adapted from [10] (see Table 3). Final form will be decided and described in final deliverable D2.2. Additionally, use cases will be documented in a visual form using the unified modelling language (UML).

Table 3 Tabular template for use case documentation

ID		
Name		
Diagrams		
Actors		
Actors Goals		
Pre-conditions		
Trigger		
Postconditions success		
Postconditions fail		
Description	**Step**	**Action**
Extensions	**Step**	**Branching Action**
Sub variations	**Step**	**Branching Action**

The tabular form allows for a structured documentation of use cases with respect to the following information:

1) *ID:* Unique ID for each use case for identification
2) *Name:* Describes the use case content
3) *Diagrams:* Reference to corresponding UML diagrams
4) *Actors:* Active entities of a use case that can be humans as well as machines or systems / system components
5) *Actors Goal:* Depicts what actors want to achieve
6) *Pre-Conditions*: Situations that need to be true in order for the use case to be executable
7) *Trigger:* An action or situation that triggers initialization of the use case
8) *PostCondition success:* The situation or acquired information after the use case terminated successfully
9) *PostCondition fail:* The situation or information after the use case terminated unsuccessfully combined with the reasons that caused the failure

10) *Description:* describes the single steps of a use case
    a. *Step:* Numbered step (starting from 1 to n)
    b. *Action:* Action describes involved actors as well as data and operations
11) *Extensions:* Lists use cases that extend the described use case:
    a. *Step:* References the step of Description where the use case is extended and introduces a corresponding numbering from a to n to relate the branching steps
    b. *Branching Action*: Describes the operations with respect to involved actors and data that causes the use case to be branched
12) *Sub-variations:* Extensions that are caused by a change of the original situation, e.g. weather influences, application of alternative technology
    a. *Step:* References the step of Description where the use case is split into a sub variation and introduces a corresponding numbering from a to n to relate the branching steps
    b. *Branching* Action: Describes the operations with respect to involved actors and data that causes the use case to be branched

2.3 Use case generation

The initial use case generation is based on the vision described in Chapter 1. Given the domain description, the HLUC. PUCs and SUCs were developed in close collaboration with the responsible persons of the different test sites. As a starting point, AS-IS and TO-BE descriptions of the current situation in the smart grid domain with respect to the test sites and the DSO's as well as the technical suppliers were analysed using tabular form templates as shown in Table 4. In order to create a common understanding of the current and the future situation with respect to possible outcomes of the Storage4Grid project, the work was focused on issues, goals, actions, challenges, technology, users, and stakeholders. The resulting facts were used as a direct input for the development of the HLUC listed in the chapters 3 to 5.

Table 4 Example of the tabular template used for HLUC creation

Name of the test site			
	ID	**As-Is**	**To-Be**
Goal			
Action			
Issue			
Challenges			
Technology			
Users			
Stakeholders			

The HLUC were written from a user perspective to emphasize user needs, goals and issues as well as initial input for possible user requirements which will be further researched in future phases of the project. As a first abstraction of the UCD approach, an initial set of PUCs was derived. This abstraction creates a better insight on the role of technical solutions, such as hardware and software and possible interactions and interfaces used for communication between actors.

From the collected set of use cases described in the following chapters, relevant requirements will be derived and enhanced during the project development. The Storage4Grid system development will be based on these requirements and their enhancements.

3 Advanced Cooperative Storage System

3.1 Actor description

Relevant actors for the Bucharest test site's use cases are listed in Table 5. Due to the current level of detail of the depicted use cases not all of the identified actors are also included in the modelled uses cases, which might change with future iterations and further development of the project.

Table 5 Actors identified for the use cases in the laboratory test site in Bucharest

Name	Description	Type
DSO	Distribution System Operator	Person
AP	Advanced prosumer; owns a storage system as well as a renewable energy source and an energy router with high flexibility for providing various energy services to the AC grid;	Person
ASRP	Advanced self-resilient prosumer; owns a storage system as well as a renewable energy source and an energy router with additional features compared with AP: DC bus for local supply of critical loads;	Person
UniRCon	Uni-directional resilient consumer; owns a RES and storage, but does not back-generate into the grid; appears to be / acts as a consumer for the DSO and can have a second DC bus which enable local power balancing with neighbours having a similar achitecture. It is a further evolution of ASRP	Person
Neighbour	Neighbour of the end-user who can be either consumer, prosumer, AP, ASRP or UniRCon	Person
USM	Unbundled smart meter; Smart meter used for communication with the DSO and the ER, which orchestrates the energy ecosystem by including also different software modules such as EMS, external actors communication and local interface.	System
RES	Renewable energy source; owned by Prosumers / AP / ASRPs / UniRCon; for example PVs (other RES types are also possible)	System
DC bus for local resilience	Component of ER which enables a local DC bus to supply resilient loads which allows DC supply. This bus is specific to ASRP	System
DC bus for neighbour enegy exchange	Component in cooperative DC microgrids; used for energy exchange between neighbouring systems. This is specific to UniRCon	System
EMS Software	Software installed in the energy management system; tries to maximize the use of locally produced energy; ensures a dynamic minimal level of energy being stored in the local battery systems; calculations are based on estimations of consumption and production for the next few hours	System
ER	Energy router; communicates with the USM	System

3.2 Resilient and efficient local ecosystem - HLUC-1

The usage of renewable energy sources increased over the past decades, causing new challenges for the grid infrastructure as well as the (AC) grid operators. The energy consumption and production of renewable energy sources highly depends on the weather and is therefore not constant, which ask for additional balancing resources and causes voltage fluctuations in the grid systems. This effect is inflated in small and weak network sections (microgrids). Additionally, in the existing paradigm the decentralized distribution of energy sources and storage causes the need for communication and remote controllable solutions. This can be avoided by increasing the resilience of local energy systems and level of intelligence through advanced local EMS.

As energy efficiency is asked as a first measure or pillar to be considered in the new vision of the Winter package [3], the solution proposed in this high level use-case is considering an architecture which increases the efficiency of energy produced, stored and used locally while enabling self-resilience and empowerment of citizen and its local community. Such empowered ecosystems can serve as well the grid with distribution-related services (ancillary services for distribution) and can use better the available energy from the Eurpoean energy market.

This target is served by using the functionality provided by the Advanced Prosumer (AP) and by the Advanced self-resilient prosumer (ASRP). The architecture of today prosumers with hybrid inverters compared with the Advanced Prosumers with an energy router is presented below in Figure 4.

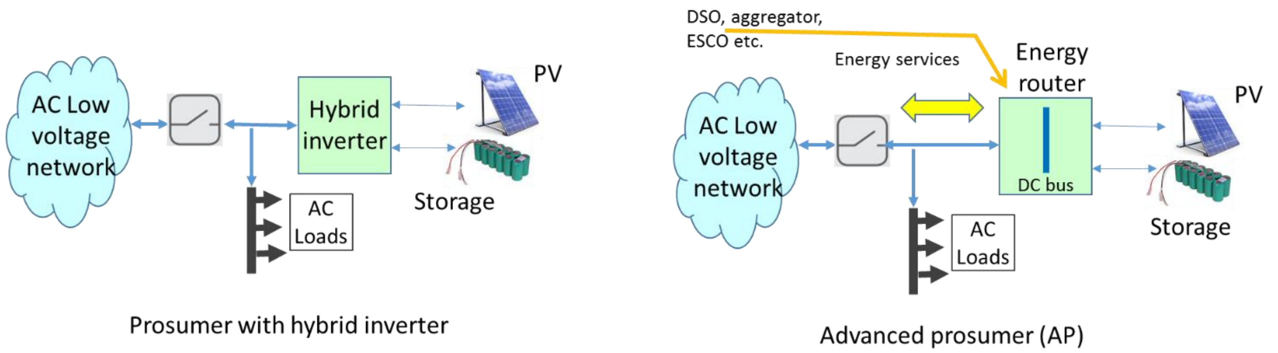

Figure 4 Prosumer with hybrid inverter and advanced prosumer (AP), having an energy router

The main difference is in the fact that due to more flexible solution, the advanced prosumer is also able to provide energy services requested by DSO, ESCO or aggregator. The advanced prosumer is able then to ensure grid strengthening and to provide on request different ancillary services and will be subject of primary use case no. 1 (PUC-1)

The resilience of the prosumer with hybrid inverter as well as of the advanced prosumer is ensured only after the breaker disconnects the prosumer from the AC network.

A more resilient prosumer is the one which uses the energy router internal bus to supply resilient DC loads at the prosumer local premises, as per Figure 5a. These loads make the prosumer even more resilient, and for the resilient local loads it is not needed that the network is disconnected.

Figure 5b gives an advanced variant comparing with ASRP, when the energy router has only consumption behaviour on DSO side and which is able to balance prosumer internal energy through an additional DC bus to connect to neighbours.

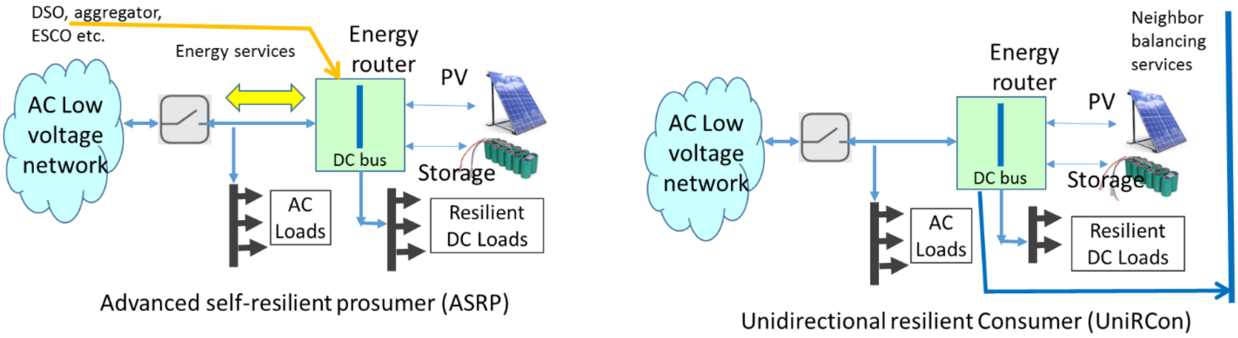

Figure 5 a) Advanced self-resilient prosumer (ASRP); b) Unidirectional resilient consumer (UniRCon)

3.3 Grid strengthening and ancillary services simulation (providing services for the DSO) – HLUC-1-PUC-1 (Advanced Prosumer – AP)

Lately, the local DSO is considering to install new technology composed of Unbundled Smart Meters (USM), energy routers, batteries for storage and the Decision Support Framework (S4G DSF) software. Energy routers and USMs allow for sophisticated remote control capabilities and offer additional services to the local DSOs, such as U-Q-Control, which allows for the seamless integration of energy from prosumers into the grid. USMs communicate with the local DSO and forward demands and storage requests to the energy router. The energy router (ER) regulates the electricity flow inside the prosumer's micro (DC) grids and provides ancillary services to the DSO's grid. The setup corresponds to an AP functionality.

3.3.1 Handle over-generation of renewable energy sources on DSO-level (avoid curtailment) – HLUC-1-PUC-1-S1

Today is a sunny day, therefore the PV energy sources produce an overhead of energy. Since the current energy demand is not high enough to consume the produced overhead, it needs to be sent back in the network or to be curtailed (classic approach) or to be stored locally in the grid where the energy is produced, in order to increase local [auto]-consumption and to avoid undesired energy flows. Locally, the energy storage is controlled automatically by the USM and the energy router.

Paul, a local DSO's grid operator is monitoring the current situation on the grid. He is using the S4G system which allows him to check on the currently produced amount of (renewably) energy and/or the net-metered energy, as well as to predict the expected demand of the overall electricity for the next hours.

Because of the sunny weather, the various prosumers' PV systems produce a vast surplus of energy. In order to ensure that this energy is not lost through curtailment due to grid limitations and in order to keep the grid voltage in the acceptable band, the surplus energy needs to be stored locally or somewhere in the storage systems distributed all over the low-voltage grid. Therefore, the S4G framework automatically detects storage systems at different grid levels with available free capacity for cooperative use. This does not only include storage owned by the DSO, but also batteries on the micro grid level owned by the various clients (prosumers). By communicating with the corresponding USMs, a redirection of energy into the local battery storage system at another prosumer level or sent to the cooperative storage is possible using different energy router modes. The process is automatic, based on the settings programmed by the prosumer and on the signals sent by the S4G framework.

From logical point of view, the use-case has always a peer of two AP or ASRPs, one which sends surplus energy in the AC network, to be stored somewhere at the grid level, and another which is able to absorb energy from the same network level, thus allowing a cooperative storage by using the AC local network. In order to be free of DSO network constraints and to allow flexible lab-testing, the DSO network is simulated, especially in the case of energy injection to the grid.

The two use-cases presented below correspond to the peer of two AP/ASRPs, in case S1a being analyzed the energy injection in the grid, while in case S1b being annalized the energy absorbtion for storing it locally.
The HLUC-1-PUC-1-S1a and b are to be simulated in the laboratory setting in Bucharest. Even if the DC bus for resilience is not relavant for these tests (specific to ASRP), ASRP will be addressed further, as being also AP. Moreover, even if the DER can be solar, wind or other type (biomass etc.), we are considering tests only with PV production, as microDerLab has this facility.

<u>Use-Case Table for HLUC-1-PUC-1-S1a – Handle over-generation of renewable energy sources on DSO-level (avoid curtailment), when surplus energy cannot be completely stored locally, thus being sent to the network</u>

<u>This use case analyses the situation of excess energy which cannot be stored locally, thus needing to be sent in the AC grid, in order to be stored at another(s) AP/ASRP(s).</u>
Based on the four-quadrant feature of the energy router, reactive power is also produced or consumed, in order to improve in the same time the voltage level in the grid.

Table 6 HLUC-1-PUC-1-S1a - Handle over-generation of renewable energy sources on DSO-level (avoid curtailment), when surplus energy cannot be completely stored locally

ID	HLUC-1-PUC-1-S1a
Name	Handle over-generation of renewable energy sources on DSO-level (avoid curtailment)
Diagrams	HLUC-1-PUC-1-S1a_v1.png (Figure 6)
Actors	• DSO (Person) • Advanced Prosumer AP (Traian) • Grid (System) • ER (System) • USM (System)
Actors Goals	Advanced Prosumer AS/ASRP (Traian): • Use as much as possible the PV production (maximize harvesting of DER production, tested in the particular case of PV) • Avoid curtailment orders received from the DSO DSO: • Prevent grid congestion
Pre-conditions	AP/ASRP has ○ Energy router ○ Production (PV as lab-tested case) ○ Storage resources ○ USM acting as energy control and gateway equipment

	• High PV production (sunny day)	
Trigger	Expected overproduction and exceeding local storage capacity, which may ask for curtailment	
Postconditions success	• Energy produced by ASRP is not curtailed at all due to storage coordination on AP-side • The network storage and S4G commnds are simulated • Local ER acts according to set-points • Simulation can be executed successfully	
Postconditions fail	• Storage resources are not enough to store all surplus energy produced by DER (PV as lab-tested case) • Local capacity is computed incorrectly / not forwarded to DSO • Set-points are not forwarded to USM and / or ER • Power is not routed into the grid • Too little power is routed into the grid • Simulation can not be executed due to missing data or system failure	
Description	**Step**	**Action**
	1	USM sends to DSO the production amount and the storage available resources: Few free capacity in local storage
	2	DSO sends signal of possible curtailment in next period to USM
	3	DSO gives a recommendation for storing surplus energy in the network to USM and ask also for reactive power participation to improve voltage level in the grid
	4	USM forwards new set-point settings to ER
	5	ER changes set-points
	6	ER routes surplus active energy into grid and sets new reactive power participation for voltage level support
Extensions	**Step**	**Branching Action**
	-	-
Sub variations	**Step**	**Branching Action**
	4a	The prosumer refuses the DSO action due to certain local situation
	5a	The set-points of the ER remain on local priority and do not obey DSO request

UML diagram for HLUC-1-PUC-1-S1a – Handle over-generation of renewable energy sources on DSO-level (avoid curtailment), when surplus energy cannot be completely stored locally.

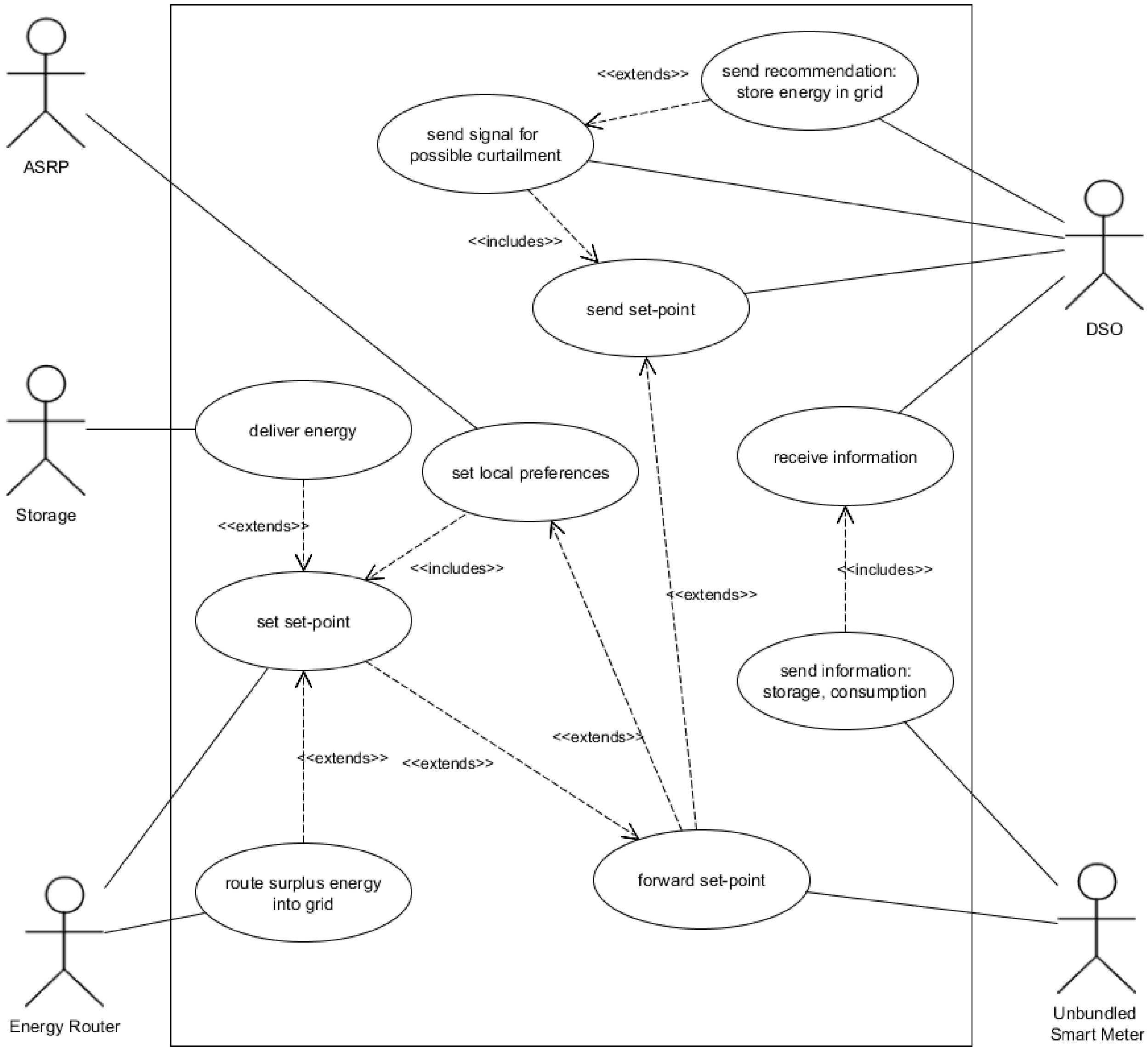

Figure 6 HLUC-1-PUC-1-S1a: Handle over-generation of renewable energy sources on DSO-level (avoid curtailment), when surplus energy cannot be completely stored locally

Use-Case Table for HLUC-1-PUC-1-S1b – Handle over-generation of renewable energy sources on DSO-level (avoid curtailment), when the local storage can absorb surplus energy from the grid

This use case analyses the situation of excess local storage, thus the AP/ASRP is able to receive active energy from the AC grid, in order to be stored locally.

Table 7 HLUC-1-PUC-1-S1b - Handle over-generation of renewable energy sources on DSO-level (avoid curtailment), when the local storage can absorb surplus energy from the grid

ID	HLUC-1-PUC-1-S1b
Name	Handle over-generation of renewable energy sources on DSO-level (avoid curtailment)

Diagrams	HLUC-1-PUC-1-S1b_v1.png (Figure 7)	
Actors	• DSO (Person) • Advanced self-resilient Prosumer ASRP (Traian) • Grid (System) • ER (System) • USM (System)	
Actors Goals	Advanced self-resilient Prosumer ASRP (Traian) • Use as much as possible the PV production and energy storage capacity • Avoid to loose harvested energy due to curtailment orders received from the DSO DSO • Prevent grid congestion	

Pre-conditions	• AP/ASRP has
	  o Energy router
	  o Production
	  o Storage resources
	  o USM acting as energy control and gateway equipment
	• High PV production (sunny day) and surplus storage capacity	

Trigger	Expected overproduction which may ask for curtailment	
Postconditions success	• Energy produced by ASRP is not curtailed at all due to storage coordination in the network • The network storage is simulated • Local ER acts according to set-points • (Enough) power is absorbed from the grid • Simulation can be executed successfully	
Postconditions fail	• Storage resources are not enough to store all surplus energy • Local capacity is computed incorrectly / not forwarded to DSO • Set-points are not forwarded to USM and / or ER • Power is not absorbed from the grid • Too little power is absorbed from the grid • Simulation can not be executed due to missing data or system failure	
Description	**Step**	**Action**
	1	USM sends the production amount and the storage available resources to DSO: There is free capacity in local battery of this ASRP
	2	DSO sends signal for asking to store surplus energy from the network (usually from an ASRP in the situation studied in S1a) to USM and ask also for reactive power participation to improve voltage levl in the grid
	3	USM forwards new set-point settings to ER
	4	ER changes set-points
	5	ER absorbs the requested active power from the grid and sets new reactive power participation for DSO voltage level support
	6	ER routes absorbed active energy into local storage
Extensions	**Step**	**Branching Action**
	-	-
Sub variations	**Step**	**Branching Action**
	-	-

UML diagram for HLUC-1-PUC-1-S1b – Handle over-generation of renewable energy sources on DSO-level (avoid curtailment), when the local storage can absorb surplus energy from the grid:

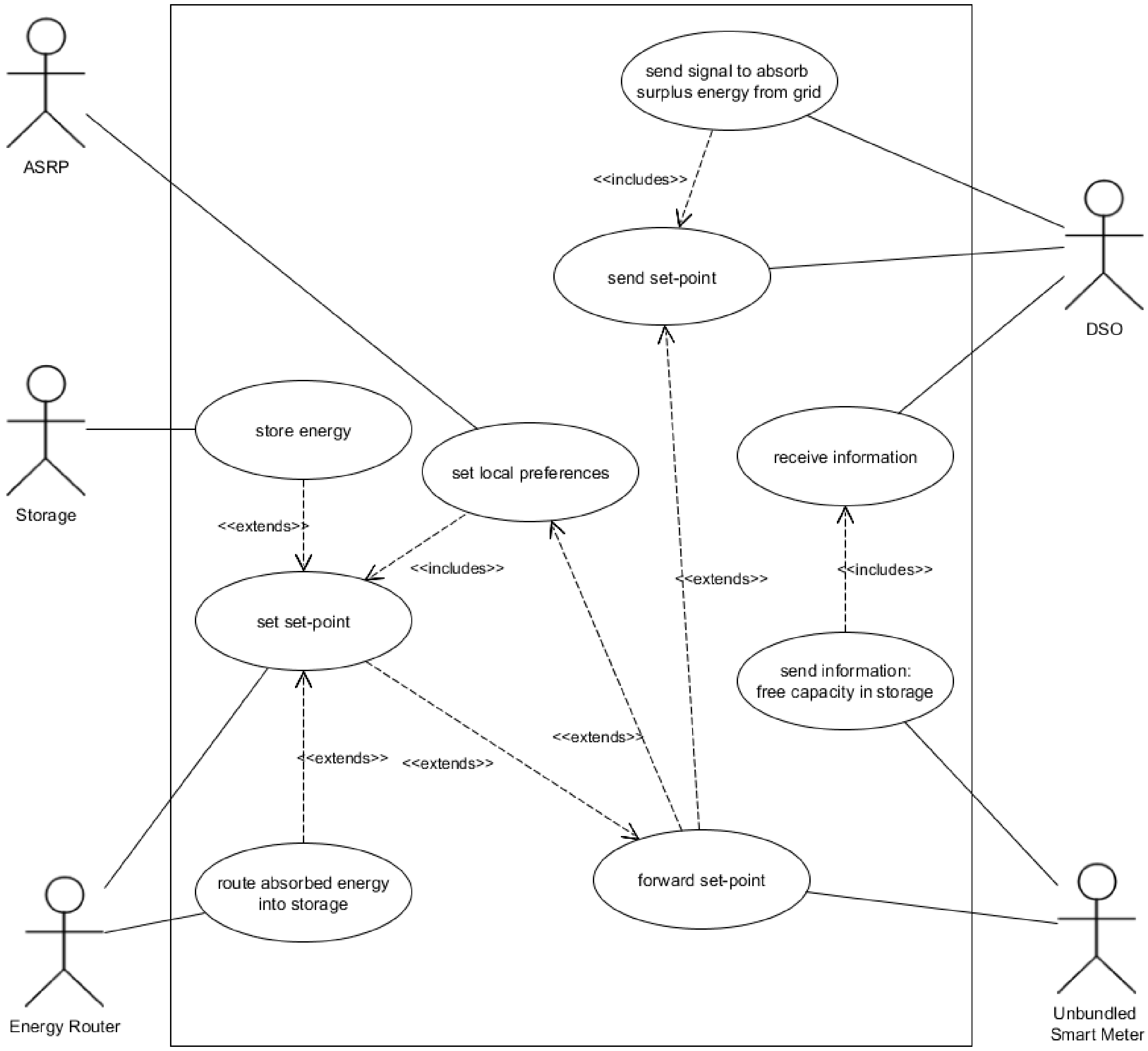

Figure 7 HLUC-1-PUC-1-S1b: Handle over-generation of renewable energy sources on DSO-level (avoid curtailment), when the local storage can absorb surplus energy from the grid

3.3.2 Serving peak demands on DSO-level – HLUC-1-PUC-1-S2

It is close to noon. Unfortunately, the sunny weather is about to change. The weather forecasting ability of the S4G DSF triggers an update for the overall demand and production for the grid. The system then notifies Paul that it is foreseen to reach the expected peak (with respect to weather changes, expected energy generation, storage load levels and historical data in a way which may brake network constraints (DSO-related problem). It suggests to activate the discharge mode of the local storage systems from low-voltage grids, which were previously charged with spare energy from private PVs in the sunny period of time, in such a way that it can reduce peak demand in the network by increasing energy release from the batteries (use them for increasing local generation with energy released from storage).

S4G automatically takes the energy demand settings from the local prosumers into account made available for the DSO by him through the USM interface) and calculates the overall possible energy to be discharged from the local storage systems on DSO and prosumer levels. The DSO system now regulates the cooperative storage resources of the low-voltage grid by communicating with the local USMs. The energy flow is regulated by the local energy routers, which directly communicate with the USMs. The energy routers can release energy from storage systems as well as from the generating sources. By superposing the coordinated storage control of various advanced prosumers, the peak period is shaved and some of the grid constraints are avoided.

Use-Case Table for HLUC-1-PUC-1-S2 – Serving peak demands on DSO-level (HLUC-1-PUC-1-S2):

The HLUC-1-PUC-1-S2 is to be simulated in the laboratory setting.

Table 8 HLUC-1-PUC-1-S2: Serving peak demands on DSO-level

ID	HLUC-1-PUC-1-S2	
Name	Serving peak demands on DSO-level	
Diagrams	HLUC-1-PUC-1-S2_v1.png (Figure 8)	
Actors	• DSO (Person) • Advanced self-resilient Prosumer ASRP (Traian) (Person) • ER (System) • USM (System) • Grid (System)	
Actors Goals	DSO: • avoid network congestion during the evening • solve congestion problem by using storage resources from the prosumer	

Pre-conditions	• AP has
	  o Energy router
	  o Production
	  o Storage resources
	  o USM acting as energy control and gateway equipment	

Trigger	High consumption expectation (possible peak network conditions: low voltage level, highpower flow, higher losses for the DSO	
Postconditions success	• Peak demand is shaved, based on injection of energy from storage resources at prosumers sites • Network storage is simulated • Local ER acts according to set-points • (Enough) power is routed into the grid	
Postconditions fail	• Storage resources are not enough in order to inject all surplus energy, even in a cooperative solution • Set-points are not forwarded to USM and / or ER • ER neglects new set-points • Power is not routed into the grid • Too little power is routed into the grid • Simulation can not be executed due to missing data or system failure	
Description	**Step**	**Action**
	1	USM sends the available storage resources to DSO: certain energy stored by local battery, partly available for the grid services

	2	DSO sends signal of possible peak situation in next period
	3	DSO gives a recommendation for injecting energy from the local storage in order to to reduce consumption from the grid up to sending stored energy in the grid, for load peak shaving at the grid level
	4	USM forwards set-points to ER
	5	ER changes the set-points
	6	ER routes available power from storage into the local consumption and/or to the grid
Extensions	**Step**	**Branching Action**
	-	-
Sub variations	**Step**	**Branching Action**
	3a	The prosumer refuses the DSO action due to certain local situation
	4a	The set-points of the ER remain on local priority and do not obey DSO request, based on a flexible contract, which allows a certain number of deny situations.

Observation: Based on the setpoint from DSO, the order to produce power from the storage resource can bring two situations:

a) The power produced by the battery is lower than the current consumption of ASRP, thus ASRP is still a consumer, but with lower energy absorbtion from the grid. This heps the peak shaving as seen e.g. at the MV/LV transformer level,, as the consumer is consuming less;
b) The power produced by the battery is higher that the current consumtion of ASRP, thus the difference is sent to the grid. This also helps the peak shaving, because acts as a production in the network, which reduces the overall grid consumption, as seen e.g. at the MV/LV transformer level.

UML diagram for HLUC-1-PUC-1-S2 – Serving peak demands on DSO-level (HLUC-1-PUC-1-S2):

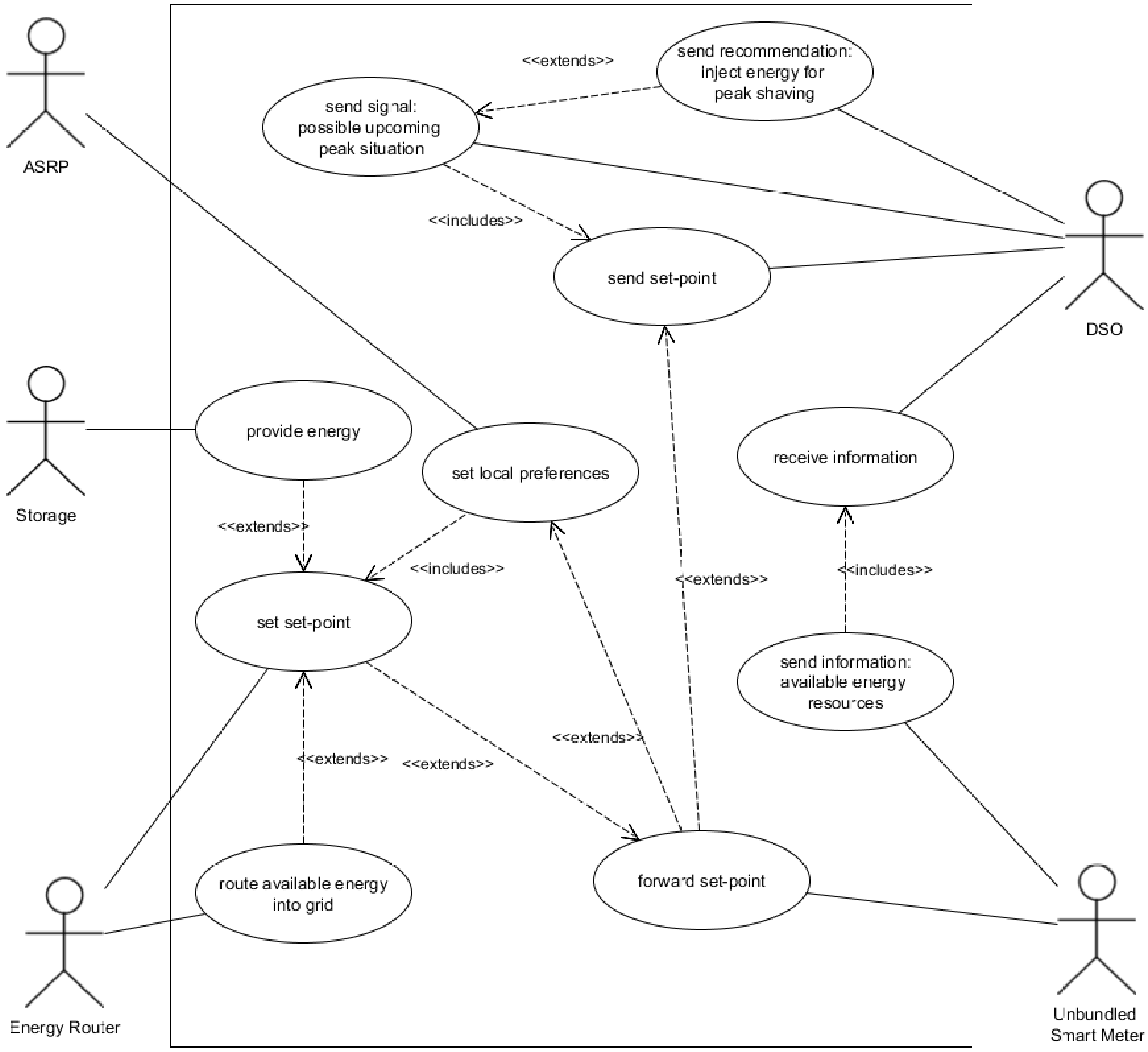

Figure 8 HLUC-1-PUC-1-S2: Serving peak demands on DSO-level

3.3.3 Provide ancillary services (black start) on DSO-level – HLUC-1-PUC-1-S3

This is a study on required future regulations allowing black start capabilities in a defined DSO area (eg. low-voltage microgrid).

This ancillary service can be requested by the DSO in order to be able to energize a local microgrid and require additional energy supply from the local prosumers. The black-start service requires specific converter design without grid signal for synchronization, thus being able to impose the microgrid frequency. The power needed to be injected in the grid cannot be higher than the nominal power of the energy router.

Use-Case Table for HLUC-1-PUC-1-S3 – Provide ancillary services (black start) at DSO-level:

Table 9 HLUC-1-PUC-1-S3 – Provide ancillary services (black start) at DSO-level

ID	HLUC-1-PUC-1-S3	
Name	Provide ancillary services (black start) at DSO-level	
Diagrams	HLUC-1-PUC-1-S3_v1.png (Figure 9)	
Actors	• DSO • Advanced self-resilient Prosumer ASRP (Traian) • ER (System) • USM (System) • Microgrid (System)	
Actors Goals	DSO: • perform black-start for the microgrid where the prosumer is connected using storage resources from the prosumer	

Pre-conditions	• AP/ASRP has
	  ○ Energy router
	  ○ Production
	  ○ Storage resources
	  ○ USM acting as energy control and gateway equipment
	• A blackout appeared in the microgrid and the DSO disconnected the microgrid from the main grid: needs to have a black-start energy service for this microgrid	

Trigger	Black start and microgrid separation from the main grid	
Postconditions success	Microgrid is supplied in a sequence which initially needed the black-start service	
Postconditions fail	• The black start is not successful (due to high load in the microgrid / microgrid is not disconnected from the main grid) • Set-points are not forwarded to USM and / or ER • DSO does not send the black-start signal • Power is not routed to DSO • Too little power is routed to DSO • ER neglects critical loads when routing energy to DSO (see HLUC-1-PUC-2) • Simulation can not be executed due to missing data or system failure	
Description	**Step**	**Action**
	1	Microgrid is disconnected from main grid by DSO
	2	DSO sends signal of a black-start need to USM
	3	USM forwards set-point to ER
	4	ER changes the set-points
	5	ER routes maximum available power to DSO respecting the current local demand
Extensions	**Step**	**Branching Action**
	-	-
Sub variations	**Step**	**Branching Action**

UML diagram for HLUC-1-PUC-1-S3 – Provide ancillary services (black start) at DSO-level:

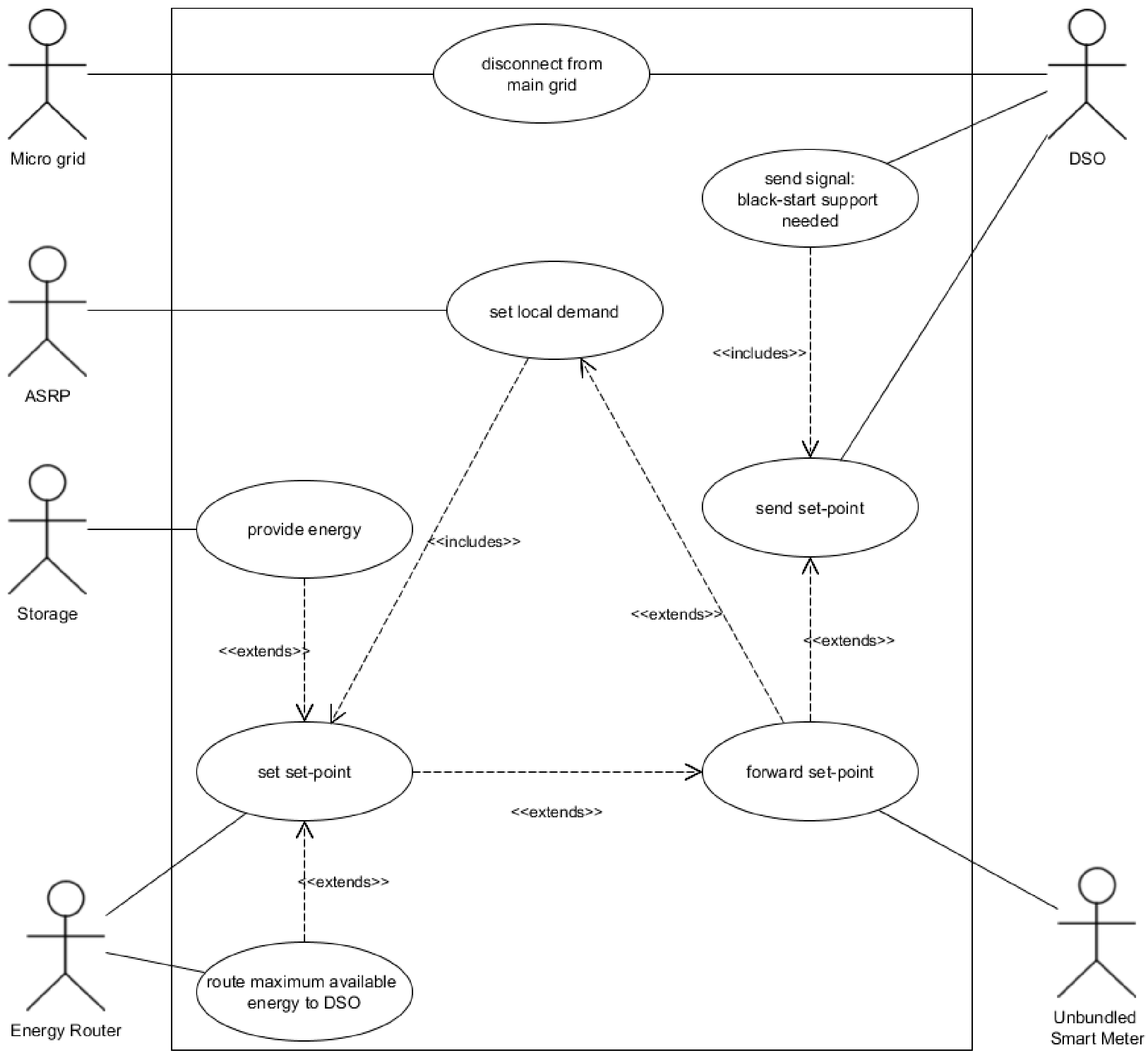

Figure 9 HLUC-1-PUC-1-S3: Provide ancillary services (black start) at DSO-level

3.4 Advanced self-resilient prosumer – HLUC-1-PUC-2

The advanced self-resilient prosumer (ASRP) has an Energy Router with a resilient DC bus available for connecting resilient DC loads. This modular Energy Router is the core interface designed for optimal usage of advanced prosumer energy resources (PV, storage). ASRP is an extension of AS which has in adition the local DC bus which can be used by the consumer.

Traian is an advanced self-resilient prosumer (ASRP), having an S4G Energy Router based local energy architecture. Traian wants to be sure that he can consume as much as possible his RES energy production (increase self-consumption). Additionally, he wants his activities to remain resilient to main grid outages. Therefore, he is using the local intelligence of the EMS to control energy production, storage and consumption such that he always has some spare energy in the batteries in case that there is a short interruption on the AC network or in case it is a complete blackout.

To do that, the EMS software is continuously trying to maximize the use of locally produced energy and keeps a dynamic level of minimal stored energy, which is based on the estimated consumption in the next hours, such that the consumption is resilient for the consumption connected to the DC bus of the ER.

In the case that the connection of the ER to the DSO grid is designed or programmed to be uni-directional, the advanced self-resilient prosumer becomes an UniRCon, meaning that he is adapting the internal strategies in order to be consumer-only when seen from the DSO side. This is transforming the prosumer in a pure consumer on DSO side, which simplifies the responsibilities and requirements of connection and allows a complete control of internal resources.

Use-Case Table for HLUC-1-PUC-2 – Advanced self-resilient prosumer:

Table 10 HLUC-1-PUC-2 – Advanced self-resilient prosumer

<table>
<tr><td>ID</td><td colspan="2">HLUC-1-PUC-2</td></tr>
<tr><td>Name</td><td colspan="2">Advanced self-resilient prosumer</td></tr>
<tr><td>Diagrams</td><td colspan="2">HLUC-1-PUC-2_v1.png (Figure 10)</td></tr>
<tr><td>Actors</td><td colspan="2">Advanced self-resilient Prosumer ASRP (Traian) (Person)
DSO (Person)
USM (System)
ER (System)
Critical load originator (System)</td></tr>
<tr><td>Actors Goals</td><td colspan="2">ASRP:
increase self-consumption as much as possible
always keep a certain resilience behavior (a certain time to be able to supply his critical loads)</td></tr>
<tr><td>Pre-conditions</td><td colspan="2">ASRP has
Energy router with the DC bus extension
Production
Storage resources
USM acting as energy control and gateway equipment
ASRP keeps storage, production and consumption in such a way that self-consumption is maximed and a certain resilience is available, based on estimated consumption, production and storage in the next hours
Black-out occurs</td></tr>
<tr><td>Trigger</td><td colspan="2">A blackout appeared in the DSO grid</td></tr>
<tr><td>Postconditions success</td><td colspan="2">The ASRP
can keep a certain resilience period of time
is able to supply his critical loads</td></tr>
<tr><td>Postconditions fail</td><td colspan="2">ASRP is not able to be resilient in terms of needed time</td></tr>
<tr><td rowspan="5">Description</td><td>Step</td><td>Action</td></tr>
<tr><td>1</td><td>ASRP turns his ER strategy to supply in resilient mode the critical loads using the USM</td></tr>
<tr><td>2</td><td>ER / USM gives continuous information about the resilience time and about measures which may increase this key performance indicator (KPI)</td></tr>
<tr><td>3</td><td>If storage runs out of energy, USM (SMX) inform ASRP</td></tr>
<tr><td>4</td><td>ASRP savely disconnects critical load originator</td></tr>
</table>

Extensions	**Step**	**Branching Action**
	5	If the supply from DSO comes back, the ASRP enters in a strategy which covers back the resilience expectancy.
Sub variations	**Step**	**Branching Action**
	1a	Additionaly to increasing self-conumption and resilience, the ASRP is acting as a UniRCon, meaning a uni-directional flow of energy (no back-generation in the DSO network); the resilience is kept as before, while self-consumption target is 100%.

UML diagram for HLUC-1-PUC-2 – Advanced self-resilient prosumer:

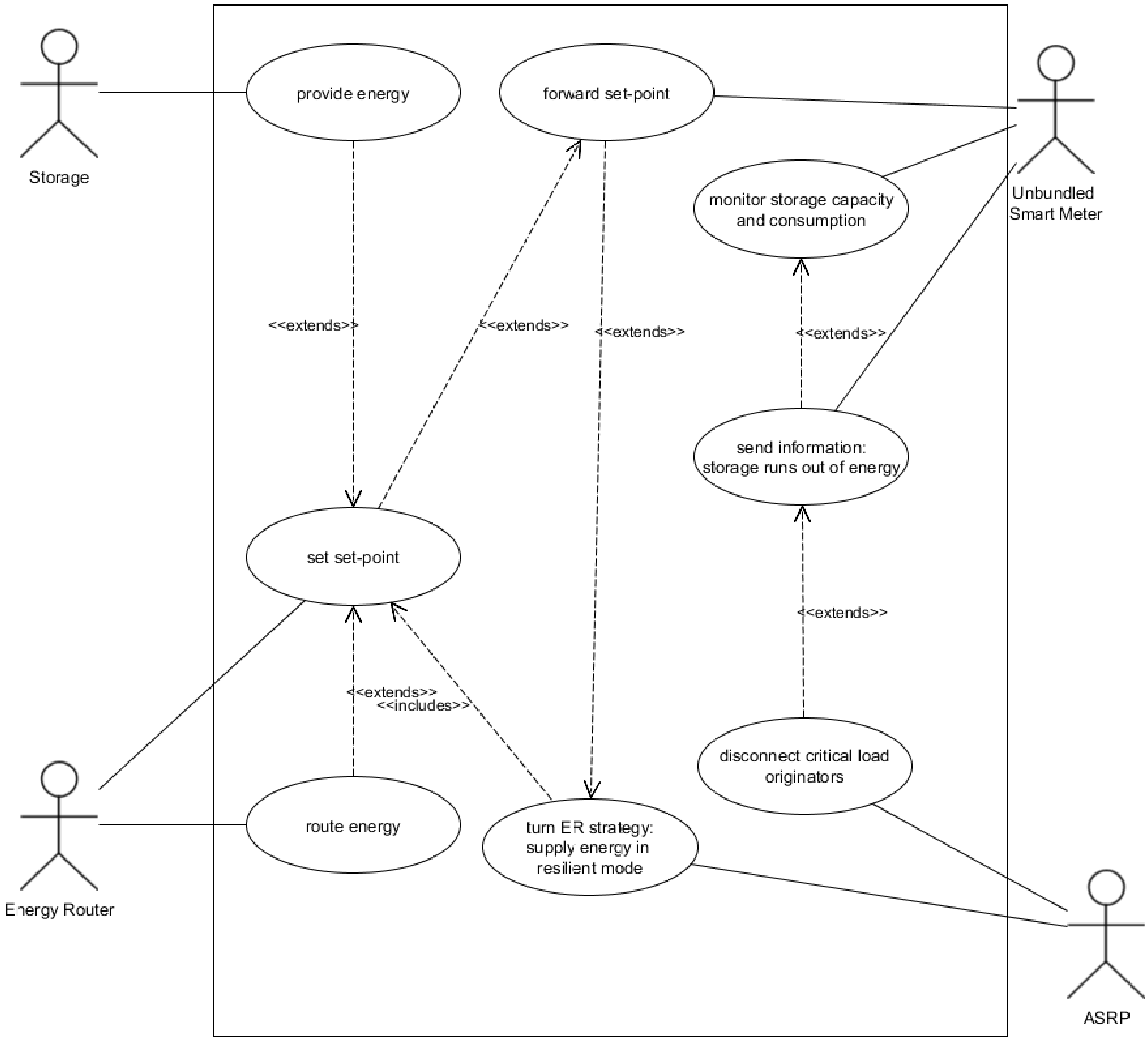

Figure 10 HLUC-1-PUC-2: Advanced self-resilient prosumer

3.5 Resilient hybrid cooperative ecosystem – HLUC-1-PUC-3

UniRCon offers energy services (based on new technology) to connected neighbourhood prosumers and consumers.

The UniRCon has a Modular Energy Router with resilient DC bus and with a DC connection for exchanging energy with neighbours. It is an evolutionary extension of ASRP.

The most complex solution is presented in Figure 11.

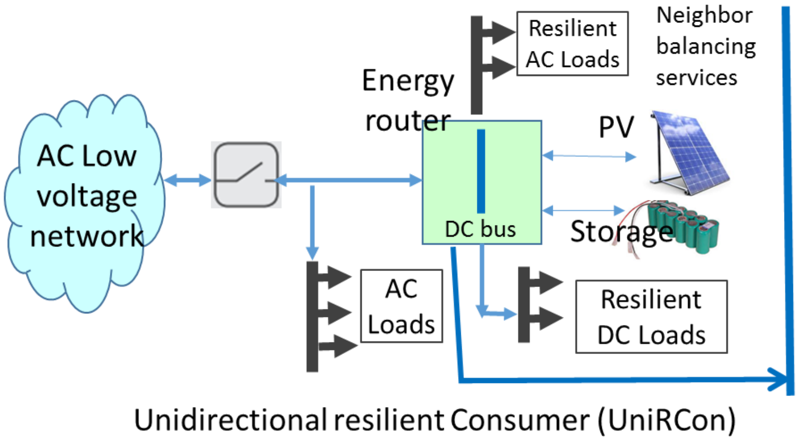

Figure 11 Complete UniRCon architecture

The solution can have in its most complex situation local AC and DC busses, to supply resilient consumers, as well as neighbour DC link, to balance energy within neighbours. However, resilient local AC bus is not studied in the use case.

Decebal is a UniRCon, having a Modular Energy router which is equipped also with a DC connection to neighbours. Decebal wants to consume his entire RES energy production inside his premises and/or together with his neighbours, by using a cooperative energy control. Moreover, the cooperation is intending to behave as a resilient cluster against different types of grid outages, thus to be used the local intelligence of the EMS to control energy production, storage and consumption for its local needs as well as to provide energy services to its neighbour consumers and prosumers.

Use-Case Table for HLUC-1-PUC-3 – Resilient hybrid cooperative ecosystem:

Table 11 HLUC-1-PUC-3 – Resilient hybrid cooperative ecosystem

ID	HLUC-1-PUC-3
Name	Resilient hybrid cooperative ecosystem
Diagrams	HLUC-1-PUC-3_v1.png (Figure 12)
Actors	Advanced self-resilient Prosumer ASRP (Person) Neighbour of ASRP (Person) DC bus for neighbour connection (System)
Actors Goals	ASRP • increase as much as possible self-consumption • keep always a certain resilience behavior • balancing his resources with neighbours using a local DC network

<table>
<tr><td></td><td colspan="2">Neighbour
• keep a certain resilience period from DSO outages</td></tr>
<tr><td>Pre-conditions</td><td colspan="2">ASRP has
• energy router with neighbour energy exchange extension
• production
• storage resources
• USM acting as energy control equipment
Neighbor has
• resilient internal network (DC)
• neighbour energy exchange extension equipment (DC bus)
ASRP
• keeps storage, production and consumption in such a way that self-consumption is maximed and a certain resilience is available
• has excess energy to be shared with the neighbour</td></tr>
<tr><td>Trigger</td><td colspan="2">The two neighbours exchange energy through the common DC connection</td></tr>
<tr><td>Postconditions success</td><td colspan="2">The critical loads of the neighbour are supplied by the ASRP</td></tr>
<tr><td>Postconditions fail</td><td colspan="2">ASRP is not able to provide energy to the neighbour, due to lack of excess energy</td></tr>
<tr><td rowspan="5">Description</td><td>Step</td><td>Action</td></tr>
<tr><td>1</td><td>Neighbour consumes energy through his resilient DC bus</td></tr>
<tr><td>2</td><td>ER coordinates energy flow of DC buses</td></tr>
<tr><td>3</td><td>ASRP offers energy thorugh the DC bus for neighbourhood energy exchange</td></tr>
<tr><td>4</td><td>Neighbour receives information about the availability of energy from the main ASRP and absorbs excess energy from UnirCon through the neighbour DC bus.</td></tr>
<tr><td rowspan="2">Extensions</td><td>Step</td><td>Branching Action</td></tr>
<tr><td>-</td><td>-</td></tr>
<tr><td rowspan="2">Sub variations</td><td>Step</td><td>Branching Action</td></tr>
<tr><td>-</td><td>-</td></tr>
</table>

UML diagram for HLUC-1-PUC-3 – Resilient hybrid cooperative ecosystem:

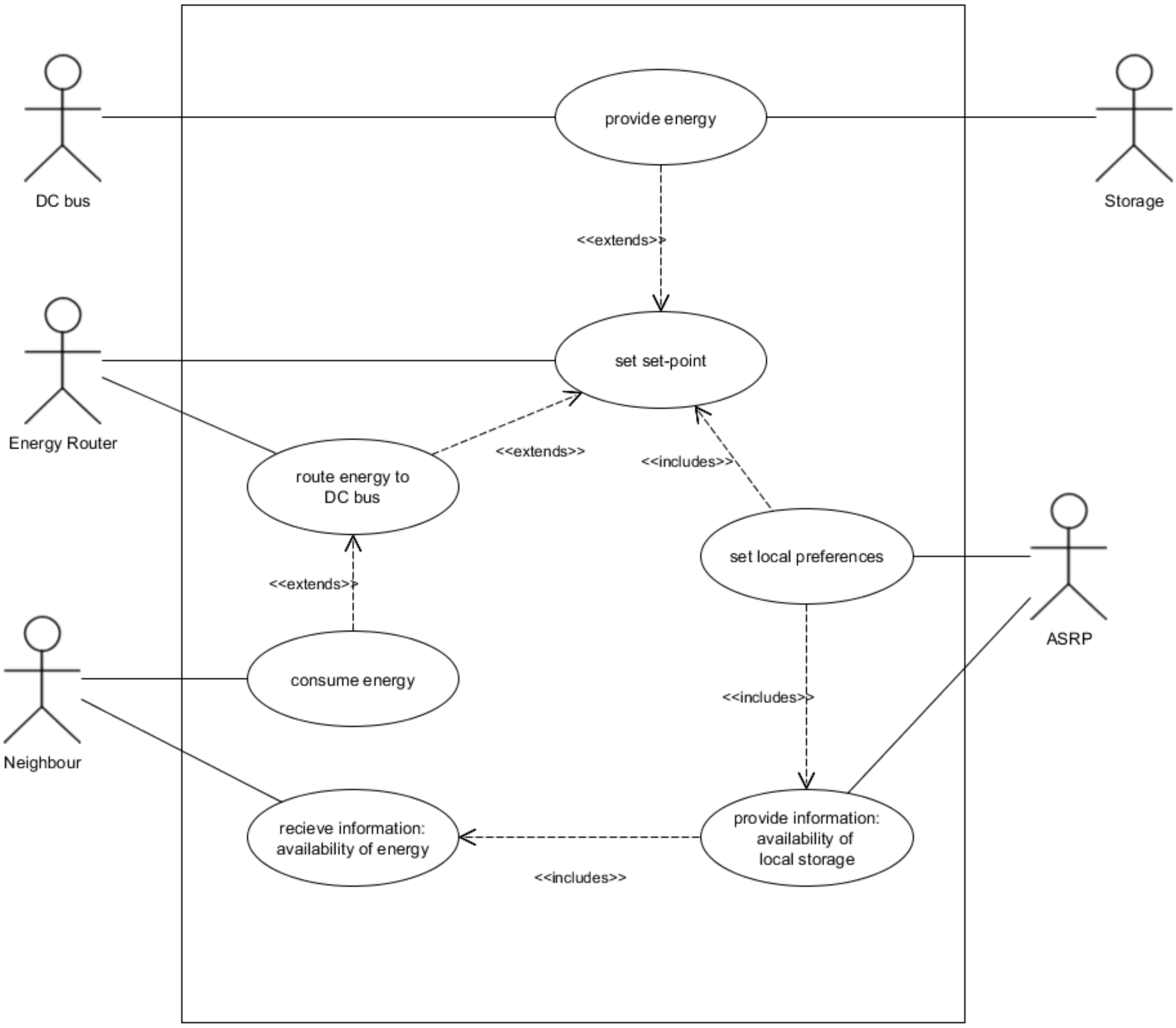

Figure 12 HLUC-1-PUC-3: Resilient hybrid cooperative ecosystem

4 Cooperation EV Charging

4.1 Actor description

EDYNA's use cases involve the actors listed in Table 12. Due to the current level of detail of the depicted use cases not all of the identified actors are also included in the modelled uses cases, which might change with future iterations and further development of the project.

Table 12 Actors identified for the Bolzano test site

Name	Description	Type
Edyna	Distribution System Operator	Person
Energy Manager	An energy consultant	Person
Prosumer	A prosumer whith production and storage behind the meter (BTM)[1]	Person
EV owner		Person
Garage	A garage with parking area which has EV chargers	System
Garage Owner	The owner of the Garage wanting to give the service for charging EVs	Person
Storage		System
USM	Unbundled Smart Meter	System
S4G DSF		System
GUI	Graphical User Interface; allows to observe the current production of the private RES and the consumption of the house; allows for preference settings	System
Charging station	A charching station of EVs	System

4.2 Cooperative EV charging – HLUC-2

The energy grid in the city of Bolzano is characterized by growing shares of intermittent power generation from Renewable Energy Sources (RES) while facing with increasing diffusion of Electrical Vehicles (EVs). Such scenario is creating new challenges for efficient management and grid stability. Michele, a manager by the local DSO, Edyna, has found a valuable solution to such challenges by using Energy Storage Systems (ESS) with the S4G application system.

4.3 Residential prosumer with storage - HLUC-2-PUC-1

Gigi and Raffaella live in a little village close to Bolzano: they have a PV plant on the roof of their house and two EVs, which need to be charged during the night in order to be ready the day after. To better exploit the energy produced by their PV plant that generates an overhead of energy during the day, while they need more energy during the night for charging the EVs, they decided to request the DSO for a rise of power of their own point of delivery (POD).

[1] Widely known in the photovoltaic industry with the term "**Behind The Meter**" (BTM), a BTM system is a renewable energy generating facility (in this case, a solar PV system) that produces power intended for on-site use in a home, office building, or other commercial facility. [Wikipedia]

Michele, after evaluation of different possible solutions, suggests Raffaella and Gigi not to apply for a rise of power, but to install a simple device with a local ESS, operating on the basis of DSF software. In the house of Gigi and Raffaella a new local ESS is installed. The system is integrated with an Unbundled Smart Meter (USM) and a Graphical User Interface (GUI). The system automatically collects data about the production of the residential PV, the state of the ESS, the electrical consumption of the household, the voltage levels, and currents, etc. Gigi reads all the data of the system on the display of the local GUI and can monitor in real time what happens, recognizing that the delivered power at the POD never exceeds the previous maximum allowed value, and in this way the economical return of investment of the system is optimized. The system manages automatically the power flow in the house and starts the EVs charging in order to complete the charge within the next morning.
Gigi and Raffaella can do all the home activities: washing, cooking, ironing and other energy consuming tasks in the evening using the energy that was produced by their own Roof PV during the day and was stored in their residential ESS.

Use-Case Table for HLUC-2-PUC-1 – Residential prosumer with storage:

Table 13 HLUC-2-PUC-1 – Residential prosumer with PV production and storage behind the meter

ID	HLUC-2-PUC-1
Name	Residential prosumer with PV production and storage behind the meter
Diagrams	HLUC-2-PUC-1_v1.png (Figure 13)
Actors	• Prosumer (Person) • DSO (Person) • Storage (System) • RES (System) • USM (System) • S4G DSF (System)
Actors Goals	Prosumer: • Accomodate the charging of it's two EVs compatible with the contract with the DSO DSO: • Storage and EV chargings in such a way that the contractual conditions regarding maximal power are preserved • All resources are well coordinated
Pre-conditions	Prosumer has: • Roof PV (selected RES in the Bolzano site) • Storage • 2 plugs for classic charging (16A) of the two EVs • Unbundled Smart Meter (USM) • Local application software for energy coordination (EMS) DSO with the help of S4G DSF can • Monitor production and total consumption • Control storage and EV charging by communication with local EMS
Trigger	• Acquisition of the two EVs and the need to charge them in addition to the existing loads of the house • Montage of local storage, use of EMS and communication with DSF
Postconditions success	The coordination of EV charging with the PV production and the consumption is made in such a way that the maximal power at POD is in the contractual limit, not needing an upgrade or needing a smaller upgrade than without storage and coordination

Postconditions fail	The POD contractual limit is exceeded	
Description	**Step**	**Action**
	1	Through its EMS, USM informs the S4G DSF about production, total consumption
	2	S4G DSF receives the task to coordinate the charging of two EVs in a way which allows maximum charging by keeping a given maximal power at POD
	3	S4G DSF coordinates the production, storage and EV charging with respect to load profiles and constraints
	4	S4G DSF reports to DSO about how well all tasks have been achieved
Extensions	**Step**	**Branching Action**
	3a	S4G DSF detects no solution to serve all needs and constraints well
	3b	S4G DSF gives advices about the usage of other consumption loads to improve the goal coverage while respecting constraints
Sub variations	**Step**	**Branching Action**
	3c	Spontaneous changes in EV needs, such as: only one car needs to be charged, or one car needs to be charged with priority (e.g. unexpected travel)

UML diagram for HLUC-2-PUC-1 – Residential prosumer with storage:

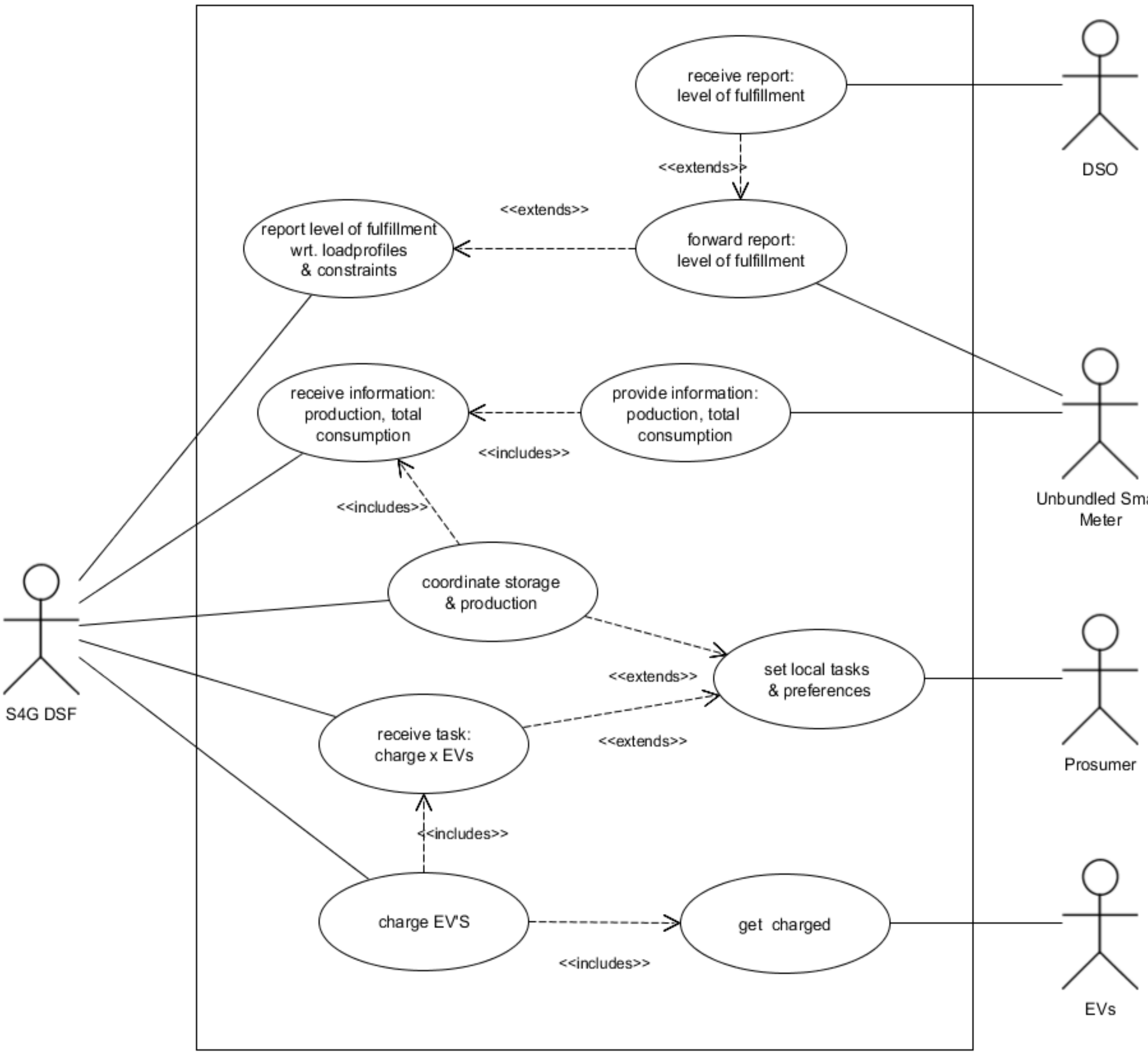

Figure 13 HLUC-2-PUC-1 – Residential prosumer with storage

4.4 Cooperative charging in the parking lot of a commercial test site - HLUC-2-PUC-2

In Bolzano, a commercial test site, with a rooftop PV installation, plans to provide itself with a fleet of EVs. The owner aims to equip the parking lot with several charging stations which will use the energy produced by the PV installation. Filippo, the owner of the company, aims to provide the parking lot with several Charging Units (CU) for the EVs fleet of the company. In addition to that he'd like to use the energy produced by his PV plant for giving green energy to the EVs of the company. His energy consultant suggests him to request the DSO Edyna for a rise of the available power needed at his point of delivery (POD).
Michele receives the application from Filippo, the garage owner. To check the possibility to increase the power he firstly uses a conventional software to simulate the behavior of the LV net. Hence, he can observe that the issue can be solved only by enforcing the LV grid, by installing a bigger transformer in the LV substation. Michele wants to observe if the issue can be solved in an unconventional way by installing additional equipment without enforcing the grid. The simulation of the "Decision Support Framework" of S4G (DSF) enables the evaluation of costs and benefits of different possible solutions. The simulation functionality

of DSF allows him to observe the positive effects of installing a new ESS in the substation and a second smaller DSF system after the POD at customer level. This appears to be the less impacting solution both at DSO and at customer level.

Use-Case Table for HLUC-2-PUC-2 – Cooperative charging in the parking lot of a commercial test site:

Table 14 HLUC-2-PUC-2 – Parking place of a commercial test site with PV and EV charging stations

<table>
<tr><td>ID</td><td colspan="2">HLUC-2-PUC-2</td></tr>
<tr><td>Name</td><td colspan="2">Parking place of a commercial test site with PV and EV charging stations</td></tr>
<tr><td>Diagrams</td><td colspan="2">HLUC-2-PUC-2_v1.png (Figure 14)</td></tr>
<tr><td>Actors</td><td colspan="2">• Garage (Person)
• DSO (Person)
• EV fleet owner (Person)
• S4G DSF (System)
• USM (System)
• Charging station (System)
• EV’s (System)</td></tr>
<tr><td>Actors Goals</td><td colspan="2">Garage:
• Accommodation of several charging stations for EVs, in a way which is compatible with the contract with the DSO
DSO:
• Prohibit the need of traditional network reinforcements (bigger transformer, new lines etc.) by storage and charching coordination</td></tr>
<tr><td>Pre-conditions</td><td colspan="2">Garage has installed behind the meter:
• Storage
• 5 chargers (22 kW)
• Unbundled Smart Meters (USM) to measure charging energy
• Uses DSF (application software for the coordination)
DSO:
• Substation storage device (to be coordinated with local storage)
• Adopted a solution with storage behind the meter at the charging point and a storage equipment at substation level based on coordination of PV production, storage and EV chargings,</td></tr>
<tr><td>Trigger</td><td colspan="2">Charging requests from EVs parked in the garage parking place (up to simultaneous charging requests from all charging stations)</td></tr>
<tr><td>Postconditions success</td><td colspan="2">• Grid is not stressed in terms of power congestion or voltage band violation (basic power quality is kept) due to storage and EV charging coordination
• Need for upgrade or small classic upgrade of grid is prohibited</td></tr>
<tr><td>Postconditions fail</td><td colspan="2">The grid constraint limits are violated (high power flow, thus congestion, voltage exceeding the limits allowed)</td></tr>
<tr><td rowspan="5">Description</td><td>Step</td><td>Action</td></tr>
<tr><td>1</td><td>USMs inform S4G DSF about production, total consumption at the garage level</td></tr>
<tr><td>2</td><td>S4G DSF receives the task to coordinate the various EV chargings in the parking place</td></tr>
<tr><td>3</td><td>S4G DSF coordinates the EV chargings in the parking place in a way which maximizes the charging services while considering PV production, local and grid storage status and network constraints set by DSO.</td></tr>
<tr><td>4</td><td>DSF reports to DSO about how well have been achieved all tasks.</td></tr>
</table>

Extensions	Step	Branching Action
	3a	S4G DSF detects no solution to serve all needs and constraints well
	3b	S4G DSF gives advices about how to schedule EV chargins while respecting constraints
Sub variations	**Step**	**Branching Action**
	-	-

UML diagram for HLUC-2-PUC-2 – Cooperative charging in the parking lot of a commercial test site:

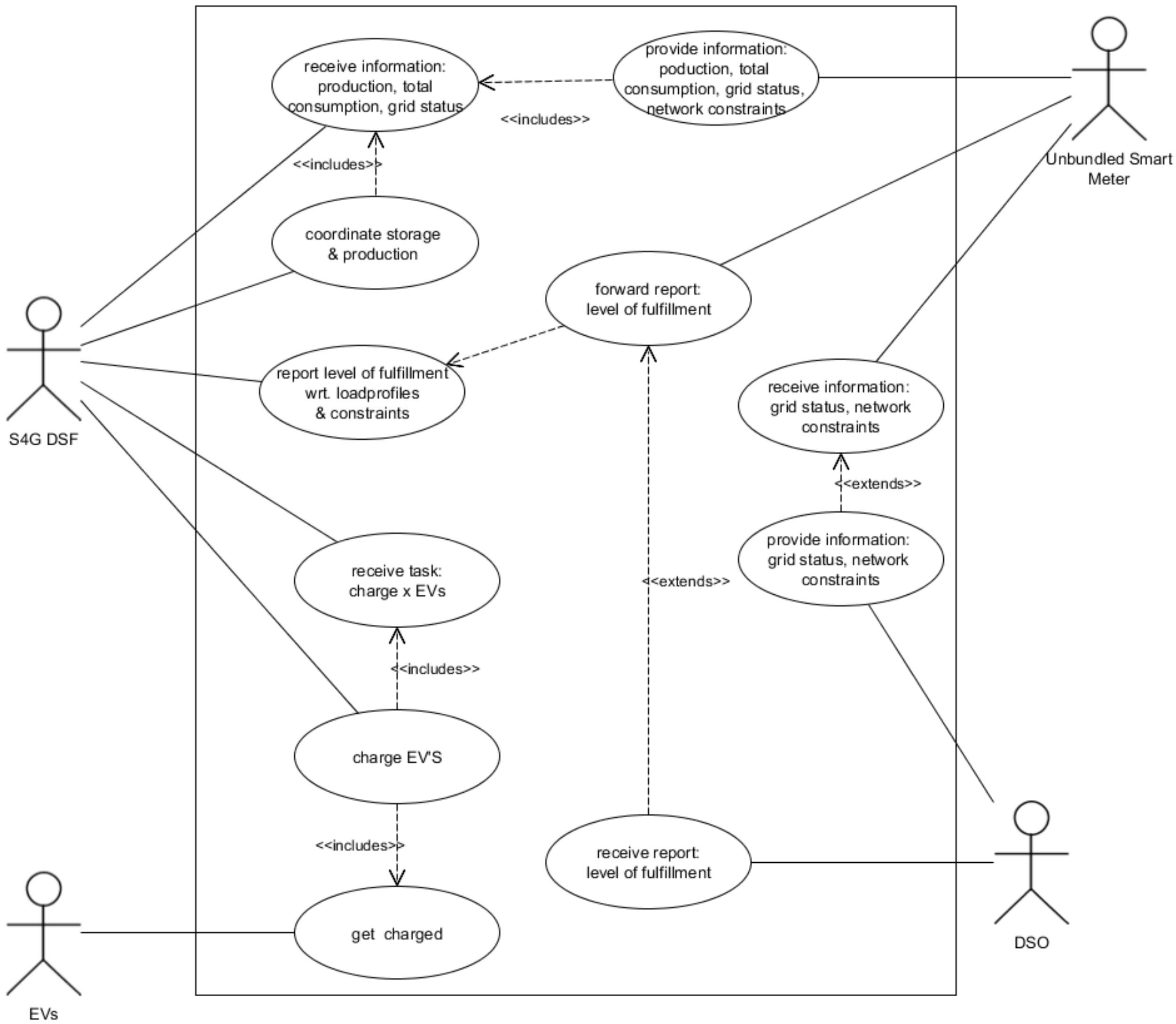

Figure 14 HLUC-2-PUC-2 – Cooperative charging in the parking lot of a commercial test site

4.5 Simulation of high penetration of EV chargers and of prosumers with storage and residential EV charging - HLUC-2-PUC-3

This Use case tries to evaluate (by simulation only) the maximum number of EV Charging stations and residential chargings that can be satisfied with the existing network and by using storage and cooperative charging, without needing to reinforce the grid. While the first two Use Cases study an existing situation, this one evaluates a future scenario, where a massive diffusion of EVs is likely to threaten the stability of the grid and the growing load may be especially difficult to handle. The simulation will be done inside DSF, by using scaling factors to simulate high EV penetration and charging services.

Use-Case for HLUC-2-PUC-3 – Simulation of high penetration of EV chargers and of prosumers with storage and residential EV charging:

Table 15 HLUC-2-PUC-3 – Scale-up EV charging and storage, considering both public and residential cases

ID	HLUC-2-PUC-3	
Name	Scale-up EV charging and storage, considering both public and residential cases	
Diagrams		
Actors	• DSF (System) • Storage (System) • RES (System) • Charging Station (System)	
Actors Goals	Prosumers • Accomodate their EV charging needs in a way which is compatible with the contract with the DSO DSO: • Have a combined solution with storage at prosumer level, at EV chargers level and at substation level, which allows a maximum number of served charging services in the existing or slightly reinforced network	
Pre-conditions	The conditions of PUC-1 and PUC-2 are met	
Trigger	It is studied (by simulation only) the scaled and mixed situation of PUC-1 and PUC-2, up to the limit of existing network, by using the coordination means already tested in PUC-1 and PUC-2.	
Postconditions success	• A high number of EV charging stations and residential chargings can be satisfied with existing network, by using storage and coordinated charging means • The maximum number can be deducted from the simulation	
Postconditions fail	The scale-up tests show that only a few new EV charging facilities can be considered and that massive classic reinforcement of the grid is still necessary	
Description	**Step**	**Action**
	1	PUC-1 and PUC-2 are scaled-up with different factors;
	2	DSO selects specific places for the EV chargings; a simplified repartition of EV chargers can be made by aggregating some of the points in a single network point
	3	DSF coordinates the production, storage and EV chargings till the grid limit, by still respecting constraints
	4	DSF is giving reports about how well have been achieved all tasks.
Extensions	**Step**	**Branching Action**
	3a	DSF detects no solution to serve all needs and constraints well
	3b	By using scaling factors, S4G DSF can show the limit of EV charging stations in existing (or slightly enforced) network while respecting constraints
Sub variations	**Step**	**Branching Action**
	3c	A new cooperative algorithm applicable at the scaled situation might increase the penetration of EV chargers in the existing network

5 Storage Coordination (HLUC 3)

5.1 Actor descriptions

For the use cases of ENIIG, the actors described in Table 16 were identified. Due to the current level of detail of the depicted use cases not all of the identified actors are also included in the modelled uses cases, which might change with future iterations and further development of the project.

Table 16 Actors identified for use cases on the Fur test site

Name	Description	Type
Eniig	Local DSO	Company
Kasper	Stratetic grid planer working for Eniig	Person
Prosumer	Residential with PV (or another RES) and a storage system	Person
S4G DSF	System that bundles several control algorithms for grid control; can also be used as simulation context with historical and/or real time data	System
SCADA	Energy Management system which operates at substation level, in high- to medium-voltage grids, records data and allows for control of BMS and tap changers	System
Grid	Power supply system (low voltage, medium voltage, high voltage)	System
BMS	Battery management system; Analyzes the grid state and gives set-points to grid or locally installed batteries, supports the SCADA system.	System
Tap changer	Grid state settings. Regulation of transformers	System
Aggregator	Supports the DSO and buys and sell anchilarry services in the DSO grid	System
Data storage	System owned by the DSO where SCADA stores acquired data	System
USM	Unbundled smart meter; can be controlled using the DSO's SCADA system; allows for data collection from prosumers	System

5.2 Grid simulation – HLUC-3

As society is focusing on becoming more environmentally friendly and zero CO_2 emitting, the DSO's will experience an added pressure on their grid both on higher and lower voltage grid. Basically, there are two topics that will influence the DSOs in the future: More DER production from renewable energy sources installed, and added consumption of electric energy as heating and transport are shifted from fossil fuels towards electricity.

Decentralized production in the low voltage grid in the form of photovoltaic and small wind generators gives a new energy flow. Earlier, the energy flow was always topdown as the energy was generated in big power plants in the high voltage grid and then distributed through the grid to the consumers at the low voltage grid. This was easier to analyze and plan. With the decentralized production the energy flow is now shifting according to the production from DER and the consumption. With high production and low consumption the energy will flow from the low voltage grid towards the higher voltage levels which causes grid loss, besides the neccessary transformation from DC produced by the RES to AC used in the high-voltage grid, which also causes grid loss. The increasing use of RES also contributes to problems caused by unstable voltage levels in the grid. In grid planning, the transformers and the tap changers are usually designed according to the voltage drops in the cables related to the consumption, but with decentralized production the grid now experiences two situations.

1) During high production and low consumption the voltage rises
2) During high consumption and low production the voltage drops

This leads to the necessity to trim the transformers in different settings during different situations. In low voltage areas there is no monitoring and no remote control, thereby trimming is a manual task as one has to go to the transformer in person.
The added amount of consumption of electric energy will naturally give an added stress on the grid as this is planned according to the historical electricity consumption. With the added focus on electric vehicles as well as electric heating, the amount of consumed energy will experience a sudden rise for which the grid is not designed. This will ultimately amount to lower voltage in the grid, less reliable supply of electricity and more grid loss.
Same situation but reversed will be present when DER are producing more than the consumption is in the local grid and a rise in voltage will occur which was not intended and will lead to grid loss and low quality electricity for the consumer, besides lower prises on selling former stored energy.
The normal way of coping with the above two problems from the DSO side will be grid strengthening by installing more and bigger cables and transformers. However installing some kind of remote controlled storage in the grid might in one or the other way help avoiding these situations and thereby avoid grid strengthening.

Kasper, a grid planning manager of Eniig, is in charge of solving this problem. He knows of more methods to do so and his task is to find the best one in terms of grid strengthening abilities, financial aspects, new normal coupling or new balance possibilities. He is using the S4G DSF to find out which is the best solution for a specific situation and a given grid constellation. He knows the topology and geography of the grid, and he can access the current data of consumed and produced energy as well as the energy flux of the grid using a web interface. Based on different data sources he can also simulate the impact of remote controllable transformers and storage, which can be installed on different grid levels.

To determine the best solution for grid stabilization, he needs to simulate a variety of options with different variables, such as investments for Eniig, financial impact for the prosumer as well as for the consumer, environmental impact and impact on energy loss, peak shaving and voltage quality. In the end, the best option is defined as the one taking expected future changes in the grid into account.

5.3 Traditional grid strengthening simulation - HLUC-3-PUC-1

First, Kasper will run the simulations of the baseline, the well known grid strengthening. Since this is the usual method, Kasper already knows all the variables for the simulation. Interactions with customers are only necessary if there is the need to rent more land for transformers or if the cables need to be replaced. Traditional grid strengthening has the highest financial impact for the customers, since the costs for this method is payed using tariffs charged by the DSO. The tariffs are computed based on the consumer's consumption, who will hardly know that the grid is being strengthened. However, they will no more discover voltage issues.
The benefit for Eniig is less voltage issues and lower grid-losses. This is the most favorable business case for the DSO today. Furthermore, there are other downsides for this option, such as power loss caused by the electricity cables or environmental damage due to the cable production or track laying itself.
This option determines the economic and technical baseline for benchmarking as it's the traditional way of overcoming congestion problems in DSO grids.

Since Eniig and therefore also Kasper is interested in finding the best option for all, customers, the environment and the DSO, he uses this well-known option to calculate a baseline used for benchmarking the alternative methods.

Use-Case Table for HLUC-3-PUC-1 – Traditional grid strengthening simulation:

Table 17 Traditional grid strengthening simulation

ID	**HLUC-3-PUC-1**	
Name	Traditional grid strengthening simulation	
Diagrams	HLUC-3-PUC-1_v1.png (Figure 15)	
Actors	Strategic grid planer (Person) S4G DSF (System) Data storage (System)	
Actors Goals	Strategic grid planer: • Calculation of baseline for comparison of different options taking into account: - financial impact for Eniig, - environmental impact - impact on energy loss, peak shaving, and voltage quality	
Pre-conditions	Instability of the grid has been announced over time Historical data (consumption, generation, demand patterns) is available Grid parameters are known Environmental impact is known	
Trigger	Instable grid due to RES (e.g. black outs) Evaluation of the best grid strengthening method needs to be done	
Postconditions success	Baseline could be calculated, results are available: voltage level improvement, reduction in losses, avoiding congestion, financial impact for ENIIG, prosumer and consumer, environmental impact	
Postconditions fail	Simulation could not be executed due to missing data or system failure	
Description	**Step**	**Action**
	1	Strategic grid planer launches S4G DSF
	2	Strategic grid planer specifies the options used for traditional grid strengthening
	3	Strategic grid planer specifies network topology which should be involved in the simulation
	4	Strategic grid planer loads historical data (consumption, production, storage) from data storage
	5	Strategic grid planer specifies tap changer settings
	6	Strategic grid planer specifies planning scheme and/or guidelines used for traditional grid strengthening
	7	Strategic grid planer starts simulation process
	8	S4G DSF simulates grid situation
	9	S4G DSF displays results
	10	Strategic grid planer analyses expected future changes in the grid

Extensions	Step	Branching Action
	3a	Manipulation of current grid topology with respect to future scenarios: • more DER • more EV • more heat-pumps
Sub variations	**Step**	**Branching Action**
	6a	Creation of new guidelines and/or planning schemes
	6b	New operation demands
	8	New normal coupling

UML diagram for HLUC-3-PUC-1 – Traditional grid strengthening simulation:

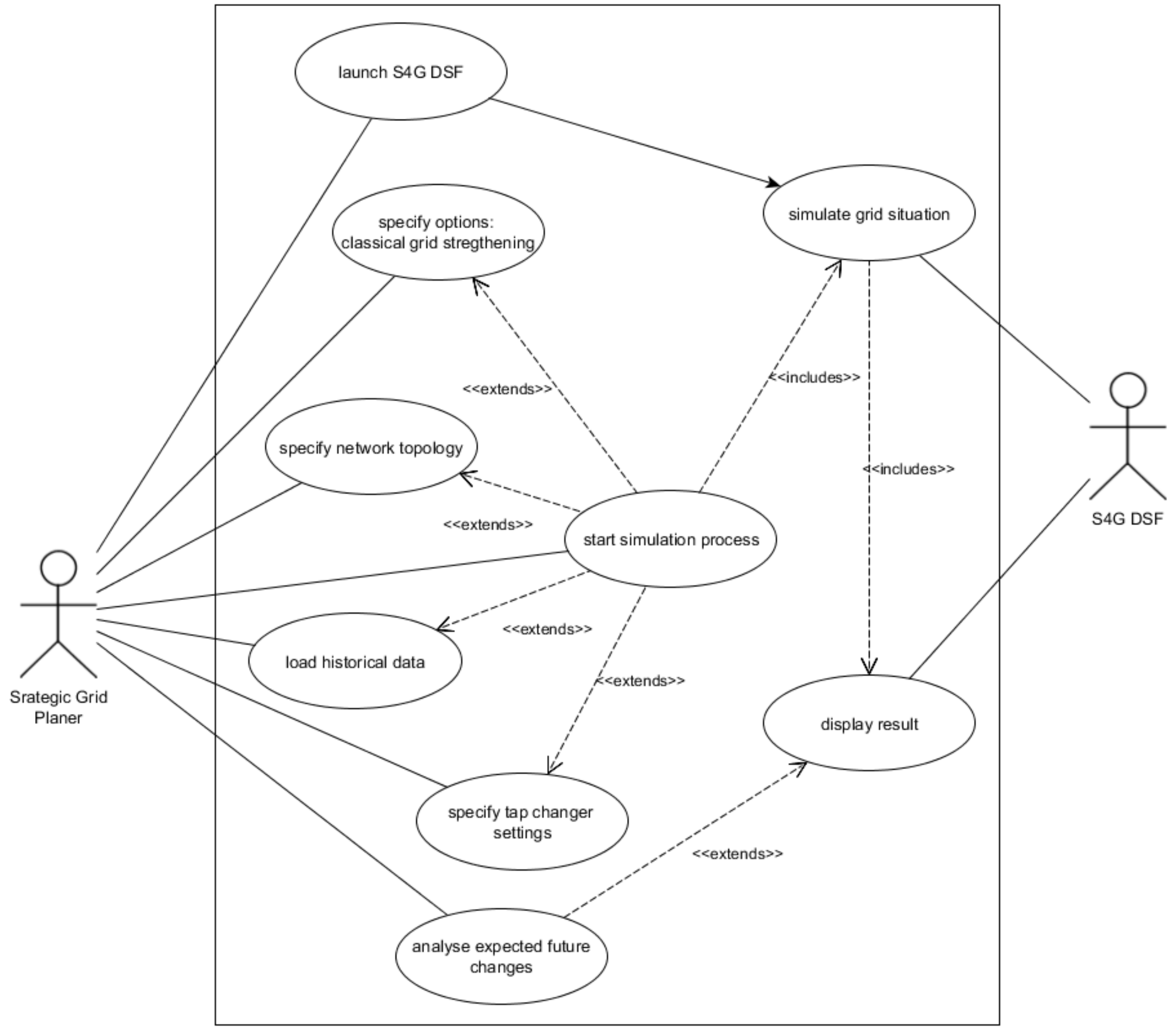

Figure 15 HLUC-3-PUC-1 – Traditional grid strengthening simulation

5.4 Simulation of private households investing in residential storage - HLUC-3-PUC-2

Kasper continues with the simulation. For the second option he simulates what happens if more private households are investing in residential storage to increase their self-sufficiency; local storage allows them to obtain more use of their own produced electricity from PV panels. These prosumers do not report the

installation to Eniig and the DSO has no access or knowledge about these installations. The battery management systems (BMS) for these storages are autonomous and run independent of the grid. Since Kasper cannot remotely access the different storage systems, the local settings of the consumers are regulating the energy flow. On days where the energy production of RES is higher than the local consumption, the produced overhead is first directed to the residential storage. If the storage is fully charged, the prosumer's energy is fed back into the low voltage grid. On the other hand, the prosumer will first empty his residential storage if the energy production from the RES is lower than the actual consumption. If the storage is empty, the prosumer will consume energy from the grid. This positively affects the costs for the prosumer, since his demand is lower compared to households without storage and RES.
For Kasper, this simulation is more complicated. He does not know about the installed storage since Eniig does not enforce notification requirements. Additionally, he realises that prosumers usually are lacking knowledge when it comes to storage dimensioning and battery life time. Therefore, he also assumes that the outcome of the simulation might not be showing the optimum case in terms of efficiency of the storage usage and the environmental impact. However, this option indirectly balances the grid because higher production and the demand of energy are damped by the use local storage.
In Kasper's opinion, this option could be enhanced by allowing him to coordinate the grid status, production, consumption and storage and by offering him a possibility to quickly determine the number and distribution of storage installed on the consumer level as well as their fill levels and the prosumers' consumption profile.
Since this is currently not possible, Kasper continues to simulate the impact on the grid stability without further control mechanisms. He can observe a positive impact depicted via peak shaving, for example during the cooking period. This impact is caused by prosumers relying on their local storage before consuming energy from the grid. He also realizes that the energy flux up- and downstream the grid is being minimized by the installation of residential storage resulting in decreasing grid loss.

Use-Case Table for HLUC-3-PUC-2 – Simulation of private households investing in residential storage:

Table 18 Private households investing in residential storage

ID	**HLUC-3-PUC-2**
Name	Private households investing in residential storage
Diagrams	
Actors	Strategic grid planer (Person) S4G DSF (System) Data storage (System)
Actors Goals	Strategic grid planer: • Grid stabilization • Simulate impact of RES • Simulate impact of BMS owned by prosumers • Determine best option for grid stabilization
Pre-conditions	Prosumers own RES and have invested in storage systems Storage systems are autonomously controlled by prosumer No interaction with the grid conditions (no control access from DSO) S4G System is up and running Simulation data is available Baseline parameters are known: • Grid topology • Grid parameters • Consumption
Trigger	Instable grid due to RES (e.g. black outs) Evaluation of the best grid strengthening method needs to be done

Postconditions success	Simulation revealed values for comparison Simulation reveals mismatch of storage and production at prosumer level Increased self supply	
Postconditions fail	Large inequalities in production and consumption Size of battery does not fit production and consumption Simulation could not be executed due to missing data or system failure	
Description	**Step**	**Action**
	1	At household level: Install a battery
	2	At household level: Optimize use of energy from production
	3	Strategic grid planer launches S4G DSF
	4	Strategic grid planer specifies the options used for traditional grid strengthening
	5	Strategic grid planer specifies network topology which should be involved in the simulation
	6	Strategic grid planer loads historical data (consumption, production, storage) from data storage
	7	Strategic grid planer loads tap changer settings
	8	Strategic grid planer specifies planning scheme and/or guidelines used for traditional grid strengthening
	9	Strategic grid planer starts simulation process
	10	S4G DSF simulates grid situation
	11	S4G DSF displays results
	12	Strategic grid planer analyses expected future changes in the grid
Extensions	**Step**	**Branching Action**
	13	Buy and sell stored energy to the grid following spotprices
Sub variations	**Step**	**Branching Action**
	14	Aggregator may be introduced

5.5 DSO investing in larger systems at substation level - HLUC-3-PUC-3

The third option for Kasper to simulate is if he can place battery systems in the medium voltage grid. This situation allows him to further investigate on the most suitable positioning and placement of storage in the grid, the correct dimension of the battery taking consumption and production into account, as well as lifetime and operational cost. Because of Eniig having expertise in buying storage, Kasper can ensure that the simulated capacity and live time of the chosen battery is optimal. The owner and operator of the battery will be Eniig which allows for enhanced storage coordination all over the grid with respect to the current grid situation, generation, and consumption. In his simulation, Kasper can now also take ancillary services like black starts into account because he can freely access the stored energy from the battery systems. Without additional storage and the option to access the residential storage systems in the prosumers' houses, he still needs the backup of centralized powerplants to overcome the gap in production and consumption during peak demand hours.

To start his simulation, Kasper collects data from production facilities and other customers. He is merely interested in generation and consumption data, which he feeds into the S4G simulation tool. He is also able to add data about the local topology to model if storage is feasible in the medium voltage grid and where it should be placed to gain the most positive effects. By optimizing the energy flux to and from the prosumers, Kasper can minimize the energy loss.
If the comparison shows that this option would be the best to stabilize the grid and Eniig decides to implement it, the DSO has to negotiate with the inhabitants. Storage needs to be placed on land owned by citizens which requires Eniig to rent or buy it in order to install battery systems. Additionally, the control algorithm for the storage coordination needs to be integrated in the DSO's SCADA system to allow daily operation and optimization of the grid.

Use-Case Table for HLUC-3-PUC-3 – DSO investing in larger systems at substation level:

Table 19 Grid operators investing distributed storage at low voltage level

ID	**HLUC-3-PUC-3**	
Name	Grid operators investing in distributed storage at low voltage level	
Diagrams		
Actors	Strategic grid planer (Person) S4G DSF (System) BMS (System) Data storage (System)	
Actors Goals	Strategic grid planer: • Determine impact of RES in the grid • Determine impact of DSO owned BMS in the grid • Determine financial and environmental aspects	
Pre-conditions	S4G System is up and running Simulation data is available Baseline parameters are known: • Grid topology • Grid parameters • Consumption • Battery power • RES power	
Trigger	Instable grid due to RES (e.g. black outs) Evaluation of the best grid strengthening method needs to be done	
Postconditions success	Impact results are shown on the dashboard of the DSO Simulation revealed values for comparison	
Postconditions fail	Simulation could not be executed due to missing data or system failure	
Description	**Step**	**Action**
	1	Strategic grid planer launches S4G DSF
	2	Strategic grid planer specifies network topology which should be involved in the simulation
	3	Strategic grid planer loads historical data (consumption, production, storage) from data storage
	4	Strategic grid planer specifies set-point behaviour
	5	Strategic grid planer starts simulation process

	6	S4G DSF simulates grid situation
	7	S4G DSF displays results
	8	Strategic grid planer analyses the results with a technical and economical perspective besides expected future changes in the grid
Extensions	**Step**	**Branching Action**
	5a	DSF scales up the situation (consumption, production, storage) to simulate on a reduced network topology a high penetration of RES (up to 100%)
Sub variations	**Step**	**Branching Action**

5.6 Deploying and enforcing distributed controllable storage at various levels - HLUC-3-PUC-4

The fourth option for Kasper is the simulation of a cooperation between prosumers and storage systems owned by Eniig. Residential and substation-level storage may be deployed jointly, meaning a more complex situation. Kasper does not know about already deployed private storage since there is no reporting requirement from the DSO or TSO. To gain knowledge and data from storage sites he needs to contact all owners for data collection permission about their storage and their consumer patterns. After the data collection, he uses the S4G simulation engine to model the situation of the grid when private storage and the storage on grid level is jointly operated and coordinated. In this situation, also ancillary services can be taken into consideration since in best case, Kasper can operate all of the installed storage systems in the grid.
Kasper realises that this situation might be complex to handle because he would need the option to separately operate single storage systems on all grid levels. Additionally, this option requires the ability to send set-points to the different battery systems to secure the optimal grid state. To be able to do this he needs consumption and production data as well as loading state of each storage in real-time or near real-time. Additionally, he highly depends on the willingness of the prosumers to accept the remote operation of their storage by the DSO.
Additionally, this option produces more work and expences and therefore requires the development of an operation strategy: Due to the missing reporting requirements for private storage installation Kasper first has to determine all prosumers before he can start negotiations with every single one about residential storage control. Furthermore, the consumer patterns and settings of the prosumers have to be respected when their storage is accessed remotely. In case prosumers do not want to contribute, they need to be treated separately, for example by using specific tariffs. Co-owned storage might further complicate neogtiations about storage operation rights.
However, Kasper also sees the potential of this option. By controlling all available storage systems the energy flux can be optimized to a maximum, therefore reducing grid loss. If battery storage systems are going to be installed and controlled both at residential and substation levels, the DSO will have specific demands and also counseling in which systems residential owners can install. This gives the benefit of more secure investments so that poor quality equipment has a minimum impact.
This will hopefully also bring the best and least environmentally harming systems to the marked thereby keeping pollution at the lowest possible state. It also allows residential owners to install bigger PV systems since their impact can be coordinated globally, thus minimizing congestion problems. For the DSO, it has the positive effect that the investments are mostly done by the prosumers.

Use-Case Table for HLUC-3-PUC-4 – Deploying and enforcing distributed controllable storage at various levels:

Table 20 Deploying and enforcing distributed controllable storage at various levels

ID	**HLUC-3-PUC-4**

Name	Deploying and enforcing distributed controllable storage at various levels	
Diagrams		
Actors	DSO or 3rd party aggregator	
Actors Goals	Strategic grid planer: • Determine impact of RES in the grid • Determine impact of DSO-coordinated and prosumer owned BMS in the grid • Determine financial and environmental aspects • Control bundled systems on radial to monitor grid and ensure grid stability	
Pre-conditions	Prosumer's BMS can be operated by the DSO (at least in the simulation) S4G System is up and running Simulation data is available Baseline parameters are known: • Grid topology • Grid parameters • Consumption • Battery power • RES power	
Trigger	How to overcome investments in stabilizing the grid in the most intelligent way?	
Postconditions success	Able to control bundled systems and impact electricity quality Impact results are shown on the dashboard Simulation revealed values for comparison	
Postconditions fail	Simulation could not be executed due to missing data or system failure Control failed because of no interaction with distributed storage systems and cooperation with system owners. Dispute of storage control between aggregator/DSO/Customer	
Description	**Step**	**Action**
	1	Strategic Grid Planer launches DSF application of S4G system
	2	Strategic grid planer specifies network topology which should be involved in the simulation
	3	Strategic grid planer loads historical data (consumption, production, storage) from data storage
	4	Strategic grid planer specifies set-point behaviour
	5	Strategic grid planer starts simulation process
	6	Strategic Grid Planer specifies location of battery in grid topology
	7	S4G DSF displays results
	8	S4G simulates impact
	9	Strategic grid planer analyses the results with a technical and economical perspective besides expected future changes in the grid
Extensions 1	**Step**	**Branching Action**

	6a	DSF receives the availiability of the storage device from each storage resource
Sub variations	**Step**	**Branching Action**
	8a	DSF simulate sending set-point to aggregator and aggregator sending set-point to BMS
Extensions 2	**Step**	**Scaling Action**
	6b	DSF receives the availiability of the storage device from each storage resource DSF scales up the situation (consumption, production, storage) to simulate on a reduced network topology a high penetration of RES (up to 100%) DSF tries to address network constraints by simulating set-point to BMS

Additional secondary use cases will be considered in the second release of the use-cases, such as “Data gathering”, to be a common use-case used for monotoring, collecting and recording data from the network, to be used in the primary use cases already presented.

6 Test sites description

6.1 Test site Bucharest: Advanced cooperative Storage System

The "Advanced Cooperative Storage Systems" scenario will be set up in Bucharest and operated by partner UPB in the MicroDERLab facilities. It will feature lower-TRL solutions proposed by S4G, namely the energy router, the use of storage jointly with DC buses and it will also address V2G services. In particular, a laboratory demonstrator will integrate innovative solutions with user's internal DC bus for direct energy transfer from/to storage units and critical consumptions which will allow 24/7 functionality for both DSO and prosumer, and for selected home appliances which can be related to survivability during blackouts. Figure 16 presents the Bucharestian test site.

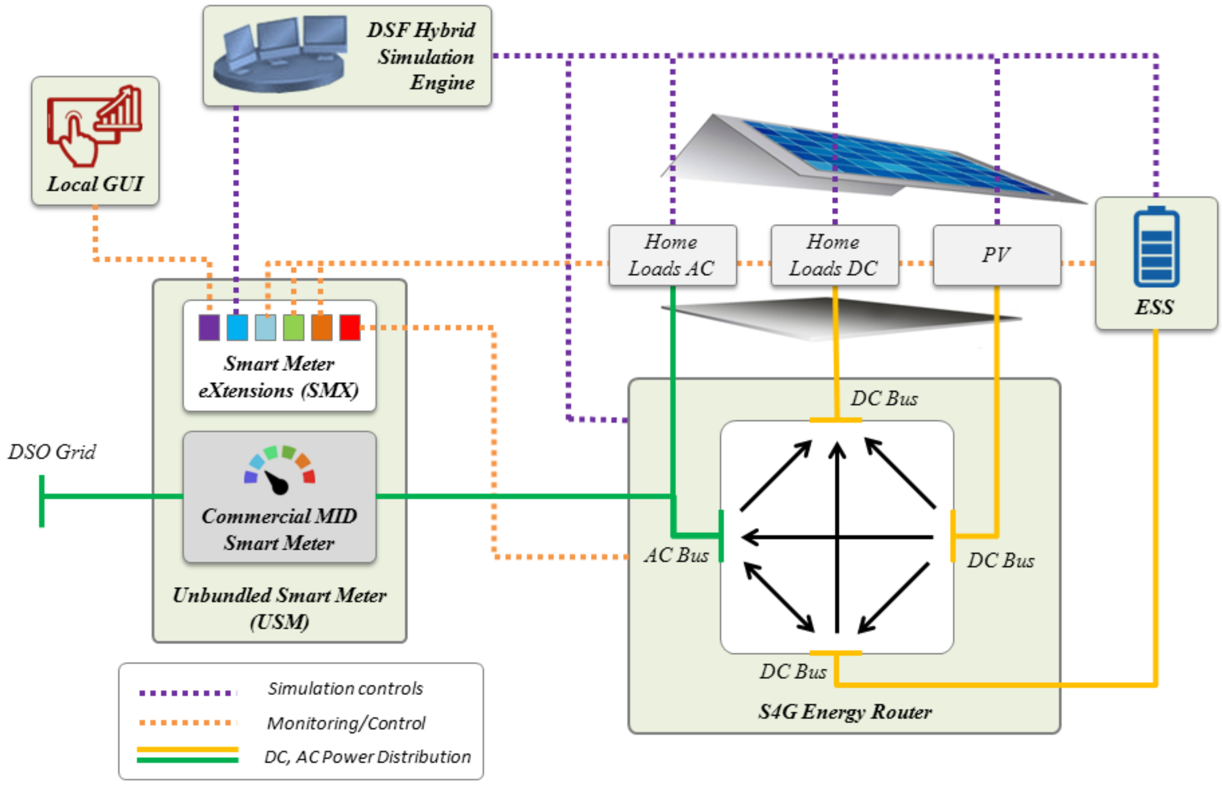

Figure 16 Test site in Bucharest

6.2 Test site Bolzano: Cooperation EV charging

The "Cooperative EV charging" scenario will be set up in Bolzano and operated by partner Edyna and Alperia. Bolzano is the capital of Alto Adige – Sudtirol , an alpine region in northern Italy characterized by the presence of two medium cities (Merano and Bolzano), and with strong seasonal changes in electricity demand and use of EVs due to the touristic nature of the site. As of today, around 250 EVs are already active in the area, using a charging network of 19 slow charging station (average power absorbed during charging: 22 kW AC) and two fast charging station (average power absorbed during charging: 45 kW DC). The diffusion of EVs is currently growing significantly in this area; therefore, EDYNA, as local utility, has already scheduled investments to activate 51 **new** charging stations (45 slow and 6 fast) in the area, before the end of 2017. The current EV charging infrastructure is monitored and controlled in realtime by EDYNA through a dedicated SCADA system.

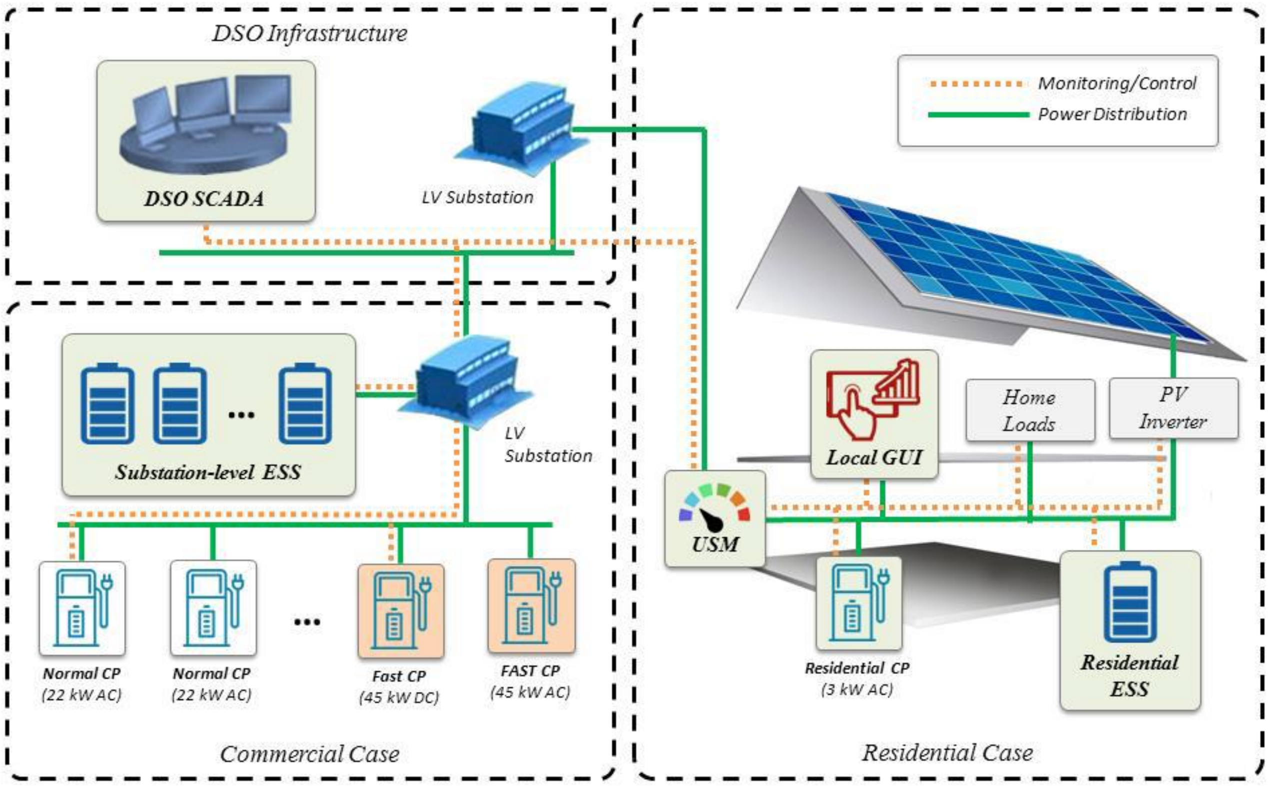

Figure 17 Testsite in Bolzano

This test site features two scenarios: a residential case and a commercial case, as depicted in Figure 17.

For the *residential case* Edyna will use as test site a single family house in a rural village close to Bolzano that is already provided with a PV installation on the roof (10 kW) and with a residential charging station. At the moment the house is not provided with a storage system, but it will be over the next months, in order to fulfil the requirements of the test site. The house will be provided with an USM, integrated with the residential ESS and a dedicated local GUI. From the planning point of view, in this case, the S4G DSF will be employed to support the design and sizing of local storage system and its impact on the cost, manageability and environmental sustainability of the EV charging process, both from the private users and from the local DSO point of view.

The *commercial case* will be tested in the parking place of Edyna in the city of Bolzano. The parking place is provided with several charging units (CU) for EVs. S4G will deploy "modified smart charge boxes" in each of the charging point, so to enable fine-grained monitoring and control of the charging process. The test site will be completed by installing a substation level ESS compliant with S4G interfaces and models. The S4G DSF will be employed in this scenario to study optimal sizing and design of the ESS. At this purpose, the S4G DSF will provide key informations about the costs and bemefits of such installations, as well as suggesting the best control strategy for such system, once the storage enters the operational phase.

6.2.1 Urban, Rural

The pilote in Bolzano consists of two different sites that are positioned in various kind of areas: the commercial case is located in the center of a city, while the residential case consists of a house located in a rural area. From the DSO point of view, this fact could be of particular interest, because the electrical grid is quite different in the two kind of areas. The commercial case will be significant for DSOs interested in planning charging stations in city centers, where the process of reinforcing the grid, e.g. by digging new distribution cables, is expensive and cumbersome. On the other hand, the residential case can show the behaviour of the rural electrical grid, characterized by long overhead lines, where the voltage drops along the line can be a critical factor.

6.2.2 Politics, Legislation, Regulations of specific country

The test site of Bolzano will not only permit the test and evaluation of technical issues, such as the joint control of EV charging stations and storage, but will also make possible the study and the application of the S4G methodology and solutions in the Italian legislative and regulatory framework, that is peculiarly complex, expecially for DSOs.
In the pilote of Bolzano will be possible to analyse market models, societal expectations and regulatory framework, pointing out the need for new policies and legislation in order to enable the accelerated uptake of S4G solutions.

6.3 Test site Fur: Storage coordination

The "Storage Coordination" scenario will be addressed in conjunction with the deployment in the Fur test site, and led by partner EMIDT. The Island of Fur is placed in the Northern part of Denmark in a fjord. Approximately, at Fur, 800 people in 400 houses. Additionally, there are app. 500 holiday houses besides app. 200.000 tourists visiting each year.

Fur is part of the Municipality of Skive. Skive has a target of being CO_2-neutral in 2029, which is also the goal of Fur.

The latest project at Fur has been converting of the gas-based district heating into waste heat from one of the huge clay industries at the island. And the other clay industry has converted their process heat form waste oil to natural gas, later to be up-graded to biogas.

The island has the last years converted into more biomass boilers, heat-pumps and photovoltaics. The share of DER is now more than 4% (this seems low, but because of the heavy industry, it is quit impressive). In the residential sector, more than 15% of all houses have PV-systems.

Table 21 The gross energy consumption for consumers and industry at the Island of Fur

	MWh/year 2010	MWh/year 2011	MWh/year 2012	MWh/year 2013
Decentralised heating	10.483	9.230	8.994	8.776
Centralised electricity and heating	15.850	11.174	12.669	11.036
Industry	60.773	78.408	82.568	80.570
Transportation	11.027	11.052	10.949	10.437
Wind power etc	479	597	617	656
Imported electricity	10.079	7.435	6.447	6.428
Total	108.690	117.896	122.244	117.902

The Island is electric connected to the mainland with 3 10 kV cables and there is 38 10/04 transformer stations.

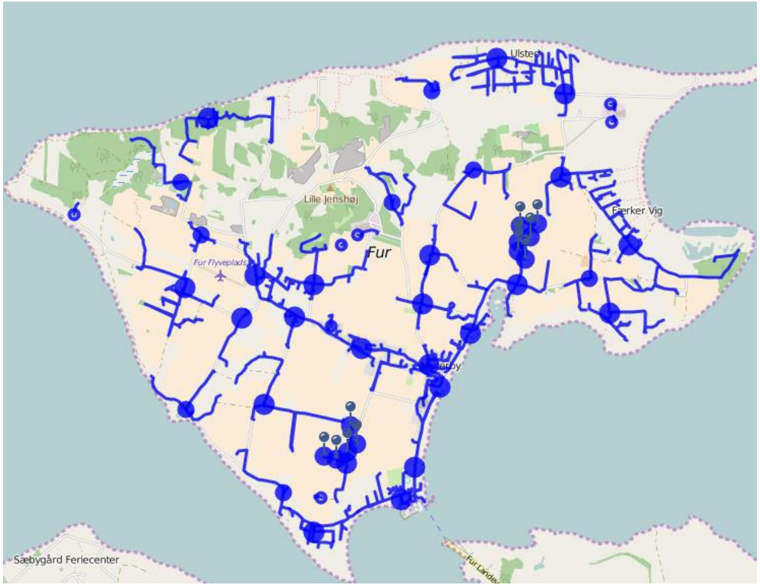

Figure 18 Transformer and grid at the Island of Fur

This test site features 5 residential Fur houses which are already provided with storage units paired with PV installations of various sizes (ranging from 3 to 6 kW sizes). The batteries already installed are Solar Batteries Li-ion 4.5 from Fronius.

The houses have an energy consumption of 4.500-6.300 kWh/year, their self-supply with PV and batteries installed ranges from 20-50%. The residents are both families and couples.

Such houses will be provided with an USM, integrated with the residential ESS and a dedicated local GUI. The project will investigate whether it is feasible to install batteries at substation-level, in case it is, a substation-level ESS will be deployed on-site (if we are able to find funding for the investments). Eniig has not got an Energy Management System (SCADA or alike) in the low voltage grid. It is all manually controlled.

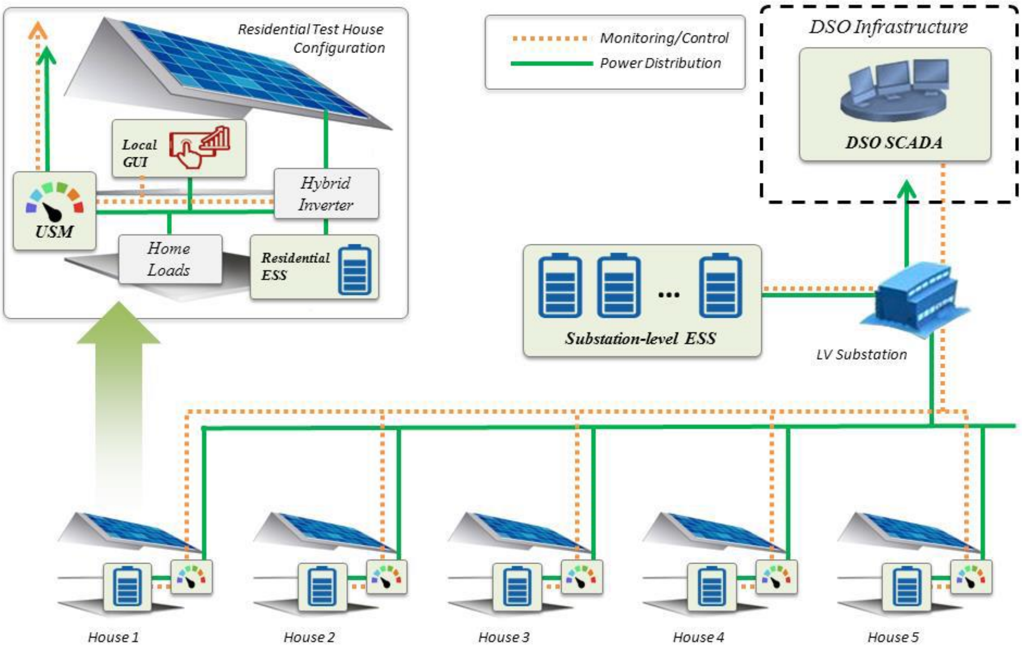

Figure 19 Storage coordination

6.3.1 Radial Geographical Location impact on use case (Urban, Rural)

The placement cost of the grid is mainly dependent on which geographical area to be served. In general, the cost in urban areas is higher than in rural areas because of pavements, more roads to be crossed, etc. Therefore, the geographical placement will determine which use case is the best to be applied.

6.3.1 Consumption and production profile impact on use case (Industry, Private, kWp DER installed)

Consumption and production profiles may impact the use case quite heavily. The profiles are very different in industry, retail, public or residential sector and also dependent on e.g. heat-pumps or EV's to come in the future. From the DSO perspective the balance in the grid is most challenged during cooking peak hours and also during peak hours in the mornings. The profile of a customer and the production profile seldomly match 100%, and as mentioned the self-supply in the houses at Fur is not much more than 50% on a yearly average. The match between the size of the PV-system and the end-user consumption also plays a significant role in all use cases; HLUC-3. If a specific radial has net overproduction or net consumption at all times, storage will not be a viable solution. However, typical radials will have times with net production and net consumption. This means that storage will have a positive effect on electricity quality in some use case.

6.3.2 Politics, Legislation, Regulations of specific country

Politics, legislation and regulations will have huge consequences in each specific country. It is nearly impossible to predict the future decisions in these areas. The only real qualified guesses can be made based on socio-economic effects and state profit loss, which have been proven in the past to be some of the major matters in decision making.
S4G will make rough estimations based on simple economic calculations when looking at politics, legislation and regulations since it is not exactly evidence based knowledge.

This pilot site is placed in Denmark. The Danish government has set up a target to be CO_2-neutral by 2050, besides being CO_2-neutral in electricity and heat by 2035. Besides this, Denmark intends to fullfill the EU-targets by 2030. For Denmark the reductiondemand is 39% of CO_2 in the non quote sector.

- Denmark has a taxation system for the electricity sector, which means that for every consumed kWh, a tax has to be payed. If there is electric heating e.g. heat-pump, customers can get a reduced tax.
- Denmark has had a scheme for feed-in-tariffs for PV-systems and generator of electricity (prosumers). This scheme has been closed, but most houses at the Island of Fur can sell their overproduction to a low feed-in tariff. Part of the feed-in-scheme, which ended in 2012, was also a limitation of 6 kWp for each system. If a customer installs a PV-system, he needs to be registered at the TSO as production site.
- Some houses in Denmark have battery systems. At the moment, there is no technical or marked regulations and feed-in tariff in this area.

Acronyms

Acronym	Explanation
ASRP	Advanced self-resilient prosumer
BMS	Battery Management System
BTM	Behind The Meter
DER	Distributed Energy Resource
DSF	Decision Support Framework
DSO	Distribution System Operator
EMS	Energy Management System
ER	Energy Router
ESG	External Stakeholder Group
EV	Electric Vehicle
G2V	Grid to Vehicle
HLUC	High Level Use Case
KPI	Key Performance Indicator
LV	Low Voltage
MD	Middle Voltage
POD	Point of Delivery
PUC	Primary Use Case
PV	Photovoltaic
RES	Renewable Energy Source
S	Scenario
SUC	Secondary Use Case
TSO	Transmission System Operator
UCD	User-Centered Design
USM	Unbundled Smart Meter
V2G	Vehicle to Grid

List of figures

List of tables

References

[1] CE Delft, “The potential of energy citizens in the European Union,” September 2016. [Online]. Available: http://www.cedelft.eu.

[2] G. Verbong, S. Beemsterboer and F. Sengers, “Smart grids or smart users? Involving users in developing a low carbon electricity economy,” *Energy Policy,* pp. 117-125, 2013.

[3] P. Devine-Wright and H. Devine-Wright, “Public Engagement with Community-Based Energy Service Provision: an Exploratory Case Study,” *Energy & Environment,* vol. 20, no. 3, pp. 303-317, 2009.

[4] V. Giordano, A. Meletiou, C. F. Covrig, A. Mengolini, M. Adelean, G. Fulli, M. Sánchez and C. Filiou, “Smart Grid projects in Europe: Lessons learned and current developments,” JRC scientific and policy reports, European Comission, Luxembourg, 2013.

[5] International Organization for Standardization, “ISO 9241-210:2010,” March 2010. [Online]. Available: http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=52075. [Accessed February 2017].

[6] N. Balta-Oskan, R. Davidson, M. Bicket and L. Whitmarsh, “Social barriers to the adoption of smart homes,” *Energy Policy,* vol. 63, pp. 363-374, 2013.

[7] L. Wienhofen, C. Lindkvist and M. Noebels, “User-centered design for smart solar-powered microgrid communities,” in *14th International Conference on Innovations for Community Services (I4CS)*, IEEE, 2014 , pp. 39-46.

[8] I. E. Commision, “IEC 62559-2:2015,” International Electrotechnical Commision, 2015.

[9] CEN-CENELEC-ETSI Smart Grid Coordination Group, “CEN-CENELEC-ETSI Smart Grid Coordination Group - Sustainable Processes M/490,” 2017.

[10] S. Adolph, A. Cockburn and P. Bramble, Patterns for Effective Use Cases, Boston, MA, USA: Addison-Wesley Longman Publishing Co., Inc., 2002.

[11] CEN-CENELEC-ETSI, “Smart Grid Reference Architecture,” 2012.