D6.12 - Phase 3 Evaluation Report

Deliverable ID	**D6.12**
Deliverable Title	**Phase 3 Evaluation Report**
Work Package	**WP6**
Dissemination Level	**PUBLIC**
Version	**1.0**
Date	**17/04/2020**
Status	**Final**
Type	**Report**
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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	2019-10-28	UNINOVA	First draft TOC available.
0.2	2020-01-09	ALPERIA	Added some inputs on Bolzano test site.
0.3	2020-01-29	FIT	Added end-user evaluation for Professional GUI.
0.4	2020-02-12	FIT	Added lessons learned summary of phase 3.
0.8	2020-03-13	Eniig	Section 4: Skive/Fur test site.
0.9	2020-03-19	LiBal	Section 4: HLUC-3-PUC-3.
0.10	2020-03-27	UPB	Consolidated document based on latest inputs.
0.11	2020-03-30	all	Various minor contributions from Eniig, Alperia, FIT, ready for review.
0.12	2020-03-31	UPB	Consolidated document for a second internal review.
0.13	2020-03-31	all	Various additional contributions from partners.
0.14	2020-03-31	UPB	Prefinal version, after all new contributions and addressing review.
0.15	2020-04-01	all	Various minor improvements.
0.16	2020-04-06	UPB	Additional inputs.
0.17	2020-04-12	UNINOVA	Revision and formatting.
1.0	2020-04-17	UNINOVA	Final version, ready for submission to the EC.

Internal Review History

Review Date	Reviewer	Summary of Comments
2020-03-30 (v0.11)	Marco Baldini (EDYNA)	Commented: • Various comments
2020-03-29 (v0.11)	Gitte Wad Thybo (ENIIG)	• Commented: Many corrections are needed • Comments on comparison between BM
2020-03-30 (v0.11)	Hamidreza Mirtaheri, Elisa Pautasso (LINKS)	Commented: • General minor corrections • Comments on figures
2020-03-31 (v0.13)	Gitte Wad Thybo (ENIIG)	• General minor corrections • Approved
2020-03-31 (v0.13)	Elisa Pautasso (LINKS)	Commented: • Minor corrections • Approved
2020-03-31 (v0.14)	Hamidreza Mirtaheri (LINKS)	Commented: • Comment on Fig. 57 • Missing definition of Mean Max Peak
2020-04-09 (0.16)	Elisa Pautasso Hamidreza Mirtaheri (LINKS)	Commented: • Table added from D6.3 • Figure numbering • Some definitions should be provided or corrected • Minor corrections required
2020-04-13 (0.17)	Elisa Pautasso Hamidreza Mirtaheri (LINKS)	Approved: • Minor comments.

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Executive Summary

This deliverable summarizes the phase 3 evaluation in all the three S4G test sites (Bucharest, Bolzano, and Fur/Skive) resulting from the planning and deployment activities documented in D6.3 [S4G-D6.3] and D6.6 [S4G-D6.6].

During phase 3, it was followed the phase 3 evaluation framework and its Key Performance Indicators (KPIs), that were defined in D6.3 [S4G-D6.3]. This final evaluation framework and its KPIs, targeted the evaluation of the high-level use-cases (HLUCs) taking into account both technical and economic aspects of the HLUCs and business cases defined in the project.

With this evaluation it was possible to verify that the S4G components and prototypes functionalities were developed and documented in their respective deliverables, namely: D4.3 [S4G-D4.3], D4.5 [S4G-D4.5], D4.7 [S4G-D4.7], D4.10 [S4G-D4.10], D4.12 [S4G-D4.12], D5.2 [S4G-5.2], D5.5 [S4G-D5.5], D5.7 [S4G-D5.7], and D6.9 [S4G-D6.9].

Each HLUC evaluation results are presented in their sections. In some cases, the business models assessment is associated with the achievements described in D7.5 [S4G-D7.5] and D7.8 [S4G-D7.8], A summary of the S4G qualitative assessment is provided in the Appendix A.

The final S4G objectives were successfully evaluated and their description is detailed. This deliverable includes insights on recommendation for future pilot implementations, suggestions to changes in policies and regulations based on generated results, dedicated "views" on evaluation results and suitable to highlight relevant results and the most potentially interesting business cases for DSOs interested in investing in storage solutions.

1 Introduction

This deliverable reports the phase 3 evaluation in all three S4G test sites, resulting from the execution of tests and evaluation activities, based on phase 3 evaluation framework and its respective KPIs. The following Milestones (MSs) allowed the evaluation procedure, namely:

- MS14 – "Components ready for integration in Phase 3 Test Site Platforms" was achieved with the integration of the following S4G components:
    - D4.3 – "Final User-side ESS control system" [S4G-D4.3].
    - D4.5 – "Final Grid-side ESS control system" [S4G-D4.5].
    - D4.7 – "Final Cooperative EV charging station control algorithms" [S4G-D4.7].
    - D4.10 – "Final USM extensions for Storage Systems" [S4G-D4.10].
    - D4.12 – "Final Energy Router" [S4G-D4.12].
    - D5.2 – "Final DSF Hybrid Simulation Engine" [S4G-5.2].
    - D5.5 – "Final DSF Connectors for external systems and services" [S4G-D5.5].
    - D5.7 – "Final DSF Predictive Models" [S4G-D5.7].
    - D6.9 – "Final Interfaces for Professional and Residential users" [S4G-D6.9].
- MS15 – "Phase 3 Platform operative in test sites and ready for evaluation" was achieved after the integration of phase 3 S4G components, reported in D6.6 [S4G-D6.6].

This deliverable also reports the phase 3 lessons learned to facilitate the iterative process in taking re-design decisions, find solutions to errors and detected inefficiencies, identify the solutions with the highest potential for impact.

1.1 Scope

This deliverable presents the phase 3 evaluation results of Task 6.5 – "Evaluation". Reporting the evaluation of the final S4G prototypes and the S4G HLUCs. This document is an update of D6.10 [S4G-D6.10] and D6.11 [S4G-D6.11]. No future updates of this deliverable are expected.

1.2 Related documents

ID	Title	Reference	Version	Date
D2.4	Final S4G Business Models	[S4G-D2.4]	1.0	2019-08-06
D2.5	Initial Lessons Learned and Requirements Report	[S4G-D2.5]	1.0	2017-05-30
D2.6	Updated Lessons Learned and Requirements Report	[S4G-D2.6]	1.0	2018-06-07
D2.7	Final Lessons Learned and Requirements Report	[S4G-D2.7]	1.0	2019-12-19
D4.1	Initial User-side ESS control system	[S4G-D4.1]	1.0	2017-08-30
D4.2	Updated User-side ESS control system	[S4G-D4.2]	1.0	2018-06-14
D4.3	Final User-side ESS control system	[S4G-D4.3]	1.0	2019-06-13
D4.4	Initial Grid-side ESS control system	[S4G-D4.4]	1.0	2018-08-30
D4.5	Final Grid-side ESS control system	[S4G-D4.5]	1.0	2019-09-25
D4.6	Initial Cooperative EV charging station control algorithms	[S4G-D4.6]	1.0	2018-08-14

ID	Title	Reference	Version	Date
D4.7	Final Cooperative EV charging station control algorithms	[S4G-D4.7]	1.0	2019-09-03
D4.8	Initial USM extensions for Storage Systems	[S4G-D4.8]	1.0	2017-08-31
D4.9	Updated USM extensions for Storage Systems	[S4G-D4.9]	1.0	2018-08-31
D4.10	Final USM extensions for Storage Systems	[S4G-D4.10]	1.0	2019-10-17
D4.11	Initial Energy Router	[S4G-D4.11]	1.0	2018-11-02
D4.12	Final Energy Router	[S4G-D4.12]	1.0	2019-09-12
D5.1	Initial DSF Hybrid Simulation Engine	[S4G-D5.1]	1.0	2018-02-22
D5.2	Final DSF Hybrid Simulation Engine	[S4G-D5.2]	1.0	2019-09-25
D5.3	Initial DSF Connectors for external systems and services	[S4G-D5.3]	1.0	2017-09-04
D5.4	Updated DSF Connectors for external systems and services	[S4G-D5.4]	1.0	2018-09-03
D5.5	Final DSF Connectors for external systems and services	[S4G-D5.5]	1.0	2019-09-25
D5.6	Initial DSF Predictive Models	[S4G-D5.6]	1.0	2018-08-30
D5.7	Final DSF Predictive Models	[S4G-D5.7]	1.0	2019-09-25
D6.2	Phase 2 Test Site Plans	[S4G-D6.2]	1.0	2018-12-28
D6.3	Phase 3 Test Site Plans	[S4G-D6.3]	1.0	2019-11-06
D6.5	Phase 2 Test Site Platforms and Deployments Report	[S4G-D6.5]	1.0	2018-12-28
D6.6	Phase 3 Test Site Platforms and Deployments Report	[S4G-D6.6]	1.0	2020-03-03
D6.7	Initial Interfaces for Professional and Residential users	[S4G-D6.8]	1.0	2017-08-31
D6.8	Updated Interfaces for Professional and Residential users	[S4G-D6.9]	1.0	2018-08-23
D6.9	Final Interfaces for Professional and Residential users	[S4G-D6.9]	1.0	2019-09-25
D6.10	Phase 1 Evaluation Report	[S4G-D6.10]	1.0	2018-05-02
D6.11	Phase 2 Evaluation Report	[S4G-D6.11]	1.0	2019-05-06
D7.5	Exemplary business cases and value propositions	[S4G-D7.5]	1.0	2020-03-03
D7.8	S4G Final exploitation plans	[S4G-D7.8]	1.0	2020-03-30
D8.1	POPD Requirement No.1	[S4G-D8.1]	1.0	2017-04-04

2 Bucharest Test Site: Advanced Cooperative Storage System Scenario

This scenario is composed by a laboratory test site where some S4G prototypes are evaluated. Moreover, a home hybrid energy system with an energy router (ER) and a DC bus was also evaluated. The detailed test site description and the phase 3 deployment diagram are available in D6.3 [S4G-D6.3].
From the solution developed and implemented in phase 2, a set of KPIs was defined to evaluate the proposed solution, testing the main control algorithms by simulation and by using a Hardware-in-the-Loop (HIL) technology, as described in D6.3 [S4G-D6.3]).

HIL was proven to be a very useful tool, to allow a flexible portfolio of scalable load and PV production profiles combined with scalable storage means, enabling the analysis of an Advanced Prosumer (AP) in different test scenarios. In all situations, HIL used the ER as real hardware device to orchestrate PV production and battery control.

As the consumption profile in the laboratory is very predictable (nearly constant behaviour) and not representative for a usual end-customer, real consumption profiles from anonymized users were used as inputs in the HIL tests. HIL is embedded in a power-flow environment, which allows to associate the prosumer Point of Common Coupling (PCC), PV or consumption power to a load connected to a simulated network, in order to analyse the impact of the prosumer resources on the grid. The HIL setup was also developed to be able to address teaching purposes, thus being also a good open tool for further research and didactic activities. Table 1 summarises the HLUC-1 evaluation KPIs defined in D6.3 [S4G-D6.3].

Table 1. HLUC-1: Phase 3 KPIs.

Use-case	KPIs
HLUC-1-PUC-1-S1: *Avoid curtailment with/without storage capacity*	Considering: • $T_{SERVICE}$ =15 min, 60 min • $P_{STOR} > 0$ The average power in the PCC during $T_{SERVICE}$ must be $P_{PCC} = P_{PCC\_NO\_STOR} + P_{STOR} \pm 10\% \, P_{PCC\_NOM}$ This evaluation will use HIL technology.
HLUC-1-PUC-1-BM-1: *Handle over-generation from RES into the grid (avoid curtailment orders from DSO)*	Economic aspects of this functionality will be analysed in different time horizons, to show the “break-even” moments for being commercially viable.
HLUC-1-PUC-1-S2: *Serving peak demands on DSO level*	Considering: • $T_{SERVICE}$ =15 min, 60 min • $P_{STOR} < 0$ The average power in the PCC during $T_{SERVICE}$ must be $P_{PCC} = P_{PCC\_NO\_STOR} + P_{STOR} \pm 10\% \, P_{PCC\_NOM}$ This evaluation will use HIL technology.
HLUC-1-PUC-1-S3: *Provide ancillary services (black-start)*	Considering: • 5 min ≤ $T_{SERVICE}$ ≤ 15 min • 100 W ≤ $P_{GridLoad}$ ≤ 500 W The nominal voltage in the PCC during $T_{SERVICE}$ must be $U_{PCC} = 230 \, V \pm 10\%$ The black-start evaluation will use a simulated grid with $P_{GridLoad}$

Use-case	KPIs
HLUC-1-PUC-2: *Advanced self-resilient prosumer*	Considering: • T = 1 hour, 1 day • $P_{DCLoad} \approx 100$ W • 30 min < T_{ASRP} < 60 min KPI2.2 to 2.4 will be evaluated during T using HIL technology $KPI2.2 = K_{USER\_E\_BACK} = \frac{E_{PCC-}}{E_{CONS}} < 10\%$ $KPI2.3 = K_{PV\_LIM} = \frac{E_{PV\_LIM}}{E_{PV\_METEO}} < 20\%$ $KPI2.4 = K_{USER\_E\_DSO} = \frac{E_{PCC+}}{E_{CONS}} < 70\%$ Regarding KPI2.5, a resiliency service during T_{ASRP}, using P_{DCLoad} connected to the ER DC bus, its DC bus voltage must be *V_{DCBus_ER} = 220 V ± 10%*
HLUC-1-PUC-2-BM-1: *Prosumer will act always as a consumer from the grid side*	Economic aspects of this functionality will be analysed in different time horizons, to show the “break-even” moments for being commercially viable.
HLUC-1-PUC-3: *Resilient hybrid cooperative ecosystem*	Considering: • T = 15 min • $P_{Lab2Load} \leq 500$ W While feeding the $P_{Lab2Load}$ during 95% of T, the 400 V DC bus voltage must be *V_{DCBus} = 400 V ± 10%*
HLUC-1-PUC-3-BM-1: *Enabling energy services to connected neighbourhood prosumers and consumers*	Economic aspects of this functionality will be analysed in different time horizons, to show the “break-even” moments for being commercially viable.

2.1 Phase 3 prototypes deployment

According to D6.6 [S4G-D6.6], the Bucharest phase 3 prototypes deployed were:

- D4.3 [S4G-D4.3].
- D4.10 [S4G-D4.10].
- D4.12 [S4G-D4.12].
- D5.2 [S4G-D5.2].
- D5.5 [S4G-D5.5].
- D5.7 [S4G-D5.7].

2.2 Phase 3 KPIs evaluation

2.2.1 HLUC-1-PUC-1-S1

2.2.1.1 *Description*

HLUC-1-PUC-1-S1: "Avoid curtailment with/without storage capacity" demonstrates that the AP is able to absorb additional power from PCC, if over-generation from Renewable energy sources (RES) is present in the grid. This High-Level Use-Case (HLUC) is considered as a "storage service" (P_{STOR} order) to be provided to the grid.

2.2.1.2 *Evaluation procedure*

The LESSAg is orchestrating resources in order to absorb additional power during a $T_{SERVICE}$ time frame (selected 15- or 60-minutes periods). In order to make the evaluation, a complete HIL setup was used, with LESSAg receiving a P_{STOR} order from HIL during $T_{SERVICE}$. The evaluation shows the AP capability to do the service asked from any entity which need it and translated in a general P_{STOR} order during $T_{SERVICE}$. The evaluation used HIL technology, and considered the following parameters:

- $T_{SERVICE}$ =15 min, 60 min
- $P_{STOR} > 0$

The average power in the PCC during $T_{SERVICE}$ must be

$$P_{PCC} = P_{PCC\_NO\_STOR} + P_{STOR} \pm 10\%\ P_{PCC\_NOM}$$

The P_{PCC_NOM} represents the nominal power allocated to the user.
In order to choose a comprehensive value which fits with regular customer (consumer or prosumer), it can be considered a value which correspond to the maximum contractual power (which depends on each case and may be a confidential information) or we can make a calculation based on the maximum current allowed for the customer, which has more to do with the practice.
It was chosen therefore to select a default P_{PCC_NOM} based on the maximum current, and while this can be seen usually between 32 and 80 A, depending on end-customer characteristics, the lower value is more demanding in terms of achieved KPIs, so the evaluation will consider the more sensitive I_{MAX} = 32 A value.
The default P_{PCC_NOM} for this value will be calculated for a single-phase end-user as being

$$P_{PCC\_NOM} = I_{MAX} * U_{NOM} = 32 \times 230 = 7360 \text{ W} = 7.36 \text{ kW}$$

This value is a maximum which is obtained only on short time-periods and may be also too high for a comprehensive evaluation from grid perspective. Consequently, the nominal power in PCC was even further reduced by considering a simultaneity factor K_{SIMULT}, which is usually considered in network design as being between 0.15 and 0.25, depending on network real conditions. The evaluation has considered as an average K_{SIMULT} = 0.2. This value allows a more sensitive value for P_{PCC_NOM} as being

$$P_{PCC\_NOM\_K} = P_{PCC\_NOM} * K_{SIMULT} = 7.36 \times 0.2 = 1472 \text{ W} = 1.47 \text{ kW}$$

To be noted that for 1 hour, the value of the energy consumption which correspond to $P_{PCC\_NOM\_K}$ is $E_{CONS\_NOM\_K}$ = $P_{PCC\_NOM\_K}$ * 1, so it has the same value: $E_{CONS\_NOM\_K}$ = 1472 Wh.
The latest value is also compliant with the load profiles which were used during all tests and with the laboratory scale demonstrator which has limited power values for the ER components.

The features of LESSAg were designed to accept storage services with a time granularity down to 1 minute, which allows that each minute can be considered a different P_{STOR} order (STOR is an abbreviation from "STORAGE"), in order to cope with more sophisticated services which ask for narrow following of a load-curve. However, the procedure considered services done as average value over 15 or 60 minutes.

2.2.1.3 Evaluation results

Several tests were made and the results of two of them are further described.

PUC-1-S1-1 test: a P_{STOR} request is asked for consuming energy from the grid during one hour (Figure 1), with two requests, namely:

- P_{STOR1} = 150 W, from minute 15 to 30.
- P_{STOR2} = 120 W, from minute 45 to 60.

All Storage as a Service (SaaS) requests are positive values, meaning that it is requested that power is consumed from the grid.

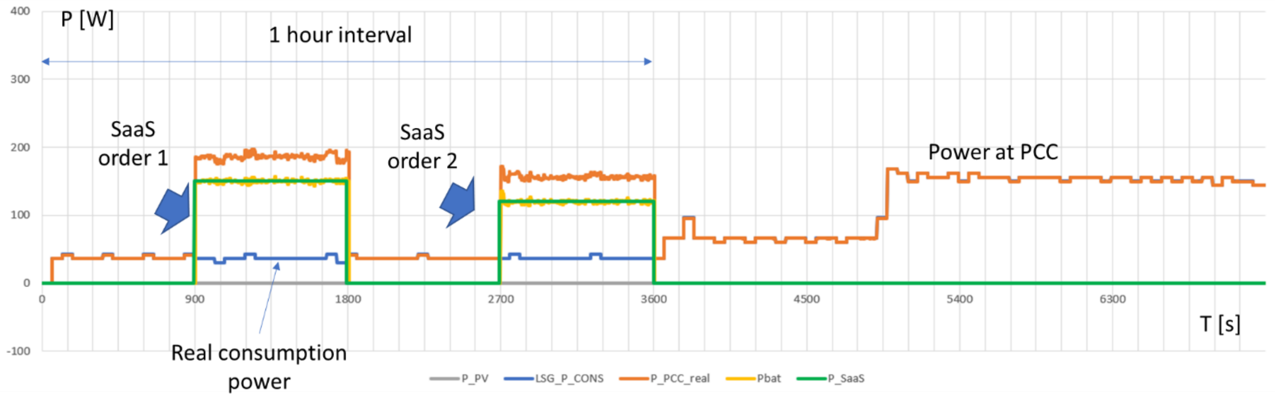

Figure 1. HLUC-1-PUC-1-S1-1 test: Request for consuming different P_{STOR} from the grid.

The test shows that the PCC consumption level (light brown colour) has increased with the SaaS order (green colour), in comparison with the real consumption power (blue line). By considering $P_{PCC\_NOM\_K}$ = 1.47 kW, the maximum error for the service needs to be ± 147 W. Figure 1 shows a good follow-up of the SaaS, which is under 50 W, according to the requested condition.

In the next test (PUC-1-S1-2), it is shown the possibility of having short or even very short time SaaS (one to 10-15 minutes services), as show in Figure 2.

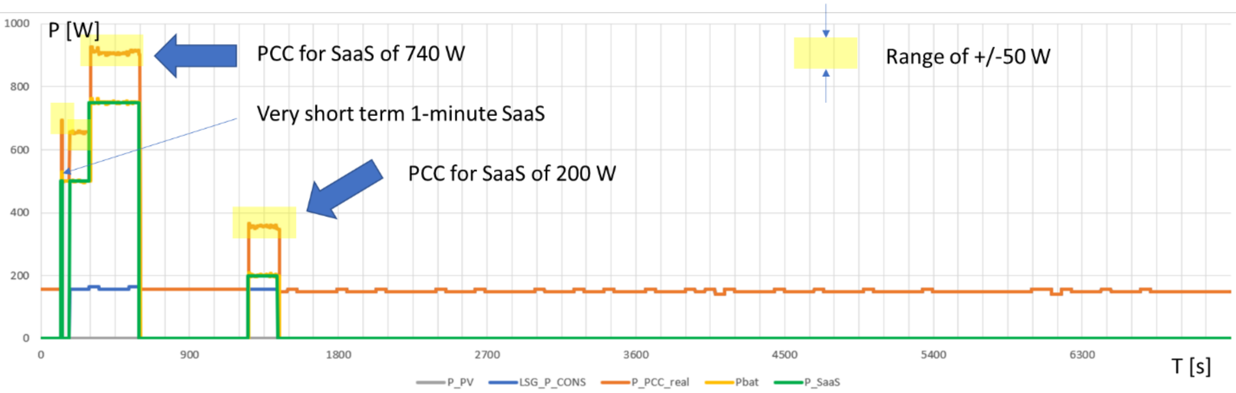

Figure 2. HLUC-1-PUC-1-S1-2 test: Request for consuming short-term P_{STOR} from the grid.

The test shows the PCC consumption (light brown colour) following the SaaS order (green colour), while the band of power variation in PCC is always less than ±50 W (the range of ± 50 W is shown in Figure 2, for easy assessment on the service accomplishment) . The band of ±50 W was chosen as a more severe test than the KPI, which allows a ±1472 W band.

Figure 3 shows a sequence of SaaS orders (by giving different values to P_{SaaS} = P_{STOR} order), as follows:

- P_{STOR1} = -250 W, from minute 0 to 15, and simulates the fact that the AP is producing more energy than it can store, then it sends it to the grid, in order to be stored by a neighbour battery. This order corresponds to HLUC-1-PUC-1-1-S1a.
- P_{STOR2} = 400 W, from minute 20 to 35, and simulates the fact that the AP is able to absorb more energy than it is producing, then it takes from the grid the corresponding SaaS order power, in order to store excess energy from a neighbour. This order corresponds to HLUC-1-PUC1-1-S1b.
- In between these SaaS, there are also two small 1-minute SaaS, negative and positive, to test more the dynamics of the services.

It can be seen that a ±100 W band deviation is never exceeded. This band is narrower than the accepted band for the KPI, which is ±147 W. The higher band than the one previous used was selected as it covers better the PCC power fluctuation in a period with PV having stochastic production. To be noted that on 15-minute average power, the deviation even lower than the selected band value: 0.28% from P_{PCC_NOM} in first SaaS order and 0.46% from P_{PCC_NOM} in last 15-minutes SaaS order. Both average deviations are much lower than the chosen 10% deviation from P_{PCC_NOM}.

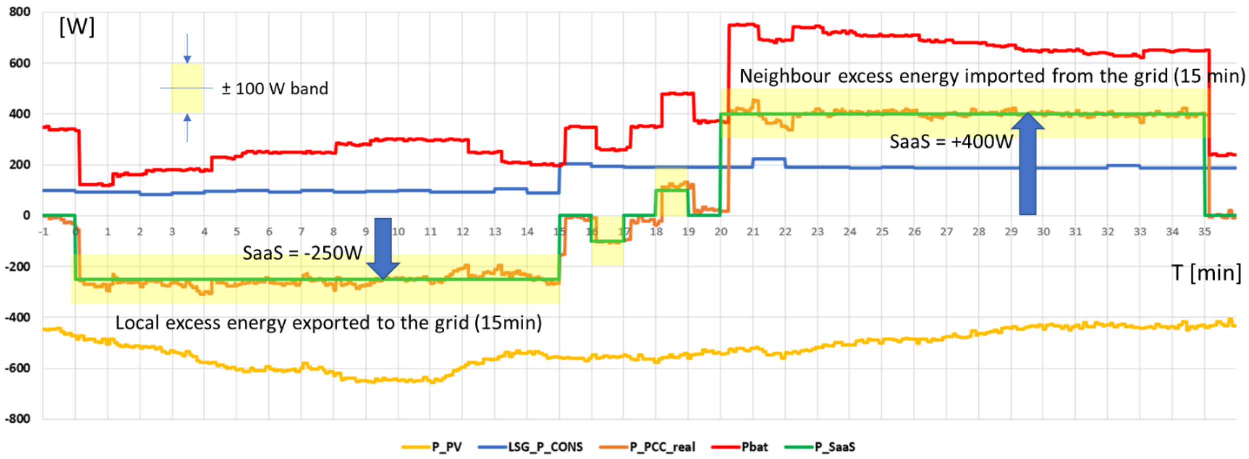

Figure 3. HLUC-1-PUC-1-S1-3 test: Requests for a sequence of negative and positive P_{STOR} (SaaS) requests (PUC-1-S1a and PUC-1-S1b).

To be noted that the first SaaS is similar from technical point of view with PUC-1-S2, as in both cases it is a negative SaaS. However, in this case, the reason for the negative SaaS is to release excess energy from PV, which cannot be stored by the local AP during the daytime, while in PUC-1-S2 the service with negative value is for helping the grid during the evening with local production from stored energy.

A sequence of image on the didactic-oriented HIL, with and without SaaS, are given in Figure 4, Figure 5, and Figure 6.

Figure 4 presents a zone of the simulated grid, having AP1 on the right side, with a power given by the real-time HIL and a scaling of 1 kW in the grid for each 10 W in the AP. AP2 acts, acting as a peer to AP1, on the left side, having a power of 9 kW. Figure 4 shows a snapshot during minute 31, when there is no SaaS.

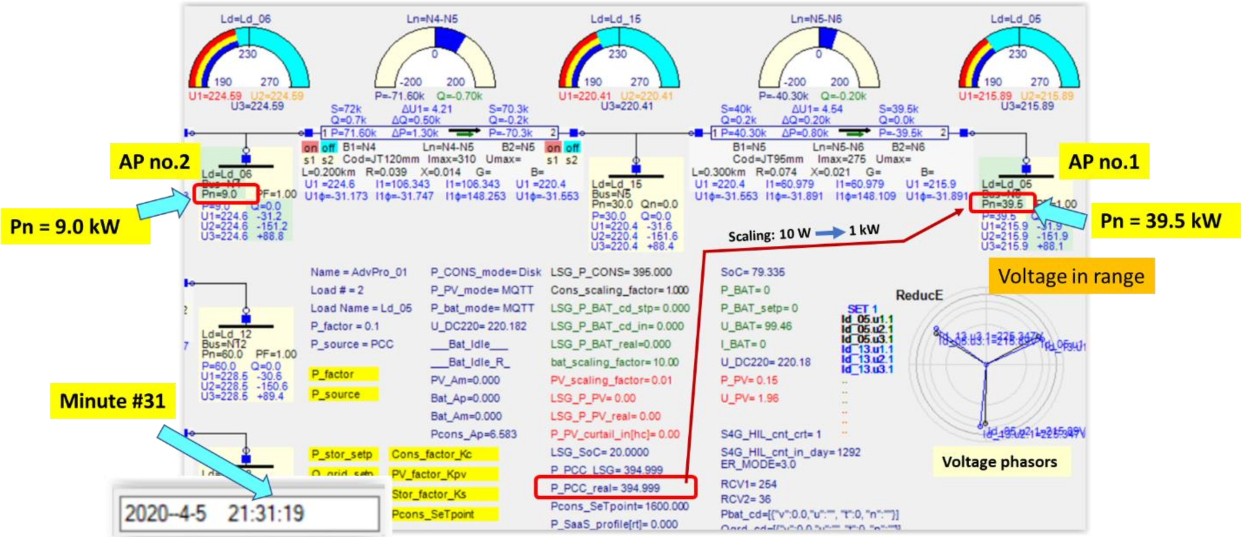

Figure 4. Details on the didactic-oriented HIL interface used for the tests (P_{STOR}= 0 W).

Figure 5 shows a SaaS request of 20 kW in the AP1 connected to the grid, while its pair AP2 receives a request of SaaS of -20 kW in the same grid, as shown on the left side. By invoking the load-flow, it can be seen that the power flow and voltages are changed, with a reduction of the voltage at AP1 bus, due to the fact that the consumption in PCC is higher.

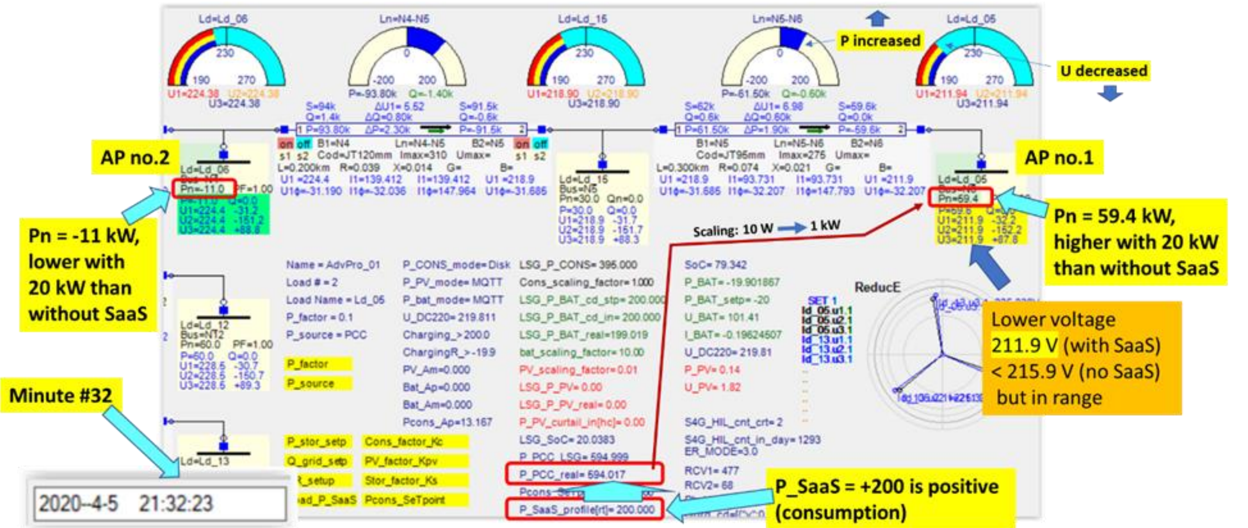

Figure 5. Details on the didactic-oriented HIL interface used for the tests (P_{STOR}= 200 W, grid consumption).

Figure 6 shows a reversed SaaS request, with -20 kW in the AP1, while its pair AP2 receives a request of SaaS = +20 kW. By invoking the load-flow, it can be seen that the power flow and voltages are again changed, with an increase of the voltage at AP1 bus, due to the fact that the consumption in PCC is now lower.

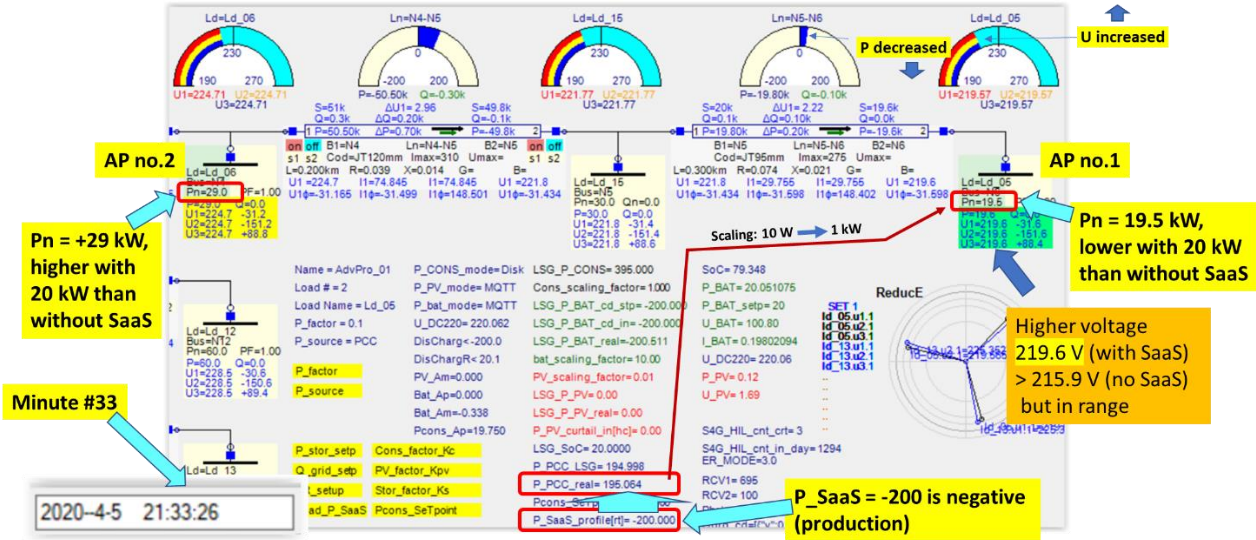

Figure 6. Details on the didactic-oriented HIL interface used for the tests (P_{STOR}= -200 W, grid injection).

The HIL functionality is embedded in the open-source GridMonK tool, developed by UPB, as special module tailored for S4G typology analysis. The whole package is able to invoke the OpenDSS load-flow program, which is an open-source application developed by EPRI.

The GridMonK and its HIL module are therefore designed to make AP related tests with storage control based on LESSAg software, by using real hardware equipment in the loop - namely the ER with PV resources and batteries, as well as to develop laboratory sessions for master and doctoral students, such that different studies can be made for didactic and research purposes in UPB.

2.2.2 HLUC-1-PUC-1-BM-1

2.2.2.1 Description

HLUC-1-PUC-1-BM-1: "Handle over-generation from RES into the grid (avoid curtailment orders from DSO)" analyses the economic aspects of HLUC-1-PUC-1 in different time horizons, to show the "break-even" moments for being commercially viable.

2.2.2.2 Evaluation procedure

The business analysis is considering SaaS possibilities of an AP for different timelines, in order to assess the horizon which brings a breakeven. The breakeven is declared positive if the investment can be paid in maximum 12 years, by considering also the technological constraints related to number of complete cycles needed to cover the investment cost. If the requested number of cycles is higher than the technical possible number of cycles, then the case is rejected due to technical considerations. Five timelines were considered: 2021, 2023, 2025, 2028 and 2030, covering the whole decade for which EU is interested to see roadmaps towards the 100% carbon neutrality till 2050.

The investment cost is calculated in two variants: without subsidies or considering subsidies. The technology evolution is presented in row 1 of Table 3 and Table 4, for a different scenario evolution:

- More conservative (Table 3) - Technology evolution V1 (slower technology evolution) and Policy V1 (higher / strong subsidy level in the first three time horizons).
- More aggressive (Table 4) - Technology evolution V2 (more aggressive technology evolution, with more scientific breakthroughs) and Policy V2 (quicker reduction of subsidies in second and third time horizons).

Specific energy cost during the excess periods (usually in the middle of the day) depend highly on the PV costs evolution (wind RES is not considered, but a similar situation may occur during some nights in windy regions). The evolution of the PV-based energy is present in row of Table 3 and Table 4.

The Return of Investment (ROI) is mainly based on the difference of price between peak hours (when it remains high during the entire time horizon, row 4 of Table 3 and Table 4) and the excess energy periods. Efficiency of the SaaS cycle is affecting the stored kWh, thus the energy cost difference for one stored kWh is given by

$$\Delta C = C_{peak} * \eta_{BESS} - C_{Excess\_energy}$$

Where ΔC is the energy cost difference [EUR /kWh], C_{peak} is the price of energy during the peak hours [EUR/kWh], η_{BESS} is the Battery Energy Storage System (BESS) efficiency and C_{Excess_energy} is the price of energy during the excess energy periods [EUR/kWh].
The number of years for ROI is given by the investment cost divided by the income each year

$$Y = Inv/\ (\Delta C * DY)$$

Where Y is the number of years [years], *Inv* is the investment costs [EUR/kWh installed], ΔC is the energy cost difference previous introduced [EUR/kWh] and DY is the number of days over a year [days], DY=365.
The number of cycles needed to reach ROI is given by:

$$N_{Cycles\_needed} = Y * DY$$

This number is compared with the effective technological limit of the BESS technology and the value need to be lower than this maximum cycle limit:

$$N_{Cycles\_needed} < N_{Cycles\_Max}$$

For simplification, it is not considered the second life of the batteries, which in some cases can add more ROI income.

2.2.2.3 Evaluation results

The two scenarios were analysed and the results are presented in Table 3 and Table 4 (cells considered as being more important are bolded). The tables have also cells with different colours, with their meaning presented in Table 2.

Table 2. Legend of the colours used HLUC-1 BMs evaluation tables.

Colours	Meaning
	ROI between 8 and 12 years
	ROI < 8 years
	ROI is reached for number of cycle higher than technically possible
	Breakeven is reached for an investment
	Breakeven is possible, and subsidies are not needed

Table 3. HLUC-1-PUC-1-BM-1: Analysis of SaaS business feasibility considering Policy 1 and Technology V1 scenarios.

Row	Economic Variable	2021	2023	2025	2028	2030
1	**Specific cost for BESS [EUR / kWh installed], Technology V1**	**1200**	**950**	**700**	**500**	**400**
2	**Subsidies per kWh of BESS [EUR / kWh installed]. Policy 1**	**900**	**500**	**100**	**0**	**0**
3	Specific cost for BESS with subsidies [EUR / kWh installed]	300	450	600	500	400
4	Energy cost during peak hours [EUR/kWh]	0.25	0.25	0.25	0.25	0.25
5	**Energy cost during excess energy period [Euro/kWh], Technology V1**	**0.12**	**0.09**	**0.07**	**0.06**	**0.04**
6	Efficiency of BESS	90%	90%	90%	90%	90%
7	Energy cost difference for one stored kWh [Euro/kWh]	0.105	0.135	0.155	0.165	0.185
8	Income for energy exchange per year [EUR/year]	38.325	49.275	56.575	60.225	67.525
9	**Number of years for ROI without subsidies**	31.3	19.3	12.4	**8.3**	**5.9**
10	**Number of years for ROI with subsidies**	**7.8**	**9.1**	**10.6**	**8.3**	**5.9**
11	Number of cycles of BESS	3000	3500	4000	5000	6000
12	Number of cycles needed to reach ROI without subsidies	11,429	7,037	4,516	**3,030**	**2,162**
13	Number of cycles needed to reach ROI with subsidies	2,857	3,333	**3,871**	**3,030**	**2,162**
14	**Breakeven without subsidies**	NO	NO	NO	**YES**	**YES**
15	**Breakeven with subsidies**	**YES**	**YES**	**YES**	**YES**	**YES**

Table 4. HLUC-1-PUC-1-BM-1: Analysis of SaaS business feasibility considering Policy 2 and Technology V2 scenarios

Row	Economic Variable	2021	2023	2025	2028	2030
1	**Specific cost for BESS [EUR / kWh installed], Technology V2**	**1200**	**900**	**600**	**400**	**300**
2	**Subsidies per kWh of BESS [EUR / kWh installed]. Policy 2**	**900**	**350**	**100**	**0**	**0**
3	Specific cost for BESS with subsidies [EUR / kWh installed]	300	550	500	400	300
4	Energy cost during peak hours [EUR /kWh]	0.25	0.25	0.25	0.25	0.25
5	**Energy cost during excess energy period [EUR/kWh], Technology V2**	**0.12**	**0.08**	**0.06**	**0.04**	**0.04**
6	Efficiency of BESS	90%	90%	90%	90%	90%

Row	Economic Variable	2021	2023	2025	2028	2030
7	Energy cost difference for one stored kWh [EUR/kWh]	0.105	0.145	0.165	0.185	0.185
8	Income for energy exchange per year [EUR/year]	38.325	52.925	60.225	67.525	67.525
9	**Number of years for ROI without subsidies**	31.3	17.0	**10.0**	**5.9**	**4.4**
10	**Number of years for ROI with subsidies**	**7.8**	**10.4**	**8.3**	**5.9**	**4.4**
11	Number of cycles of BESS	3000	4000	5000	6000	6000
12	Number of cycles needed to reach ROI, without subsidies	11,429	6,207	**3,636**	**2,162**	**1,622**
13	Number of cycles needed to reach ROI, with subsidies	**2,857**	**3,793**	**3,030**	**2,162**	**1,622**
14	**Breakeven without subsidies**	NO	NO	**YES**	**YES**	**YES**
15	**Breakeven with subsidies**	**YES**	**YES**	**YES**	**YES**	**YES**

The business case conclusions regarding the use of SaaS are the following:

- The breakeven of self-sustained business without any subsidies is foreseen only for the horizons related to 2028 and 2030 timeline for Technology evolution V1 (slower technology evolution) and Policy V1 (higher / strong subsidy level in the first three time horizons) , while for Technology evolution V2 (more aggressive technology evolution, with more scientific breakthroughs)and Policy V2 (quicker reduction of subsidies in second and third time horizons) there is sooner self-sustained business, starting with timeline 2025.
- There is business sustainability even in short time (timeline 2021) if aggressive subsidies are implemented from the very beginning. The numbers show that in 2021 it is needed to have a subsidy of 3/4 of the total BESS cost, for the energy prices considered in the peak hours versus daytime with excess energy due to high PV production.
- Two classes of investment attractivity are considered in the feasible situations: a shorter-term ROI (ROI ≤ 8 years, highlighted with light green cells), and more strategic investments which are accepted for 8 to 12 years for the ROI (highlighted with darker green). Starting with the second timeline (year 2023), investment can be done if it is seen as strategic or preparatory for learning for the future. The first timeline has ROI smaller than 8 years because it is needed a high subsidy to allow ROI before reaching the technical number of total cycles, while in next time horizons this limitation becomes less important.
- All cases show that the policy of having strong subsidies at the very beginning, with reduction during the decade, are essential to deploy BESS needed in high RES penetration scenarios
- Table 4 shows that technology play an essential role to bring self-sustained business sooner. This is an input for policies to increase research activities in order to advance sooner to a healthy development of much needed BESS to support high RES penetration.

2.2.3 HLUC-1-PUC-1-S2

2.2.3.1 Description

HLUC-1-PUC-1-S2: "Serving peak demands on DSO level" demonstrates that the AP is able to produce additional PCC power, if over-consumption is present in the grid, in order to avoid grid congestions. This HLUC is considered as a "storage service" (P_{STOR} order) to be provided to the grid during peak hours (e.g. in the evening).

2.2.3.2 Evaluation procedure

The LESSAg is orchestrating resources for producing additional power during a $T_{SERVICE}$ time frame (selected 15- or 60-minutes periods).
In order to make the tests, a complete HIL setup with LESSAg receives a P_{STOR} order from HIL during $T_{SERVICE}$. To be noticed that due to the fact that in this HLUC there is an order for energy production, P_{STOR} demand is negative, according to the consumption convention (which states that consumption power is positive and generated power is negative). The evaluation used HIL technology, and considered the following parameters:

- $T_{SERVICE}$ =15 min, 60 min
- $P_{STOR} < 0$

The average power in the PCC during $T_{SERVICE}$ must be

$$P_{PCC} = P_{PCC\_NO\_STOR} + P_{STOR} \pm 10\% \, P_{PCC\_NOM}$$

2.2.3.3 Evaluation results

Several tests were made and a representative test with its results are considered as follows.

PUC-1-S2 test: A P_{STOR} request is asked for releasing energy to the grid for two consecutive hours (Figure 7), whit two request, namely:

- P_{STOR1} = -150 W, during the first hour.
- P_{STOR2} = -40 W and P_{STOR3} = -120 W, during the second hour.

All SaaS requests are negative values, meaning that it is requested that power is injected power to the grid.

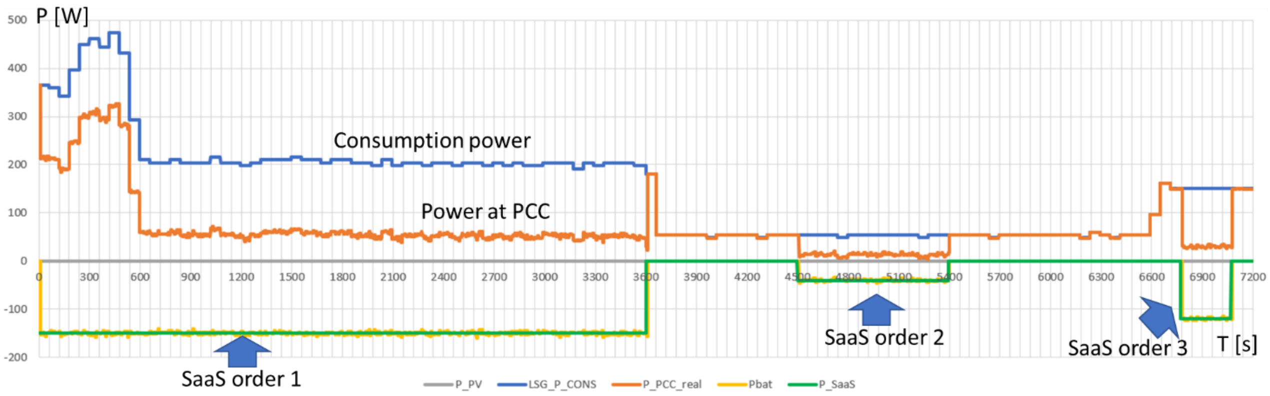

Figure 7. HLUC-1-PUC-1-S2-1 test: Request for injecting P_{STOR} to the grid.

Figure 8 shows a zoom of the third order, showing that the order is taken with a delay (usually 10 to 20 seconds), due to the real ER + HIL environment which was used. This shows also the possibility for future improvements, if the whole communication and execution process involved in the test is accelerated, e.g. at controls every 30 or even 1- second, comparing with the existing implementation which has full control loops each 1-minute.

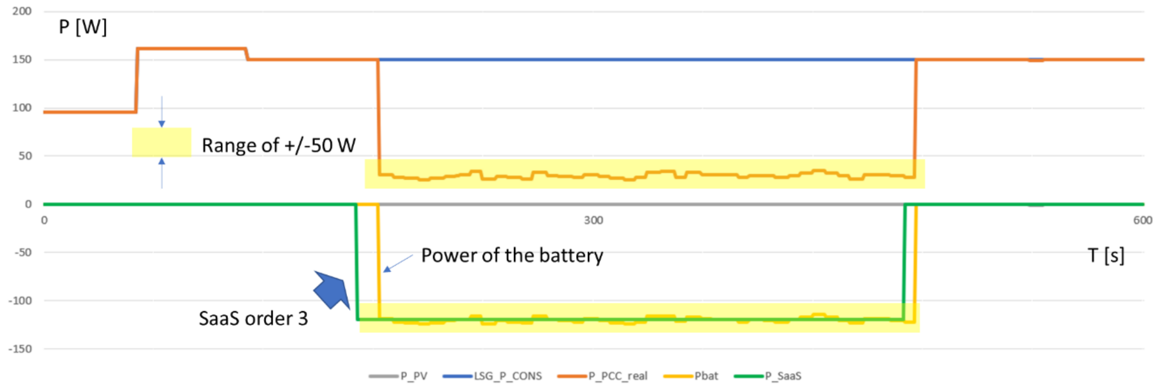

Figure 8. HLUC-1-PUC-1-S2-1 test: Zoom on the 3rd SaaS order.

The tests show successful execution of the SaaS request, with PCC power variation less than ±50 W. Another P_{STOR} request asked to be inject energy to the grid is also presented in Figure 9, as PUC-1-S2-2.

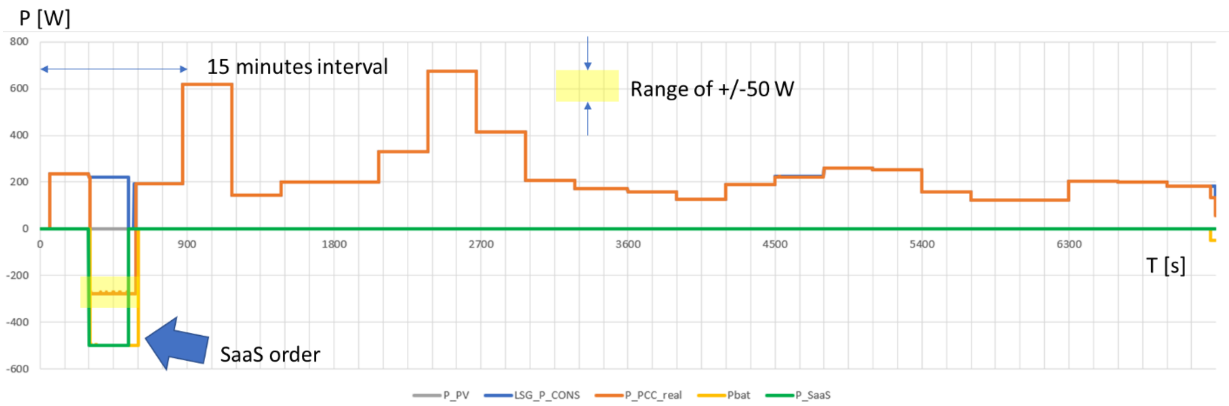

Figure 9. HLUC-1-PUC-1-S2-2: Request for injecting P_{STOR} to the grid.

Similar with HLUC-1-PUC-1-S1, the band of ±50 W was chosen for both situations as a more severe test than the KPI, which allows a ±1472 W band.

The HLUC-1-PUC-1-S2 has a SaaS business model similar with the one for HLUC-1-PUC-1-S1, while SaaS is in this case about injecting the power in the grid, which is symmetrical to the consumption during excess PV production. The HLUC-1-PUC-1-BM-1 applies as well for HLUC-1-PUC-1-S2.

2.2.4 HLUC-1-PUC-1-S3

2.2.4.1 Description

HLUC-1-PUC-1-S3: "Provide ancillary services (black-start)" demonstrates that in case of grid failure the AP is able to provide a certain power towards the islanded grid, while the islanded grid has a total load lower than the black-start power.

2.2.4.2 Evaluation procedure

HLUC-1-PUC-1-S3 was evaluated by recording during a $T_{SERVICE}$ time frame (between 5- and 15-minutes period). The ER production towards the simulated grid, while the voltage level has to be kept in a band between ± 10% of the nominal voltage (U_N=230 V), with the following parameters:

- 5 min ≤ $T_{SERVICE}$ ≤ 15 min
- 100 W ≤ $P_{GridLoad}$ ≤ 500 W

The nominal voltage in the PCC during $T_{SERVICE}$ must be

$$U_{PCC} = 230\ V \pm 10\%$$

The black-start evaluation used a simulated grid with $P_{GridLoad}$. The current and voltage on the grid-side receiving black-start service were measured each minute.
Figure 10 shows the general setup for the tests and Figure 11 gives a detail about the used battery.

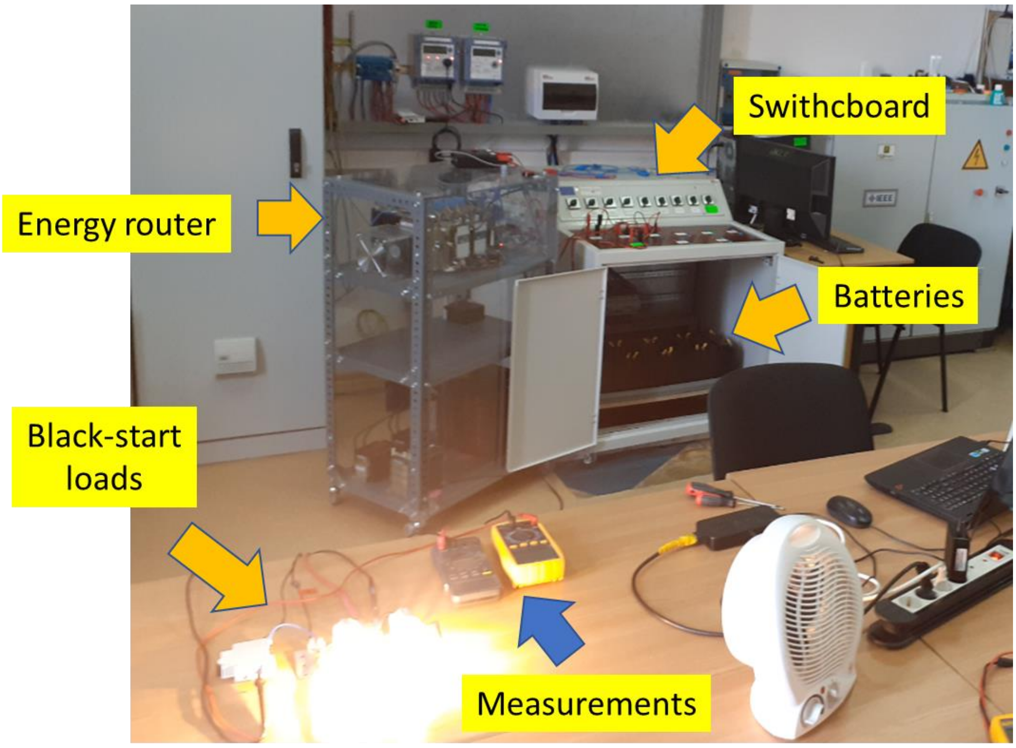

Figure 10. HLUC-1-PUC-1-S3 test: General setup.

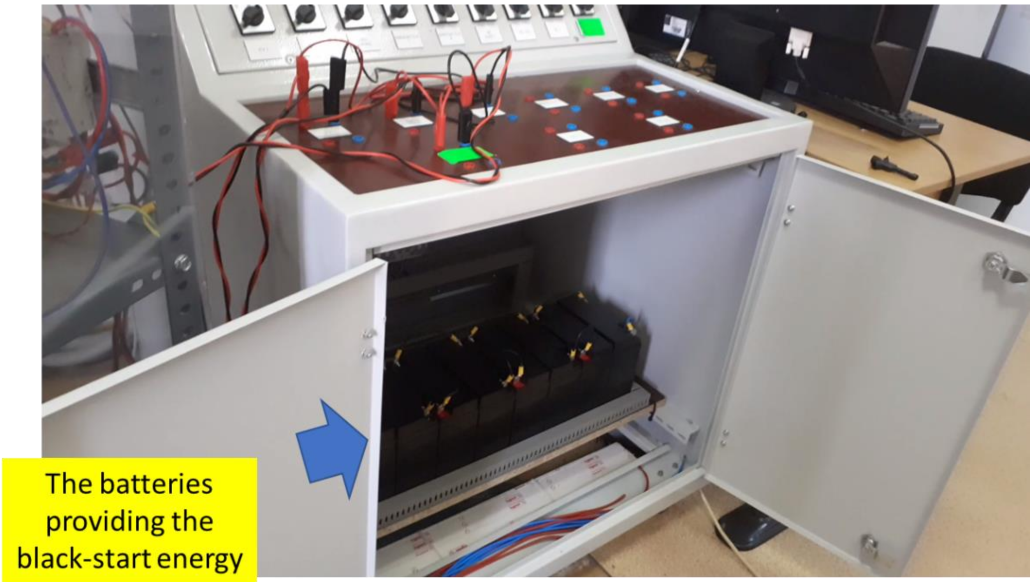

Figure 11. HLUC-1-PUC-1-S3 test: Batteries (UN = 96 V DC) used by ER for black-start service

The test was made by considering the grid load as having maximum a selected value between 100 W and 500 W. The used load was a set of two light bulbs of 65 W each, which were mounted in parallel in order to provide around 130 W (Figure 12). For security reasons, the full setup was operational mainly for the test purposes.

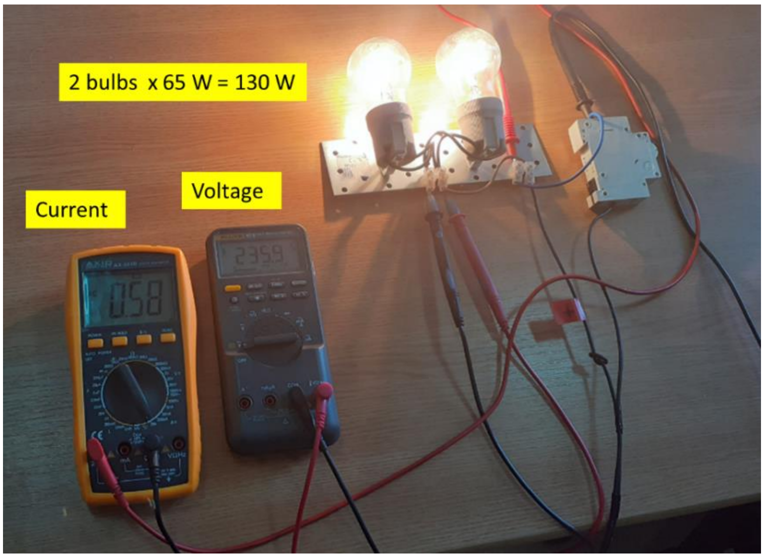

Figure 12. HLUC-1-PUC-1-S3 test: Setup for loads and measurements.

The nominal voltage in the PCC during $T_{SERVICE}$ must be U_{PCC} = *230 V ± 10%*, showing a stable supply used as black-start service.
In order to provide black-start service, the ER works in Mode 8 (Black-start). The procedure used various steps to reach this mode: from Mode 3 (MPPT with grid ON) to Mode 5 (Standby, Grid OFF).

2.2.4.3 Evaluation results

The test was made by islanding the ER grid, meaning by decoupling the ER from main grid, putting it in Mode 8 (Black-start) and by connecting the load to the 230 V AC of ER, which acts as an black-start service provider. Table 5 provides the values of voltage during the tests, considering 230 V AC grid and U_N = 230 V AC.

Table 5. HLUC-1-PUC-1-S3 test: Results.

Minute (time)	Voltage [V]	Current [A]	Power [W]	Deviation $\Delta U/U_N$ [%]	Observations
1 (12:11)	235.8	0.58	136.76	2.52%	Comply
2 (12:12)	235.7	0.58	136.71	2.48%	Comply
3 (12:13)	235.9	0.58	136.82	2.57%	Comply
4 (12:14)	235.7	0.58	136.71	2.48%	Comply
5 (12:15)	235.8	0.58	136.76	2.52%	Comply
6 (12:16)	235.8	0.58	136.76	2.52%	Comply
7 (12:17)	235.9	0.58	136.82	2.57%	Comply

The tests were successful, showing a deviation of the output voltage of ER as being in the interval 230 V ± 2.57%, which is inside the accepted interval of 230 V ± 10%. Figure 13 shows the evolution of main measurements and the deviation error.

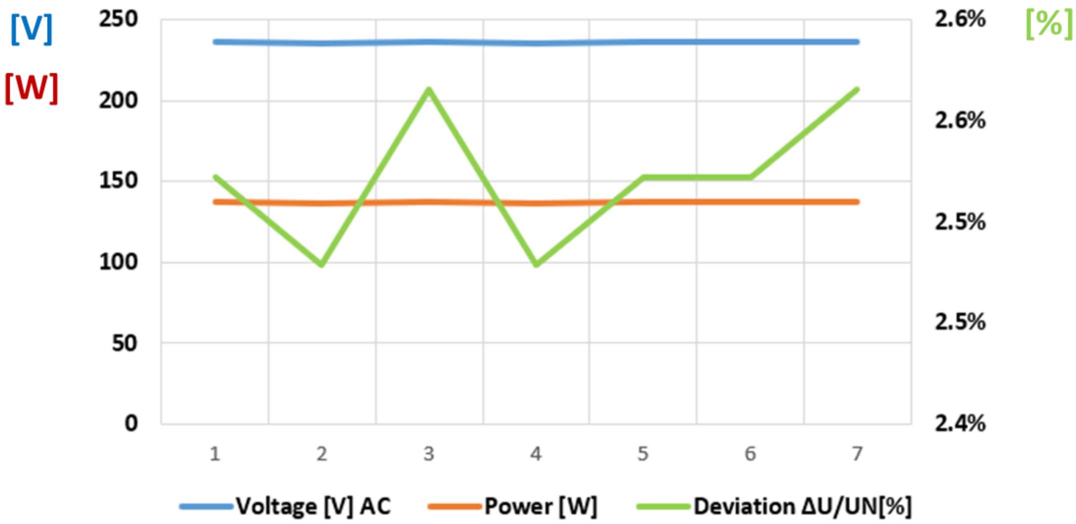

Figure 13. HLUC-1-PUC-1-S3 test: Evolution of the measurements and voltage deviation error.

2.2.5 HLUC-1-PUC-2

2.2.5.1 Description

HLUC-1-PUC-2: "Advanced self-resilient prosumer" demonstrate the UniRCon functionality in a prosumer setup where there is a very small power injection to the grid, such that the grid is not stressed by local production and can accommodate therefore additional distributed RES production. The following KPIs were considered, according with their description in D6.3 [S4G-D6.3].

2.2.5.1.1 KPI2.2

The ability of the AP to act as a consumer even if there is extra production of energy in the prosumer's area. The reason for this KPI is to assess if the prosumer with control of its local production has or has not an impact on the grid, meaning that the prosumer is not impacting on an average basis the business as usual, meaning that the local production is not bringing distribution grid operation disturbances.

In order to consider the impact of a prosumer on a statistical basis, as in the LV grid are usually many end-customers which act in a different way, the consumption was considered in conjunction with the contractual PCC power adjusted by the simultaneity factor K_{SIMULT}, as was also done in HLUC-1-PUC-1-S1. This KPI equation is as follows:

$$KPI2.2 = K_{USER\_E\_BACK} = \frac{E_{PCC-}}{E_{CONS}} < 10\%$$

with E_{PPC-} as energy injected to the grid while E_{CONS} (where CONS means "consumption") is deducted from the contractual power $E_{CONS} = E_{CONS\_NOM\_K}$.

2.2.5.1.2 KPI2.3

The ability of the AP to absorb as much as possible the energy from the PV module (given by E_{PV_METEO}), such that it is not wasted by curtailment more than a limited percentage:

$$KPI2.3 = K_{PV\_LIM} = \frac{E_{PV\_LIM}}{E_{PV\_METEO}} < 20\%$$

2.2.5.1.3 KPI2.4

The ability of the AP to increase self-consumption seen as a reduction of the energy absorbed over a time period (one day) from the grid:

$$KPI2.4 = K_{USER\_E\_DSO} = \frac{E_{PCC+}}{E_{CONS}} < 70\%$$

2.2.5.1.4 KPI2.5

The ability of the AP to provide resilience for its internal loads connected to the DC bus, while

$$V_{DCBus\_ER} = 220\ V \pm 10\%$$

2.2.5.2 Evaluation procedure

The evaluation was made in several 24-hours intervals (one day interval), by using HIL setup and by combining selected consumption profiles from real LV users with PV production acquired by ER and storage resource connected to the same ER device.

KPI2.2 and KPI2.3 were calculated on a daily and hour interval basis (1 day, and each 1 hour), while KPI2.4 was assessed on daily basis only, as an average during the nigh hours when there is only consumption and the day period when usually appears excess energy. The evaluation used HIL technology, and considered the following parameters:

- T = 1 hour, 1 day
- $P_{DCLoad} \approx 100$ W
- 30 min < T_{ASRP} < 60 min

In addition, KPI2.2 and KPI2.3 were also tested over 1-hour intervals.

The KPI2.5 is of a different type and needed a special setup using the PV and storage connected to ER and an external load connected to the 220 V DC bus available from the same ER device. A period for the resilience service was needed to be proven, meaning a period of time according with the condition: 30 min < T_{ASRP} < 60 min
The test for KPI2.5 was made by considering the DC load as having $P_{DCLoad} \approx 100$ W or higher. The used load was a set of two light bulbs of 65 W each, which were mounted in parallel in order to provide around 120 - 130 W, which is covering the minimum request of around 100 W. To be noted that the electrical bulbs are designed for 230 V AC, while they were used to be supplied by 220 V DC, which is a safe voltage level for the bulbs.

The resiliency service during T_{ASRP}, using P_{DCLoad} connected to the ER DC bus, its DC bus voltage must be $V_{DCBus\_ER} = 220\ V \pm 10\%$.

The same model based on daily energies was also used in the business models analysis

2.2.5.3 Evaluation results

2.2.5.3.1 KPI2.2, KPI2.3 and KPI2.4

The tests for KPI2.2, KPI2.3 and KPI2.4 were made on several one-day time periods.

The tests records and results are followed presented, labelled as PUC-2-KPI2-4.RecX, where X is the day under analysis. The evolution of the main parameters over the day are presented in Figure 14.

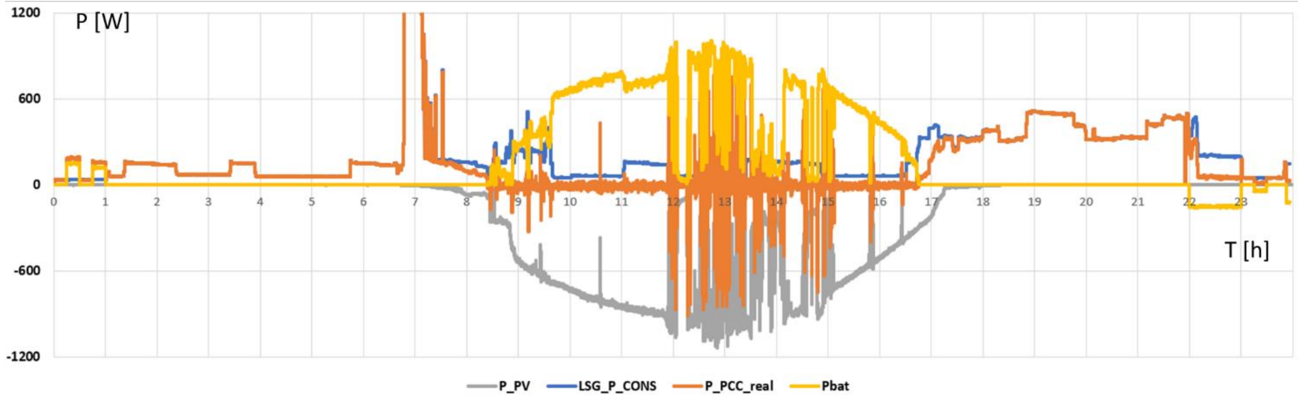

Figure 14. HLUC-1-PUC-2-KPI2-4-Rec1 test: Evolution of AP data during a day.

The selected day is characterized by a dynamic evolution of PV production (P_PV), due to many changes in light intensity due to clouds under a windy situation. Around hour 7:00 it is a high consumption (LSG_P_CONS), which is not fully visible in the graph, as being not representative for the KPIs. Additional small SaaS were simulated at the beginning (charging) and at the end of the day (discharging), which can be seen in the battery power evolution (Pbat). The calculated values of the daily KPIs are presented in Table 6.

Table 6. HLUC-1-PUC-2-KPI2-4-Rec1 test: Results.

PUC-2 KPIs	Value over 1 day	Condition	Observation
$KPI2.2 = K_{USER\_E\_BACK}$	3.20 %	< 10%	Comply
$KPI2.3 = K_{PV\_LIM}$	0.12 %	< 20%	Comply
$KPI2.4 = K_{USER\_E\_DSO}$	68.54 %	< 70%	Comply

A small quantity of energy sent back to the grid occurred during the dynamic PV production, as the storage need is calculated in the tests every one-minute. This situation gives a certain period of time when the change of PV production and internal consumption can produce a different PCC power exchange. Higher rate for storage algorithm decision may bring better results. However, even with a cost-effective solution having control once per minute gives still KPI values in the expected range.
Figure 15 gives the hourly evolution of KPI2.2 and KPI2.3, which comply with the imposed condition of having a percentage value under 10%.

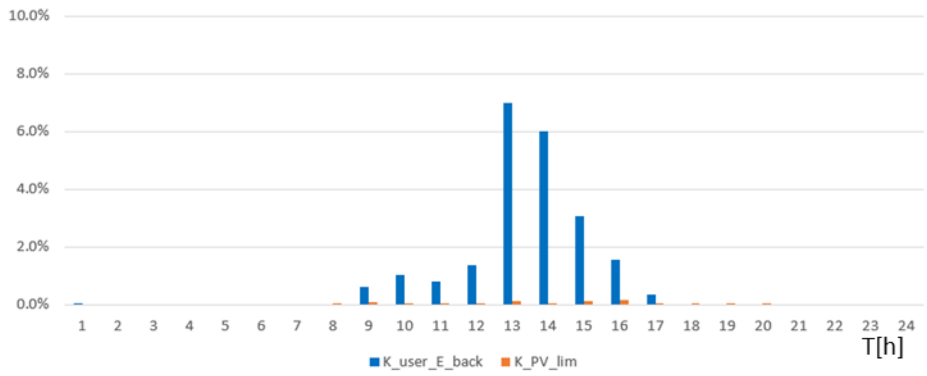

Figure 15. HLUC-1-PUC-2-KPI2-4-Rec1 test: Evolution of KPI2.2 and KPI2.3 during a day.

It can be observed that the highest values for the KPIs were reached during the daytime, when PV production occurs. This is an expected behaviour, as both KPIs involve the PV production and have to do with the capacity of not injecting energy back to the grid and harvesting as much of possible of this energy inside the AP internal network. It can be also noticed that the KPI2.3 and KPI2.3 values are much lower during the entire day period, as this period considers also the non-local production period, when these KPIs values are practically zero. PUC-2-KPI2-4-Rec2, with evolution of main parameters is presented in Figure 16.

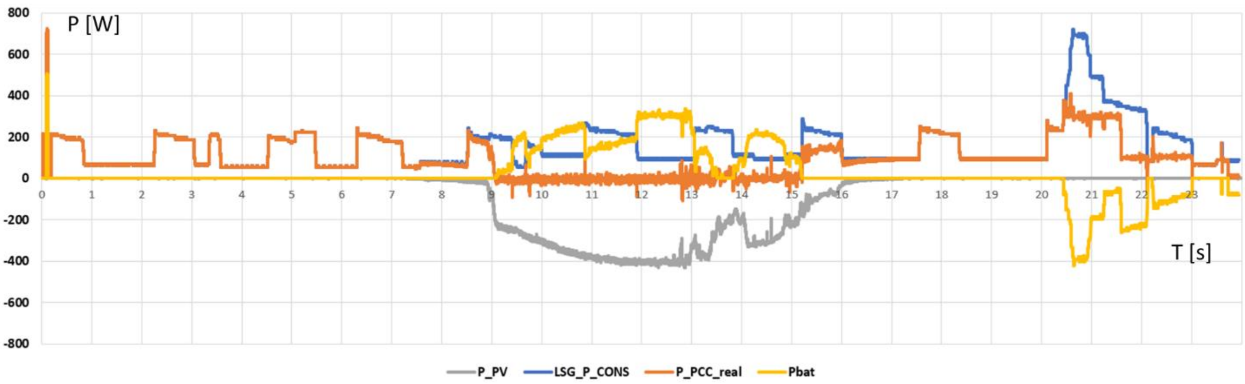

Figure 16. HLUC-1-PUC-2-KPI2-4-Rec2 test: Evolution of AP data during a day.

Figure 17 gives the hourly evolution of KPI2.2 and KPI2.3, which comply with the imposed conditions. KPI2.3, KPI2.3 and KPI2.4 for the whole day are presented in Table 7.

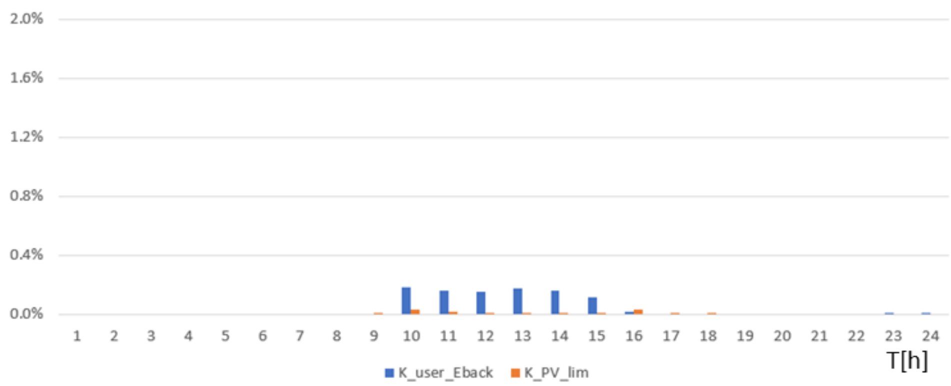

Figure 17. HLUC-1-PUC-2-KPI2-4-Rec2 test: Evolution of KPI2.2 and KPI2.3 during a day.

Table 7. HLUC-1-PUC-2-KPI2-4-Rec2 test: Results.

PUC-2 KPIs	Value over 1 day	Condition	Observation
$KPI2.2 = K_{USER\_E\_BACK}$	0.75 %	< 10%	Comply
$KPI2.3 = K_{PV\_LIM}$	0.02 %	< 20%	Comply
$KPI2.4 = K_{USER\_E\_DSO}$	62.12 %	< 70%	Comply

Additional records were made, with results being in the acceptable range of the KPIs, as shown in Table 8, Table 9 and Table 10. The daily KPIs were calculated for the other selected cases.

Table 8. HLUC-1-PUC-2-KPI2-4-Rec3 test: Results.

PUC-2 KPIs	Value over 1 day	Condition	Observation
$KPI2.2 = K_{USER\_E\_BACK}$	1.61 %	< 10%	Comply
$KPI2.3 = K_{PV\_LIM}$	0.36 %	< 20%	Comply
$KPI2.4 = K_{USER\_E\_DSO}$	68.42 %	< 70%	Comply

Table 9. HLUC-1-PUC-2-KPI2-4-Rec4 test: Results.

PUC-2 KPIs	Value over 1 day	Condition	Observation
$KPI2.2 = K_{USER\_E\_BACK}$	0.43 %	< 10%	Comply
$KPI2.3 = K_{PV\_LIM}$	0.01 %	< 20%	Comply
$KPI2.4 = K_{USER\_E\_DSO}$	67.36 %	< 70%	Comply

Table 10. HLUC-1-PUC-2-KPI2-4-Rec5 test: Results.

PUC-2 KPIs	Value over 1 day	Condition	Observation
$KPI2.2 = K_{USER\_E\_BACK}$	1.04 %	< 10%	Comply
$KPI2.3 = K_{PV\_LIM}$	0.30 %	< 20%	Comply
$KPI2.4 = K_{USER\_E\_DSO}$	69.70 %	< 70%	Comply

2.2.5.3.2 KPI2.5

The test for KPI2.5 (resiliency service during T_{ASRP}) was made by islanding the ER grid, meaning by decoupling the ER from main grid, and by connecting the load to the 220 V DC of the ER, which acts as a resiliency service provider.

Figure 18 shows the environment for testing the resilience service. The ER was switched to Mode 7 (MPPT, Grid OFF). Figure 19 gives provides some of the measurements which were recorded every 1 minute.

Figure 18. HLUC-1-PUC-2-KPI2.5 test: Laboratory view.

Figure 19. HLUC-1-PUC-2-KPI2.5 test: Measurements of voltage and currents.

Table 11 provides the values of voltage, current and power during the tests, during a 32-minutes period, considering 230 V AC grid and U_N = 230 V AC.

Table 11. HLUC-1-PUC-2-KPI2.5 test: Results.

Minute (time)	Voltage [V]	Current [A]	Power [W]	Deviation $\Delta U/U_N$ [%]	Observations
1 (17:18)	216.8	0.59	127.912	-1.45%	Comply
2 (17:19)	216.6	0.59	127.794	-1.55%	Comply
3 (17:20)	216.5	0.59	127.735	-1.59%	Comply
4 (17:21)	216.5	0.59	127.735	-1.59%	Comply
5 (17:22)	216.6	0.59	127.794	-1.55%	Comply
6 (17:23)	216.5	0.59	127.735	-1.59%	Comply
7 (17:24)	216.5	0.59	127.735	-1.59%	Comply
8 (17:25)	216.5	0.59	127.735	-1.59%	Comply

Minute (time)	**Voltage [V]**	**Current [A]**	**Power [W]**	**Deviation $\Delta U/U_N$ [%]**	**Observations**
9 (17:26)	216.5	0.59	127.735	-1.59%	Comply
10 (17:27)	216.5	0.59	127.735	-1.59%	Comply
11 (17:28)	216.5	0.59	127.735	-1.59%	Comply
12 (17:29)	216.5	0.59	127.735	-1.59%	Comply
13 (17:30)	216.5	0.59	127.735	-1.59%	Comply
14 (17:31)	216.5	0.59	127.735	-1.59%	Comply
15 (17:32)	216.5	0.59	127.735	-1.59%	Comply
16 (17:33)	216.5	0.59	127.735	-1.59%	Comply
17 (17:34)	216.6	0.59	127.794	-1.55%	Comply
18 (17:35)	216.5	0.59	127.735	-1.59%	Comply
19 (17:36)	216.5	0.59	127.735	-1.59%	Comply
20 (17:37)	216.5	0.59	127.735	-1.59%	Comply
21 (17:38)	216.5	0.59	127.735	-1.59%	Comply
22 (17:39)	216.5	0.59	127.735	-1.59%	Comply
23 (17:40)	216.5	0.59	127.735	-1.59%	Comply
24 (17:41)	216.6	0.59	127.794	-1.55%	Comply
25 (17:42)	216.5	0.59	127.735	-1.59%	Comply
26 (17:43)	216.5	0.59	127.735	-1.59%	Comply
27 (17:44)	216.5	0.59	127.735	-1.59%	Comply
28 (17:45)	216.6	0.59	127.794	-1.55%	Comply
29 (17:46)	216.5	0.59	127.735	-1.59%	Comply
30 (17:47)	216.5	0.59	127.735	-1.59%	Comply
31 (17:48)	216.6	0.59	127.794	-1.55%	Comply
32 (17:49)	216.5	0.59	127.735	-1.59%	Comply

Figure 20 provides the values of voltage, current and voltage deviation error during the tests.

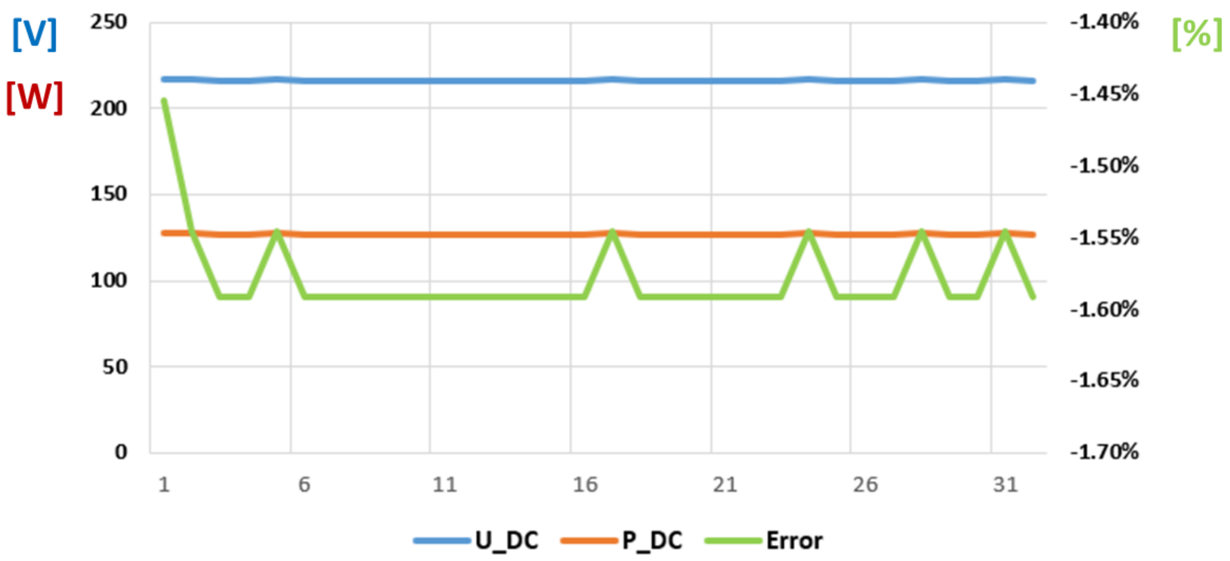

Figure 20. HLUC-1-PUC-2-KPI2.5 test: Evolution of voltage (U_DC [V]), power (P_DC [W]) and voltage deviation (Error).

All errors are well inside the boundary of 220 V DC ±10%. As previous presented, the PUC-2-KPI2.5 test shown results in compliance with the defined KPI. All tests made within this PUC shows good characteristics, with KPI2.2, KPI2.3 and KPI2.4 also in the expected range.

2.2.6 HLUC-1-PUC-2-BM-1

2.2.6.1 Description

HLUC-1-PUC-3-BM-1: "Enabling energy services to connected neighbourhood prosumers and consumers" analysed the economic aspect of HLUC-1-PUC-2 in different time horizons, to show the "break-even" moments for being commercially viable. The ASRP is adapting its behaviour such that there is practically no energy injected to the grid, by using its internal storage resources such that entire surplus energy produced by the PVs can be stored locally and consumed when it is a local need. Such behaviour allows easier connection and less impact to the main grid, while in the future it is progressive bigger difference between the price of consumed kWh during peak hours from the grid and the price of kWh sold to the grid during excess PV production.

2.2.6.2 Evaluation procedure

The evaluation of HLUC-1-PUC-2-BM-1 analyses the advantages of self-consuming entire energy produced locally while not sending at all energy to the public grid. It is based on the fact that the price obtained from the energy injected to the grid has lowered each year, meaning that it is not attractive to sell energy to the grid through incentives such as the feed-in tariff.

The business analysis is considering the storage means of the AP to be used for fully self-consumption with no or very low energy sent back to the grid, for different timelines, in order to assess the horizon which bring a breakeven. The breakeven is declared positive if the investment can be paid in maximum 12 years, by considering also the technological constraints related to number of complete cycles needed to cover the investment cost. If the requested number of cycles is higher than the technical possible number of cycles, then the case is rejected due to technical considerations.

The same five timelines used in HLUC-1-PUC-1-BM-1 were considered also in this procedure: year 2021, 2023, 2025, 2028 and 2030, covering the whole decade for which EU is interested to assess roadmaps towards the 100% carbon neutrality till 2050.

The investment cost is calculated in two variants: without subsidies or considering subsidies. The BESS specific cost evolution is presented in row 1 of Table 12. The specific tariff for the energy injected to the grid is given in row 5 of Table 12 ([EUR/kWh]).

The ROI is mainly based on the difference of price between peak hours (when it remains high during the entire time horizon, line 5 of Table 12) and the specific tariff for the energy send back to the grid. Efficiency of the battery cycle is affecting the stored kWh, thus the energy cost difference for one stored kWh is given by:

$$\Delta C = C_{peak} * \eta_{BESS} - C_{Back\_energy}$$

Where ΔC is the energy cost difference [EUR/kWh], C_{peak} is the price of energy during the peak hours [EUR/kWh], η_{BESS} is the BESS efficiency and C_{Back_energy} is the specific tariff for the energy send back to the grid [EUR/kWh].

The number of years for ROI is given by the investment cost divided by the income each year:

$$Y = Inv / (\Delta C * DY)$$

Where Y is the number of years [years], *Inv* is the investment costs [EUR/kWh installed], ΔC is the energy cost difference previous introduced [EUR/kWh] and DY is the number of days over a year [days], DY=365.

To be noted that the investment is related to the specific investment in BESS, but includes also a share of the ER, as a necessary device to achieve the control of energy sent back to the grid, which has to be close to zero, in order not to disturb the main grid during excess energy periods. The number of cycles needed to reach ROI is:

$$N_{Cycles\_needed} = Y * DY$$

This number is compared with the effective technological limit of the BESS technology and the value need to be lower than this maximum cycle limit N_{Cycles_Max}:

$$N_{Cycles\_needed} < N_{Cycles\_Max}$$

If $N_{Cycles\_needed} < N_{Cycles\_Max}$, and ROI is lower than 12 years, the breakeven is considered to be reached. The breakeven is therefore understood as the timeline when both technology is mature (ROI is reached before the battery is depleted due to the number of cycles) and business is applicable (ROI is less than 12 years, or even less than 8 years).

As for HLUC-1-PUC-1-BM-1, for simplification, it is not considered the second life of the batteries, which in some cases can add more ROI.

2.2.6.3 Evaluation results

The evaluation results are presented in Table 12, with the different colours cells meaning presented in Table 2.

Table 12. HLUC-1-PUC-2-BM-1: Analysis of business feasibility considering no energy injected back to the main grid.

Row	Economic Variable	2021	2023	2025	2028	2030
1	**Specific cost for BESS [EUR / kWh installed]**	**1400**	**1200**	**900**	**700**	**600**
2	**Subsidies per kWh of BESS [EUR / kWh installed]**	**1050**	**700**	**300**	**0**	**0**
3	Specific cost for BESS with subsidies [EUR / kWh installed]	350	500	600	700	600
4	Energy cost consumed during peak hours [EUR/kWh]	0.25	0.25	0.25	0.25	0.25
5	**Specific tariff for energy sent back to the grid [EUR/kWh]**	**0.1**	**0.08**	**0.07**	**0.05**	**0.03**
6	Efficiency of BESS	90%	91%	92%	93%	94%
7	Energy cost difference for one stored kWh [EUR/kWh]	0.125	0.145	0.155	0.175	0.195
8	Income for energy exchange per year [EUR/year]	45.625	52.925	56.575	63.875	71.175
9	**Number of years for ROI without subsidies**	30.7	22.7	15.9	**11.0**	**8.4**
10	**Number of years for ROI with subsidies**	**7.7**	**9.4**	**10.6**	**11.0**	**8.4**
11	Number of cycles of BESS	3000	3500	4000	4000	4000
12	Number of cycles needed to reach ROI, without subsidies	11,200	8,276	5,806	**4,000**	**3,077**
13	Number of cycles needed to reach ROI, with subsidies	**2,800**	**3,448**	**3,871**	**4,000**	**3,077**
14	**Breakeven without subsidies**	NO	NO	NO	**YES**	**YES**
15	**Breakeven with subsidies**	**YES**	**YES**	**YES**	**YES**	**YES**

Conclusions for the business regarding the use of storage means and ER to control the energy exchanged with the main grid (no or low energy injected back to the grid) are the following:

- The breakeven of self-sustained business without any subsidies is foreseen only for the horizons related to 2028 and 2030 timeline.
- There is business attractivity even in short time (timeline 2021) if aggressive subsidies are implemented from the very beginning. The numbers show that in 2021 it is needed to have a subsidy of 3/4 of the total BESS plus ER cost, for the energy prices considered in the peak hours versus payback of energy injected to the grid during excess energy periods.
- The same classes of investment attractivity are considered in the feasible situations: a shorter-term ROI (ROI ≤ 8 years, highlighted with light green cells), and more strategic investments which are accepted for 8 to 12 years for the ROI (highlighted with darker green). Starting with the second timeline (year 2023), investment can be done if it is seen as strategic or preparatory for learning for the future.

The first timeline has ROI smaller than 8 years because it is needed a high subsidy to allow ROI before reaching the technical number of total cycles, while in next time horizons this limitation is not any more important.

- All cases show that the policy of having strong subsidies at the very beginning, with reduction during the decade – even in 2025, are essential to deploy BESS and ER needed in high RES penetration scenarios when the AP is not stressing the main grid, thus avoiding or postponing grid reinforcements.

2.2.7 HLUC-1-PUC-3

2.2.7.1 Description

HLUC-1-PUC-3: "Resilient hybrid cooperative ecosystem" demonstrates the technical solution and its economics, by showing the possibility to supply consumers in the second laboratory through the 400 V DC line.

2.2.7.2 Evaluation procedure

The setup used the ER with the boost converter connected to the DC bus of the ER and providing 400 V DC to the line towards the laboratory 2 (EG111), acting as a neighbour needing this energy exchange. The limit of 500 W for the Laboratory 2 load is an average load over the 15 minutes. For security reasons, the full setup was operational mainly for the test purposes. The following parameters were considered:

- T = 15 min
- $P_{Lab2Load} \leq 500$ W

While feeding the $P_{Lab2Load}$ (placed in EG111 laboratory) during 95% of T, the 400 V DC bus voltage must be

$$V_{DCBus} = 400 \text{ V} \pm 10\%$$

This use-case is focused on enabling energy supply to neighbourhood prosumers and consumers connected through the 400 V DC line. During the supply of the neighbour, the DC voltage need to be stable, such that the quality of supply is ensured. The ±10% of voltage band and the 95% of the time give a certain similarity with the voltage level acceptance in AC grids.

2.2.7.3 Evaluation results

Several measurements were made, with two representative tests detailed in the following sections.

2.2.7.3.1 PUC-3-SR Test

This test considers the full setup with boost converter at the AP side. The SR suffix denotes the fact that the test was made with self-records of the voltages, while measurements with proof based on equipment snapshots was also done, for calibration purpose.

This is a complete test made in both EB105 (as having the ER and the boost converter) and EG111 (used as having a neighbour with DC load), with the boost converter rising the voltage from 220 V DC, provided by ER, to 400 V DC. Figure 21 presents EB105 having both ER and boost converter, with power exchange to the neighbour considered in the second EG111 laboratory.

Figure 21. HLUC-1-PUC-3-SR test: EB105 laboratory view

2.2.7.3.2 PUC-3-2 Test.

This test considers the setup with boost converter at neighbour side. This is a complete test made in both EB105 (as having the ER) and EG111 (used as having a neighbour with and the boost converter and DC load), with the boost converter rising the voltage from 220 V DC, provided by ER, to 400 V DC. Figure 22 presents EB105 having both ER and boost converter, with power exchange to the neighbour considered in the second EG111 laboratory.

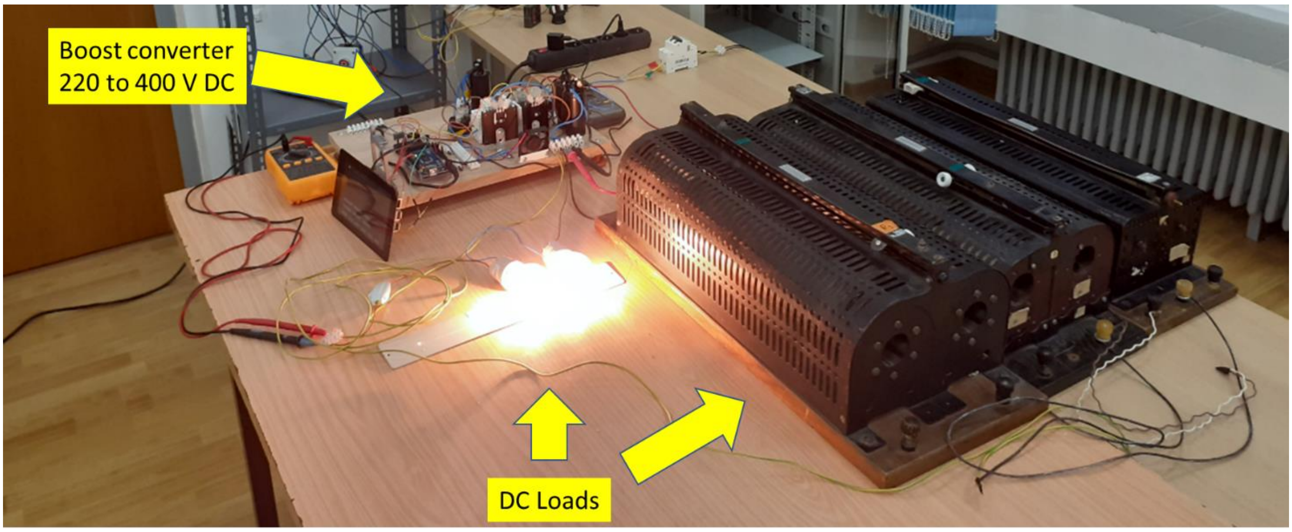

Figure 22. HLUC-1-PUC-3-2 test: EG111 Laboratory view.

In both tests, the measurements were made with exchange powers around the value $P_{Lab2Load}$ = 500 W.
The two bulbs are present in both tests and consume around 100 W from 400 V DC, by using 2x 65 W classic halogen lamp (still available in the market, as being efficiency class C). These bulbs are also acting as “visible” additional load to the main load obtained with high power variable resistors. In all situations, the high power

variable resistors were placed in EG111 (Figure 22), while the "visible" additional load with two bulbs in series are placed in EG111 or in EB105, depending of the test position of the boost converter.

The electrical measurements for PUC-3.Test.SR were obtained for a period of more than 30 minutes. Table 13 provides the values of voltage, current and powers injected in the 400 V DC line towards the neighbour during PUC-3-2 test. Additional 2 x bulbs of 65 W were also added as proof of stable voltage behind the measurements. Figure 23 presents measurements made during the PUC-3.SR test.

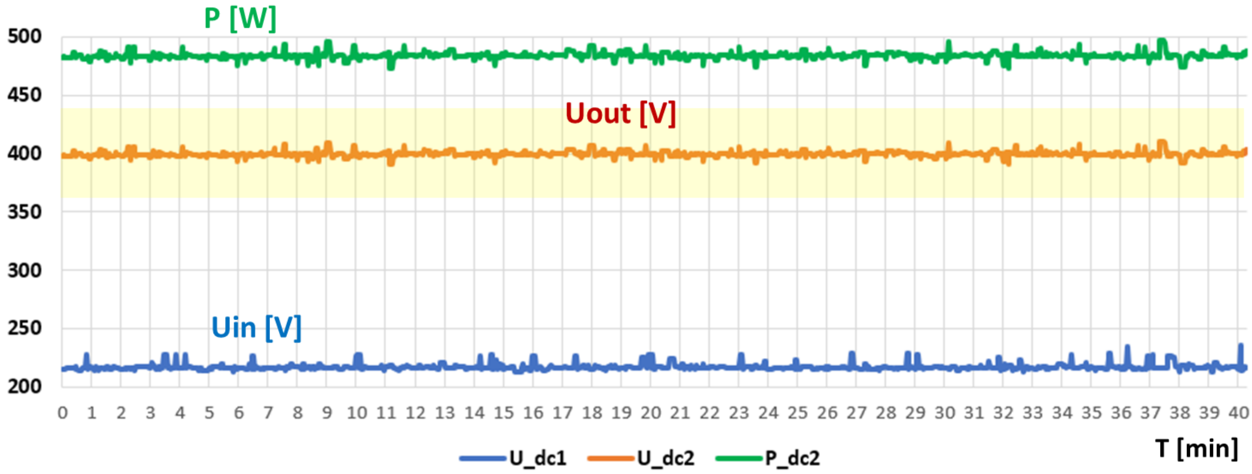

Figure 23. HLUC-1-PUC-3-SR: Measurements in EB105 laboratory.

Test 1 (PUC-3-SR) was made with self-recording of voltage variation, being in fact made as a refinement of test 2 (PUC-3-2) made after the recording feature was implemented in the boost converter.
The second set of electrical measurements were obtained during at least 30 minutes test. Table 13 provides the values of voltage, current and powers injected in the 400 V DC line towards the neighbour. Additional 2 x bulbs of 65 W were also added as proof of stable voltage behind the measurements (consuming together approximate 100 W from the 400 V bus), bringing a total load on the 400 DC bus of more than 600 W. The values were obtained by taking snapshots of the measurement equipment at representative moments in the time period of the test. Figure 24 shows some of the snapshots taken from measurement equipment.

Table 13. HLUC-1-PUC-3-2 test: Measurements of voltage, currents, power and voltage deviation.

Minute (time)	**Voltage on 400 V DC line [V]**	**Current on 400 V DC line [A]**	**Power on 400 V DC line [W]**	**Deviation [%]**	**Observations**
1 (18:10)	403.2	1.30	524.16	0.80	Comply
2 (18.11)	403.3	1.30	524.29	0.83	Comply
3 (18.12)	403.5	1.31	528.585	0.88	Comply
4 (18:13)	403.4	1.30	524.42	0.85	Comply
5 (18:14)	404.0	1.31	529.24	1.00	Comply
6 (18:15)	403.9	1.31	529.109	0.97	Comply
7 (18:16)	403.9	1.31	529.109	0.97	Comply
8 (18:17)	403.8	1.31	528.978	0.95	Comply

Minute (time)	Voltage on 400 V DC line [V]	Current on 400 V DC line [A]	Power on 400 V DC line [W]	Deviation [%]	Observations
9 (18:18)	403.7	1.31	528.847	0.92	Comply
10 (18:19)	403.8	1.31	528.978	0.95	Comply
11 (18:20)	403.8	1.31	528.978	0.95	Comply
12 (18:21)	404.7	1.31	530.157	1.18	Comply
13 (18:22)	403.6	1.31	528.716	0.90	Comply
14 (18:23)	403.9	1.31	529.109	0.97	Comply
15(18:24)	403.5	1.31	528.585	0.88	Comply
16(18:25)	404.1	1.31	529.371	1.03	Comply
17(18:26)	403.9	1.31	529.109	0.97	Comply
18(18:27)	403.9	1.31	529.109	0.97	Comply

Figure 24. HLUC-1-PUC-3-2 test: Measurements of voltage and currents.

In both tests the results were analysed and the DC voltage was in the boundaries for 100% of the time. Therefore, all tests were successful.

2.2.8 HLUC-1-PUC-3-BM-1

2.2.8.1 Description

HLUC-1-PUC-3-BM-1: "Enabling energy services to connected neighbourhood prosumers and consumers" analyses the economic aspects of HLUC-1-PUC-3 in different time horizons, to show the "break-even" moments for being commercially viable. The following time horizons were considered: 2021, 2023, 2025.
The energy is supplied to the neighbour (simulated as being a load in EG111 laboratory) through the 400 V DC line.

2.2.8.2 Evaluation procedure

The business model analyses the business-wise opportunity to exchange energy with a neighbour in an energy community setup. It is considered that the prosumer acting as energy provider to the neighbour through the backyard DC bus can have a viable business model in a specific time horizon. The following assumptions were made:

- The neighbour receives an average power of 500 W, as in the previous test.

- The period of time for the transfer of energy from the prosumer having an ER and a boost converter connection towards the neighbour is seen as having the exchange profile corresponding to 4 hours at 500 W, per day; this gives an energy transfer of 4 x 0.5 = 2 kWh / day.
- Energy provided by the supplier (E) has a standard price in two variants: E1_peak = 0.24 EUR/kWh and E2_peak = 0.30 EUR/kWh, during peak hours (2-3 hours in the morning, 3-5 hours during the evening).
- The energy sold during off-peak hours (E_offpeak) is much cheaper, meaning E1_offpeak = 0.07 EUR/kWh and E2_offpeak = 0.10 EUR/kWh, corresponding to situations when the energy is abundant (day time for PV, night time for wind, use of based power plants energy during the night etc.).
- The specific price for the storage resource controlled by ER (Esp_bat) is decreasing over time. It was chosen Esp_bat_2021 = 500 EUR/kW installed, Esp_bat_2023 = 400 EUR/kW installed, Esp_bat_2025 = 300 EUR/kW installed.
- The prosumer sells the energy to the neighbour with 10% reduction compared with the regular price (price reduction factor R=0.1)
- A specific price is also allocated to the boost converter (Esp_boost), which is considered during the three time horizons as being Esp_boost_2021 = 200 EUR/kW, Esp_boost_2023 = 160 EUR/kWh and Esp_boost_2025 = 120 EUR/KW installed, while the 500 W require a 1 kW device, for being able to cover also peak power requests.

Therefore, the storage investment (E_inv) is:

- E_inv_2021 = 500 EUR/kWh * 2 kWh + 200 EUR/boost = 1,200 EUR
- E_inv_2023 = 400 EUR/kWh * 2 kWh + 160 EUR/boost = 960 EUR
- E_inv_2025 = 300 EUR/kWh * 2 kWh + 120 EUR/boost = 720 EUR

The difference of energy cost between the two hourly periods is:

- ΔE1 = E1_peak*(1-R) - E1_offpeak = 0.24 * 90% – 0.07 = 0.146 EUR/kWh
- ΔE2 = E2_peak*(1-R) – E2_offpeak = 0.30 * 90% – 0.10 = 0.170 EUR/kWh

where R is the price reduction for the neighbour, such that he is also winning from buying energy from the "local community", represented here by the AP.

As the difference between the two variants is small, the lowers difference is taken into consideration:

- ΔE = 0.146 EUR/kWh

An efficiency η = 85% is considered for storing and exchanging stored energy in the neighbourhood, thus allowing the equivalent supply of 0.85 kWh for each 1 kWh from the AP. This will be counted as a reduced ΔEr into the calculation. For a 4 hours per day exchange, the daily exchanged energy is 2 kWh for an average power of 500 W, thus the net income will be 2*0.146*0.85 = 0.2482 EUR/day.

2.2.8.3 Evaluation results

ROI is considered in a simplified model, without costs for financing. The investment can be considered as a strategic measure, which has benefits by itself, thus being able to get financed with low or no additional costs. Table 14 shows the obtained ROI periods.

Table 14. ROI for the neighbourhood exchange of energy with the main prosumer of the energy community.

No	Economic Variable	2021	2023	2025
1	Specific cost for storage [EUR/kWh installed]	500	400	300
2	Total storage capacity [kWh]	2	2	2
3	Specific cost for boost conv. [EUR/kW installed]	200	160	120
4	Total investment (sum 1+2+3) [EUR]	1200	960	720
5	Energy cost difference [EUR/kWh]	0.146	0. 146	0. 146
6	Power for the exchange link between neighbours [W]	500	500	500
7	Hours of operation per day [h/day]	4	4	4
8	Total exchanged energy per day, prosumer side ΔE [kWh]	2	2	2
9	Income for energy exchange per day [EUR/day]	0.2482	0. 2482	0. 2482
10	Income per year [EUR/year]	90.6	90.6	90.6
11	**ROI [years]**	**13.2**	**10.6**	**7.9**

For the previous inputs, the breakeven period for an acceptable business case (ROI < 8 years) is at the 2025 time horizon. The energy cost difference can play an important role in increasing or decreasing the overall calculation. Other scenarios, with different input data may be also considered. Consequently, more conservative approach may consider that the breakeven will happen between 2025 and 2030.

To be noted that the calculations were made without considering any subsidies. While such subsidies are given in some countries for the storage investment of a prosumer, it is yet not usual under discussion to have such subsidies for an energy community. A certain level of subsidies for energy communities may help in giving a clearer message for the attractivity of such neighbourhood solutions. Moreover, the previous calculations do not consider also a price for energy resilience over the energy community, which is also an increasing value in the future designs for smart cities and communities. Therefore, an evolving business model may bring new dimensions of the neighbourhood energy solution, which eventually can make it more attractive and more stable related to the contextual inputs, such as market price during peak and off-peak hours.

2.3 Phase 3 evaluation summary

The phase 3 evaluation covered the HLUC-1 defined in D2.2 [S4G-D2.2] and its business models defined in D2.4 [S4G-D2.4] using the evaluation framework and the KPIs defined in D6.3 [S4G-D6.3]. Part of the HLUC-1-PUCs were tested by using a HIL environment developed by UPB using a GridMonK interfacing environment with a HIL extension, an open-source load-flow application named OpenDSS, the LESSAg application for managing an ER interfacing the AP's PV and storage resources. Other HLUC-1-PUCs were tested using special setups to simulate the scenarios which were necessary in the HLUC-1. To be noted that the HIL used in UPB was developed to enable tests and analysis related to the HLUC-1, while it has been also designed for a didactic oriented activity, supporting laboratory and research activities for master and doctoral students.

3 Bolzano Test Site: Cooperation EV Charging Scenario

This scenario is composed by the residential and the commercial case. The residential case is a private house near Bolzano, which has PV panels, an EV charging station and an ESS with its respective inverter. The commercial case is in EDYNA's headquarters garage, where 5 SMART charging stations and some dummy charging stations are installed, which number increases continuously. Today 19 EVs can be charged. There are also PV panels which are directly connected to the distribution grid. The detailed test site description and the phase 3 deployment diagram are available in D6.3 [S4G-D6.3].
In order to evaluate the test site deployment from the user perspective, a remote usability and user experience (UX) study involving 7 professional users (grid planners, 4 from Bolzano, 3 from Fur) was conducted in the end of M36. The subject is developed more in section 4. Table 15 summarises the HLUC-2 evaluation KPIs defined in D6.3 [S4G-D6.3].

Table 15. HLUC-2: Phase 3 KPIs.

Use-case	KPIs
HLUC-2-PUC-1: *Residential prosumer with storage and EV*	The maximum power consumed from the grid (P_{DSO}) will be monitored for 3 months and it must be $P_{DSO\_consumed\_S4G} \leq P_{DSO\_consumed\_noS4G}$, *and* $P_{DSO\_consumed\_S4G} \leq 10$ *kW (contractual limit)*
HLUC-2-PUC-1-BM-1: *Prosumer with ESS "stand-alone" (baseline)*	Baseline. Analyse if it is profitable for a residential prosumer with an EV charging station to invest money in a residential ESS.
HLUC-2-PUC-1-BM-2: *Prosumer with grid integration*	Analyse the possibility for prosumers to make business by providing ancillary services to DSO by installing batteries in addition to the benefits obtained by the HLUC-2-PUC-1-BM-1.
HLUC-2-PUC-2: *Cooperative charging in the parking lot of a commercial test site*	The three phases voltages will be monitored for 3 months and it must be $V_{PCC} = 230$ *V ± 10% (EN 50160 standard)*
HLUC-2-PUC-2-BM-1: *Cooperative Charging at Commercial or Fleet level*	Analyse if it is profitable for a commercial site (or a Company Fleet site) with some EV charging stations to invest money in an ESS with or without a PV plant. The ROI time should be less than 20 years. Moreover, the Professional GUI System Usability Scale (SUS) should be classified as "good" and the DSF-SE results should be equal to the OpenDSS results.
HLUC-2-PUC-3: *Simulation of high penetration of EV chargers and of prosumers with storage and residential EV charging*	Analyse if it is profitable for a commercial site (or a Company Fleet site) with some EV charging stations to invest money in an ESS with or without a PV plant. The ROI time should be less than 20 years. Moreover, the Professional GUI SUS should be classified as "good".

3.1 Phase 3 deployments evaluation results

According to D6.6 [S4G-D6.6], the Bolzano phase 3 prototypes deployed were:

- D4.5 [S4G-D4.5].
- D4.7 [S4G-D4.7].
- D4.10 [S4G-D4.10].
- D5.2 [S4G-D5.2].

- D5.5 [S4G-D5.5].
- D5.7 [S4G-D5.7].
- D6.9 [S4G-D6.9].

3.2 Phase 3 KPIs evaluation

The HLUCs evaluation of the Bolzano test site (HLUC-2-PUC-1) using the Professional GUI was not directly conducted since the GUI was missing the grid topology of both the residential and the commercial grid. Additionally, the simulation using the EV charging stations took too long to be evaluated within 45 minutes, which was the time frame in which the professional users were available. However, from the UX point of view, the interaction and logic behind the simulation is the same compared to the Fur scenarios and was therefore evaluated on the grid topology of HLUC-3. Therefore, UX related results of Fur can directly be transferred to the commercial test cases since the interaction and GUI behaviour is the same. Thus, the following sections report on transferred findings from testing the Fur HLUCs whenever they are applicable. It is important to note that the UX evaluation is not meant to show the validity of the single test cases.

Moreover, it reports on findings concerning usability and UX measures for the Professional GUI and delivers subjective hints if the HLUC was perceived as being useful. However, the evaluation was conducted using grid planners. That might bias the results concerning HLUCs which were not designed for the respective user group. The detailed description of the test is reported in section 4. The evaluation of the business models of the Bolzano test site was conducted with the help of the economic model in the Professional GUI. Further details about the Professional GUI are described in D6.9 [S4G-D6.9].

3.2.1 HLUC-2-PUC-1

3.2.1.1 Description

HLUC-2-PUC-1: “Residential prosumer with storage and EV” demonstrates the possibility to decrease the exchange of power between the prosumer and the DSO and the possibility for the DSO to exploit an ESS.

3.2.1.2 Evaluation procedure

HLUC-2-PUC-1 was evaluated by monitoring the power exchange between the prosumer and the DSO grid. The maximum power consumed from the grid (P_{DSO}) was monitored for 3 months and it must be: $P_{DSO\_consumed\_S4G} \leq P_{DSO\_consumed\_noS4G}$, and $P_{DSO\_consumed\_S4G} \leq 10$ kW (contractual limit).

For this evaluation, power data stored in the DSF-DWH of S4G was queried and used. During the evaluation, data from Load, PV, ESS, Grid and EV was used. Furthermore, these data was resample to a 10-minute timestep, in order to eliminate outsider points and to keep mean power peaks in this frequency. With this step, we filtered noise from the data and assured the evaluation of peaks that lasted at least the 10-minute frequency. Missing data points for a period of time longer than 10 minutes were replaced by 0.

Additionally, we simulated the working of the system without ESS and with Fronius system in order to make a comparison of the different system responses. The Fronius system simulation consisted in charging the ESS just when the PV production exceeded Load consumption and discharging it when the Load consumption exceeded the PV production. We set a limit of 20% SoC as the minimal value for ESS during the simulation, so the results can be compared with the one using PROFEV in S4G (D4.7 [S4G-D4.7]), where the minimal ESS SoC is 20%. Finally, the analysis is presented monthly for a duration of three months: January to March.

The interaction with the DSF-DWH was conducted through the S4G-OpenVpn Tunnel including certificates, in order to keep security of the data. After the evaluation, all data was erased from the local computer.

The Residential GUI is a tool to show to the residential user relevant information from their systems installed at home such as EV, PV, ESS with respect to produced/consumed energy as well as the interaction from/to grid of the house. To show the information, the Residential GUI depends on the SMX south-bound connectors (Fronius south-bound connector, EV south-bound connector) to enable the Residential GUI back/front-end to process and show relevant information to the residential user. Thus, the evaluation of the Residential GUI was focussed on testing the integration with the south-bound connectors and the correct interpretation of the data compared with offline analysis from data available at the DSF-DWH. Besides, two sessions with project partners were held to evaluate the UX while interpreting data.

3.2.1.3 Evaluation results

The optimization objective chosen for this test site is the minimization of the power exchange with the grid including GESSCon. It means that PROFEV will try to find the optimal setpoint at each timestep that reduces the import of power from the grid as well as the export of power to the grid analysing the next 24-hours of the input variables. Because PROFEV is running a stochastic optimization algorithm inside, PROFEV takes into consideration future events related to the system in form of predictions too (D4.7 [S4G-D4.7]). These predictions are related to the load consumption and PV generation in the test site. Furthermore, uncertainties about the plugging time of the EVs to the charging stations are also included in the algorithm, in order to optimize the charging of the EV. Because of some problems with the Siemens Cloud Service that provides access through an API to control the charging station in the test site, the charging station could only be controlled since March 14th, 2020.
For a better understanding of the data, Figure 25 presents one day-data.

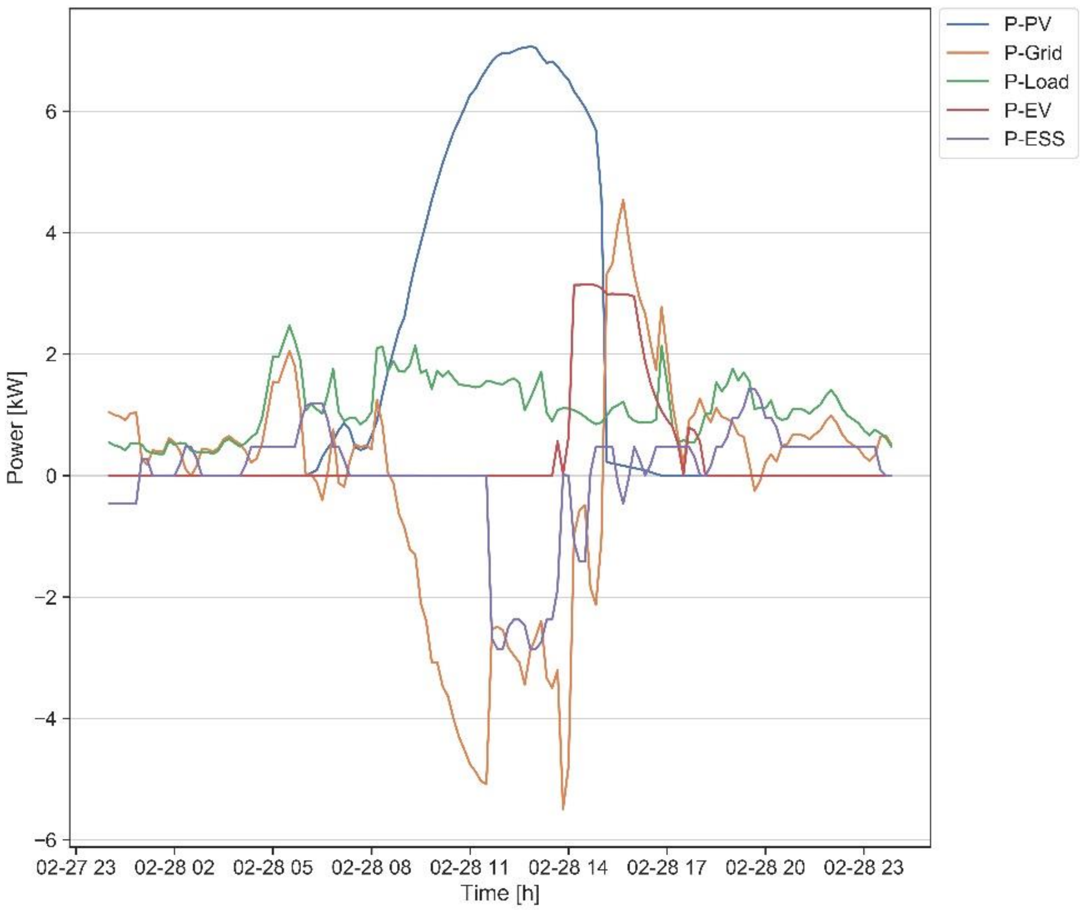

Figure 25. Bolzano Residential test site: One-day data.

In the one-day data, it is depicted how the PROFEV realizes the control of the ESS. Positive values of P_ESS (purple colour) show the discharging of the ESS, whereas negative values show the charging of the ESS. In this way, the ESS tries to charge when the PV is generating power, while at the same time it tries to cut the generation peak offered by the PV. In the other hours when there is no PV generation, the ESS discharges on the load. Because PROFEV works with mathematical optimization and because the inputs variables are changing continuously, outputs of PROFEV can vary depending on the day. Moreover, PROFEV does not run a real-time control but a discrete one, which in this test site was set to a 30-minute frequency. The frequency was chosen based on the computing power needed to calculate each timestep that in a Debian-9 server with 12 Intel(R) Xeon(R) Platinum 8268 CPU @ 2.90GHz is 19 minutes.

Figure 26, Figure 27, and Figure 28 show, respectively data from January to March 2020. The evaluation is based on this data taken from the DSF-DWH. In these figures, one can observe the completeness of the data and have an idea about the behaviour of each electrical variable of the system.

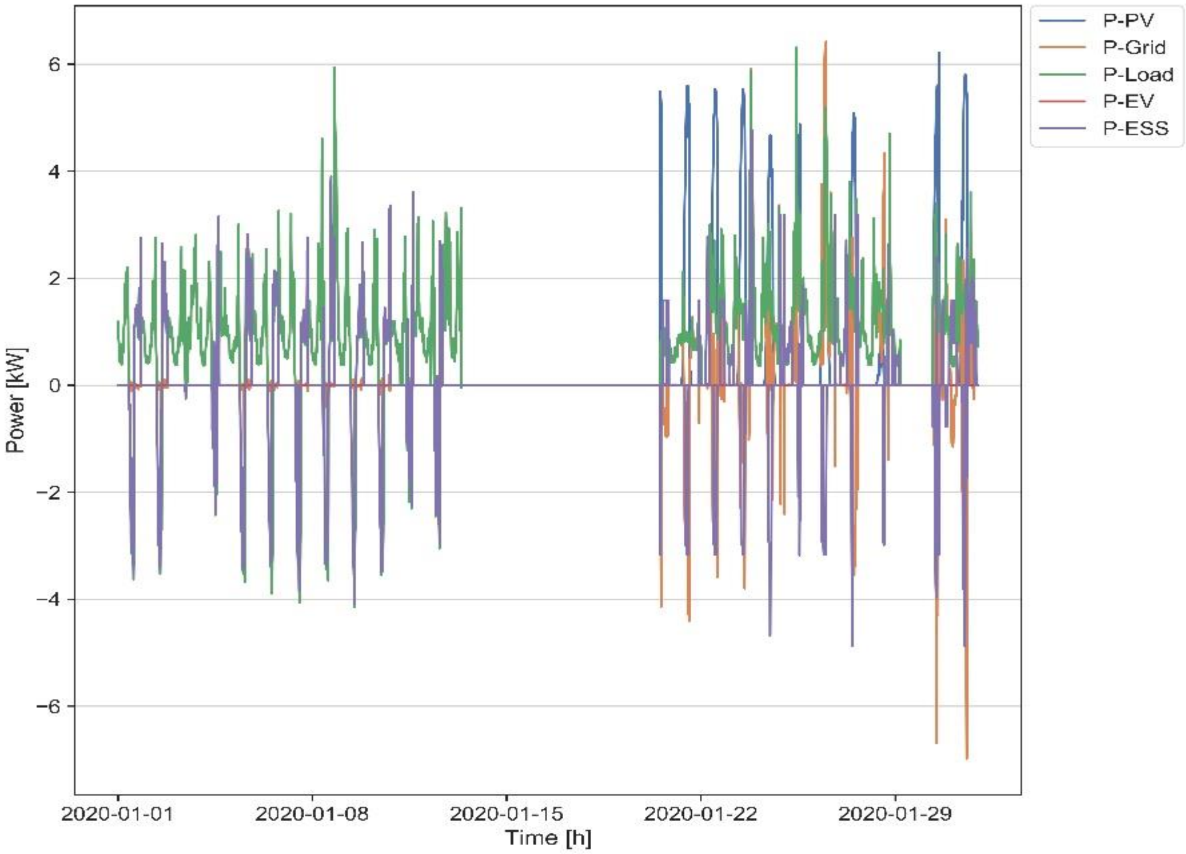

Figure 26. Bolzano Residential test site: January 2020 data.

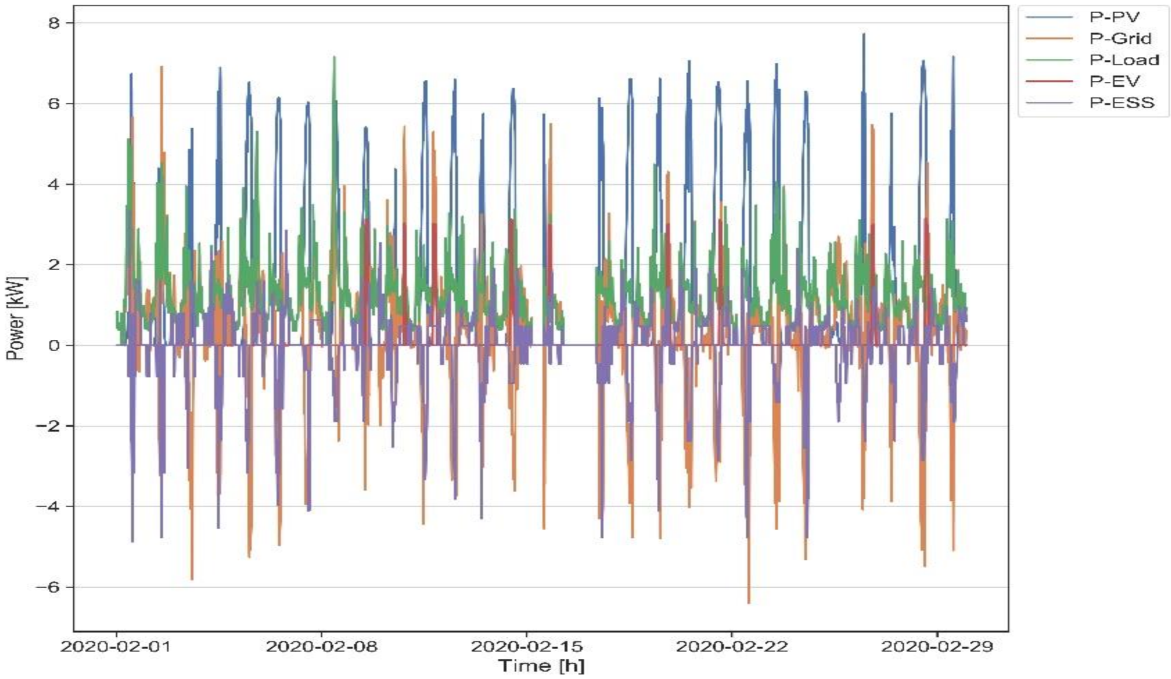

Figure 27. Bolzano Residential test site: February 2020 data.

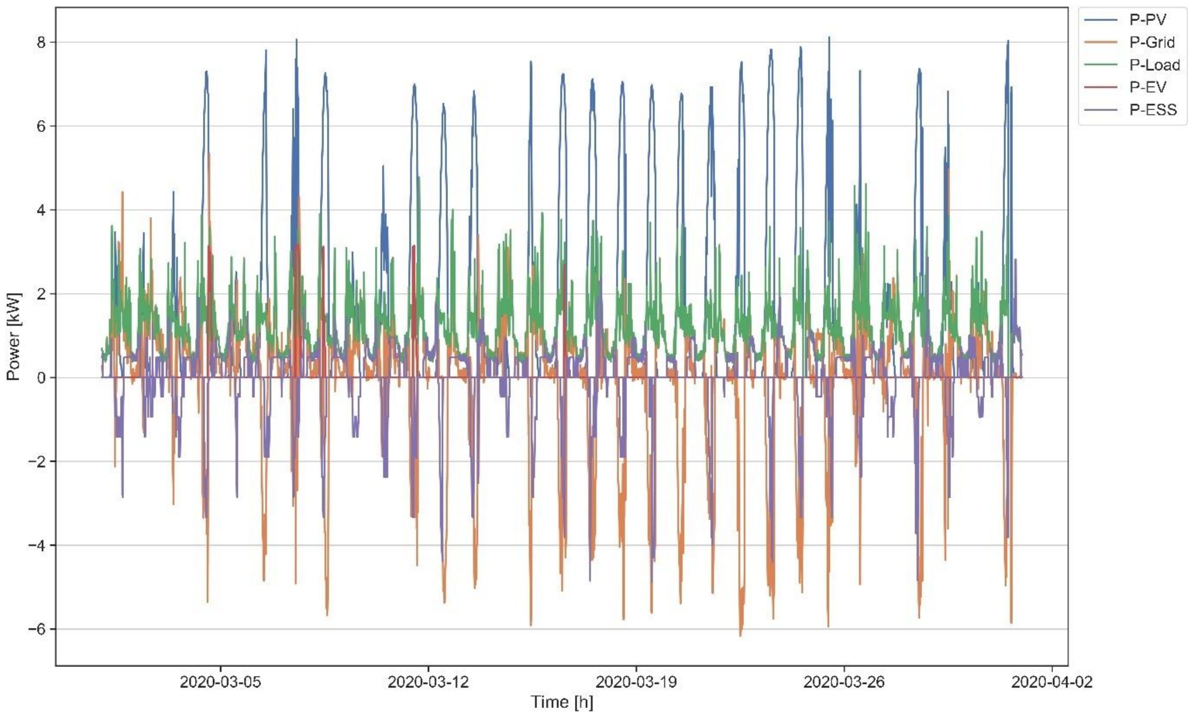

Figure 28. Bolzano Residential test site: March 2020 data.

The correct working of PROFEV was evaluated intrinsically by receiving the different setpoints every 30-min. Additionally, the results of one optimization step were collected and verified that they make sense for given inputs. The reason is that PROFEV calculates an optimization problem, which requires that all its inputs are present at the required instant of time. If some input is missing, it is impossible for the algorithm to start working and even worse to publish a setpoint as an output. In this sense, the MQTT-based communication, internal predictions and dynamic programming way of solving the optimization problem were successfully tested. Furthermore, PROFEV works together with the Fronius Connector, which sets the control setpoints of the ESS. The setpoints sent by PROFEV are successfully translated into power changes of the ESS. This interaction works also in the Fur/Skive test site. The Bolzano Commercial test site does not make use of the Fronius Connector. For the analysis some performance indicators were calculated and summarized per month from January until March 2020 in Table 16, Table 17 and Table 18, respectively. The analysis was done using the procedure described in the previous section. In that case, the average values are calculated from the whole analysed information. As an example, the "Average of daily maximum power peaks exported to the grid" is calculated finding all the daily power peaks exported to the grid from the whole data and calculating its average.

The KPI of $P_{DSO\_consumed\_S4G} \leq P_{DSO\_consumed\_noS4G}$, and $P_{DSO\_consumed\_S4G} \leq 10$ kW was achieved successfully using PROFEV because the average of daily maximum power peaks from the grid is around 3 ± 1.15 kW, which is 30% of the allowed 10 kW. Furthermore, it is interesting to compare the behaviour of the stochastic optimization model in PROFEV with the cases when there is no ESS present or when the ESS is being controlled by the Fronius system, as it used to work before S4G. In fact, the comparison between the three control mechanisms shows that PROFEV allowed a higher local use of PV generation during the three months of analysis. We attribute it to the way of working of the optimization model, which tries not to get immediately the PV generation present but rather distributes the charging of the ESS during the whole PV generation. Because of this fact, the mean peak exported power to the grid also reduces using PROFEV in comparison to Fronius simulation. Due to the 30 min control frequency of PROFEV, some peak exported power outsiders can be found in the data which are higher than with the Fronius simulation. Nevertheless, these outsiders have a maximal duration of 10 min. Important to notice is that the optimization algorithm in PROFEV can also load the ESS from the grid if it considers it necessary. For that reason, the energy imported from the grid can be sometimes higher with PROFEV. Moreover, in the third month was added a control setting inside PROFEV that does not allow to export energy from the ESS to the grid as required by the test site owner.

Moreover, we implemented another control mechanism that analysed the conditions of the system at the exact moment when the setpoint had to be published. Sometimes it happened that when PROFEV started calculating the optimal setpoint for the ESS the system had certain values of Load and PV. However, after the 19 minutes of calculation the conditions changed reducing significantly the Load or PV, which caused an export of power from ESS. Consequently, due to these two corrections during the deployment, the export to the grid decreased in March.

In conclusion, PROFEV could manage the energy flow in the Bolzano Residential test site using a stochastic optimization algorithm solved using dynamic programming. Even though the connection of the electrical elements in this test site do not allow the direct control of the PV energy (connected in 2 phases) and because the EV is connected in just one phase, the results still show an increase in the local use of PV energy while the mean peak of power exported to the grid is also reduced. Because of some problems with Siemens service for the control of charging stations, the charging station at the Bolzano Residential test site could just be controlled since March 17th, 2020. This issue increases the peak power taken from the grid because PROFEV cannot shift the charging of the EV to another time.

Table 16. Bolzano Residential test site: Performance Indicators for January 2020.

	PROFEV	**Without ESS**	**Fronius Simulation**
Total PV generation [kWh]	203.06	203.06	203.06
Total Grid Export [kWh]	89.07	112.65	78.58

	PROFEV	Without ESS	Fronius Simulation
Total Grid Import [kWh]	415.09	514.82	482.82
Grid Import - Grid Export [kWh]	326.02	402.17	404.24
Average of daily maximum power peaks exported to the grid [kW]	3.28 ± 1.51	3.28 ± 1.51	4.33 ± 0.64
Average of daily maximum power peaks imported from the grid [kW]	2.99 ± 1.15	3.07 ± 0.93	3.09 ± 0.9
Maximum peak of power exported to the grid [kW]	6.98	6.98	5.21
Maximum peak of power imported from the grid [kW]	6.42	5.94	5.94
PV energy absorbed by ESS [kWh]	54.56	-	35.91
PV energy absorbed by ESS [%]	26.87	-	17.68
PV energy absorbed by Load [kWh]	90.41	90.41	90.41
PV energy absorbed by Load [%]	44.52	44.52	44.52
PV energy used locally [%]	71.39	44.52	62.21
PV peak [kW]	6.21	6.21	6.21

Table 17. Bolzano Residential test site: Performance Indicators for February 2020.

	PROFEV	Without ESS	Fronius Simulation
Total PV generation [kWh]	692.1	692.1	692.1
Total Grid Export [kWh]	256.72	386.57	283.61
Total Grid Import [kWh]	491	570.78	476.05
Grid Import - Grid Export [kWh]	234.27	184.21	192.44
Average of daily maximum power peaks exported to the grid [kW]	3.97 ± 1.27	3.97 ± 1.27	4.55 ± 1.37
Average of daily maximum power peaks imported from the grid [kW]	3.15 ± 1.34	3.09 ± 1.04	2.98 ± 1.1
Maximum peak of power exported to the grid [kW]	6.4	6.4	5.97
Maximum peak of power imported from the grid [kW]	6.92	5.85	5.85
PV energy absorbed by ESS [kWh]	142.6	-	111.82
PV energy absorbed by ESS [%]	20.6	-	16.16
PV energy absorbed by Load [kWh]	283.84	283.84	283.84
PV energy absorbed by Load [%]	41.01	41.01	41.01
PV energy used locally [%]	61.61	41.01	57.17
PV peak [kW]	7.73	7.73	7.73

Table 18. Bolzano Residential test site: Performance Indicators for March 2020.

	PROFEV	Without ESS	Fronius Simulation
Total PV generation [kWh]	930.43	930.43	930.43
Total Grid Export [kWh]	390.43	539.76	438.91
Total Grid Import [kWh]	419.08	520.79	426.79
Grid Import - Grid Export [kWh]	28.21	-18.97	-12.12
Average of daily maximum power peaks exported to the grid [kW]	4.83 ±1.29	4.83 ± 1.29	5.44 ± 1.47
Average of daily maximum power peaks imported from the grid [kW]	2.72 ±1.06	2.68 ± 0.9	2.44 ± 0.85
Maximum peak of power exported to the grid [kW]	6.17	6.17	6.68
Maximum peak of power imported from the grid [kW]	5.35	5.26	4.67
PV energy absorbed by ESS [kWh]	148.26	-	110.05
PV energy absorbed by ESS [%]	15.93	-	11.83
PV energy absorbed by Load [kWh]	366.44	366.44	366.44
PV energy absorbed by Load [%]	39.38	39.38	39.38
PV energy used locally [%]	55.32	39.38	51.21
PV peak [kW]	8.12	8.12	8.12

Figure 29, Figure 30, and Figure 31 show the PV energy locally used per month. In the figures, the total PV energy, the PV energy used with PROFEV, and the PV energy used with the Fronius simulation are depicted per day.

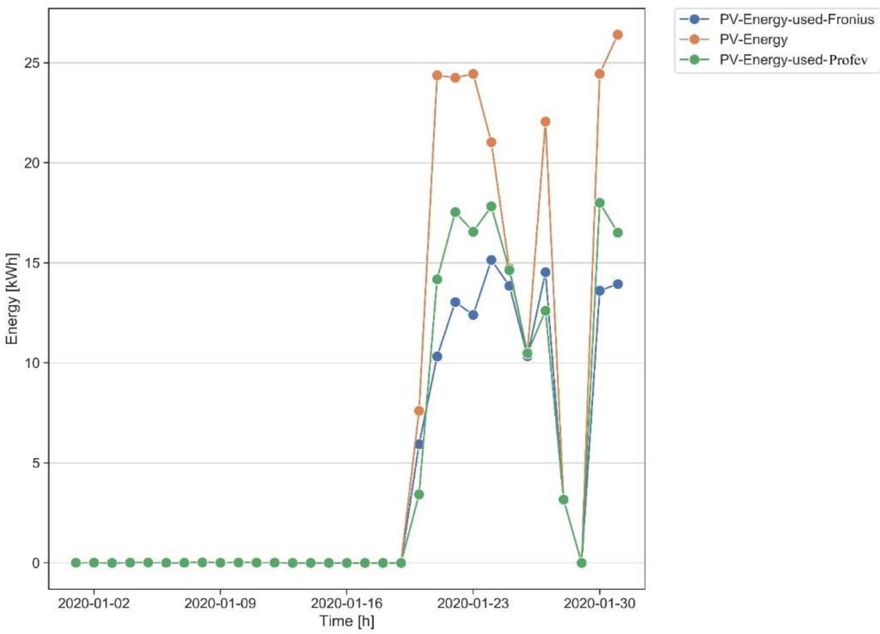

Figure 29. Bolzano Residential test site: PV energy use in January 2020.

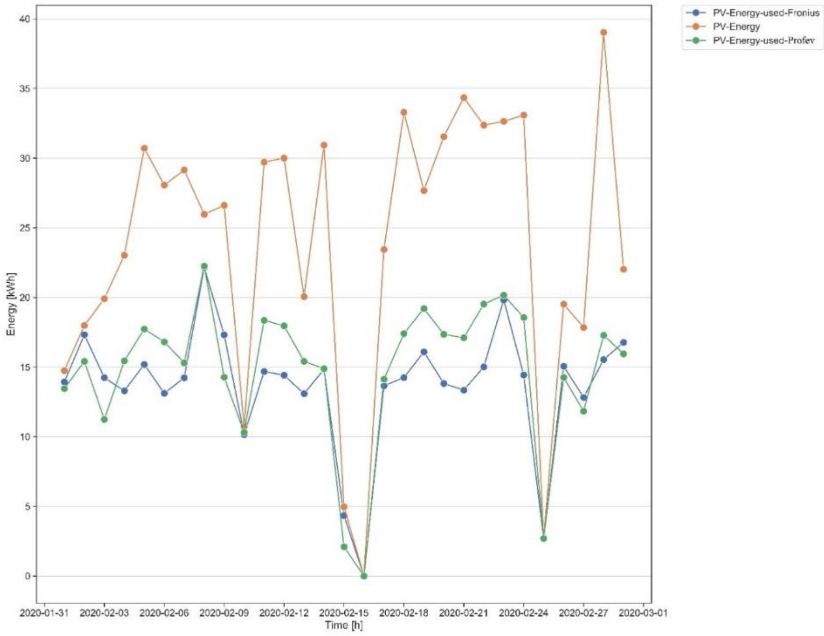

Figure 30. Bolzano Residential test site: PV energy use in February 2020.

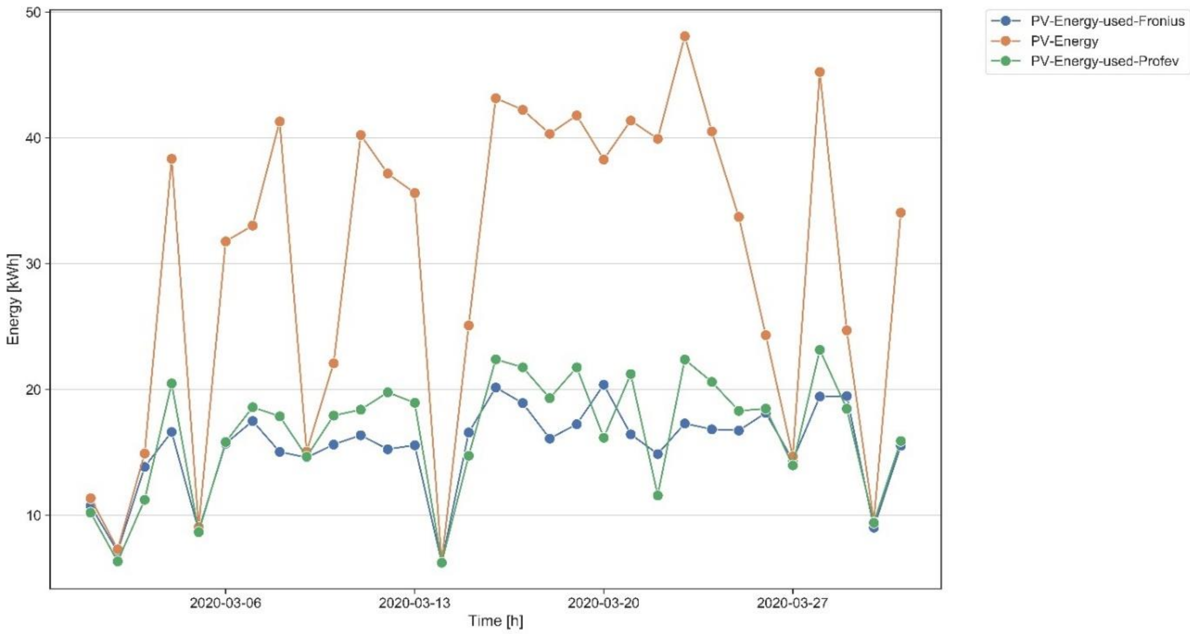

Figure 31. Bolzano Residential test site: PV energy use in March 2020.

The Residential GUI integration testing with south-bound connectors was performed for 3 months. During this period south-bound connectors were also evaluated, updated and consequently the Residential GUI. Furthermore, measurements from Fronius system were integrated instead of SMX as it had more descriptive information such as device status. However, PV measurements from SMX were integrated by the Fronius south-bound connector to compensate wrong PV measurements from Fronius due to deployment limitations. Furthermore, the Residential GUI was integrated with the EV connector to show EV related information as well as with PROFESS/PROFEV to control house elements following a specific operational mode (maximize self-consumption, minimize power-exchange with the grid, minimize bill costs)[1]. The Residential GUI is able to show real-time information on its home page (Figure 32):

- System Connectivity of PV, ESS and EV with the following possible statuses: ok, warning, error. This information was produced by Residential GUI back-end and by the actual reception of values from the Fronius south-bound connectors within a certain amount of time.
- Storage Status with SoC and charging status with following possible values: empty, charging, idle, holding, discharging, full. This information was received directly from Fronius south-bound connector.
- Electric Vehicle Status with SoC and the following possible statuses: no status, charging, not charging. This information was received directly from the EV connector.
- Energy balance for the current day was evaluated from DSF-DWH values; the actual power measurements instead, were estimated from the Fronius south-bound connector real-time values. The Residential GUI showed energy produced / consumed balance and energy from / to grid balance for each specific view.

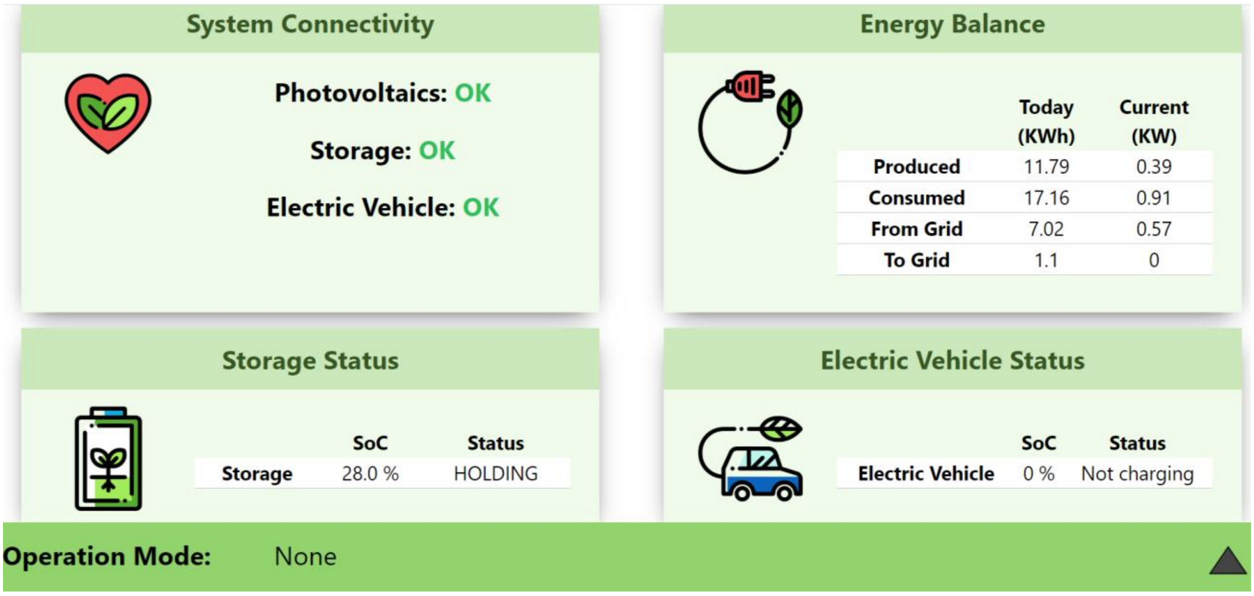

Figure 32. Real-time Residential GUI readings: Home view.

To evaluate production/consumption view it was used the offline approach in order to assess computations from Residential GUI. During this process, with respect to D6.9 [S4G-D6.9], were updated the computations to consider ESS charging and discharging from/to grid, improved the usability of the Residential GUI reducing visualization time, improved granularity of daily view, removed weekly view and modified month/year view adopting a bar graph and presenting energy instead of mean power for the specific period.

The following figures present the new organization of the consumption/ production information. The dynamic interface allows users to select among three main views:

- **Day** view presents the Instant Power Production/Consumption of all the assets supported within the project with a high granularity (1 sample every 5 minutes) - Figure 33 and Figure 34.
- **Month** view presents the average Energy consumed or produced by the supported asset with a medium granularity (1 sample per day) - Figure 35 and Figure 36.
- **Year** view presents the average Energy consumed or produced by the supported asset with a low granularity (1 sample per month) - Figure 37 and Figure 38.

[1] The evaluation of the operational mode belongs to the PROVEF evaluation process. The Residential GUI was only used to trigger its functionalities.

The "Day" view exploits linear charts to let users consult the behaviour of all the available assets and compare the Power related available information among an interval of days. While, the "Month" and "Year" views aggregates data per day or month to let users have an overview of the total energy managed by the system in the selected month or year.

Finally, at the top of the interface, the total Energy produced/consumed is shown near the button used to export all the shown data.

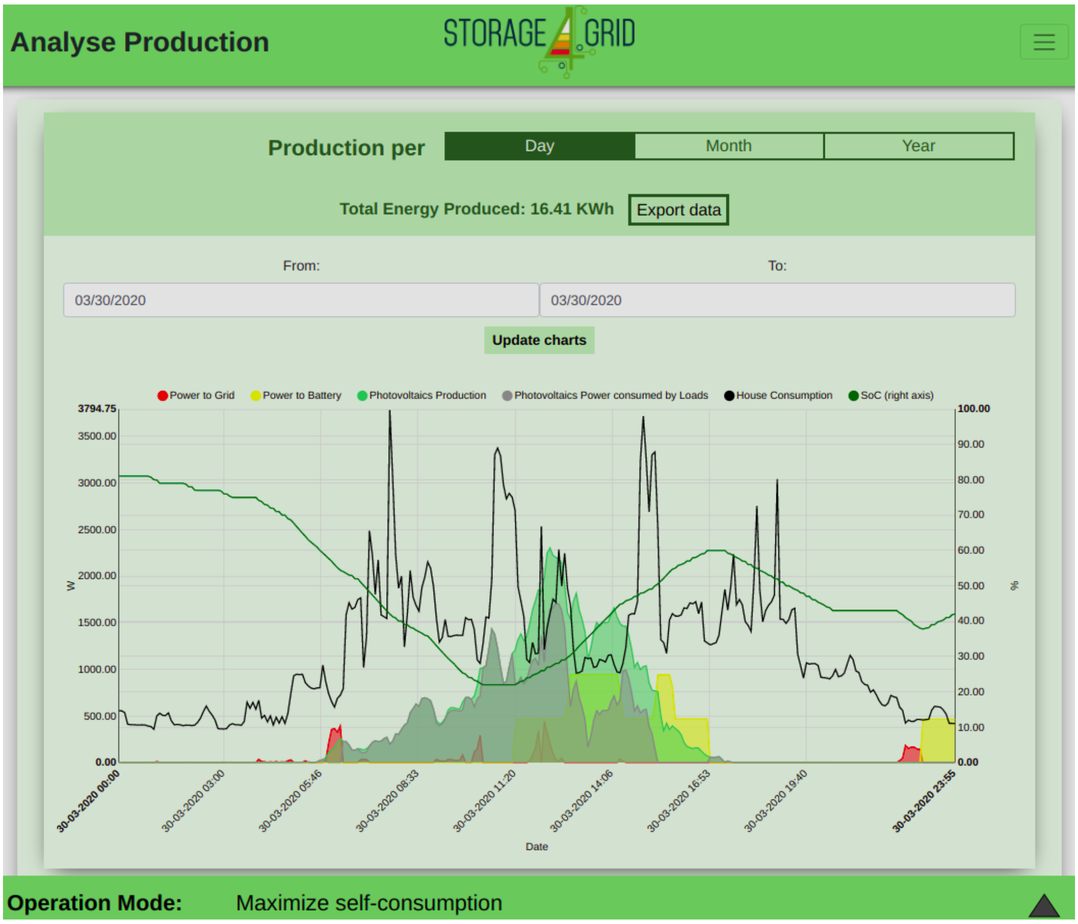

Figure 33. Historical data Residential GUI Production: Day view.

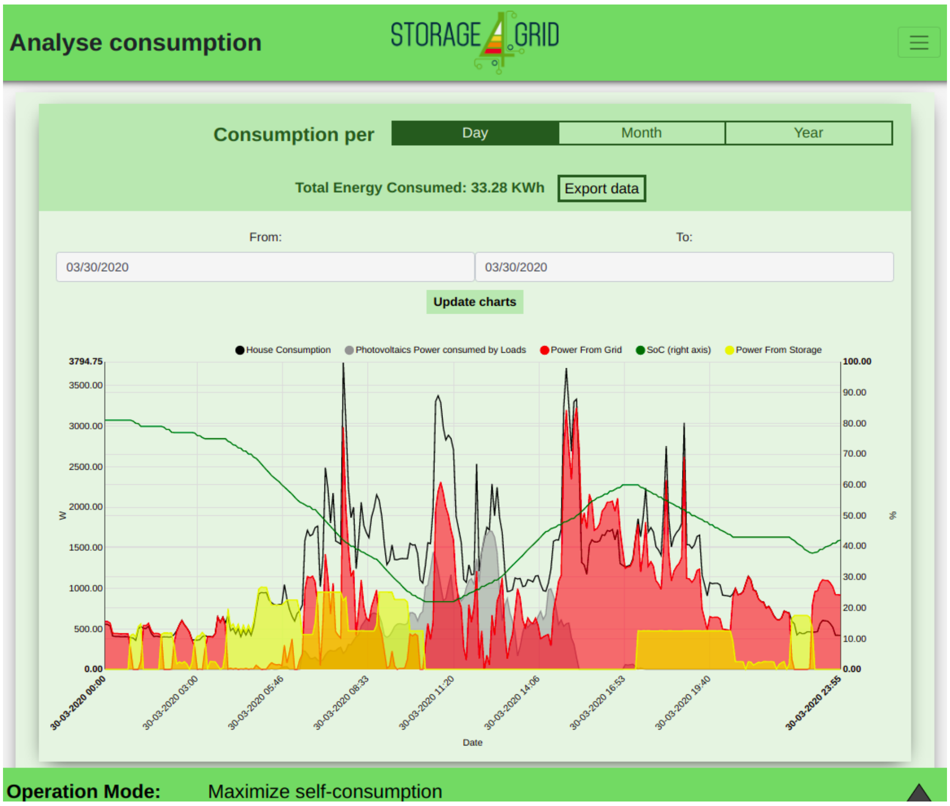

Figure 34. Historical data Residential GUI Consumption: Day view.

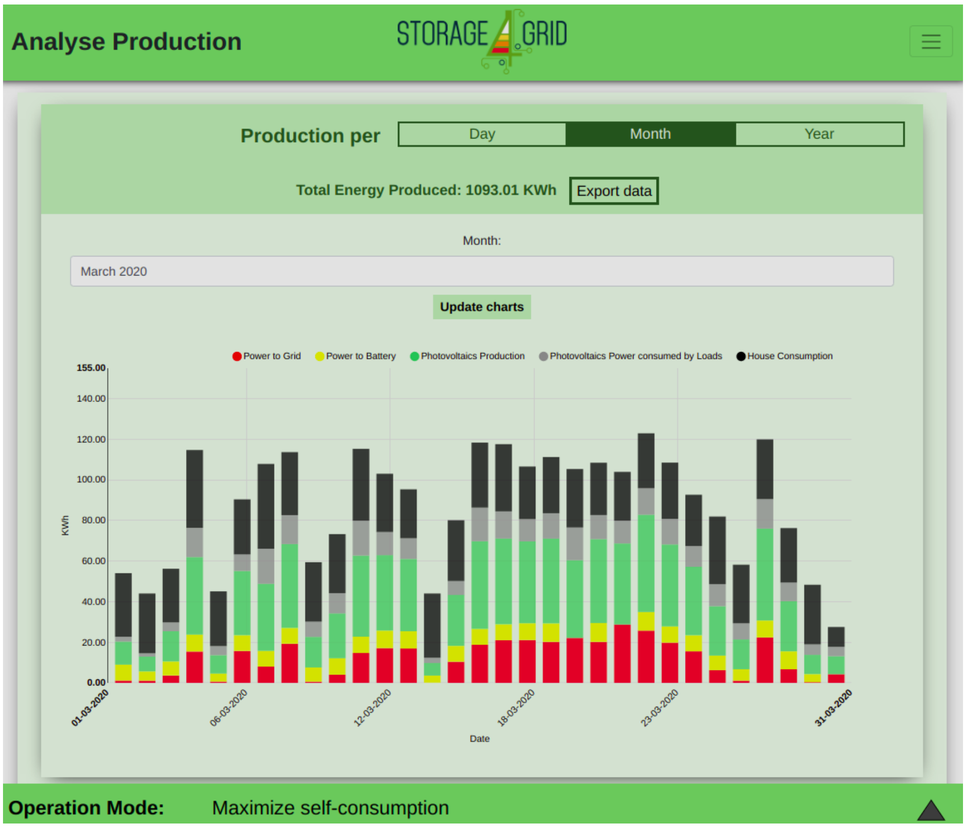

Figure 35. Historical data Residential GUI Production: Month view.

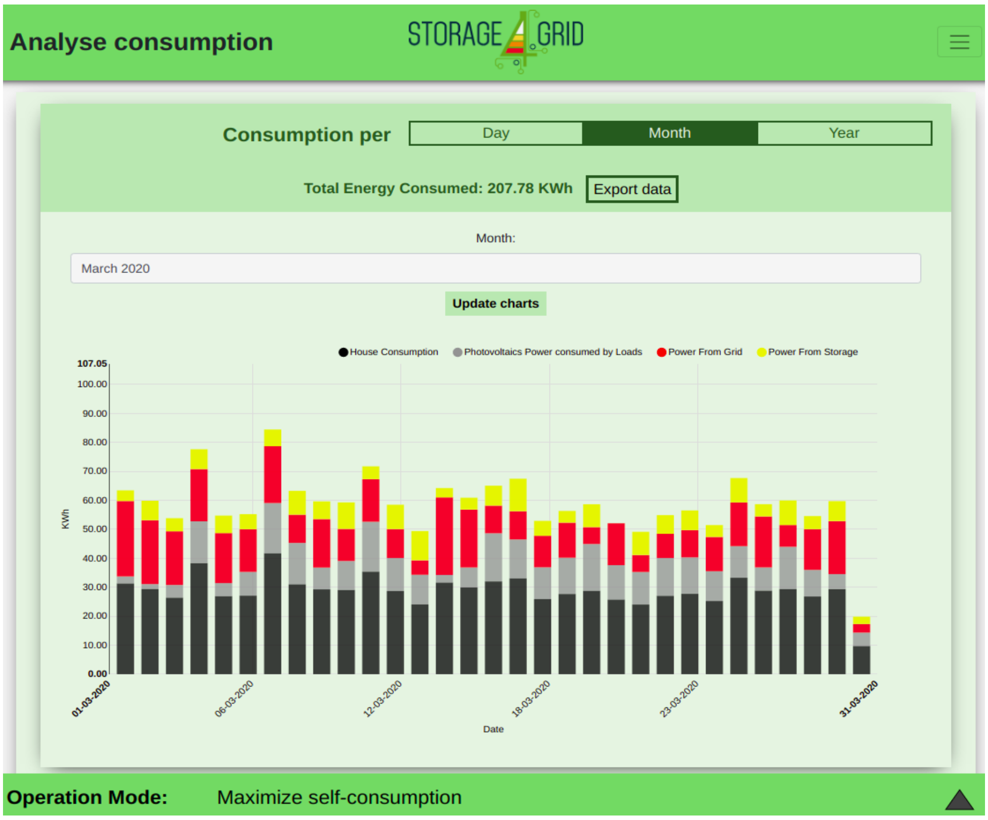

Figure 36. Historical data Residential GUI Consumption: Month view.

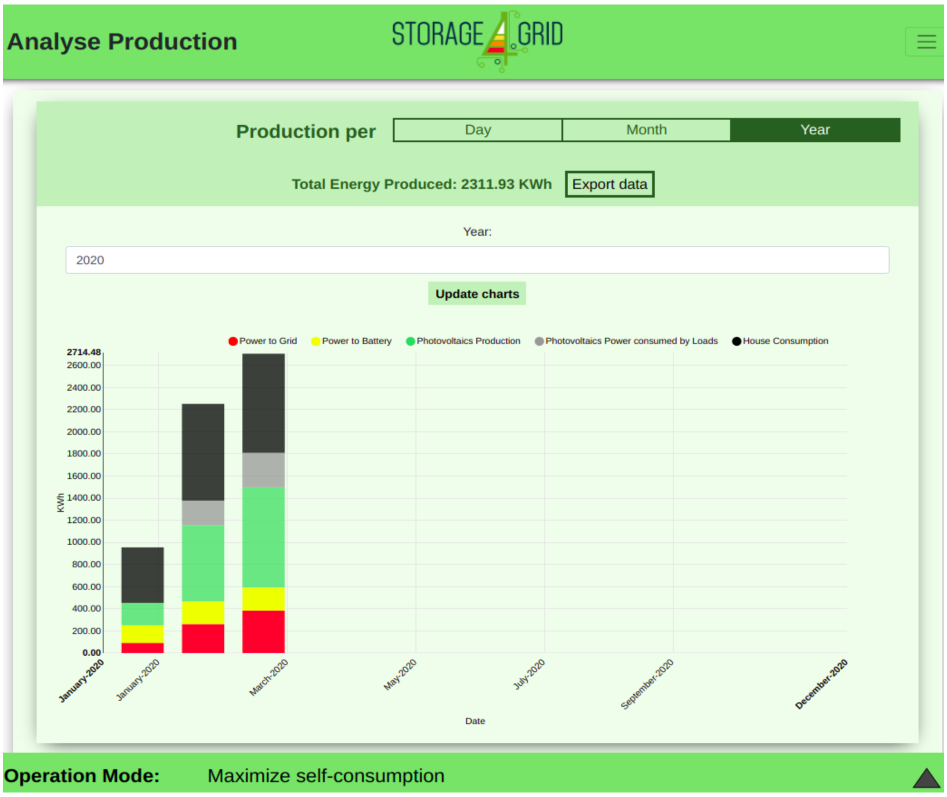

Figure 37. Historical data Residential GUI Production: Year view.

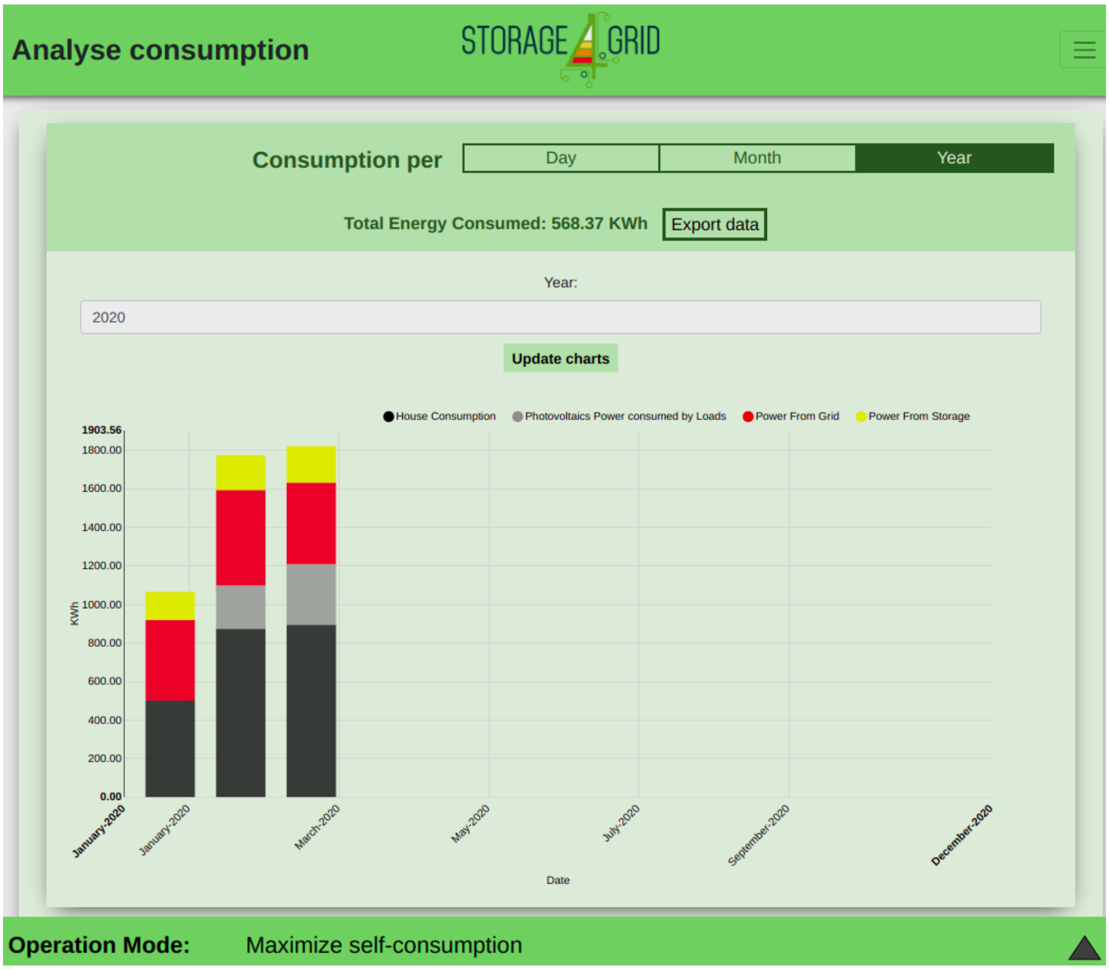

Figure 38. Historical data Residential GUI Consumption. Year view.

Finally, outcomes from the sessions with project partners were related to information validation, UX and graphic representation already considered during the offline testing and updated in the latest version of the Residential GUI. During the phase 3 evaluation, the Residential GUI requirements were updated and implemented with respect to the latest deployment of components as well as available information.

3.2.2 HLUC-2-PUC-1-BM-1

3.2.2.1 Description

HLUC-2-PUC-1-BM-1: "Prosumer with ESS "stand-alone" (baseline)" evaluates if it is profitable for a residential prosumer with an EV charging station to invest money in a residential ESS. It is the baseline for other business models concerning the residential prosumer in the Italian context and in the Bolzano test site.

3.2.2.2 Evaluation procedure

HLUC-2-PUC-1-BM-1 was evaluated by collecting the measurement values from the USMs (Grid, PV, ESS and EV) and with this an analysis was performed using the Professional GUI to carry out if it is profitable or not to invest in an ESS.

3.2.2.3 Evaluation results

To do the economic model developed within the Decision Support Framework Economic Engine (DSF-EE) relevant simulations could be performed, which shows the profitability of installing ESS in the Bolzano grid considering different grid configurations and 21 households. The DSF-EE is based on a Total Cost of Ownership (TCO) function. HLUC-2-PUC-1-BM-1 simulations where made only by installing ESS at prosumer level. In addition to that, in the numerical computation, different PV penetration levels where implemented, which are 15%, 30%, 50%, 70% and 100% of the total load of the connected power in the grid. The ESS penetration level was in one simulation series fixed at 48% of the installed PV power in the grid. This means by increasing the PV power also the ESS power increases. In the second simulation series the ESS power was fixed by about 23 kW, which can be seen as a realistic hypothesis. The EV penetration is fixed at 20% of the total load. The total load of the grid is about 160 kW. The simulation results are presented in Table 19 and Table 20.

Table 19. DSF-EE results with different PV penetration rates and fixed ESS power.

Penetration rate [%]			Economic Model results	
of total load	of total load	of installed PV	Decentralized Storage at household level	Traditional grid strengthening
PV	EV	ESS	TCO households [EUR]	
15	20	97	524,899	516,538
30	20	48	510,192	504,819
50	20	29	501,873	485,998
70	20	20	493,203	475,328
100	20	14	472,471	456,841

Table 20. DSF-EE results with different PV penetration and fixed ESS power penetration rates.

Penetration rate [%]			Economic Model results	
of total load	of total load	of installed PV	Decentralized Storage at household level	Traditional grid strengthening
PV	EV	ESS	TCO households [EUR]	
15	20	48	527,977	516,538
30	20	48	510,192	504,819
50	20	48	492,885	485,998
70	20	48	475,692	475,328
100	20	48	459,549	456,841

Both results show that the increasing PV penetration rate reduces the system TCO due to higher energy purchase in the market. Therefore, the system will be paid off faster. At higher PV penetration levels (50, 70 and 100%) Table 20 shows 2-4% lower TCO values than in Table 19. The reason lies in the right ratio between PV penetration and ESS penetration. The ESS power in the first simulation series is fixed, therefore the ratio between PV and ESS penetration changes. With higher PV penetration the impact from the ESS decreases. The ESS penetration value of 48% in the second simulation series is a high value, which is an advantage at high PV penetration (70 and 100%).

In this area the differences between the TCO values of the traditional grid strengthening and the decentralised storage at household level is very low. Nevertheless, simulations show the TCO for traditional grid strengthening is in each simulation lower, therefore from a strictly economic point of view the traditional grid strengthening is the economic best solution for a household. The high costs of storage systems represent a barrier for their adoption. For this situation, it has not been possible to define some price thresholds under which the business case become profitable. In this regard, the availability of government-sponsored financial incentives could help to overcome the storage price issue. The second important point is the right balance between PV and ESS penetration. The simple and quick handling of the DSF-EE could certainly contribute to a significant improvement of this situation.

This evaluation considers only the economic side, while consumers are often driven to adopt a battery also for "ethical-political" reasons, such as being more independent and using the clean energy produced with the sun as much as possible.

3.2.3 HLUC-2-PUC-1-BM-2

3.2.3.1 Description

HLUC-2-PUC-1-BM-2: *"Prosumer with grid integration"* evaluates the prosumers possibility of making business by providing ancillary services to the DSO by installing batteries in addition to the benefits obtained by the HLUC-2-PUC-1-BM-1.

3.2.3.2 Evaluation procedure

HLUC-2-PUC-1-BM-2 was evaluated by collecting the measurement values from the USMs (Grid, PV, ESS and EV) and with this an analysis was performed to carry out if it is profitable or not for the DSO to install batteries.

3.2.3.3 Evaluation results

The field of providing ancillary services traditionally appears only in the middle and high voltage area. The most important goal is to generate a balance between active and reactive power production and consumption which directly impacts the frequency in the grid. During the last years a new field of ancillary services is under discussion. The providing of ancillary services in the low voltage grid, where until today a handful pilot projects were performed. The difference between the two ancillary services types is, that due to the smaller power exchange in the low voltage grid the regulation has the main impact on the local voltage and less to the frequency level. Nevertheless, due to the increasing small size PV penetration and progressive expansion of electric charging stations on residential and commercial places the voltage fluctuations getting more frequent and having a larger magnitude. To counteract this behaviour, the DSO offers the prosumer to buy a battery which provides automatic voltage control within defined limits controlled by the DSO. For this service, the DSO offers a limited payment to the prosumer for the ancillary services. Therefore, the prosumer will reduce the payback period from PV and storage investment and the DSO could reduce grid strengthening costs and improve voltage quality.

The impact of storage availability on the voltage deviation ΔU will vary from day to day and from installation to installation depending on production and consumption locally and in the local feeder lines. It is also a function of the grid conditions (substation voltage level) and therefore setpoints might vary according to the actual grid operation. In this phase, the target is to keep the voltage (RMS) deviation from the rated value (ΔU) within ± 10% of 230 V (single phase connection point PCC) due to legislation and regulation demands.

The calculations were conducted with the Professional GUI by implementing the PV penetration and fixed ESS power penetration rates like the HLUC-2-PUC-1-BM-1 simulations in Table 20. Only the prosumer is considered which is furthest away from the substation, because it has the biggest voltage problems in the grid. Therefore, the effect of the voltage regulation may be best assessed. Figure 39 to Figure 43 show the simulations results. The TOC for the household (prosumer) are the same as in Table 20.

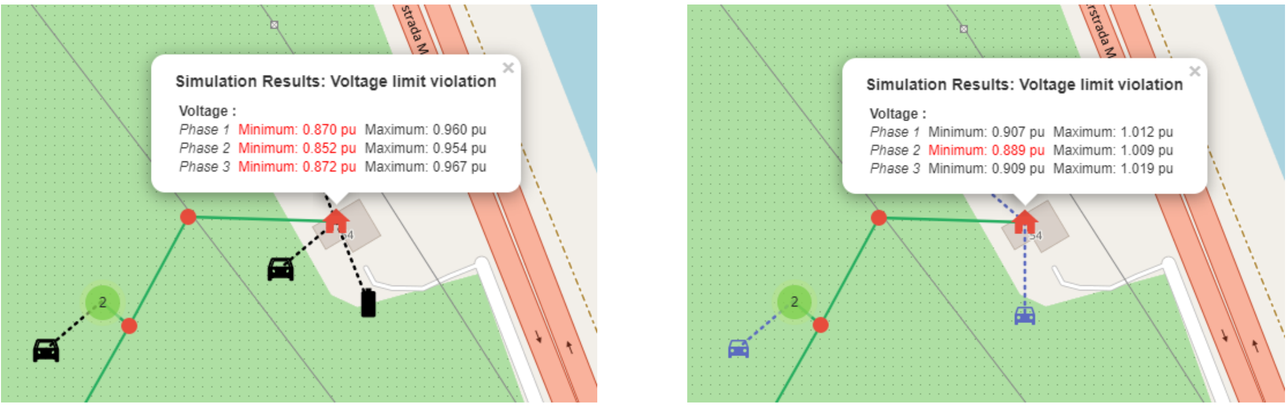

Figure 39. Simulation case 15% PV, 20% EV and 48% ESS penetration by decentralized storage at household level (left) and traditional grid strengthening (right).

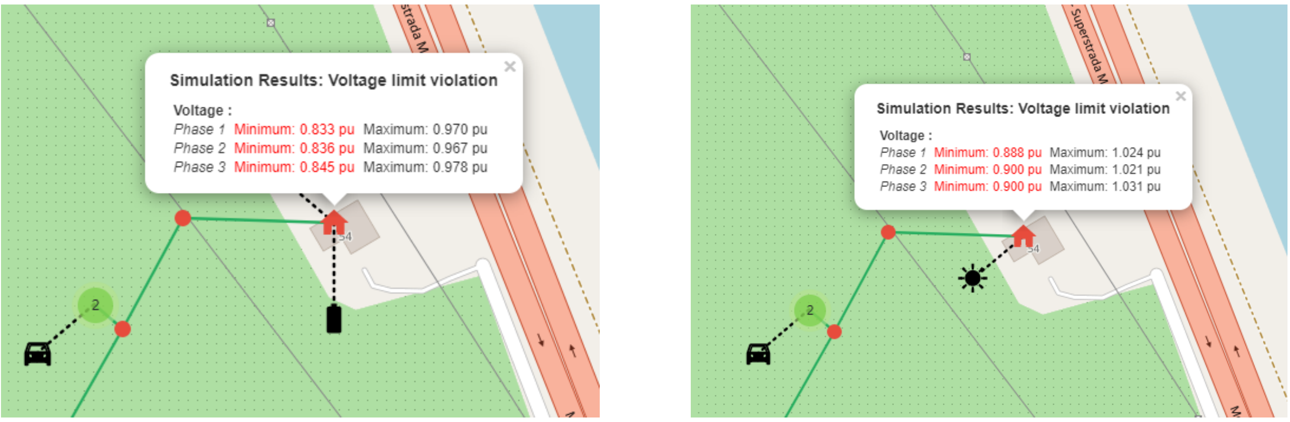

Figure 40. Simulation case 30% PV, 20% EV and 48% ESS penetration by decentralized storage at household level (left) and traditional grid strengthening (right).

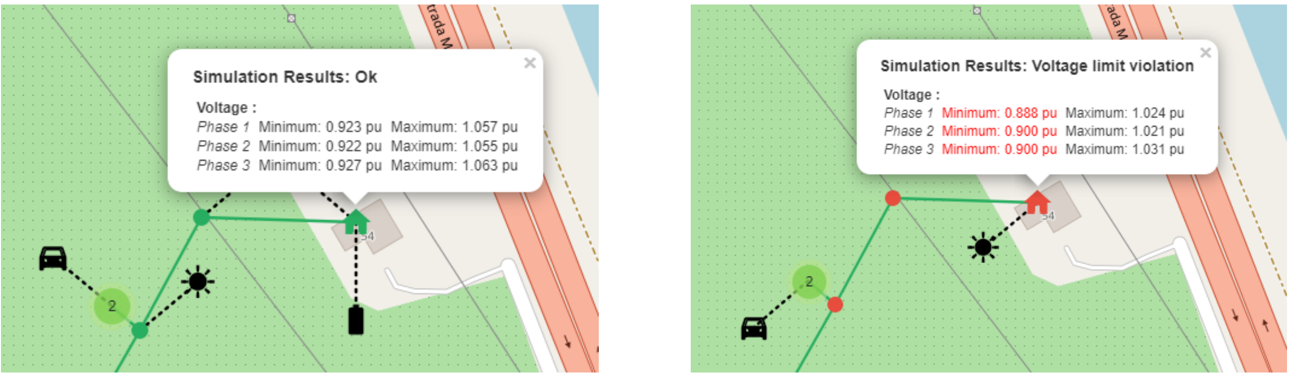

Figure 41. Simulation case 50% PV, 20% EV and 48% ESS penetration by decentralized storage at household level (left) and traditional grid strengthening (right).

Figure 42. Simulation case 70% PV, 20% EV and 48% ESS penetration by decentralized storage at household level (left) and traditional grid strengthening (right).

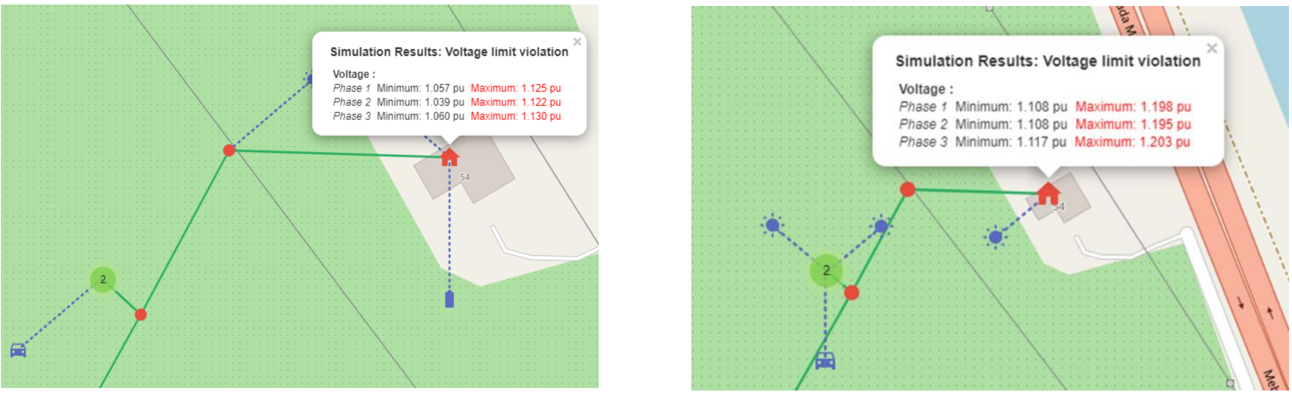

Figure 43. Simulation case 100% PV, 20% EV and 48% ESS penetration by decentralized storage at household level (left) and traditional grid strengthening (right).

Figure 39 to Figure 43 show voltage limit violations. With low PV penetration rates (15% and 30%), the voltage on the PCC of the household is lower than the limit of 0.9 PU. The opposite appears with high PV penetration rates (70% and 100%), the voltage on the PCC of the household is higher than the upper limit of 1.1 PU. The ESS is not able to stabilize the voltage within the default limits. The results with low PV penetration rates are even worse than the traditional grid strengthening. In comparison to that the ESS decreases the voltage peaks at high PV penetration rates. Thus, the ESS alleviates the voltage problems.

Nevertheless, at high PV penetration the power of the ESS is too small to cover the whole voltage issues of the system. Satisfactory results reach the decentralized storage at household model, at a PV penetration rate of 50%, the voltages are in the default limits. If we assume with the right balance between the PV and ESS size the voltage could remain within the limits as shown in Figure 41, than we are able to compare it economically with the traditional grid strengthening model. Table 20 shows the economical difference between the two models which is about 7000 EUR in 20 years. The average yearly difference is about 350 EUR. This would have to be the lowest payment for the provision of ancillary services to be profitable for the household. The DSO would have to pay about 1 EUR each day to the prosumer.

For the prosumer point of view the combination of higher self-consumption rate and providing ancillary services to the DSO with the help of an ESS could be economically reasonable. In order to be useful for the DSO the resulting costs must be taken into account and the right balance between PV and ESS penetration is not only for the economic point of view but also regarding the voltage stabilization an important relation.

3.2.4 HLUC-2-PUC-2

3.2.4.1 Description

HLUC-2-PUC-2: "Cooperative charging in the parking lot of a commercial test site" demonstrates the possibility to increase the self-consumption and to decrease power consumption from the grid. The goal of this HLUC is that the grid is not stressed in terms of voltage band violation (basic power quality is kept) due to storage and EV charging coordination.

3.2.4.2 Evaluation procedure

HLUC-2-PUC-2 was evaluated with the monitoring of the total energy consumed from the grid. The three phases voltages were monitored for 3 months and it must be

- V_{PCC} = 230 V ± 10% (EN 50160 standard)

In the same form as with the Bolzano Residential test site, power data stored in the DSF-DWH of S4G was queried and used for the evaluation. During the evaluation, data from Load, PV, ESS, Grid and EV was used. Furthermore, these data was resample to a 10-minute timestep, in order to eliminate outsider points and to keep mean power peaks in this frequency. With this step, we filtered noise from the data and assured the evaluation of peaks that lasted at least the 10-min frequency. Missing data points for a period of time longer than 10 minutes were replaced by 0.

Additionally, we simulated the working of the system without ESS and with Fronius system in order to make a comparison of the different system responses. The Fronius system simulation consisted in charging the ESS just when the PV production exceeded Load consumption and discharging it when the Load consumption exceeded the PV production. We set a limit of 20% SoC as the minimal value for ESS during the simulation, so the results can be compared with the one using PROFEV in S4G, where the minimal ESS SoC 20% is. Finally, the analysis is presented in two parts: the first one from the February 6th until February 25th, 2020; and the second one from the February 26th until end of March 2020. The division corresponds to the dates when the ESS started working in Bolzano Commercial test site until the definition of Load was changed as an input to PROFEV.

In the first period Load (as input for the PROFEV) took into consideration the load of the dummy charging stations plus the load of the Warehouse in Bolzano Commercial test site. Dummy charging stations are the ones that cannot be controlled by another component. However, Warehouse Load was too high for the ESS used. For this reason, the new Load took into consideration just the load of the dummy charging stations in Bolzano Commercial test site. The sense of the tests of controlling the cooperative charging of EVs in the parking lot was still achieved.

The interaction with the DSF-DWH was conducted through the S4G-OpenVpn Tunnel including certificates, in order to keep security of the data. After the evaluation, all data was erased from the local computer.

3.2.4.3 Evaluation results

The optimization objective chosen for this test site is the minimization of the power exchange with the grid including GESSCon, exactly as in the Bolzano Residential test site. It means that PROFEV will try to find the optimal setpoint at each timestep that reduces the import of power from the grid as well as the export of power to the grid analysing the next 24-hours of the input variables. However, the setpoints for the next 24-hours sent by GESSCon influence the output of PROFEV. GESSCon has as objective the minimization of the energy costs in the grid, which differs from the PROFEV optimization objective. For this reason, PROFEV calculates a multi-objective stochastic optimization algorithm giving a higher weight to the local PROFEV objective. In this way, both objectives are mixed and the corresponding optimal setpoint is calculated.

Because PROFEV is running a stochastic optimization algorithm inside, PROFEV takes into consideration future events related to the system in form of predictions too (D4.7 [S4G-D4.7]). These predictions are related to the load consumption and PV generation in the test site. Furthermore, uncertainties about the number of EVs plugged at the same time to the charging stations are also included in the algorithm, in order to optimize the charging of the EVs. Because of some problems with the Siemens Cloud Service that provides access through an API to control the charging station in the test site, the charging stations could be controlled since March 14^{th}, 2020. For a better understanding of the data, Figure 44 presents one day-data.

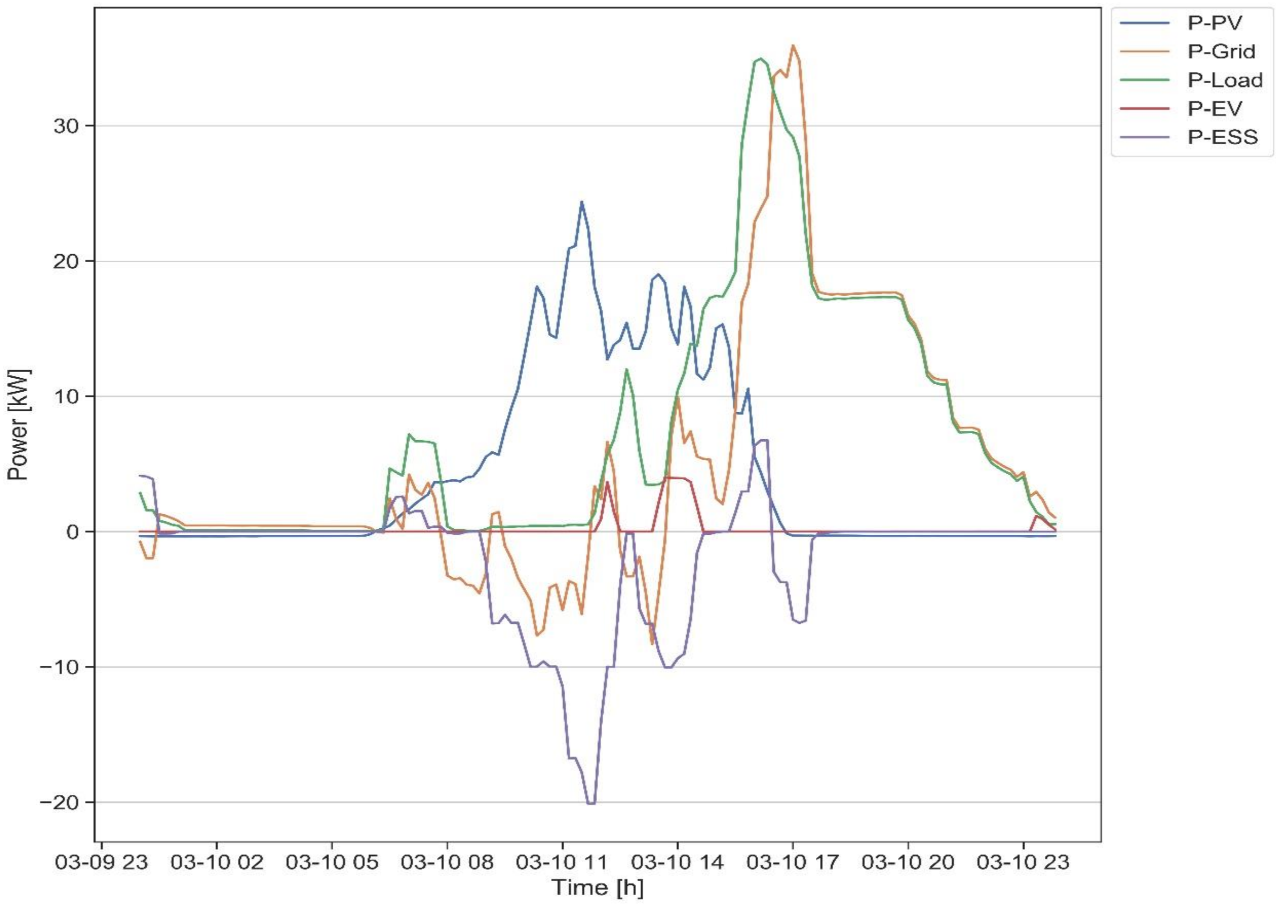

Figure 44. Bolzano Commercial test site: One-day data.

In the one-day data, it is depicted how the PROFEV realizes the control of the ESS. Positive values of P_ESS (purple colour) show the discharging of the ESS, whereas negative values show the charging of the ESS. In this way, the ESS tries to charge when the PV is generating power, while at the same time it tries to cut the generation peak offered by the PV. In the other hours when there is no PV generation, the ESS discharges on the load. The difference with the Load of the Bolzano Residential test site is seen at early hours of the day, when it is low. Because PROFEV works with mathematical optimization and because the inputs variables are changing continuously, outputs of PROFEV can vary depending on the day. Moreover, PROFEV does not run a real-time control but a discrete one, which in this test site was set to a 30-minute frequency. The frequency was chosen based on the computing power needed to calculate each timestep that in a Debian-9 server with 12 Intel(R) Xeon(R) Platinum 8268 CPU @ 2.90GHz is 21 minutes.

Figure 45 presents data from February 6^{th} until February 25^{th}, 2020. The evaluation is based on this data taken from the DSF-DWH. In this figure, one can observe the completeness of the data and have an idea about the behaviour of each electrical variable of the system. Figure 46 shows data from February 26th until March 31st, 2020.

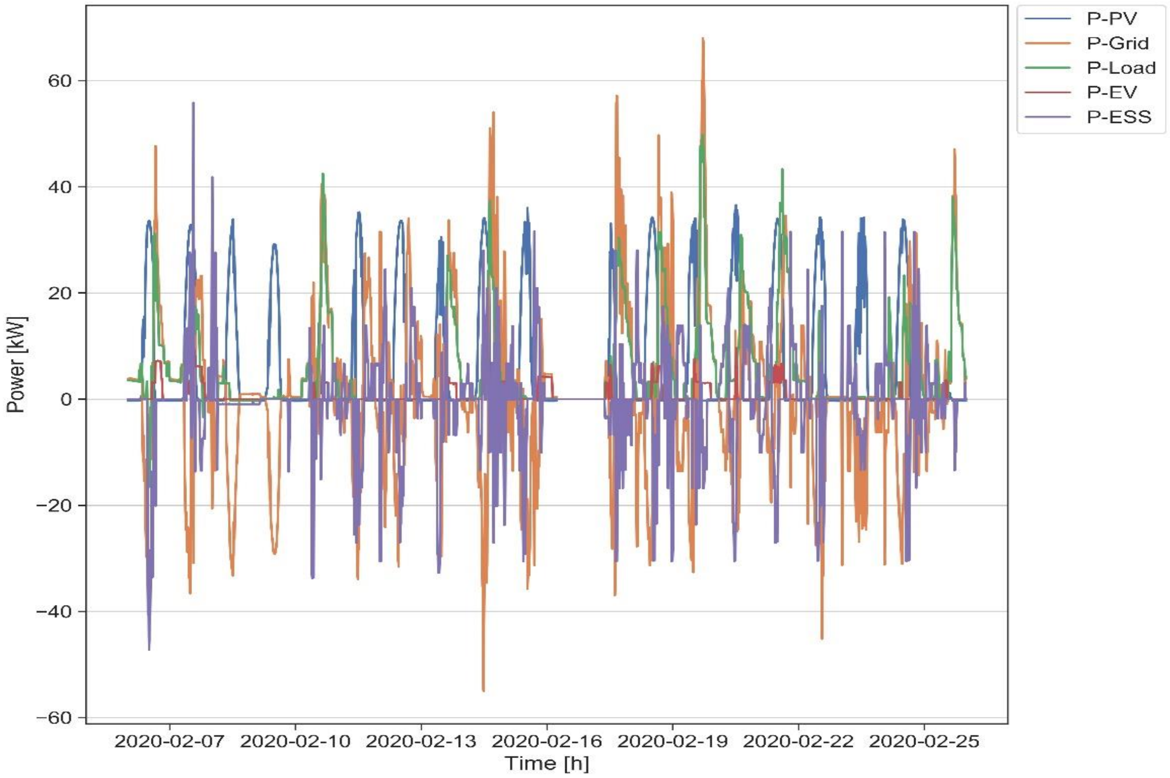

Figure 45. Bolzano Commercial test site: February 2020 data.

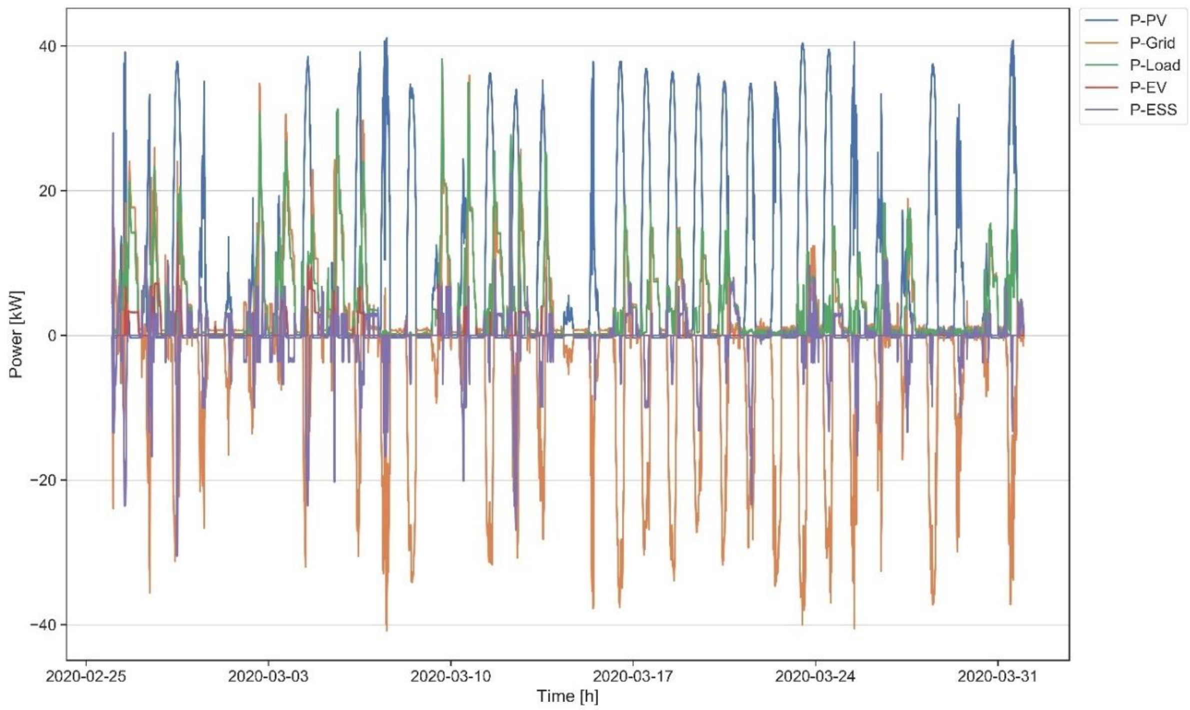

Figure 46. Bolzano Commercial test site: March 2020 data.

In the same way as in the Bolzano Residential test site, the correct working of PROFEV was evaluated intrinsically by receiving the different setpoints every 30-min. Additionally, the results of one optimization step were collected and verified that they make sense for given inputs. In this sense, the MQTT-based communication, internal predictions and dynamic programming way of solving the optimization problem were successfully tested. Furthermore, PROFEV works together with GESSCon, which sets the control setpoints of the ESS in this test site. The setpoints sent by PROFEV are successfully translated into power changes of the ESS.
For the analysis some performance indicators were calculated and summarized in Table 21 and Table 22.

The KPI of V_{PCC} = 230 V ± 10% was achieved successfully using PROFEV because the minimum and maximum voltages measured in the PCC are within the defined limits, as presented in Figure 47. Furthermore, it is interesting to compare the behaviour of the stochastic optimization model in PROFEV with the cases when there is no ESS present or when the ESS is being controlled by the Fronius system. Similarly, to the Bolzano Residential test site, the comparison between the three control mechanisms shows that PROFEV allowed a local higher use of PV generation during the time of analysis. In the same way, we attribute it to the way of working of the optimization model, which tries not to get immediately the PV generation present but rather distributes the charging of the ESS during the whole PV generation. Because of this fact, the mean peak exported power to the grid also reduces using PROFEV in comparison to Fronius simulation. Due to the 30 min control frequency of PROFEV, the peak exported power outsiders found in the data are also higher than with the Fronius simulation, as in the Bolzano Residential test site. Nevertheless, these outsiders have a maximal duration of 10 min. Important to notice is that the optimization algorithm in PROFEV can also load the ESS from the grid if it considers necessary. For that reason, the energy imported from the grid is higher with PROFEV.

Moreover, in March the control setting inside PROFEV that does not allow to export energy from the ESS to the grid and real-time condition analysis were also added. Nevertheless, the grid export remained 127.24 W higher than with the Fronius simulation.

In conclusion, PROFEV could manage the energy flow in the Bolzano Commercial test site a stochastic optimization algorithm solved using dynamic programming. The results show an increase in the local use of PV energy while the mean peak of power exported to the grid is reduced. Because of some problems with Siemens service for the control of charging stations, the charging station at the Bolzano Commercial test site could just be controlled since March 17th, 2020. This issue increases the peak power taken from the grid in the previous days because PROFEV cannot shift the charging of the EVs to another time.

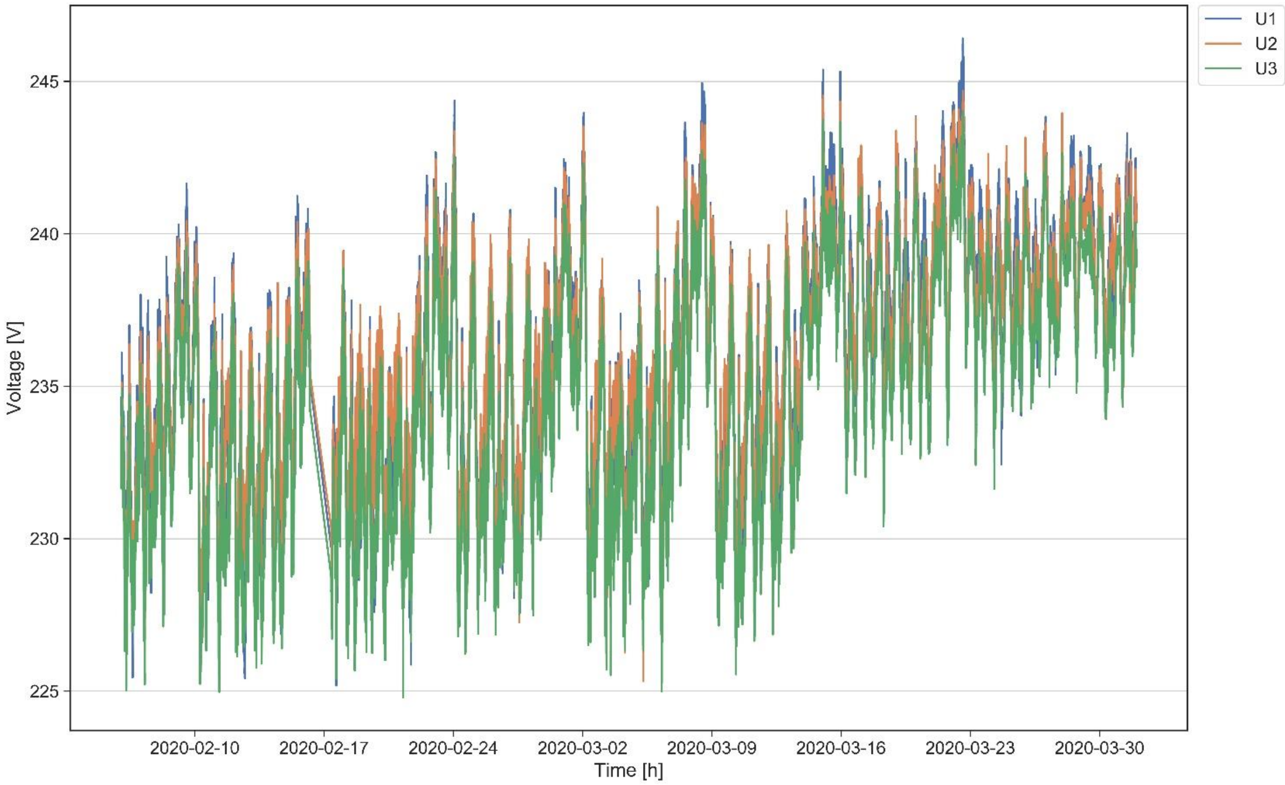

Figure 47. Bolzano Commercial test site: Voltage profile (U_1 [225.2; 246.4] V, U_2 [225.3; 244.7] V, U_3 [224.8; 244.0] V).

Table 21. Bolzano Commercial test site: Performance Indicators for February 2020.

	PROFEV	Without ESS	Fronius Simulation
Total PV generation [kWh]	2941.31	2941.31	2941.31
Total Load [kWh]	2451.03	2451.03	2451.03
Total Grid Export [kWh]	2132.44	2472.39	2052.53
Total Grid Import [kWh]	2785.2	1982.11	1679.23
Grid Import - Grid Export [kWh]	652.76	490.28	373.3
Average of daily maximum power peaks exported to the grid [kW]	28.51 ± 10.59	28.51 ± 10.59	30.41 ± 9.06
Average of daily maximum power peaks imported from the grid [kW]	26.69 ± 18.88	22.93 ± 13.42	20.72 ± 13.11
Maximum peak power exported to the grid [kW]	55.02	55.02	50.2
Maximum peak power imported from the grid [kW]	68.06	49.79	50.09
PV energy absorbed by ESS [kWh]	758.81	-	430.92
PV energy absorbed by ESS [%]	26.80	-	14.65
PV energy absorbed by Load [kWh]	530.51	530.51	530.51

	PROFEV	Without ESS	Fronius Simulation
PV energy absorbed by Load [%]	18.04	18.04	18.04
PV energy used locally [%]	43.83	18.04	32.69
PV peak [kW]	36.58	36.58	36.58
Mean voltage [V]	233.94 ± 3.35		

Table 22. Bolzano Commercial test site: Performance Indicators for March 2020.

	PROFEV	Without ESS	Fronius Simulation
Total PV generation [kWh]	5905.58	5905.58	5905.58
Total Load [kWh]	3453.69	3453.69	3453.69
Total Grid Export [kWh]	4230.42	4867.79	4103.18
Total Grid Import [kWh]	2525.77	2415.9	1864.96
Grid Import - Grid Export [kWh]	-1704.65	-2451.89	-2238.22
Average of daily maximum power peaks exported to the grid [kW]	23.93 ± 13.20	23.93 ± 13.20	28.82 ± 12.01
Average of daily maximum power peaks imported from the grid [kW]	13.20 ± 10.72	14.24 ± 9.09	11 ± 8.74
Maximum peak power exported to the grid [kW]	40.83	40.83	41
Maximum peak power imported from the grid [kW]	35.95	35.51	31.23
PV energy absorbed by ESS [kWh]	697.10	-	788.13
PV energy absorbed by ESS [%]	11.8	-	13.35
PV energy absorbed by Load [kWh]	1037.79	1037.79	1037.79
PV energy absorbed by Load [%]	17.57	17.57	17.57
PV energy used locally [%]	29.38	17.57	30.92
PV peak [kW]	41.11	41.11	41.11
Mean voltage [V]	234.96 ± 3.67		

Figure 48 and Figure 49 show the PV energy locally used in February and March 2020. In the figures, the total PV energy, the PV energy used with PROFEV, and the PV energy used with the Fronius simulation are depicted per day.

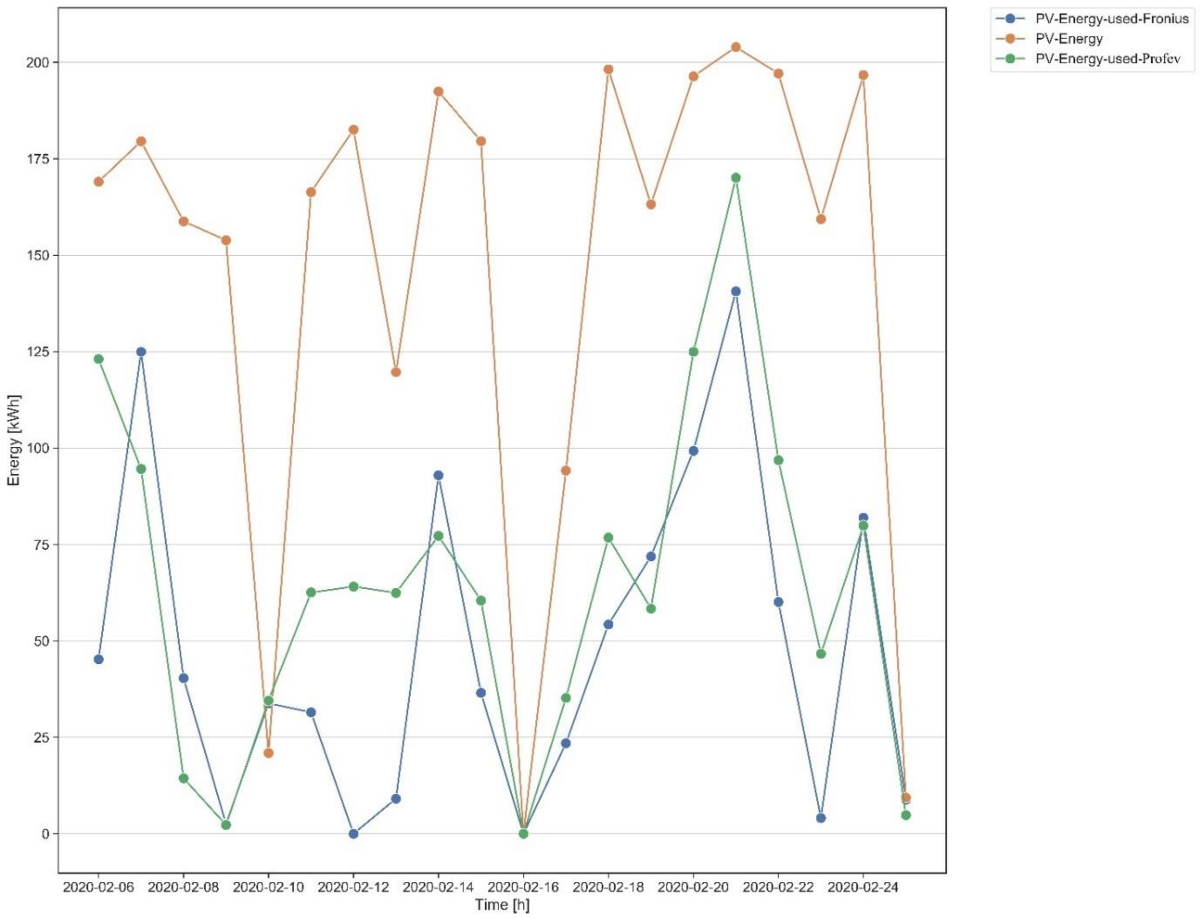

Figure 48. Bolzano Commercial test site: PV energy use in February 2020.

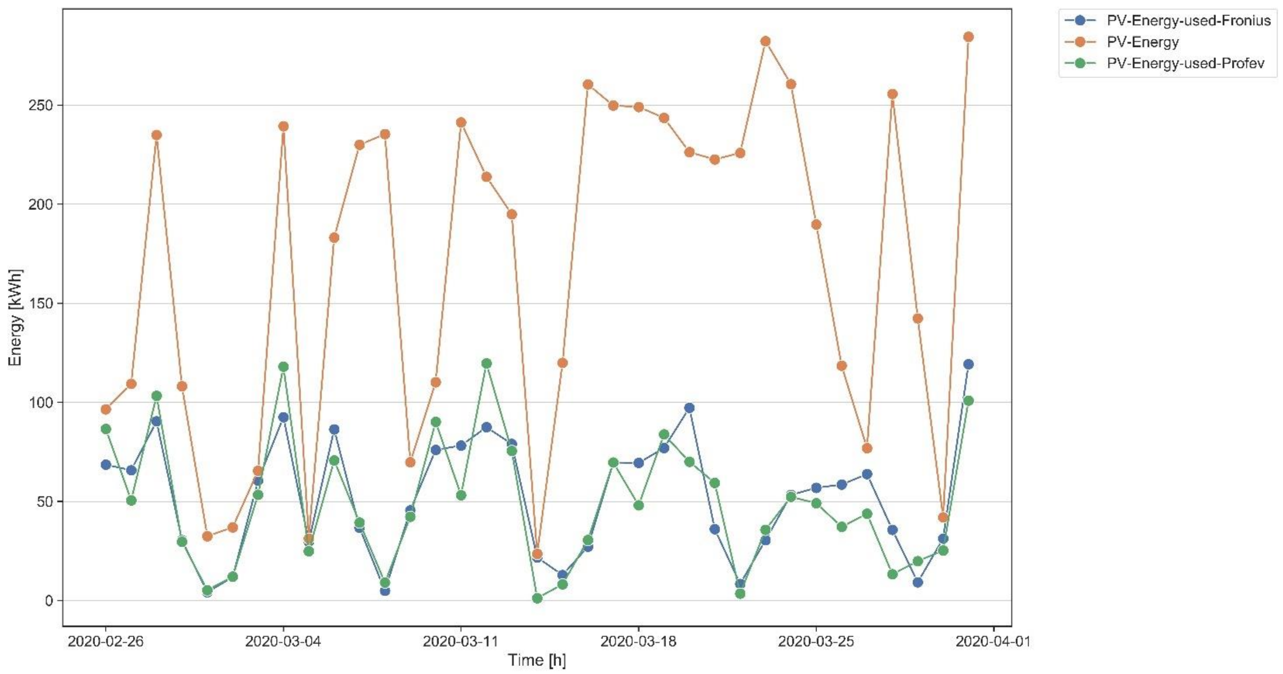

Figure 49. Bolzano Commercial test site: PV energy use in March 2020.

3.2.5 HLUC-2-PUC-2-BM-1

3.2.5.1 Description

HLUC-2-PUC-2-BM-1: "Cooperative Charging at Commercial or Fleet level" evaluates the ROI time, for this purpose the use of storage is compared with the cost of installation of the ESS.

3.2.5.2 Evaluation procedure

HLUC-2-PUC-2-BM-1 was analysed if it is profitable for a commercial site (or a Company Fleet site) with some EV charging stations to invest money in an ESS with or without a PV plant.

- The ROI time should be less than 20 years.
- The Professional GUI SUS should be classified as "good".
- The DSF-SE results should be equal to the OpenDSS results.

3.2.5.3 Evaluation results

HLUC-2-PUC-2-BM-1 was not evaluated directly due to the situation described in section 3.2. Based on the user feedback deduced from other tests, it became clear that the Professional GUI is able to show voltage violations depending on the installation of additional loads and scenarios. Based on those visualizations, grid planners are able to plan the future grid situation based on either storage or PV installations or traditional grid strengthening. The findings are further detailed in section 3.2.6 and section 4.

3.2.6 HLUC-2-PUC-3

3.2.6.1 Description

HLUC-2-PUC-3: "Simulation of high penetration of EV chargers and of prosumers with storage and residential EV charging" calculates the maximum value of EV chargers that can be installed in the Edyna grid without grid strengthening needs and it evaluates the result obtained with or without the use of ESS.

3.2.6.2 Evaluation procedure

HLUC-2-PUC-3 was evaluated by comparing the findings, and a feasibility study was carried out to determine whether the additional storage represents an economic solution for the DSO. The results were given by the Professional GUI together with the DSF-SE, and they were also verified by the OpenDSS software.

Whereas the Professional GUI does in fact support the simulation of storage combined with EV charging stations in the grid, the needed time for executing the computation exceeded the time frame in which the participants of the UX study were available. Therefore, it was decided to test this use-case without specifically installing EV charging stations and just evaluate the internal validity of interacting with the Professional GUI regarding feasibility simulations of storage systems combined with PVs.
However, charging stations for EVs can be either distributed randomly all over the selected radial in the low-voltage grid by entering a percentage for the penetration level of interest (depicted in Figure 50), or placed directly at specific houses as shown in Figure 51. Available charging station sizes were 3 kW and 22 kW. The user could select between residential and commercial charging stations as well as two different EV types (Volkswagen e-Up with a battery capacity of 18.7 kWh and a consumption of 16.8 kWh / 100 km; Renault Zoe with a battery capacity of 44.1 kWh and a consumption of 15.8 kWh / 100 km).
The overall study design as well as further details concerning single tasks and evaluation methods are detailed in section 4.

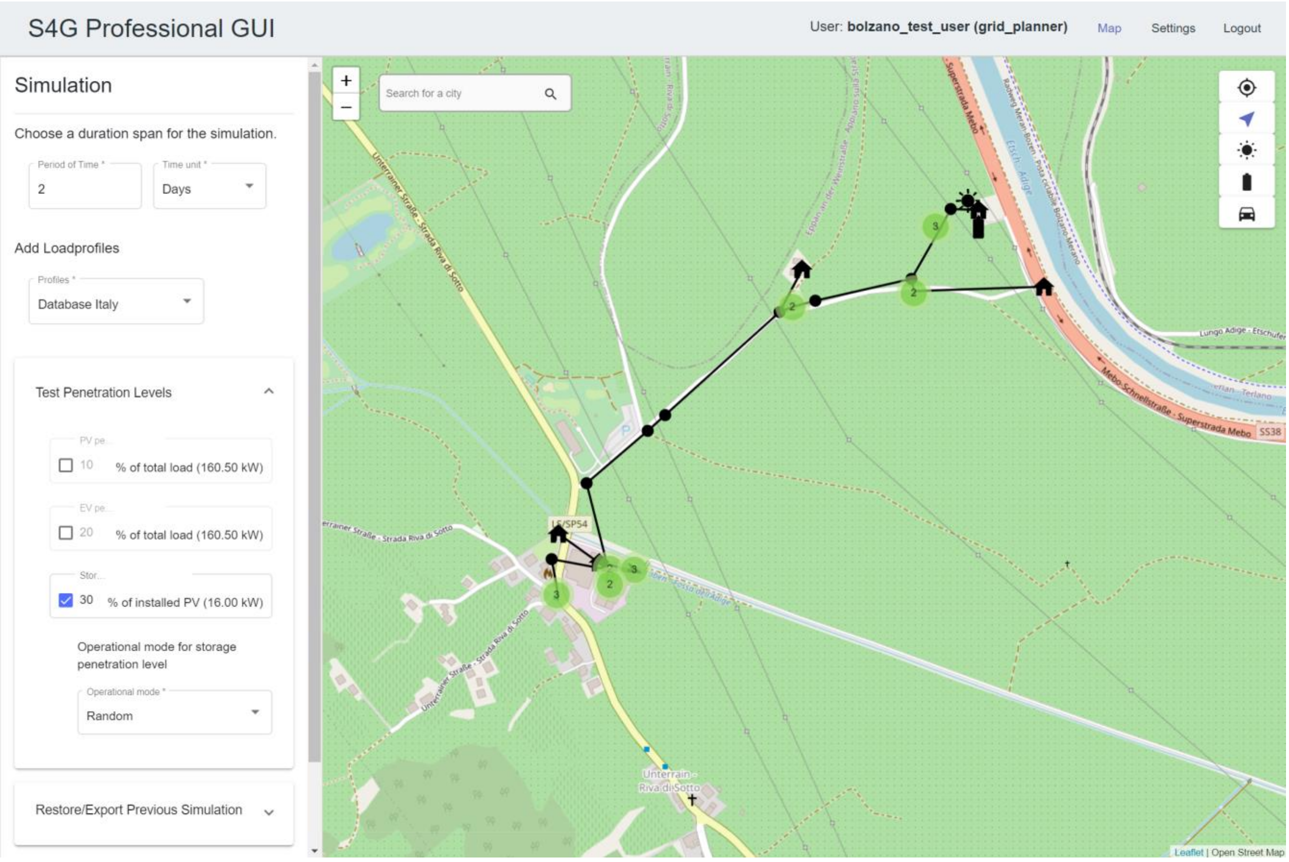

Figure 50. Professional GUI: Dialogue for entering the penetration levels with randomly distributed charging stations.

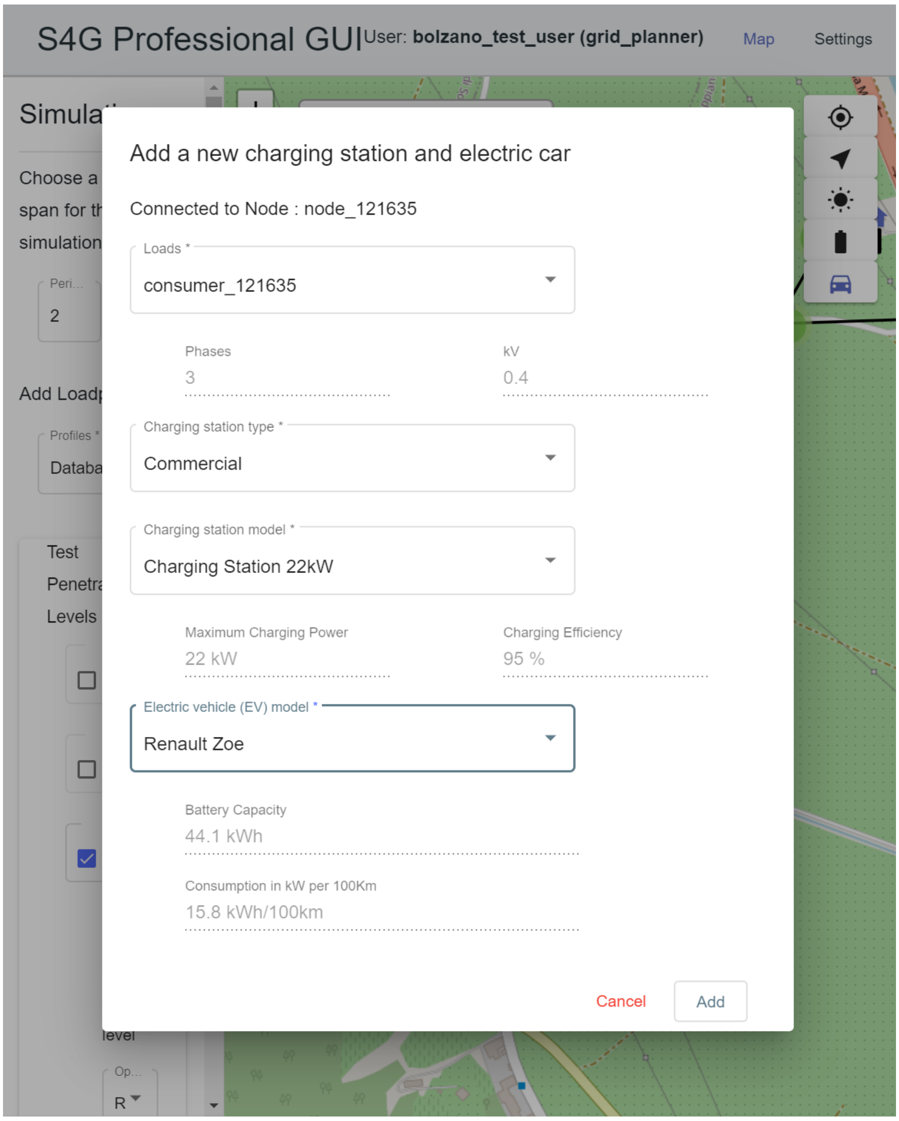

Figure 51. Professional GUI: Dialogue shown to the user if an EV charging station is installed manually at a house.

3.2.6.3 Evaluation results

The evaluation results from the UX perspective are further detailed in section 4 with reference to HLUC-3-PUC-1-BM-1. In general, the available information on the Professional GUI concerning was rated as feasible and users did not have major problems in understanding how the elements need to be installed in the grid. Simulation results highlighted problems in the grid topology concerning voltage levels by colouring respective areas in red. Negative comments addressed mainly the necessary tool selection before elements can be installed, as well as the fact that simulation results were no longer displayed if the user switched from grid inspection to grid manipulation mode.

Additionally, the available information from the economic model integration was criticised by the Professional GUI users (that have a technical profile) as not being helpful or detailed enough. This could be due to the fact that the Professional GUI user employed for the Professional GUI evaluation (technical grid planner) is not working with data concerning economic feasibility. Therefore, it was difficult for them to understand the meaning of the displayed numbers and the relation of their grid manipulation actions concerning the displayed results. The real added value of the DSF-EE is, in fact, to help decision makers (i.e., grid planning managers responsible for investments) to evaluate the profitability of installing ESS in the grid considering different grid configurations (ESS at prosumer or at grid level). Therefore, the right person to evaluate such holistic tool, should have a wider vision over issues, more than what concerns an electrical technician. D7.8 [S4G-D7.8] proposes an example of how DSF-EE results can be used by a decision maker.

3.3 Phase 3 evaluation summary

The phase 3 evaluation conducted in Bolzano Residential and Commercial test sites have shown positive results. In the Residential test site, PROFEV allowed a better use of the resources, with a minor consumption of power for the household. However, sometimes the results were opposite to those desired. With some minor improvements, PROFEV behaviour will be further improved. Unfortunately, due to the characteristics of the installed storage system, it was not able to solve the voltage issues of that test site. The Residential GUI was very appreciated by the user, due to its interface and usage simplicity. All production and consumption data of the house are well represented and easy to interpret.

The HLUC-2-PUC-1-BM-1 evaluation shown that, actually, in Italy there is no convenience for a costumer to buy a storage system. Only with subsidies, or a change of the rules for the storage connection, people could be interested in using storage systems. Regarding HLUC-2-PUC-1-BM-2 the results achieved with the DSF-EE showed that there is not an economic advantage in using the private storage to solve grid congestion, instead of the traditional strengthening. Even in the technical results, the storage use does not always help to keep the voltage within the standard limit. Nevertheless, the problem of the voltage limit violation in the LV and MV, due to the high RES penetration and the use of the storage remains. In the future, DSOs could benefit with other costs and connection rules.

The results in the Commercial test site were similar to the ones in the Residential test site. PROFEV helped to reduce the power exchange with the grid, and the optimized use of the storage allowed to limit the power peaks when many EVs were being charged at the same. In this case, there was also an appreciable improvement of the voltage values. The Professional GUI turned out to be a good product ease to use and with a pleasant appearance. However, it needs further developments to be a good tool for DSO technicians. For example, it does not show all the wanted results, the grid modifications and the addable items are limited, and the calculation time is too high. The real added value of this tool it the possibility to have an economic result at the end of the simulation.

4 Fur/Skive Test Site: Storage Coordination Scenario

This scenario features a residential test site (Fur), a grid-side ESS (Skive), and the deployment of the three-phase ER at ENIIG premises (Skive). The residential case is composed by 5 houses fitted with PV panels, ESS and its respective inverter. The grid case is one grid-side ESS installed behind the meter in the sports arena. The detailed test site description and the phase 3 deployment diagram are available in D6.3 [S4G-D6.3].

In order to evaluate the test site deployment from the user perspective, a remote usability and UX study involving 7 professional users (grid planners, 4 from Bolzano, 3 from Fur) was conducted in the end of M36. The focus lied on evaluating the Professional GUI regarding the interaction concepts, the feasibility of the displayed data as well as the system's complexity. The time frame for the remote study was 45 minutes per participant. GDPR-conform consent forms were signet before the study took place. The tests were conducted individually and hosted by FIT.

Using the conference software go2meeting, the study host's screen was shared. The Professional GUI as well as supporting study material and questionnaires were streamed from the host's laptop. The test sessions were recorded using screen capturing and sound recording from the go2meeting tool.
During the test, the Professional GUI as well as the questionnaires were operated by the test user who had access to the host's keyboard and mouse. During the study, the test users were always asked to verbalize their thoughts and actions, state issues and problems as well as explain their intentions.
The overall user satisfaction was measured using the standardized questionnaire SUS, which was digitized and presented using lime survey. The overall study was conducted as follows:

1. Introduction to the purpose of this study, including familiarization with the go2meeting tool and the remote-control functionality of the host's mouse and keyboard.
2. Introduction to the setting and the test user's role; answering questions concerning the study.
3. First task:
   a. Presentation of the task description: The user was asked to login to the Professional GUI using the provided credentials.
   b. Execution of the task on the Professional GUI until the Definition of Done (DOD) was reached: The user logged in successfully.
   c. Discussion of the way the task was solved.
4. Second task:
   a. Presentation of the task description: The user was asked to run a baseline simulation for the current grid topology (Fur) over the duration of 5 days.
   b. Execution of the task on the Professional GUI until the (DOD) was reached: Simulation was executed successfully; the results were displayed.
   c. Discussion of the way the task was solved.
5. Third task:
   a. Presentation of the task description: The user was asked to analyse the current simulation result with a focus on available and missing information.
   b. Execution of the task on the Professional GUI until the DOD was reached: The user gained an overview on the current grid situation.
   c. Discussion of the way the task was solved.
6. Fourth task:
   a. Presentation of the task description: The user was asked to access the "test penetration panel" and run a simulation for the penetration of PVs of 120% penetration of total load; the simulation duration was asked to be set to 2 days (mainly due to time constraint reasons): The user was then asked to interpret the results.
   b. Execution of the task on the Professional GUI until the DOD was reached: The user tested the penetration levels (and was able to interpret displayed voltage violations).
   c. Discussion of the way the task was solved.

7. Fifth Task:
    a. Presentation of the task description: The user was asked to solve the occurring voltage issues by installing batteries (model Battery 9.0) in the grid. The storage operational mode should be set to "maximize self-consumption" or "support of voltage regulation".
    b. Execution of the task on the Professional GUI until the DOD was reached: The user managed to install batteries in the grid and solve the voltage issues.
    c. Discussion of the way the task was solved.
8. Sixth Task:
    a. Presentation of the task description: The user was asked to interpret the results of the economic model for the last conducted simulation.
    b. Execution of the task on the Professional GUI until the DOD was reached: The user was informed about the economic results of the last simulation.
    c. Discussion of the way the task was solved.
9. Answering the demographic questionnaire and the SUS questionnaire (lime survey).

The overall rating of the Professional GUI using the SUS resulted in a score of 63.93, which can be interpreted as still being acceptable with room for improvement[i]. The global mean is 68. Systems that score higher than 70 deliver in general good to excellent UX. The major problems identified in the tests will be described in detail in the respective use-cases. Table 23 summarises the HLUC-1 evaluation KPIs defined in D6.3 [S4G-D6.3].

Table 23. HLUC-3: Phase 3 KPIs.

Use-case	KPIs
HLUC-3-PUC-1: *Support for analysing storage dimensioning and positioning in the low-voltage grid*	Calculation of the traditional grid strengthening cost. Moreover, the Professional GUI System Usability Scale (SUS) should be classified as "good".
HLUC-3-PUC-1-BM-1: *Baseline*	Calculation of the traditional grid strengthening cost.
HLUC-3-PUC-2: *Autonomous control of storage installed at user premises and distributed in the grid*	The RMS voltage in the PCC during household ESS (dis)charging must be *V_{PCC} = 230 V ± 10% (EN 50160 standard)*.
HLUC-3-PUC-2-BM-1: *"Autonomous" voltage control at household battery*	CapEx and OpEx evaluation, and comparison with HLUC-3-PUC-1-BM-1 (baseline) to verify if the ESS household installation can be a better economical solution for the DSO.
HLUC-3-PUC-3: *Voltage and flux control at grid side storage*	The simulation results of the RMS voltage in the PCC during grid ESS (dis)charging must be *V_{PCC} = 230 V ± 10% (EN 50160 standard)*.
HLUC-3-PUC-3-BM-1: *Voltage control at grid side battery*	CapEx and OpEx evaluation, and comparison with HLUC-3-PUC-1-BM-1 (baseline) to verify if the ESS installation can be a better economical solution for the DSO.
HLUC-3-PUC-4: *Coordinated Distributed storage in the grid*	The simulation results of an ESS global control approach will be used for the analysis of grid constraints comparing with a grid without ESS (and the voltage levels must also comply with the EN 50160 standard).

Use-case	KPIs
	Moreover, the Professional GUI SUS should be classified as "good".
HLUC-3-PUC-4-BM-2: *Voltage control at both household and grid side battery and Energy Flux control at grid side battery*	CapEx and OpEx evaluation, and comparison with HLUC-3-PUC-1-BM-1 (baseline) to verify if the ESS household installation can be a better economical solution for the DSO.
HLUC-3-PUC-4-BM-3: *Flux control and load shaving at households with PV and battery*	CapEx and OpEx evaluation, and comparison with HLUC-3-PUC-1-BM-1 (baseline) to verify if the ESS household installation can be a better economical solution for the DSO.

4.1 Phase 3 deployments evaluation results

According to D6.6 [S4G-D6.6], the Fur/Skive phase 3 prototypes deployed were:

- D4.3 [S4G-D4.3].
- D4.5 [S4G-D4.5].
- D4.10 [S4G-D4.10].
- D5.2 [S4G-D5.2].
- D5.5 [S4G-D5.5].
- D5.7 [S4G-D5.7].
- D6.9 [S4G-D6.9].

4.2 Phase 3 KPIs evaluation

The evaluation approach is similar with the one for used in Bolzano test site, described in section 3.2.

4.2.1 HLUC-3-PUC-1

4.2.1.1 Description

HLUC-3-PUC-1: "Support for analysing storage dimensioning and positioning in the low-voltage grid" is the baseline for the other business cases, to make it possible to compare cost of installation and operation TCO of storage with traditional grid strengthening. The results of this comparison decide if storage is a feasible solution to solve voltage issues in the selected topology.

4.2.1.2 Evaluation procedure

The evaluation of this HLUC consists of the calculation of the traditional grid strengthening cost (Task 2 ,3, 5 & 6). The results of this comparison will help to decide if storage is a feasible solution to solve voltage issues in the selected topology. Moreover, the Professional GUI System SUS should be classified as "good".

4.2.1.3 Evaluation results

Regarding the execution of a simulation, it could be observed that - in contrast to the first evaluation of the Professional GUI - the users had no problems in entering the key data of the simulation (period of time, time unit). However, the selection of a radial poses a problem for the users. Either they did not see the message "please select a radial on the map", or they did not know what and how to select. Some of them tried to select the radial by clicking on the map, but could not do so because they were in the "explore" mode and not in the "select" mode. In general, it turned out that the mode change was cumbersome, because they have to switch between the different modes quite often. Furthermore, it turned out to be inconvenient that the simulation results disappear as soon as the mode is changed.

The simulation results, which are reflected in the colour of the grid, were self-explanatory for all users. The installation of batteries and PVs also proved to be unproblematic. Only accessing the information of the inserted elements was critically noted by some users, as this is not possible in "explore" or "select" mode. Restoring simulation results was also criticized by some users. The naming consisting of the simulation ID and the time was considered as not appropriate for the task. It was noted that more information about the simulation would be helpful for recognition.

As already mentioned in section 3.2.6.3, the available information from the economic model integration was evaluated as not being helpful or detailed enough for the technical end-user employed for the Professional GUI evaluation. Some users noted that they could not gain any added value from the economic data because they had no experience. Nowadays, Professional GUI users are not working with data concerning economic feasibility. Therefore, it was difficult for them to understand the meaning of the displayed numbers and the relation of their grid manipulation actions concerning the displayed results. The real added value of the DSF-EE, in fact, is to help decision makers (i.e., grid planning managers responsible for investments) to evaluate the profitability of installing ESS in the grid considering different grid configurations (ESS at prosumer or at grid level). Therefore, the right person to evaluate such holistic tool, should have a wider vision over issues, more than what concerns an electrical technician. In this regard, D7.8 [S4G-D7.8] proposes an example of how DSF-EE results can be used by a decision maker. Some noted that this will change once they start working with the values more often.

4.2.2 HLUC-3-PUC-1-BM-1

4.2.2.1 Description

HLUC-3-PUC-1 describes "Support for analysing storage dimensioning and positioning in the low-voltage grid". Private house owners have invested in local PV production, this causes increasing voltage in local feeder lines. Which also can cause capacity issues, due to higher production compared to local consumption, this means export of electricity through the transformer representing additional grid loss.
The business model HLUC-3-PUC-1-BM-1 is the baseline for the other business cases, which makes it possible to compare TCO, of installation and operation of storage with traditional grid strengthening. The results of this comparison will decide if storage is a feasible solution to solve voltage issues in the selected topology.

4.2.2.2 Evaluation procedure

HLUC-3-PUC-1-BM-1 was evaluated by collecting the measurement values from the USMs (Grid and PV) and with this an analysis was performed to carry out the baseline. The operational mode was set to maximize self-consumption, which is an ordinary and autonomous way of controlling residential PV systems. The chosen duration was 5 days.

4.2.2.3 Evaluation results

Figure 52 shows the results from the Professional GUI, and the traditional grid strengthening with more PV systems is shown in Table 24. The PV penetration level is a percentage of maximum expected kWp installed, which in this case is set to 102 kWp.

Table 24. HLUC-3-PUC-1-BM-1: Baseline results.

PV penetration level [%]	PV power [kWp]	PV power /consumer [kWp]	Problem	TCO DSO [EUR]
20	20.4	1.02	None	33,160
40	40.8	2.04	None	36,969
60	61.2	3.06	None	39,706
80	81.6	4.08	None	39,797
100	102	5.10	ΔU	39,812
120	122.4	6.12	ΔU	33,380
140	142.8	7.14	ΔU	32,147

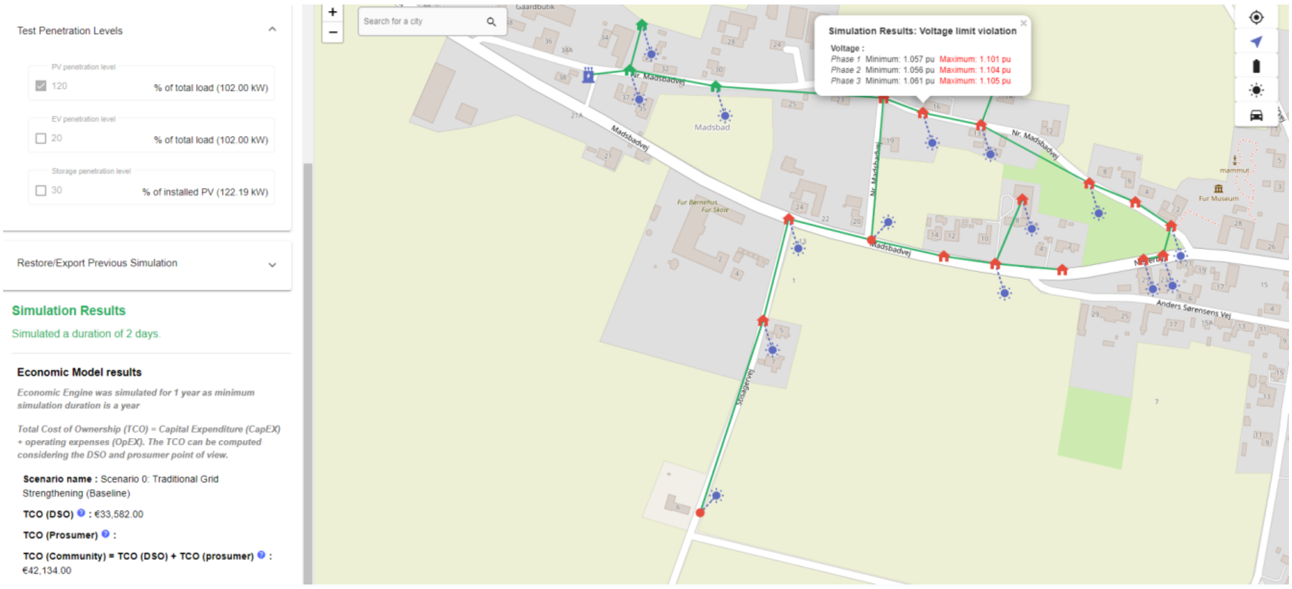

Figure 52. Professional GUI: Snapshot.

The Professional GUI reports voltage issues when the installation of PV systems increases to around 80-100% of all houses, which means that each house has a PV system of 5.1 kWp, which is 64% of the kVA for the transformer (150 kVA). The DSO's TCO includes grid loss and grid strengthening over a period of 20 years.

4.2.3 HLUC-3-PUC-2

4.2.3.1 Description

HLUC-3-PUC-2 describes "Autonomous control of storage installed at user premises and distributed in the grid". This use-case involves private households 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 (legislations has since been changed, so it is now mandatory to report new storage installation to the DSO). The BMS for these storages are autonomous and run independent of the grid (usually the operational mode it set to maximize self-consumption). The DSO cannot remotely access the different storage systems.

4.2.3.2 Evaluation procedure

The KPI defined in D6.3 [S4G-D6.3] says that the RMS voltage in the PCC during household ESS (dis)charging must be $V_{PCC} = 230\ V \pm 10\%$, during 95% of the evaluation time.

For the evaluation of the Fur/Skive test site, it was used the same evaluation procedure as explained in the Bolzano test site (described in section 3.2.1.2).

Finally, the analysis is divided into the three optimization objectives used in the houses and for a period of three months: from January to March 2020. The three optimization objectives are:

- Minimization of the power exchange with the grid
- Maximization of the self-consumption
- Minimization of the local energy costs

The interaction with the DSF-DWH was conducted through the S4G-OpenVpn Tunnel including certificates, in order to keep security of the data. After the evaluation, all data was erased from the local computer.

4.2.3.3 Evaluation results

In the same way as in the Bolzano test site, the correct working of PROFESS was evaluated intrinsically by receiving the different setpoints every 5-min. Additionally, the results of one optimization step were collected and verified that they make sense for given inputs. In this sense, the MQTT-based communication, internal predictions and algorithm itself of the optimization problem were successfully tested. Furthermore, PROFESS works together with the Price Connector, which sends the price signal predictions in this test site. The setpoints sent by PROFESS were successfully translated into power changes of the ESS and the price signals were correctly received. Important to notice is the fact that PROFESS is running in a RPi 3 platform, which does not have a high computational power. It means that continuous predictions and optimization calculations are possible in a low-cost architecture.

4.2.3.3.1 Minimization of the power exchange with the grid

In three of the Fur houses, the chosen optimization objective is the minimization of the power exchange with the grid. The houses where this optimization objective is running are House_20, House_25 and House_26. However, House_25 has a linearization of the quadratic linear programming problem, in order to facilitate its calculation. The idea with this optimization objective is that PROFESS tries to find the optimal setpoint at each timestep that reduces the import of power from the grid as well as the export of power to the grid analysing the next 24-hours of the input variables. Input variables are load consumption prediction, PV generation prediction as well as factors describing the electrical system. For this reason, it is supposed intrinsically that the optimization will try to use the maximal amount of PV generation locally minimizing the amount of energy exported and imported from the grid.
For the analysis some performance indicators were calculated and summarized in Table 25, Table 26, and Table 27. The analysis was done using the procedure explained in the Bolzano test (described in section 3.2.1.2). In that case, the average values are calculated from the whole analysed information. As an example, the "Average of daily maximum power peaks exported to the grid" is calculated finding all the daily power peaks exported to the grid from the whole data and calculating its average.

The KPI of $V_{PCC} = 230\ V \pm 10\%$ was achieved successfully using PROFESS because the minimum and maximum voltages measured in the PCC are within the defined limits, as shown in Figure 53, Figure 54, and Figure 55, and presented in Table 25, Table 26, and Table 27. Furthermore, it is interesting to compare the behaviour of PROFESS with the cases when there is no ESS present or when the ESS is being controlled by the Fronius system. Contrary to what was found in Bolzano test site, the PV use in the three houses with PROFESS was smaller than the use of PV with the Fronius simulation. However, PV use was much higher than when there is no ESS present in the system. Analysing this result, we can conclude that a control like the one in the Fronius system works better when the amount of PV generation in the system is small. In fact, the Fronius reacts almost in real-time to any change in the PV generation and because the amount of energy is too small, the ESS can absorb all the remaining energy.

PROFESS calculates the setpoint every 5 minutes and depends on the reliability of the predictions. Because no prediction is 100% accurate and the 5-min control frequency, PROFESS does not react that fast. For this reason, the differences in the PV use are small in terms of energy. Besides, PROFESS charges and discharges the ESS even though there is no PV generation present. That is a big difference with the Fronius simulation, where the ESS is only charged if there is surplus of PV energy. It causes that the import energy from the grid increases, while the discharge is distributed all over the time. Nevertheless, the mean maximum and minimum peaks are always under 6kW that is permitted in the contract.

One hypothesis that remain and will be further analysed is that with the linearized objective function, the PV use increased compared with the two other houses. One explanation could be the capabilities of the open source solver ipopt working in the raspberries. Because it is not possible to use Gurobi in the RPi platform at the moment, we included the Ipopt solver for solving the quadratic linear programming problem. Because the linearization simplifies the problem, it is possible to think that Ipopt finds the best optimal points with this kind of problems.

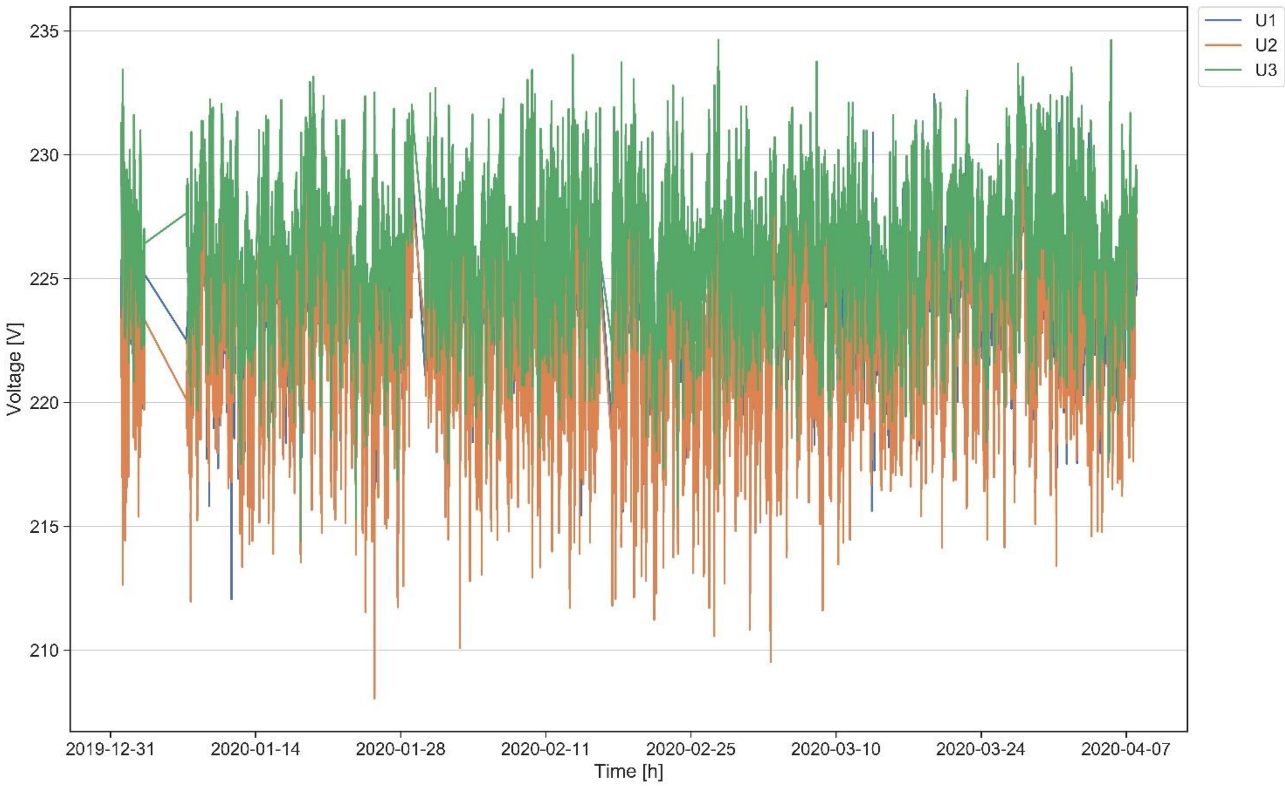

Figure 53. Fur House_20: Voltage profile.

Table 25. Fur House_20: Performance Indicators.

	PROFESS	Without ESS	Fronius Simulation
Total PV generation [kWh]	147.09	147.09	147.09
Total Load [kWh]	1005.29	1005.29	1005.29
Total Grid Export [kWh]	10.7	30.44	0.09
Total Grid Import [kWh]	943.17	888.77	858.23
Grid Import - Grid Export [kWh]	932.47	858.33	858.14
Average of daily maximum power peaks exported to the grid [kW]	0.66 ± 0.29	0.66 ± 0.29	0.37 ± 0.1
Average of daily maximum power peaks imported from the grid [kW]	3.22 ± 1.6	3.13 ± 1.5	3.09 ± 1.53
Maximum peak of power exported to the grid [kW]	1.26	1.26	0.37
Maximum peak of power imported from the grid [kW]	7.63	7.1	7.1
PV energy absorbed by ESS [kWh]	21.89	-	30.35
PV energy absorbed by ESS [%]	14.9	-	20.65
PV energy absorbed by Load [kWh]	116.52	116.52	116.52
PV energy absorbed by Load [%]	79.29	79.29	79.29
PV energy used locally [%]	94.18	79.29	99.94
PV peak [kW]	3.13	3.13	3.13
Price from Import [EUR]	406.96	385.98	372.77
Price from Export [EUR]	4.05	10.81	0.03
Total Price [EUR]	402.92	375.17	372.74
Mean Voltage [V]	224.3 ± 2.23		
Minimum Voltage [V]	U_1 = 212.1 U_2 = 208.0 U_3 = 214.4		
Maximum Voltage [V]	U_1 = 233.8 U_2 = 230.6 U_3 = 234.7		

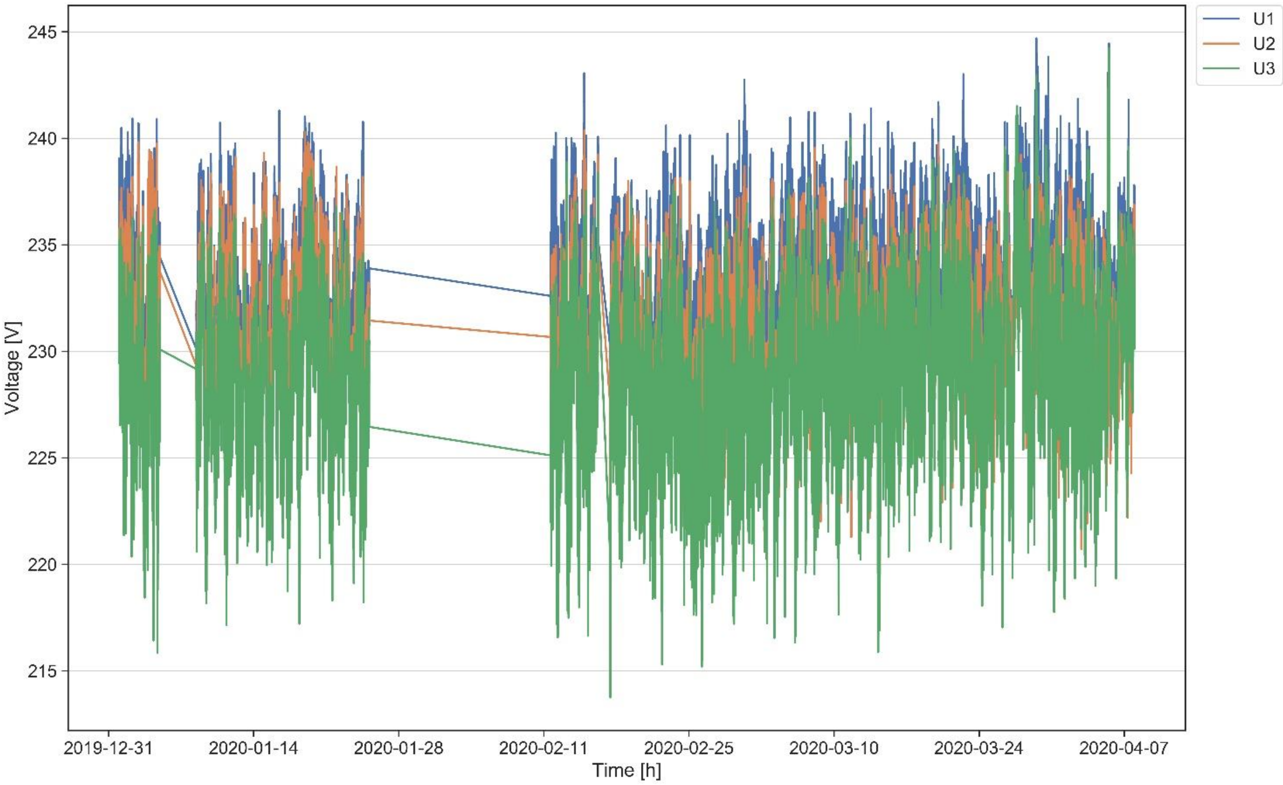

Figure 54. Fur House_25: Voltage profile.

Table 26. Fur House_25: Performance Indicators.

	PROFESS	Without ESS	Fronius Simulation
Total PV generation [kWh]	66.62	66.62	66.62
Total Load [kWh]	793.46	793.46	793.46
Total Grid Export [kWh]	2.92	3.63	0
Total Grid Import [kWh]	837.47	730.48	726.7
Grid Import - Grid Export [kWh]	834.55	726.84	726.7
Average of daily maximum power peaks exported to the grid [kW]	0.47 ± 0.15	0.47 ± 0.15	0
Average of daily maximum power peaks imported from the grid [kW]	2.35 ± 0.95	2.39 ± 0.87	2.38 ± 0.87
Maximum peak of power exported to the grid [kW]	0.71	0.71	-
Maximum peak of power imported from the grid [kW]	5.7	5.65	5.65
PV energy absorbed by ESS [kWh]	2.79	-	3.63
PV energy absorbed by ESS [%]	4.19	-	5.45
PV energy absorbed by Load [kWh]	62.99	62.99	62.99
PV energy absorbed by Load [%]	94.55	94.55	94.55

	PROFESS	Without ESS	Fronius Simulation
PV energy used locally [%]	98.73	94.55	100
PV peak [kW]	1.71	1.71	1.71
Price from Import [EUR]	347.5	304.22	302.7
Price from Export [EUR]	1.21	1.35	0
Total Price [EUR]	346.29	302.9	302.7
Mean Voltage [V]	231.3 ± 2.8		
Minimum Voltage [V]	U_1 = 221.7 U_2 = 219.3 U_3 = 213.8		
Maximum Voltage [V]	U_1 = 244.7 U_2 = 240.4 U_3 = 244.2		

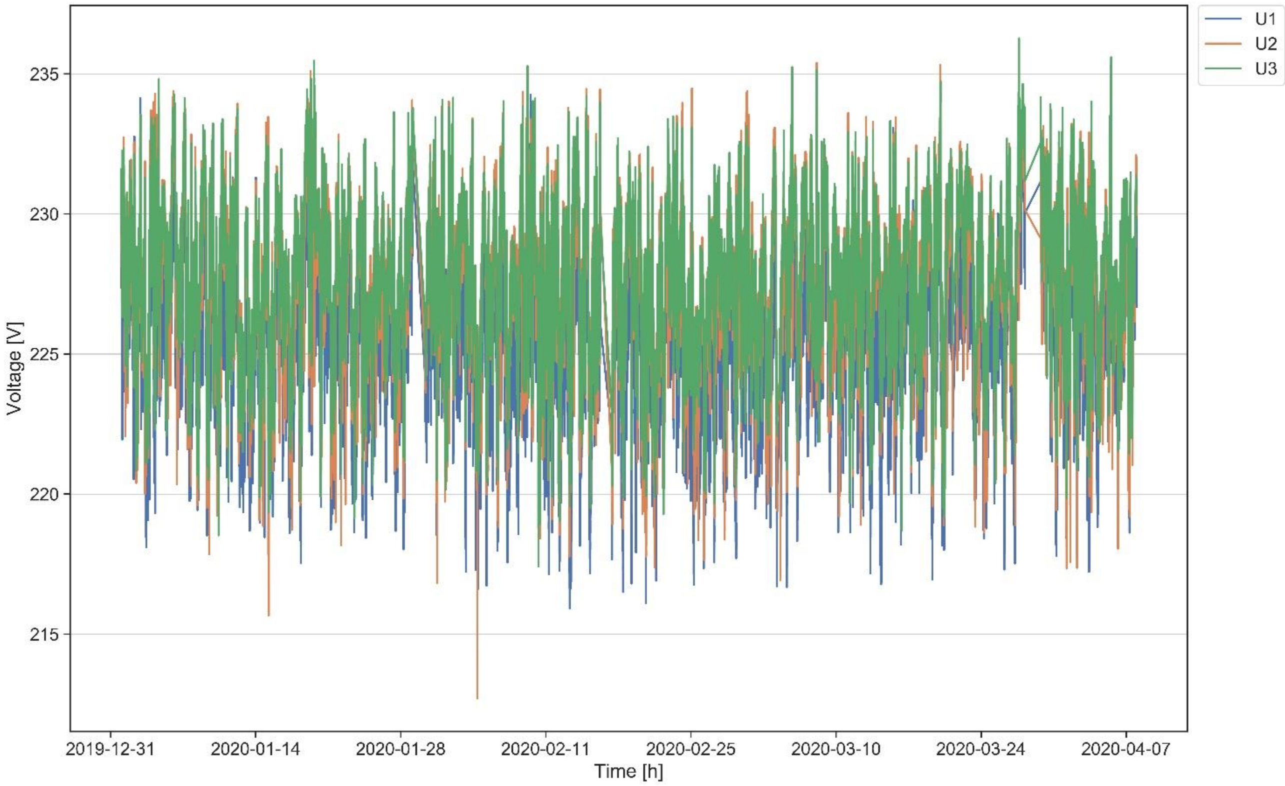

Figure 55. Fur House_26: Voltage profile.

Table 27. Fur House_26: Performance Indicators.

	PROFESS	Without ESS	Fronius Simulation
Total PV generation [kWh]	77.41	77.41	77.41
Total Load [kWh]	426.54	426.54	426.54
Total Grid Export [kWh]	32.77	25.53	0.01
Total Grid Import [kWh]	440.07	374.66	349
Grid Import - Grid Export [kWh]	407.3	349.13	348.98
Average of daily maximum power peaks exported to the grid [kW]	1.01 ± 0.37	1.01 ± 0.37	0
Average of daily maximum power peaks imported from the grid [kW]	2.36 ± 0.88	2.33 ± 0.94	2.4 ± 0.94
Maximum peak of power exported to the grid [kW]	1.64	1.64	-
Maximum peak of power imported from the grid [kW]	4.82	5.01	5.01
PV energy absorbed by ESS [kWh]	10.45	-	25.53
PV energy absorbed by ESS [%]	13.5	-	32.98
PV energy absorbed by Load [kWh]	51.88	51.88	51.88
PV energy absorbed by Load [%]	67.02	67.02	67.02
PV energy used locally [%]	80.52	67.02	100
PV peak [kW]	1.27	1.27	1.27
Price from Import [EUR]	171.9	147.64	136.4
Price from Export [EUR]	11.86	8.31	0
Total Price [EUR]	160.02	349.13	136.4
Mean Voltage [V]	226.9 ± 2.55		
Minimum Voltage [V]	U_1 = 215.9 U_2 = 212.7 U_3 = 217.4		
Maximum Voltage [V]	U_1 = 235.3 U_2 = 235.4 U_3 = 236.3		

Figure 60, Figure 62, and Figure 63 show the PV energy locally used in House_20, House_25, and House_26, respectively. In the figures, the total PV energy, the PV energy used with PROFESS, and the PV energy used with the Fronius simulation are depicted per day. We can see minimal differences in PV energy per day.

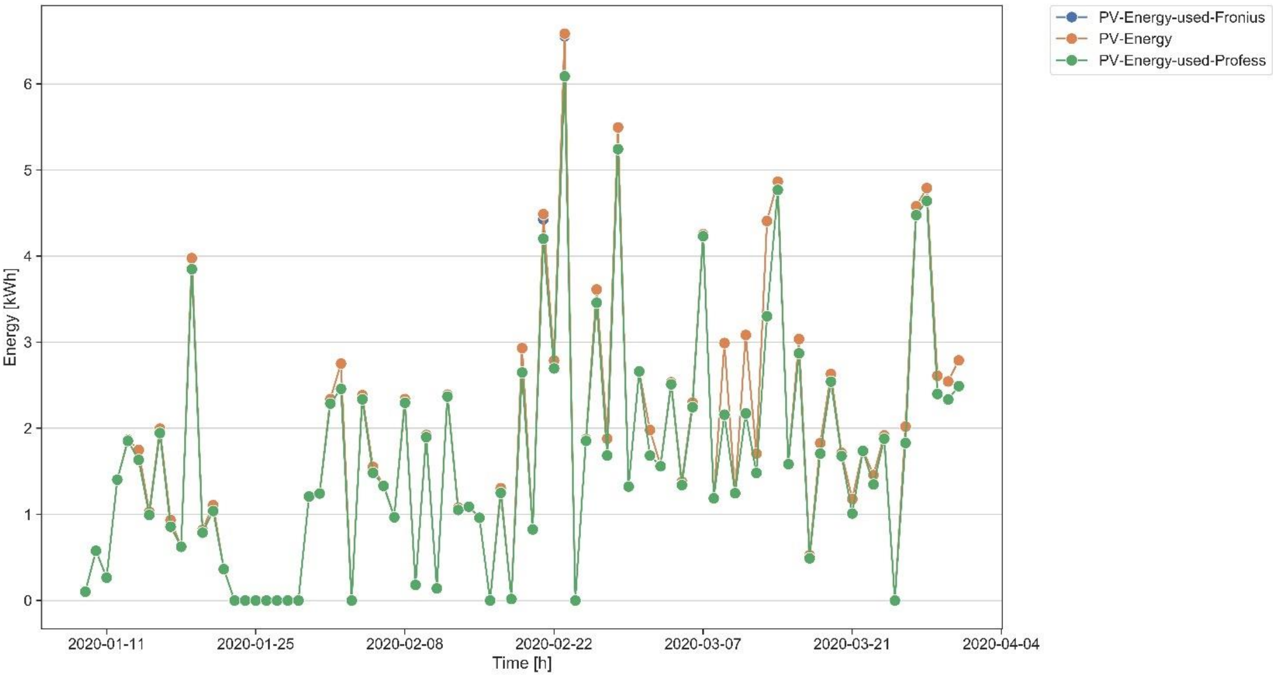

Figure 56. Fur House_20: PV energy use.

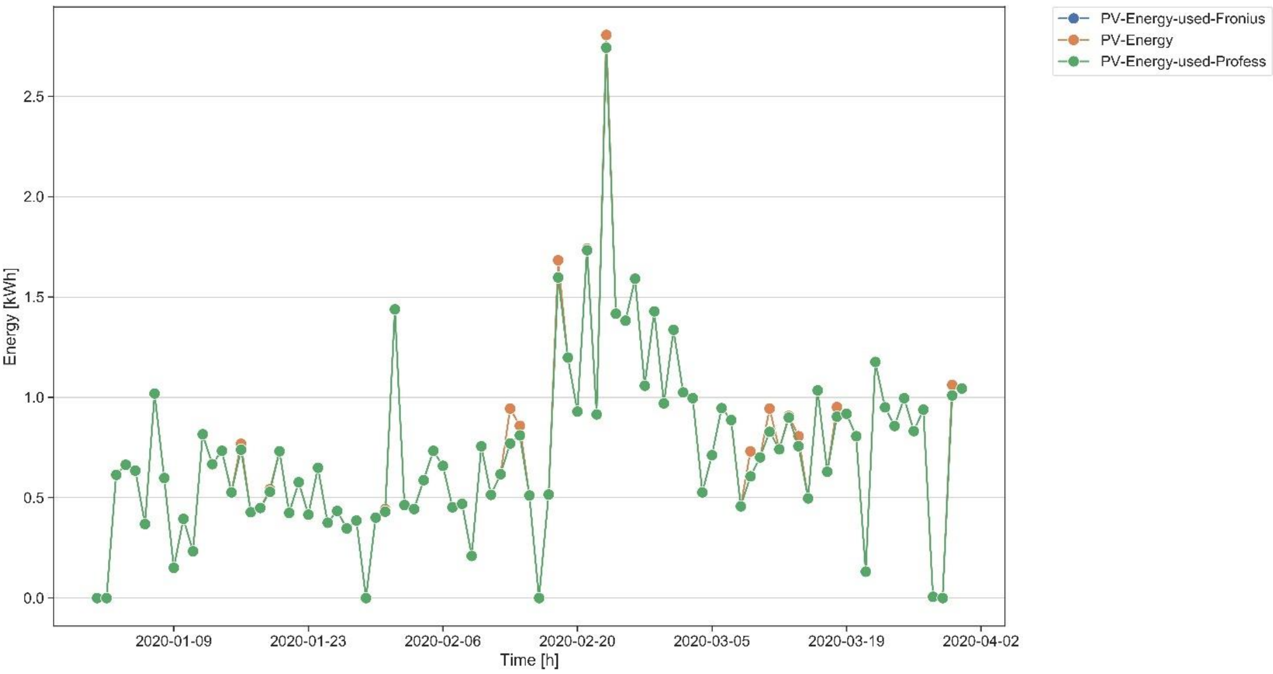

Figure 57. Fur House_25: PV energy use.

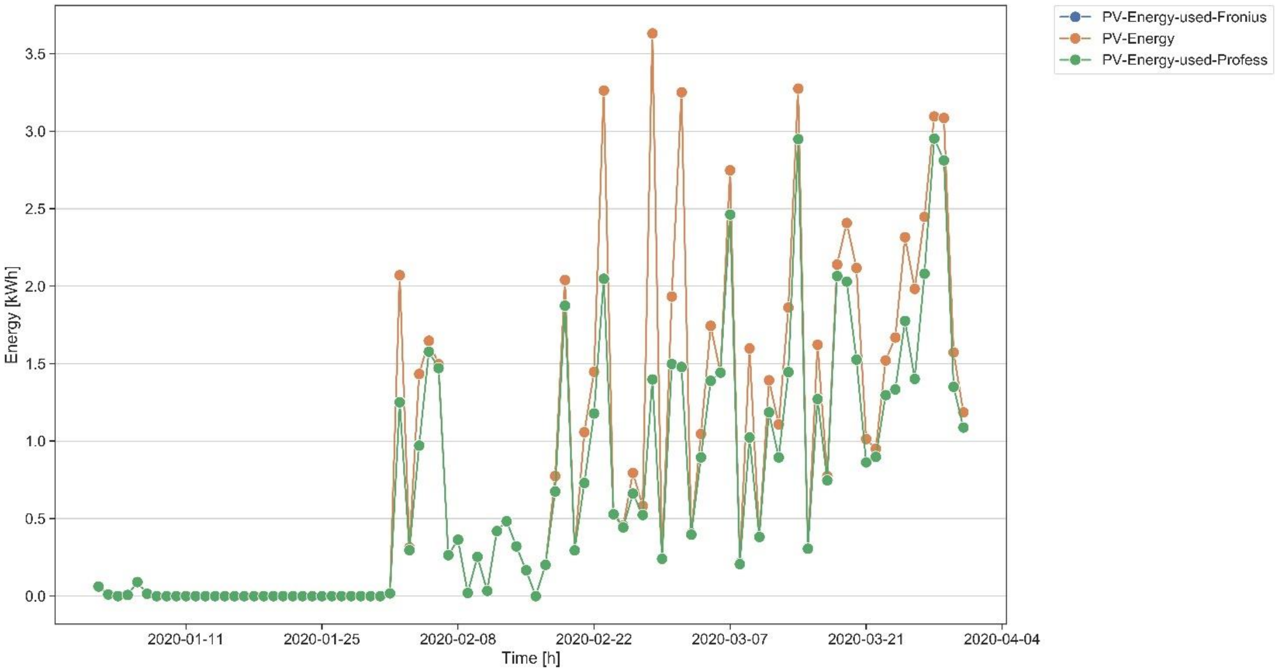

Figure 58. Fur House_26: PV energy use.

4.2.3.3.2 Maximization of the self-consumption

In House_24 the chosen optimization objective is the maximization of the self-consumption. The idea with this optimization objective is that PROFESS tries to find the optimal setpoint at each timestep that maximizes the use of PV energy analysing the next 24-hours of the input variables. Input variables are load consumption prediction, PV generation prediction as well as factors describing the electrical system. The optimization will try to use the maximal amount of PV generation even though it means to export the rest of generated energy. For the analysis some performance indicators were calculated and summarized in Table 28.

The KPI of V_{PCC} = 230 V ± 10% was achieved successfully using PROFESS because the minimum and maximum voltages measured in the PCC are within the defined limits, as shown in Figure 59, and presented in Table 28. Comparing the results with the Fronius simulation, the PV use locally is much smaller with the PROFESS. The reason why is because the surplus of the PV energy, that was not used for charging the ESS, was exported to the grid at different times. Additionally, the small amount of PV generation present in the system makes the optimization algorithm to try to charge the ESS directly from the grid, in order to have enough energy when the load increases. This increases the imported power from the grid and reduces the ability of the ESS to absorb more PV energy, if it appears suddenly.

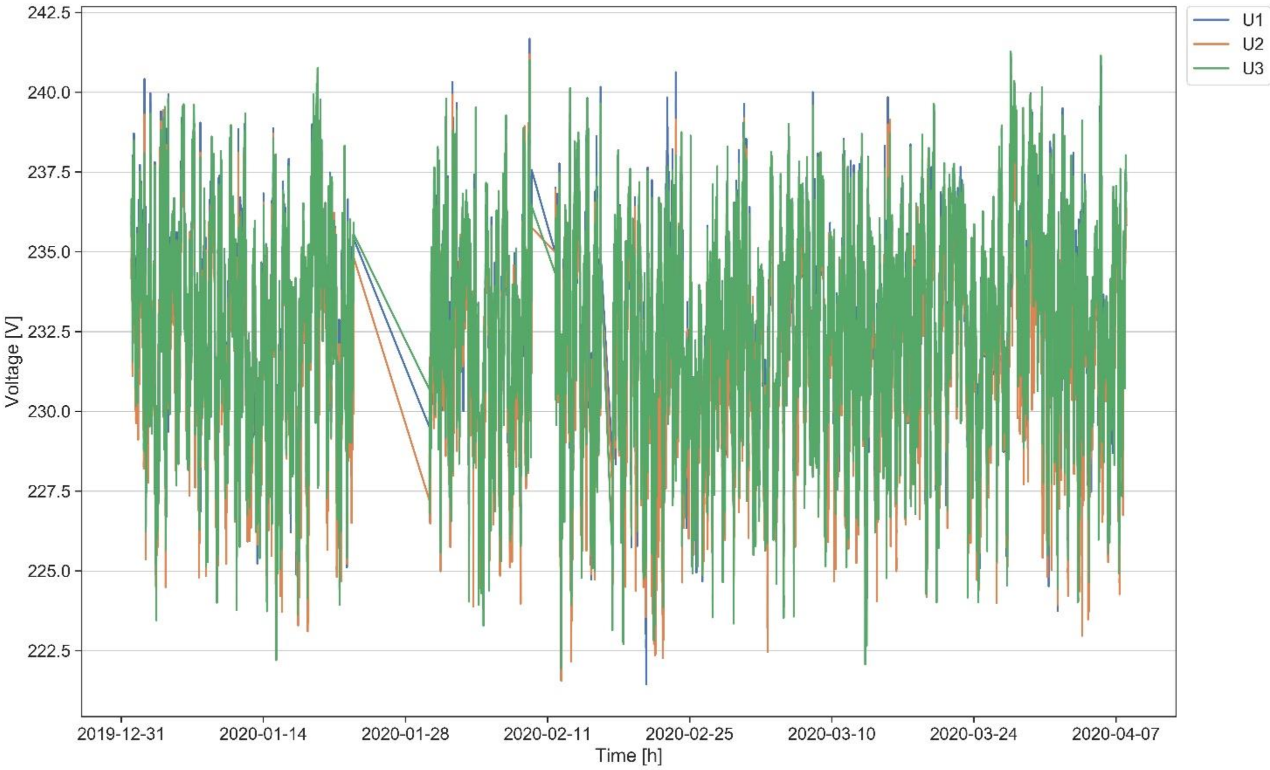

Figure 59. Fur House_24: Voltage profile.

Table 28. Fur House_24: Performance Indicators.

	PROFESS	Without ESS	Fronius Simulation
Total PV generation [kWh]	344.7	344.7	344.7
Total Load [kWh]	774.61	774.61	774.61
Total Grid Export [kWh]	151.35	154.37	60.57
Total Grid Import [kWh]	665.75	584.28	492.57
Grid Import - Grid Export [kWh]	514.39	429.91	432
Average of daily maximum power peaks exported to the grid [kW]	1.29 ± 0.79	1.29 ± 0.79	2.37 ± 0.73
Average of daily maximum power peaks imported from the grid [kW]	2.65 ± 0.84	2.48 ± 0.8	2.2 ± 0.82
Maximum peak of power exported to the grid [kW]	3.8	3.8	3.21
Maximum peak of power imported from the grid [kW]	4.83	4.23	4.23
PV energy absorbed by ESS [kWh]	23	-	93.81
PV energy absorbed by ESS [%]	6.67	-	27.22
PV energy absorbed by Load [kWh]	190.33	190.33	190.33
PV energy absorbed by Load [%]	55.22	55.22	55.22

	PROFESS	Without ESS	Fronius Simulation
PV energy used locally [%]	61.89	55.22	82.43
PV peak [kW]	3.47	3.47	3.47
Price from Import [EUR]	280	245.8	205.8
Price from Export [EUR]	46.66	47.08	17.33
Total Price [EUR]	233.31	198.73	188.42
Mean Voltage [V]	232.44 ± 2.75		
Minimum Voltage [V]	U_1 = 221.4 U_2 = 221.6 U_3 = 221.9		
Maximum Voltage [V]	U_1 = 241.7 U_2 = 241.2 U_3 = 241.3		

Figure 60 shows the PV energy locally used in House_24. In the figure, the total PV energy, the PV energy used with PROFESS, and the PV energy used with the Fronius simulation are depicted per day.

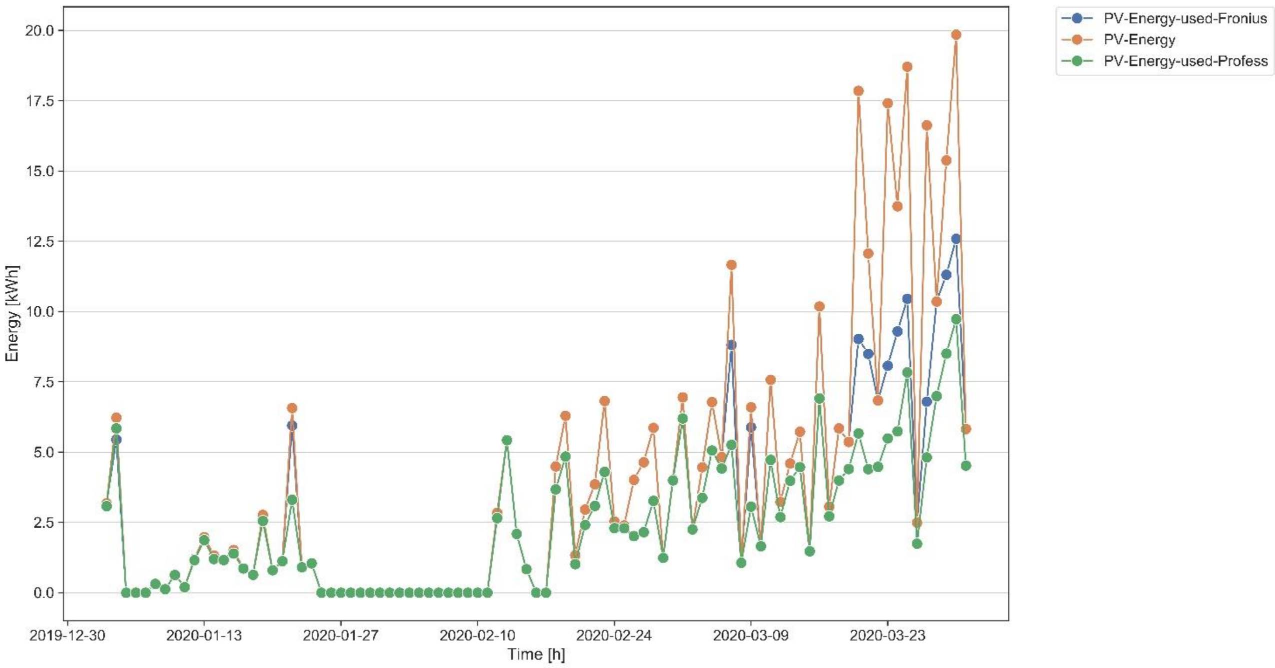

Figure 60. Fur House_24: PV energy use.

4.2.3.3.3 Minimization of the local energy costs

In House_27 the chosen optimization objective chosen is the minimization of the local energy costs. The idea with this optimization objective is that PROFESS tries to find the optimal setpoint at each timestep that minimizes the final cost of the total energy consumed (import - export) analysing the next 24-hours of the input variables. Input variables are load consumption prediction, PV generation prediction as well as factors describing the electrical system. The optimization will not try to use optimally the energy of the PV, but it will try to find the minimal energy bill's price depending on the price signal for the related house. For the analysis some performance indicators were calculated and summarized in Table 29.

The KPI of V_{PCC} = 230 V ± 10% was achieved successfully using PROFESS because the minimum and maximum voltages measured in the PCC are within the defined limits, as shown in Figure 61, and presented in Table 29. Comparing the results with the Fronius simulation and with the system without ESS, PROFESS got the lowest total price of energy of 413.13 EUR. If we take the price without ESS as the maximal price, PROFESS reduced it by 10.2% whereas the Fronius simulation just did in 2.6%. Important to notice is that PROFESS tries to minimize the total energy price and not just the import price. For this reason, the total energy imported and exported from the grid is higher than with the Fronius and without ESS simulation.

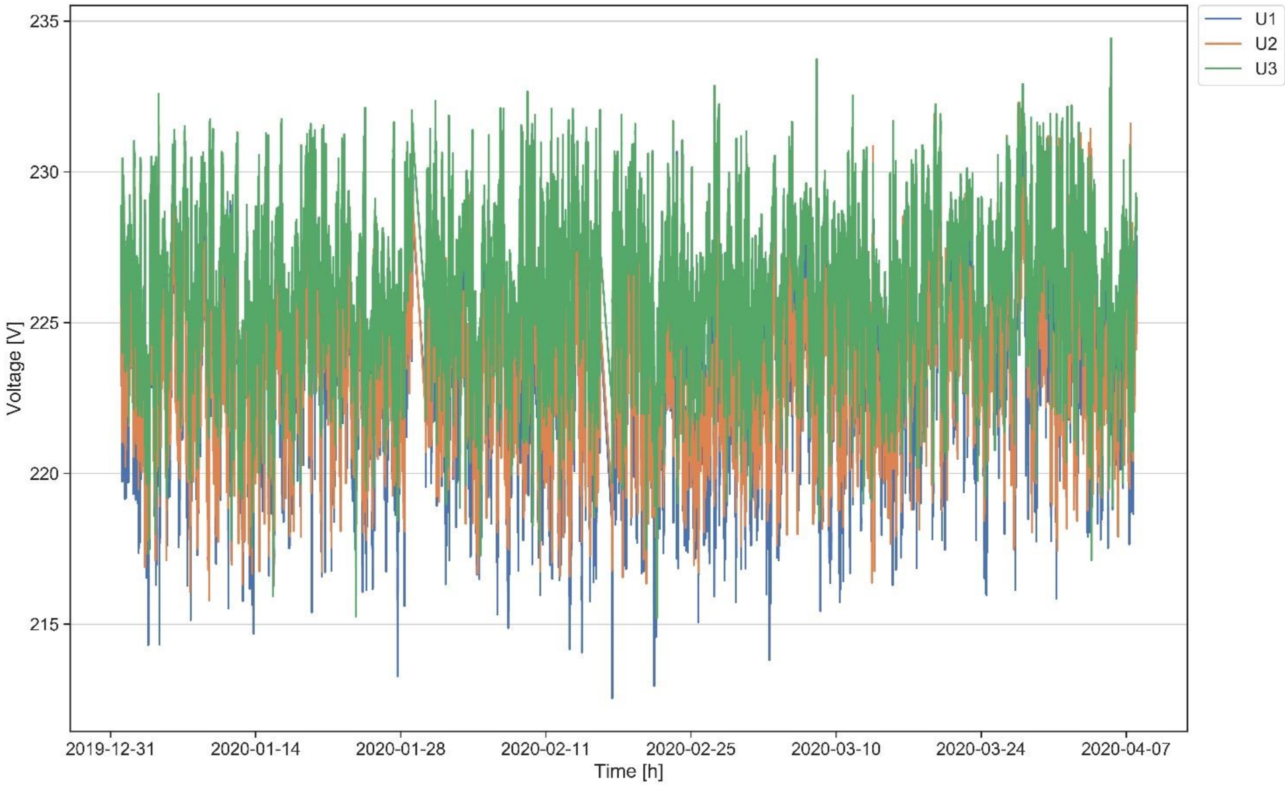

Figure 61. Fur House_27: Voltage profile.

Table 29. Fur House_27: Performance Indicators.

Description	**PROFESS**	**Without ESS**	**Fronius Simulation**
Total PV generation [kWh]	392.72	392.72	392.72
Total Load [kWh]	1407.6	1407.6	1407.6
Total Grid Export [kWh]	344.76	171.76	64.32
Total Grid Import [kWh]	1455.46	1186.64	1082.2
Grid Import - Grid Export [kWh]	1110.69	1014.88	1017.88
Average of daily maximum power peaks exported to the grid [kW]	1.85 ± 0.63	1.85 ± 0.63	2.21 ± 1.1

Description	PROFESS	Without ESS	Fronius Simulation
Average of daily maximum power peaks imported from the grid [kW]	3.9 ± 1.17	3.32 ± 1.26	3.18 ± 1.26
Maximum peak of power exported to the grid [kW]	4.16	4.16	3.77
Maximum peak of power imported from the grid [kW]	7.63	7.28	7.28
PV energy absorbed by ESS [kWh]	75.66	-	107.45
PV energy absorbed by ESS [%]	19.27	-	27.36
PV energy absorbed by Load [kWh]	220.96	220.96	220.96
PV energy absorbed by Load [%]	56.26	56.26	56.26
PV energy used locally [%]	75.53	56.26	83.62
PV peak [kW]	4.45	4.45	4.45
Price from Import [EUR]	550.24	510.98	466.06
Price from Export [EUR]	137.1	50.96	17.82
Total Price [EUR]	413.13	460.02	448.24
Mean Voltage [V]	224.4 ± 2.22		
Minimum Voltage [V]	U_1 = 212.5 U_2 = 215.8 U_3 = 215.2		
Maximum Voltage [V]	U_1 = 231.2 U_2 = 233.2 U_3 = 234.4		

Figure 62 shows the PV energy locally used in House_27. In the figure, the total PV energy, the PV energy used with PROFESS, and the PV energy used with the Fronius simulation are depicted per day.

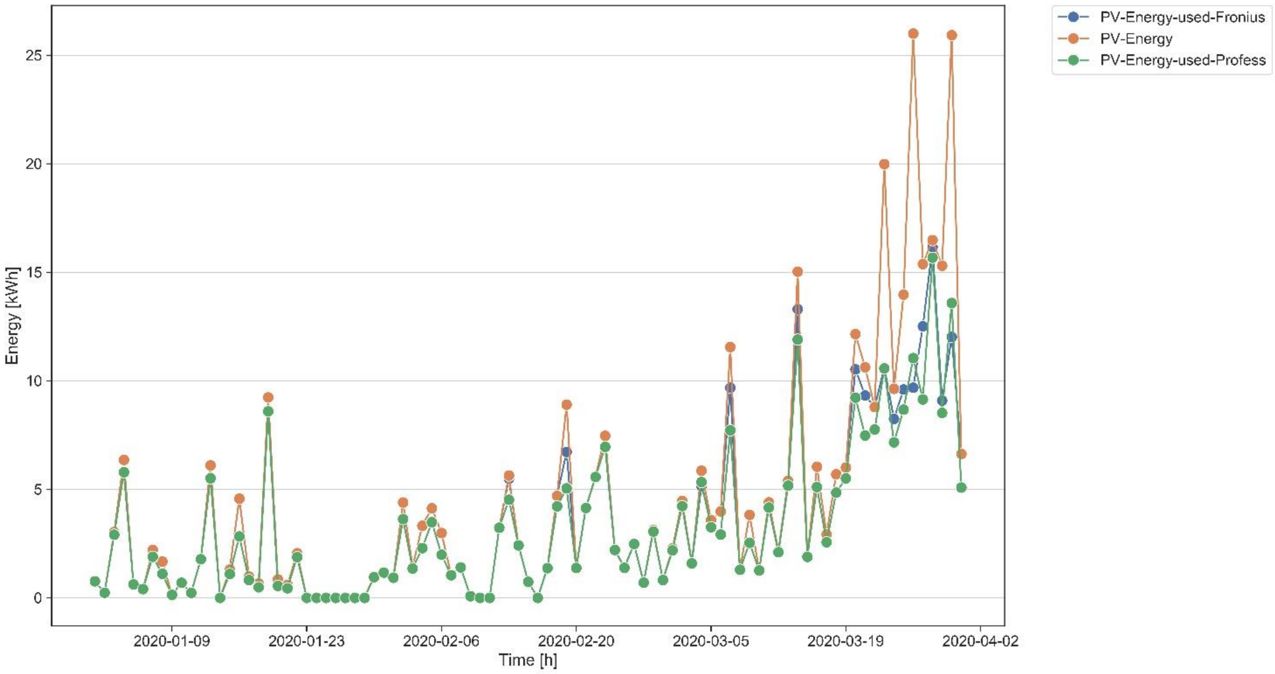

Figure 62. Fur House_27: PV energy use.

4.2.4 HLUC-3-PUC-2-BM-1

4.2.4.1 Description

HLUC-3-PUC-2-BM-1: "Autonomous voltage control at household battery" investigates how the DSO manages the voltage issues along the grid in order to setup voltage levels for the real-time power flow control at user premises. The case is that one feeder is filled with PV penetration and that one (some) customer experiences instability electricity in their house. After investigating the problem, the DSO offers the prosumer to buy a battery and have automatic voltage control within defined limits controlled by the DSO. For this service, the DSO offers a limited payment to the prosumer. The DSO avoid reinforcing the grid or defer the reinforcement.

The autonomous business model is to be understood as there is no necessity for external control. The battery controls the voltage level itself within some defined DSO limits, with no external signals exchanged with the BMS. The BMS monitors the local voltage level and regulates the level inside the demands. The BMS system does not interact with any external systems or cloud solutions.
The business case for the house owner must balance revenue from ancillary services and feed-in tariffs. In the other hand the business case must balance the DSO reinforcing cost, and expenses on ancillary services and related operational cost.

4.2.4.2 Evaluation procedure

We have used the Professional GUI, and we have started the evaluation from the level, where too many PV systems gives issues in the grid, from the level of 100% PV penetration of total load or 64% of transformer size. The operational mode of the batteries was individual voltage regulation, without overall control. The voltage level must be 230 V ± 10%. Figure 63 shows the Professional GUI during the evaluation.

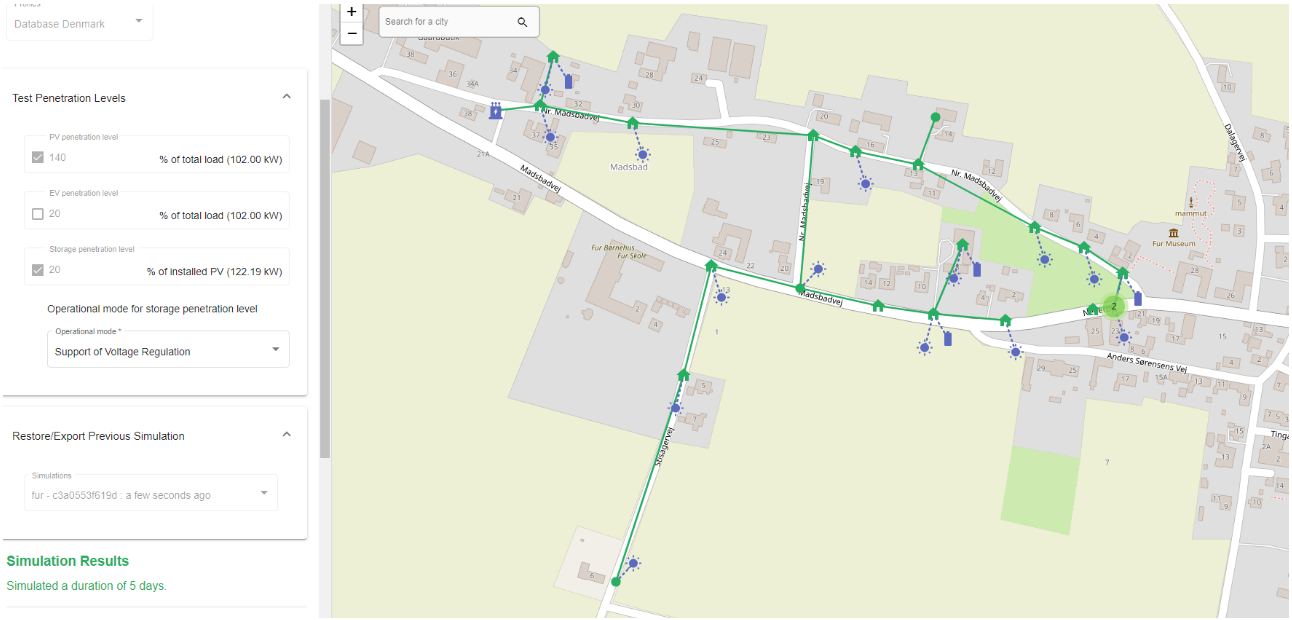

Figure 63. Professional GUI result: 140% PV penetration and 20% storage.

4.2.4.3 Evaluation results

As show in Table 30, the simulation results are very depended on where storage is placed. With 100% PV penetration it is possible to find solutions with only 5% storage, just the placement is in the correct place in the grid. It is interesting to discover, that with 20% of storage, it suddenly becomes the same price level as for grid strengthening. But again with 25% of storage the DSO TCO is the lowest, underlining the importance of placing the storage in the correct places. With PV penetration between 120% and 140%, the business case is more expensive with storage than grid strengthening.

Table 30. HLUC-3-PUC-2-BM-1 simulation results.

PV penetration [%]	Storage of installed PV [%]	Operational mode	Problem	TCO (DSO) [EUR]	TCO (DSO) Baseline [EUR]
100	5	Support of voltage regulation	No issues	40,550	39,812
100	10	Support of voltage regulation	No issues	40,963	39,812
100	15	Support of voltage regulation	No issues	40,743	39,812
100	20	Support of voltage regulation	No issues	39,704	39,812

PV penetration [%]	Storage of installed PV [%]	Operational mode	Problem	TCO (DSO) [EUR]	TCO (DSO) Baseline [EUR]
100	25	Support of voltage regulation	No issues	40,132	39,812
120	20	Support of voltage regulation	Is very depended on where storage is placed	39,839	33,380
140	20	Support of voltage regulation	Is very depended on where storage is placed	40,338	32,147

The overall conclusion is that the model is very sensitive to where the storage is placed and the differences between installing storage with voltage control and traditional grid strengthening is limited. The batteries are still too expensive, and it does not leave any profitable solution for selling ancillary services for the house owner to the DSO.

4.2.5 HLUC-3-PUC-3

4.2.5.1 Description

HLUC-3-PUC-3: "Voltage and flux control at grid-side storage" demonstrates a grid-side storage, installed close to the transformer secondary side, which can follow DSO's instruction and work as a voltage support unit to maintain the local voltage stability.

4.2.5.2 Evaluation procedure

The evaluation of this use-case starts by monitoring the normal voltage fluctuation at the PCC of the premise. A reference voltage is then decided based to the observation. According to the load type and local grid situation, a droop control curve based on active power is designed and then applied to the local ESS control unit (site controller). When activate the ESS to "Voltage support" mode, the control algorithm will start running and regulates the voltage towards the reference voltage.
From user's point of view, the only action needed is to start the ESS and go to "Voltage support" mode. The regulated voltage should stay within safety operational range of 230 V ±10%.

4.2.5.3 Evaluation results

The test started in late December 2019 and finished by January 2020. The total testing time took only 2 days, due to the lack of sunlight in Denmark during the winter period. Moreover, voltage support is not interesting to the site owner, since currently there is no subsidies which have applied to LV grid in Denmark for performing voltage support applications. In this case, the site owner lose profit by running ESS in voltage support mode for long periods of time. Since then, the consortium decided to run the test as short as possible until a valid result can be extracted and presented (during springtime).

The test started with one-week observation of the local grid demand, PV production, and the overall voltage fluctuation range as shown in Figure 64 and Figure 65.

It is noticed that the PV production is very poor in terms of a 75 kWp PV system, on the contrary the demand has large magnitude. It fluctuates with periodic peaks that is due to the heat pump running on the site day and night.

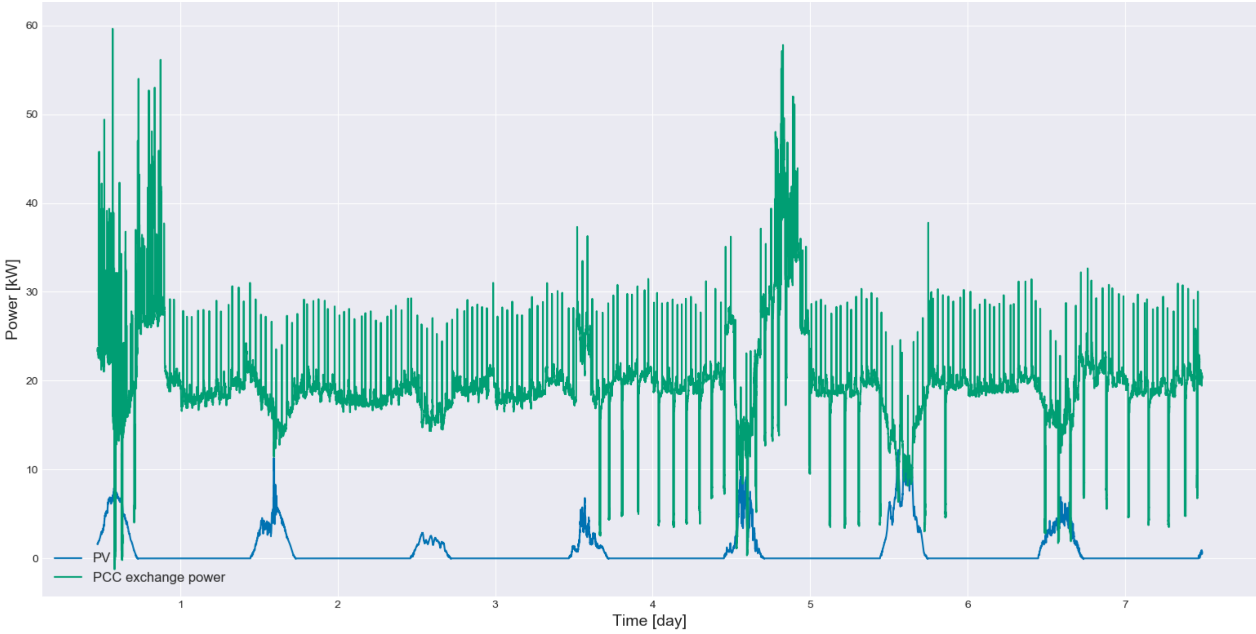

Figure 64. Fur/Skive grid test site: One-week observation on demand and PV production.

Figure 65 shows a histogram of the voltage this period, giving a better understanding of the voltage on site. Based on the observation it shows that although the voltage varies in 12V difference, which is still under the safety operational limit of 230 V ±10% according to the grid code. This means that there is no need of voltage support in this grid.

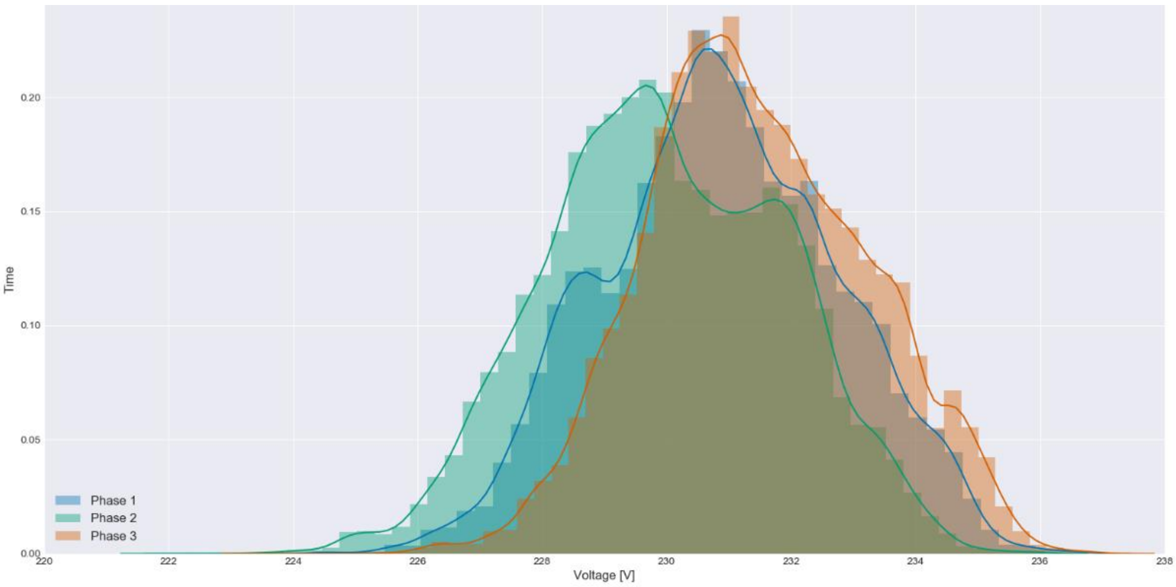

Figure 65. Fur/Skive grid test site: Voltage status overview.

However, in order to prove that the voltage support algorithm that was developed within the project is valid, we decided to design a more aggressive droop which can be applied to the current situation. The expected result should show the variance of the voltage distribution curve in Figure 65 will narrowed down and the amplitude of the distribution curve should be higher as well. The voltage distribution in Figure 65 will be used as baseline during the following test.

On day 1, the voltage reference is set to be 230 V. By operating ESS voltage support for a day, the average three-phase voltage distribution in Figure 66 could be found has a smaller variance compared to the baseline but the whole distribution was shifted to the left for approximately 1V, and therefore the weight of the voltage distribution has shifted approximately 1V as well. Since ESS is supposed to only support but not correct the voltage, thus a second test is conducted.

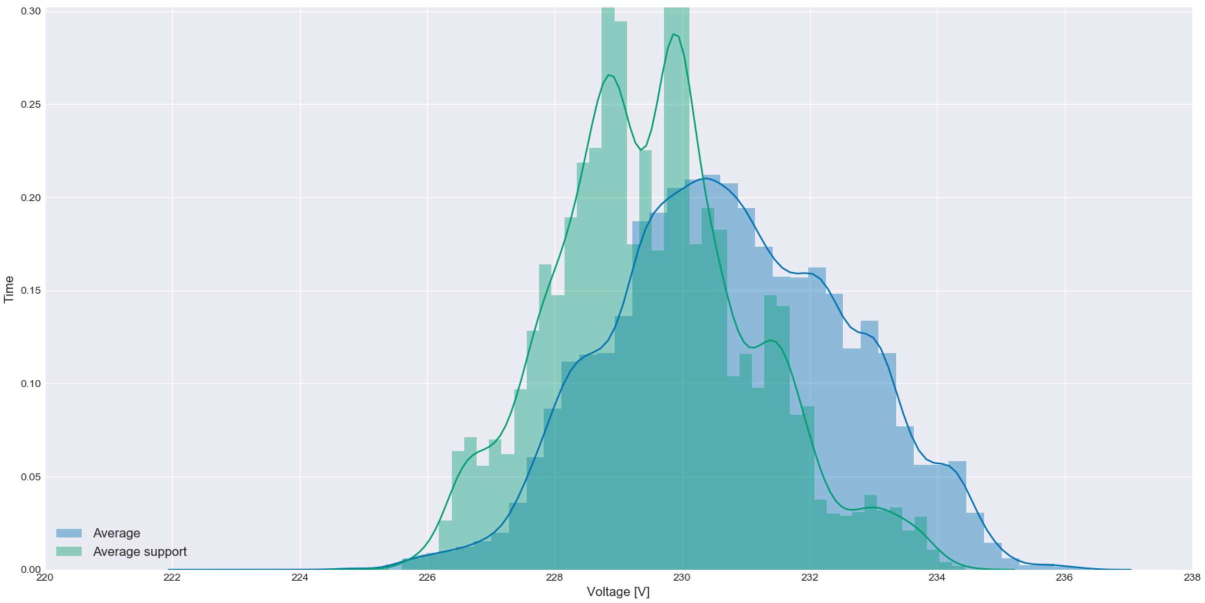

Figure 66. Fur/Skive grid test site: Day 1 versus baseline average voltage.

On day 2, the voltage reference is set to be 231 V. By operating ESS voltage support mode for a day, the average three-phase voltage distribution in Figure 67 could be found has even smaller variance compared to the day 1 result and the amplitude is noticeable higher which means the fluctuation of the voltage during the day is much smaller.

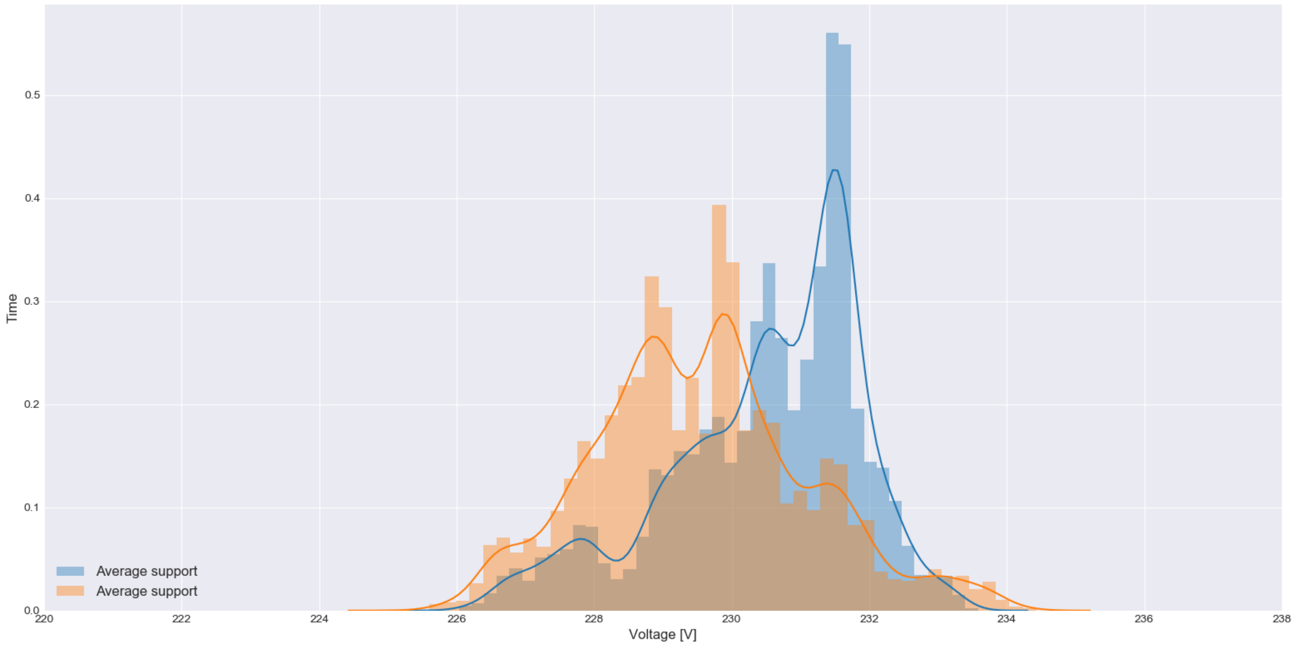

Figure 67. Fur/Skive grid test site: Day 1 vs day 2 average voltage (day 1 – orange line, day 2 - blue line).

By looking at the inverter power versus voltage on day 2 in Figure 68, the ESS inverter reacts on voltage changes rapidly, and by comparing with Figure 69 it would be seen that when the ESS reaches fully charge or discharge the inverter will stop providing voltage support, otherwise the request was well handled.

Figure 68. Fur/Skive grid test site: Day 2 inverter power versus voltage.

Figure 69. Fur/Skive grid test site: Day 2 inverter power versus ESS SoC.

The conclusion of the tests show that the voltage support algorithm is valid. Moreover, there are some learning from the test, which is when setting up reference voltage, it should fit the local grid situation. Therefore, a period of observation is recommended before setting up the voltage support mode.

4.2.6 HLUC-3-PUC-3-BM-1

4.2.6.1 Description

HLUC-3-PUC-3-BM-1: "Voltage control at grid-side battery" demonstrates voltage control at substation level by controlling the battery charge/discharge power to stabilize the voltage level at the feeder line while flux fluctuates.

4.2.6.2 Evaluation procedure

A comparison with HLUC-3-PUC-1-BM-1 (baseline) based on CapEx and OpEx to verify if the ESS household installation can be a better economical solution for the DSO is used as evaluation. In order to make such a calculation, there are few inputs need to be dimensioned in advance. Firstly, a study related to ancillary service regarding voltage support should be done, which includes how the service functioned and what is the tariff. Secondly the power fluctuation in the local grid should be observed and analysed in order to determine the size/capacity of the transformer and the cable. Last, historical energy/power data in the local network should be obtained and used for projecting the voltage status during a whole year.

4.2.6.3 Evaluation results

According to the observation that has mentioned in section 4.2.5.3, the voltage level at Fur/Skive grid test site is within the safety operational range (230 V ±10%). This means that currently there is no need to upgrade the facilities for the local network. Besides, currently there is no regulation regarding voltage support in the Denmark LV grid. This means that the quantitative evaluation for HLUC-3-PUC-3-BM-1 is not possible to make. However, a qualitative evaluation of this business case can be found in D7.5 [S4G-D7.5].

4.2.7 HLUC-3-PUC-4

4.2.7.1 Description

HLUC-3-PUC-4: "Coordinated distributed storage in the grid" demonstrates the situation of the grid when private storage and the storage on grid level is jointly operated and coordinated. The results of this comparison decide if the storage global control is a feasible solution to solve voltage issues in the selected topology.

4.2.7.2 Evaluation procedure

The activation of the global control could not be tested explicitly with end-users because of technical issues (as explained in section 3.2.6.2). However, the user was asked in task 5 to insert a battery into the grid and set either the operational mode to "maximize self-consumption" or "support of voltage regulation". Since it does not make much difference regarding the form of interaction, the user behaviour of these tasks can be used to draw conclusions about the UX.

The evaluation was performed using the Professional GUI, starting from the level where too many PV systems give issues in the grid, from the level of 120% PV penetration of total load or 81% of transformer size. The operational mode of the individual batteries are voltage control and the overall global control was activated, which is the GESSCon to coordinate the different storage systems distributed in the grid. The KPI for the voltage level is to be 230V ±10%. More and more storage is added primarily at the end of feeder lines until the voltage is inside the limits. Besides that, different operational modes was tested in the optimal scenario, as show in Figure 70.

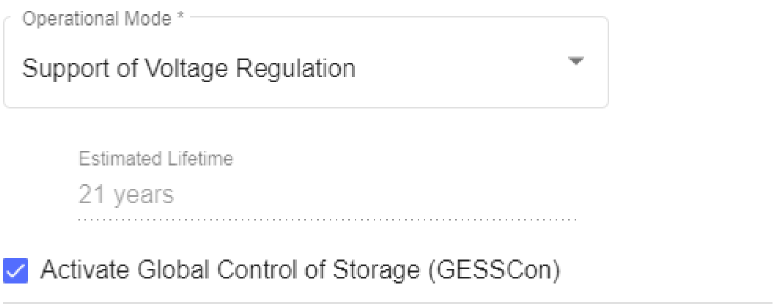

Figure 70. Professional GUI: Operational mode of one specific battery.

4.2.7.3 Evaluation results

Figure 71 shows the first test scenario with 120% PV penetration and one storage (5.6 kW) placed at the end of one feeder line. As the results show, there is an overall voltage issue (red houses).

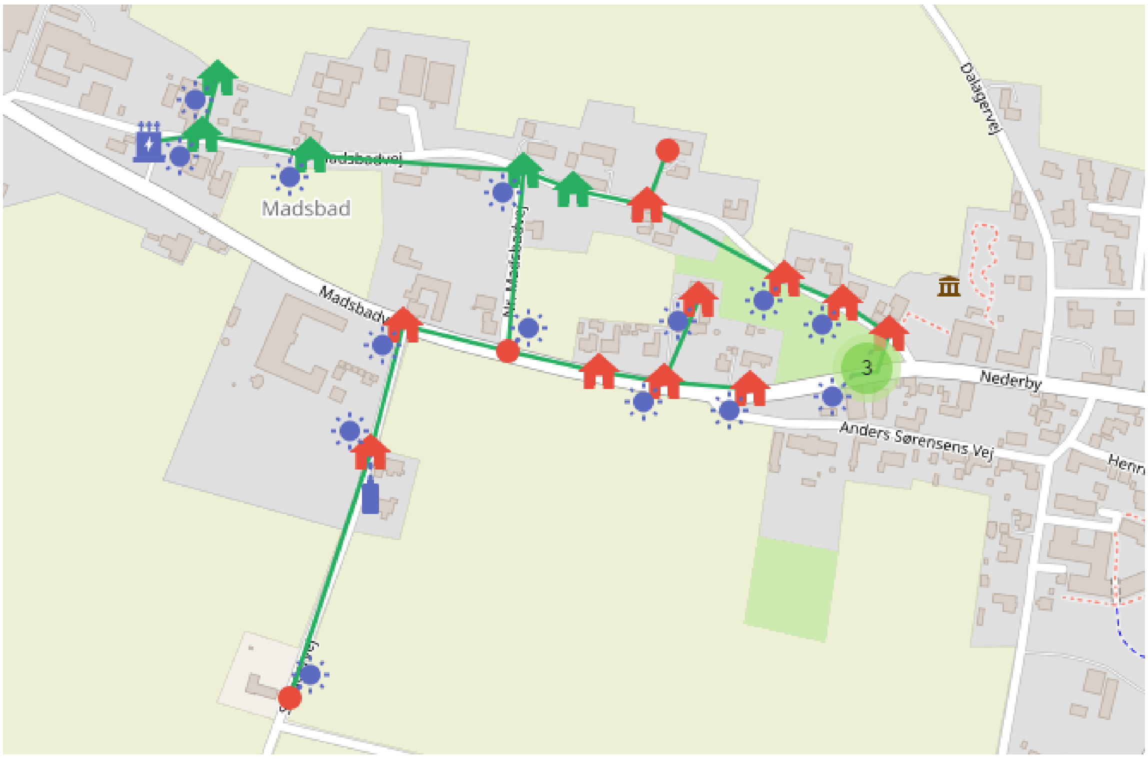

Figure 71. Professional GUI results: 120% PV penetration and one storage at the end of a feeder line (operational mode = global control with support of voltage regulation).

When adding another storage and enlarging it its maximum size (12 kWh, 6.4 kW) for each placement at the end of the feeder line the voltage issue is being solved at these feeder lines, as show in Figure 72.

Figure 72. Professional GUI results: 120% PV penetration and two storages at the end of two feeder lines (operational mode = global control with support of voltage regulation).

Changing the operational mode from voltage control to maximize self-consumptions and no global control, some voltages issues arise in more houses, as show in Figure 73.

Figure 73. Professional GUI results: 120% PV penetration and storage placed at feeder lines at three houses (operational mode = no global control and maximize self-consumption).

The main results from HLUC-3-PUC-4 simulations are shown in Table 31.

Table 31. HLUC-3-PUC-4 simulations results.

PV penetration [%]	Storage of installed PV [%]	# of storage and size [kW]	Operational mode	Placement	Problem
120	4.5	#1 5.4	Voltage control with global control	At the end of one feeder line	ΔU in all feeder lines
120	10	#2 6.4	Voltage control with global control	At the end of one feeder line	ΔU in one feeder line
120	16	#3 6.4	Voltage control with global control	At the end of three feeder line	No problems
120	16	#3 6.4	Voltage control NO global control	At the end of three feeder line	No problems
120	16	#3 6.4	Maximize self-consumption NO global control	At the end of three feeder line	ΔU in all feeder lines

Strategic placed storage in the grid, at the end of feeder lines solves the voltage issues. The storage could either be owned by the DSO or the house owner. The simulations with different operation modes show that the global control does not make a difference in this scenario, as long as the local storages are set to voltage control. If the operational mode is set to maximize self-consumption, then voltage issues occurs in every feeder line.

4.2.8 HLUC-3-PUC-4-BM-2

4.2.8.1 Description

HLUC-3-PUC-4-BM-2: "Voltage control at both household and grid-side battery and Energy Flux control at grid-side battery" is the case where one feeder is filled with PV penetration, more than 100% of the houses have PV systems and that many customers experience instability electricity in their house. The installation of storage systems at different levels in the grid are considered by the DSO as a potentially interesting solution to help improving self-consumption, increase grid flexibility and deferring grid reinforcement. Such systems must be controlled externally to achieve adaptation to current grid conditions; achieving coordinated behaviour e.g. to exploit synergies arising between houses connected to the same radial and/or with storage at substation level.

4.2.8.2 Evaluation procedure

The DSF-SE is used 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 should be taken into consideration, depending on the market and regulatory environment.

4.2.8.3 Evaluation results

This business model was evaluated using the DSF-EE within the different scenarios, as shown in Table 32.

Table 32. DSF-EE results: Different scenarios for HLUC-3-PUC-4-BM-2 (simulation time = 20 years).

Storage of installed PV [%]	# of storage and size [kW]	Operational mode	Problem	TCO DSO [EUR]	Baseline DSO [EUR]	TCO Community [EUR]
4.5	#1 5.4	Voltage control with global control	ΔU in all feeder lines	34,760	33,380	473,606
10	#2 6.4	Voltage control with global control	ΔU in one feeder line	37,695	33,380	477,787
16	#3 6.4	Voltage control with global control	No problems	39,430	33,380	479,191
16	#3 6.4	Voltage control NO global control	No problems	39,961	33,380	479,057
16	#3 6.4	Maximize self-consumption NO global control	ΔU in all feeder lines	36,315	33,380	478,511

All the scenarios were calculated with 120% of PV penetration and in every case, the business case is more expensive with storage than with traditional grid strengthening.
The overall conclusion is that storage needs to be placed in strategic places, primary at the end of feeder lines, not much storage is needed to solve voltage issues, but the batteries are still too expensive, and it does not leave any profitable solution for selling ancillary services for the house owner to the DSO.

4.2.9 HLUC-3-PUC-4-BM-3

4.2.9.1 Description

HLUC-3-PUC-4-BM-3: “Flux control and loads shaving at households with PV and battery” is about controlling when to charge and discharge the battery depending on the grid state. The sun peak and the consumption peak does not coincide, which gives imbalances in the local grid. This case is about postponing storage until sun peak (during noon) and to discharge during cooking peak (during late afternoon time 5-8 pm). This is the ideal case, mostly only during summertime. Part of the use-case is also to have weather forecasts to be able to charge/discharge depending on sunshine (during spring and fall). Another case is being able to charge from the grid during night-time to consume from storage in the morning or on days without sunshine (mainly during wintertime). See details in Figure 74 and Figure 75.

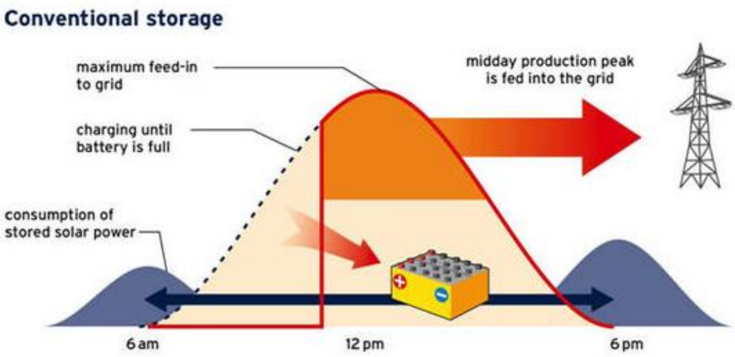

Figure 74. Self-managed battery system

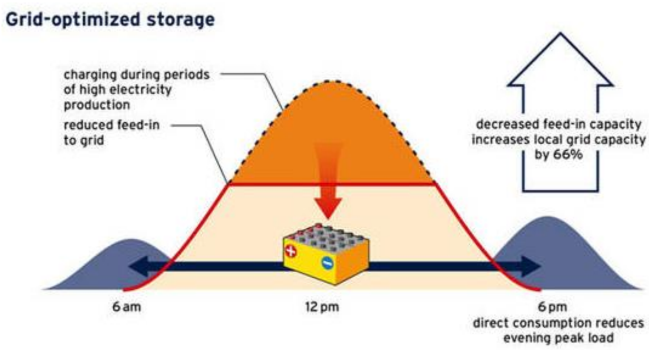

Figure 75. Grid optimization storage

The case is a feeder line with many customers, mostly prosumers, and some prosumers with storage. The house owner gets the possibility to invest in storage to be more self-sufficient.

4.2.9.2 Evaluation procedure

HLUC-3-PUC-4-BM-3 was evaluated with one year of collected data in the project and was simulated, since the operational mode cannot be chosen in the Professional GUI. The evaluation was performed considering a specific procedure which analyses which minimum battery is needed at grid-side in order to avoid grid constraints on the MV/LV connection of the local grid with the main grid. In order to evaluate the control of

BESS at grid level, in order to ensure the grid optimisation storage, it was first chosen a set of representative days, one for each season. These days were chosen based on patterns of production and consumption recorded in Fur grid over one year, and such that the average energy over a year is equal with the average energy for the representative days.

In addition, three scenarios were considered for the PV production in the chosen grid:

1. **MAX_P50% scenario:** A PV penetration which has the highest power over the representative days (representing a peak hour for PVs over the whole year) a value which is 50% of the peak power consumption over the same period (representing a peak hour for the consumption over the whole year).
2. **MAX_P100% scenario:** A PV penetration which has the highest power over the representative days a value which is 100% of the peak power consumption over the same period.
3. **MAX_E100% scenario:** A PV penetration which has the whole year energy production (calculated by using four representative days, one for each season) a value which is 100% of the energy consumption over the same period.

The same consumption pattern was considered for all PV penetration scenarios, as being an input data depending on the de facto users' portfolio. A number of 17 prosumers were selected, each with a 3.5 kWh of local BESS, to be available for SaaS through GESSCON scheduling of both local and grid-side storage, in order to optimize the overall cost of energy for the entire community. An additional node in the grid was considered, the one where the grid-side battery is connected.

The evolution of PV production and of consumption for one prosumer is given in Table 33, for the scenario MAX_E100%.

Table 33. MAX_E100% scenario: Evolution of production and consumption over the four representative days.

	Spring		Summer		Autumn		Winter	
Hour	**PV**	**Cons**	**PV**	**Cons**	**PV**	**Cons**	**PV**	**Cons**
-	**[Wh]**	**[Wh]**	**[Wh]**	**[Wh]**	**[Wh]**	**[Wh]**	**[Wh]**	**[Wh]**
1	0	760	0	455	0	323	0	668
2	0	671	0	421	0	286	0	584
3	0	641	0	417	0	279	0	548
4	0	632	0	429	0	278	0	560
5	0	644	0	460	0	307	0	553
6	0	661	761	576	32	404	0	608
7	0	810	1,841	736	698	558	0	727
8	771	1,051	2,826	656	427	508	0	882
9	848	1,033	3,733	571	2,613	451	1,289	844
10	224	898	4,478	549	867	452	2,002	729
11	164	883	4,788	536	2,767	461	2,291	712
12	1,236	855	4,746	516	2,034	451	2,193	710
13	2,798	820	4,341	496	3,922	437	1,690	701

	Spring		**Summer**		**Autumn**		**Winter**	
14	2,124	818	3,611	489	310	430	803	685
15	476	804	2,651	503	954	442	0	714
16	0	848	1,482	564	1,259	502	0	779
17	0	1,025	179	701	15	608	0	974
18	0	1,354	0	796	0	676	0	1,312
19	0	1,610	0	913	0	755	0	1,504
20	0	1,591	0	1,106	0	924	0	1,456
21	0	1,478	0	1,138	0	1,031	0	1,389
22	0	1,355	0	937	0	820	0	1,269
23	0	1,140	0	745	0	616	0	1,055
24	0	923	0	549	0	406	0	856
Total	**8,641**	**23,306**	**35,437**	**14,805**	**15,897**	**12,082**	**10,267**	**20,150**
Max	**2,798**	**1,610**	**4,788**	**1,138**	**3,922**	**1,031**	**2,291**	**1,504**

The line with totals shows the total energy produced and consumed for each representative day. The sum of production over all representative days is:

$$\mathbf{P_{PV}} = 8641 + 35437 + 15897 + 10267 = \mathbf{70242\ Wh}$$

While the sum of consumption over all representative days is:

$$\mathbf{P_{CONS}} = 23306 + 14805 + 12082 + 20150 = \mathbf{70344\ Wh}$$

which show that the energy produced and consumed are almost the same.
Figure 76 shows the evolution of PV production and of consumption in the second day (representative summer day).

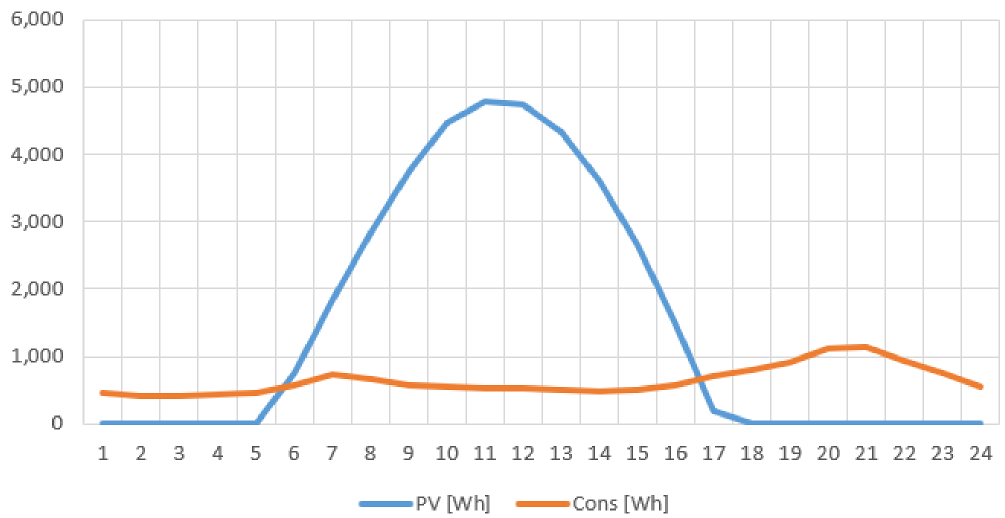

Figure 76. Evolution of production and consumption in a typical summer day.

With BESS resources at prosumer's level already established by DSF, the GESSCON was launched for scheduling storage operations on both local and grid-side. While different charging schedules were obtained for different price patterns over 24-hours, in order to maximize the total cost over the whole day and for the entire energy community, the main goal for this use-case was to determine the grid-side storage that needed to be present, invested by the DSO or by an flexibility service provider.

GESSCON is making the optimisation of total cost based on market price of the energy for each hour in the daily timeframe, but the solution also needs to comply with grid constraints. In this BM the main constrain is the transformer maximum power which allows more or less maximum exchange with the main grid, acting as a huge "battery" which can absorb any unbalance, if the transformer allows the power flow (also presented as "flux").

As a first analysis, with very low constraints on grid-side, especially regarding the MV/LV transformer, it showed that there is no need for a grid-side storage, as all misfit between PV production and consumption is solved by exchanging the power with the main grid, through the MV/LV transformer, without any practical limitation. This situation was clearly checked with the Professional GUI, showing possible scenarios with cost optimisation in the absence of any grid-side battery.

However, in order to entire evaluate the overall situation, it was needed to consider grid-side battery in addition to the local prosumers' battery, and a limit/stressful situation was needed to be considered. While various days were analysed for each previous scenario (MAX_P50%, MAX_P100% and MAX_E100%), the most relevant (and demanding) situation was the MAX_E100% scenario in the representative day for the summer season.

The representative days for the whole year showed a maximum exchange power P_{EXC_MAX} at midday of the summer day, in the MAX_E100% scenario. This maximum exchange power was exceeding the maximum power during the peak hours in the evening, no matter the season.

This P_{EXC_MAX} was considered as criteria for the MV/LV transformer, meaning that the transformer was sized to accept an overcharge factor K comparing with the P_{EXC_MAX}. While different variants can be considered, in our example we have chosen K=1.4, meaning that the MV/LV transformer can support even 40% more power. This factor is an example of a grid which is already oversized, despite not high enough to avoid grid constraints, in case that no grid battery means are used.

4.2.9.3 Evaluation results

In order to determine the minimum grid-side battery capacity, a progressively increased value for the grid-side BESS capacity was considered and GESSCON was used to find optimized schedules for both local and grid-side batteries. The minimal capacity was reached when GESSCON started to bring solutions. For any lower grid-side BESS capacity it was not possible to find an optimisation, as the algorithm always failed to find it due to transformer constraints.

The power of the grid-side storage is given from the CAISO style Duck chart[ii] of the same day (Figure 77), where the presented evolution is the difference between consumption and PV production for each hour in the day. The evolution of the power is therefore in each hour equal to $P = P_{CONS} – P_{PV}$, which is in fact in this situation ta value which approximates the exchanged power with the grid through the MV/LV transformer.

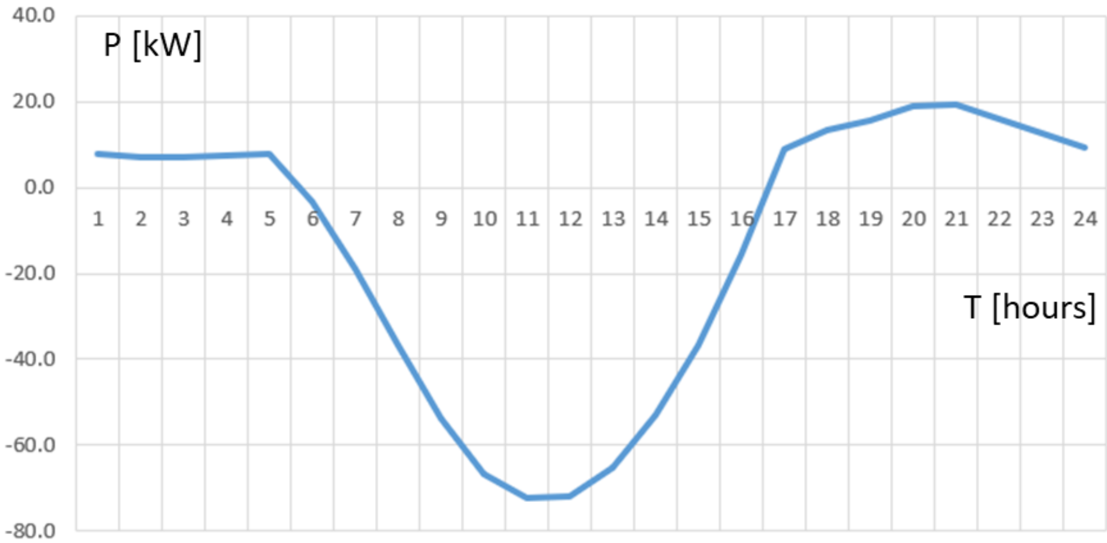

Figure 77. “Duck chart” for the summer day.

Figure 77 shows that the maximum power exchanged with the main grid (through the MV/LV transformer) is around hour 11, with a value of approximate 72 kW for the total of 17 prosumers. To be noted that the result is scalable for any higher number of prosumers, e.g. for a number of 170 prosumers the power sent back to the MV grid through the MV/LV transformer is 720 kW. For simplicity, reactive power is considered to be small enough, such that the analysis can be made in terms of active power only. Nevertheless, reactive power can be mitigated with local or grid-side storage means, thus leaving the congestion aspects to be related mainly to active power.

For this BM, the boundary where GESSCON started to give solution was around 90 kWh of grid-side BESS. At this level of grid BESS, the hourly price of the energy had no influence on the solution of BESS scheduling, as it was at the limit of feasibility.

As a conclusion related to business model of a grid-side battery, its investment cost needs to be compared with the reinforcement of the grid, in a particular PV penetration. See more details in section 4.2.8 and in D7.5 [S4G-D7.5].

Regarding more grid-side storage, the tests show that with higher BESS resources, the energy price starts to play a role in the total price optimisation. This conclusion is based on the fact that only after overpassing the first boundary of 90 kWh for the grid-side BESS the charging/discharging schedules become influenced by the hourly price, while around the boundary the price of energy is not influencing the charging schedule, as the condition of surpassing network constraints is essentially shaping the schedule. The extra BESS over the boundary which solved power flow congestion need to be able to be paid by the money spared by energy market incentives associated with the hourly prices.

4.3 Phase 3 evaluation summary

In the Fur/Skive Local test site, PROFESS allowed a higher PV usage when there was no ESS present in the system. The Professional GUI received good feedback in terms of UX, however it was reported that it was not detailed enough for the technical end-user, and there was no added value from the economic information due to their lack of experience. The real added value of the DSF-EE, in fact, is to help decision makers (i.e., grid planning managers responsible for investments) to evaluate the profitability of installing ESS in the grid considering different grid configurations (ESS at prosumer or at grid level).

The tests in the Fur/Skive Grid test site shown that the voltage support algorithm is valid. Moreover, when setting up reference voltage, it should fit the local grid situation. Therefore, a period of observation is recommended before setting up the voltage support mode.

During the business models evaluation, the Professional GUI reports voltage issues when the installation of PV systems increases to around 80-100% of all houses, which means that each house has a PV system of 5.1 kWp, which is 64% of the kVA for the transformer (150 kVA). The DSO's TCO includes grid loss and grid strengthening over a period of 20 years.

The model is very sensitive to where the storage is placed and the differences between installing storage with voltage control and traditional grid strengthening is limited. The batteries are still too expensive, and it does not leave any profitable solution for selling ancillary services for the house owner to the DSO. Additionally, for the DSO, is more economic viable to do grid strengthening than to install a grid ESS, due to their high cost. Moreover, the storage needs to be placed in strategic places and with the correct operation mode to decrease the voltage issues probability. The storage could either be owned by the DSO or the house owner.

5 S4G Environmental Impacts

The environmental impact is targeted in the S4G's HLUCs, as follows:

- HLUC-1 is treating AP which maximises the self-consumption of its PV production, while different use-cases show also resiliency and energy exchange with the neighbours. With the scenario having no or low injection of power to the grid, the distribution network being able to accept a high level of renewables penetration, as the grid preserves business as usual.
- HLUC-2 considers cooperative EV charging, which analyses solutions for high EV penetration, used in a cooperative strategy, enabling a low impact on the grid by using storage means while PV production is also part of the optimisation process.
- HLUC-3 deals with storage coordination at local and grid level, highlighting solutions to enable high RES penetration. It studies different use-cases, which include high RES penetration, with maximum PV power going up to 100% of the maximum power consumption, both considered over the same set of representative days over the year, or even PV energy production going up to 100% of the energy consumption. The latest scenario corresponds to the highest RES penetration in the studied premises boundaries, and correspond to a 2050 scenario when the studied cluster has 100% CO_2 neutrality on the electricity side.

As a conclusion, the S4G project is pursuing different measures for targeting decarbonisation, considering both RES production and its local mitigation such that the electrical ecosystem can support the new situation, and EV charging optimisation, thus supporting also a higher EV penetration with minimum impact on the grid. In addition, AP and local communities are also considered as solutions for high RES penetration in condition of developing energy communities and enhance end-user energy resilience.

6 S4G Policy Implications

The analysis that has conducted in S4G, specifically within D7.5 [S4G-D7.5], D7.8 [S4G-D7.8], and in this deliverable, allowed to identify some policy issues that can be summarised in the following sections.

6.1 Policy and regulations play a crucial role in the future energy sector

As highlighted by the PWC report[iii], policy and regulations can be considered key levers for developing future business models in the energy sector (Figure 78). Specifically, the transformation of the energy sector involves several factors: customers behaviours, competition, the production service model, distribution channels, as well as government policy and regulation. In short, according to PWC, energy sector is going to evolve into a new market paradigm characterised by a new and more active role of customers (customers become producers, active participants in the market, can go-off grid) and the management of decentralized and distributed resources. In this context, the European and national regulations have to be adequately reframed.

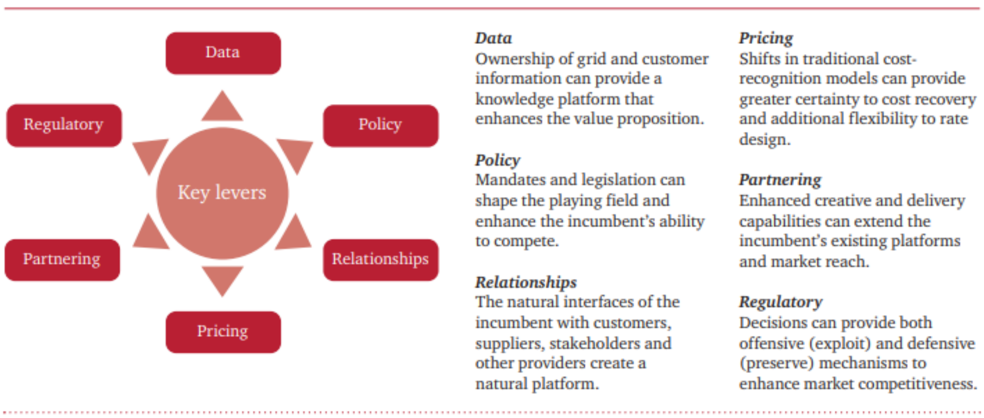

Figure 78. Future business model levers[iii].

Moreover, as highlighted by the Energy Union Strategy[iv], energy storage could play a crucial role in this energy transition, by enhancing the reliability, flexibility and security of the European energy industry. In addition, the combination of ESS with RES can help to significantly reduce the risks and impacts of climate change[v]. As a consequence, new relevant business models combining ESS and RES are emerging.

6.2 National policies and legislations vary from country to country

For many countries, renewables plus storage can represent a new way to reduce their dependence from energy imports, fill gaps in their generation mix, and to obtain a better environmental quality. Examples of European countries that have launched specific policies aimed at promoting battery adoption are UK, Spain, Italy, Germany and the Netherlands[vi]. In this regard, Table 34 proposes a summary of main pros and cons of energy storage national policies. analysed by the EU funded project Batstorm (2016-2018)[vii].

Table 34. Energy storage national policies (pros and cons)[vi].

Policies that encourage energy storage	Policies that do not encourage energy storage
No preferential remuneration for feeding into the grid PV generated electricity by households [Germany]	Subsidies and incentives for conventional energy generation
Policy support schemes for combining electricity storage with renewable energy [Germany]	Net metering[2]
Regulatory exemptions [Netherland - Electricity Law Experiments]	Unclear licences and unclear regulation [Spain]
No double counting of electricity used by storage[3] (and possibly even complete exemptions from grid charges) [Germany and UK]	De-rating of storage in capacity market auctions[4]
Limit to the minimum RES subsidies in times of negative prices[5]	Unstable policies and abrupt changes in the policy environment
Good access to ancillary services [UK - Enhanced Frequency Response]	
Domestic charge points for electric vehicles [Scotland initiative][6]	
Lower tax rates for energy clubs[7]	

6.3 Role of government-sponsored financial incentives to overcome high costs for energy storage issues

Despite energy storage can represent a proper solution for optimising energy production and consumption in presence of DER, ESS seems to be too expansive and the perceived high costs are a barrier for their adoption. However, many studies forecast decreasing costs trends and higher performances for the storage systems. According to IRENA[viii], the main technical factors that are likely to significantly influence Li-ion technology costs are: the increase in the scale of production capacity, improvements in materials, more competitive supply chains, performance improvements benefits of broader operating experience feeding back into product design and development. These drivers are not exclusive to Li-ion, and other storage technologies are likely to experience a similar dynamic as their deployment grows. However, the scale of deployment that Li-ion batteries are going to be orders of magnitude higher than for other battery technologies. This will result in significant cost reduction opportunities. As high costs are a barrier for ESS adoption, the availability of government-sponsored financial incentives could help to overcome this issue. The incentives can be a percentage of battery system costs refunded directly or through tax rebates, or capital support through grants or subsidised

[2] Net metering allows to feed electricity into the grid and receive the same amount back at a later point in time. While this might incentivise residential renewable energy generation, it discourages investments in energy storage.
[3] Currently often a levy applies while taking electricity from the grid and again after distributing energy from the storage.
[4] De-rating the capacity of batteries with a capacity to provide electricity up to 1 hour, without leaving enough time to develop new batteries which last longer, can send out the wrong signals to the developers. Hence, leading to fewer participants in capacity market auctions.
[5] Maintaining subsidies during negative price periods gives no incentive to install or develop storage capacity, but rather to rely on an oversupply of renewable energy.
[6] Scotland initiative that provides a fund £1,000 of the approximate £1,400 cost of installing a charge point at home.
[7] Lower energy tax rates for people who locally club together to generate energy from sustainable resources are worth considering

financing. These incentives appear to be particularly generous in countries that have energy security concerns, like for example Italy which offered a 50-percentage tax deduction for residential storage installations.

6.4 Lack of standardisation and national regulatory policy

Lastly, one of the main barriers for the development of the energy storage market is related to the fact that the sector is held back by a lack of standardisation. Clear, wide-ranging standards, in addition to a regulatory environment that recognises the significance of energy storage, are needed.
Standardisation could be particularly important to the proliferation of battery storage because of "balance of charge" issues associated with batteries.

On the other hand, also regulatory policy is lagging the energy storage technology that exists today. For example: many countries are working to update ancillary services market rules to support storage deployment. Moreover, also retail rules need to be updated, especially as residential and Commercial and Industrial (C&I) interest in energy storage systems grows.
Despite these issues at European level, some progress has been made in the last year. In this regard, recent normative has focused on flexibility and storage under the Clean Energy Package (CEP):

- **DIRECTIVE (EU) 2019/944**[ix] of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU (recast).
- **REGULATION (EU) 2019/943**[x] of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity.

This new normative introduces a new framework for a flexible system that considers: new actors; the role of energy storage in the electricity market as market based activity under competitive terms; a new role for TSO/DSO that can use and facilitate flexibility[8].

Another aspect is related to the standardisation of DC networks voltage level. There are several practiced levels between 48 and 800 V DC, however there is no clear definition for LV DC distribution voltage.

Finally, through the participation to international working groups (e.g., the "Low TRL Smart Grid & Storage Projects Clustering Initiative") and the discussion with experts coming from the industrial sector and members of the S4G External Stakeholder Group, it has been possible to bring to the fore some elements that policy makers that are going to outline the future energy sector policy context should consider. They are recapped as follows:

1. There are many opportunities leveraged by smart grid domain, however there is the need to understand how to take advantage from such opportunities and enhance the awareness of end-users that need to understand how smart grids applications could affect their everyday life.
2. Technologies play a crucial role in enabling new business opportunities:
    a. They are in place, but they need to be used in the right way.
    b. There is a gap in the technological competences, especially between users and suppliers that need to be covered.
    c. There is a need of integration and coordination between technologies.
    d. High capital investments required for some technologies could be a barrier for their adoption.
3. Smart grids are complex systems: their complexity needs to be managed with a particular focus on:
    a. Standards: there are many standards that need to be harmonised.
    b. Legislation: there are different legislations, different constraints on technologies between the countries.

[8] This topic was discussed during the SHAR-Q and S4G joint final event that took place in Brussels on 24th October 2019 with Mr. Kostas Stamatis member of the European Commission (DG-Ener) and reported in D7.5 [S4G-D7.5].

7 S4G Objectives Evaluation

Table 35 presents the M39 achievements of the S4G technical and strategic objectives (TO and SO) defined in the Description of Action (DoA).

Table 35. S4G measurable objectives.

Obj. #	Indicator	End of phase 3 Target	Phase 3 Status	Achievements/Description
TO1	Prototypes supporting S4G interfaces and Models for storage coordination	9	Achieved (9)	1. PROFESS 2. LESSAg 3. GESSCon 4. PROFEV 5. USM 5.1. ER Connector 5.2. Hybrid Inverter Connector 5.3. Extension connector for receiving grid-side storage services requests 5.4. Local technical GUI Connector 5.5. EV Connector 6. ER 7. DSF 7.1. DSF-DWH 7.2. Data Dispatcher 7.3. OGC Wrapper 7.4. DSO SCADA System Connector 7.5. DSO Grid Models Connector 7.6. DSO EV Connector 7.7. Geolocation Connector 7.8. Weather Forecast Connector 7.9. Energy Price Connector 7.10. PROFESS/PROFEV Solar Radiation Connector 7.11. ER Control Connector 7.12. LiBal System Control Connector 7.13. LESSAg Control Connector 7.14. HIL control Connector 7.15. DSF-SE Hybrid Simulator Connector 7.16. DSF Predictive Models Connector 7.17. DSF-EE 7.18. DSF-SE Hybrid Simulator Plug-in 7.19. DSF-SE 8. Residential GUI 9. Professional GUI
TO2	Sets of distributed and centralized storage control algorithms prototypes developed	9	Achieved (19)	**PROFESS:** 1. Predictive algorithm for minimizing power exchange with the grid 2. Predictive algorithm for minimizing energy cost

Obj. #	Indicator	End of phase 3 Target	Phase 3 Status	Achievements/Description
				3. Predictive algorithm for maximizing self-consumption 4. Predictive algorithm for minimizing power exchange with the grid including global control 5. Predictive algorithm for minimizing energy cost including global control 6. Predictive algorithm for maximizing self-consumption including global control **LESSAg:** 1. A local storage control algorithm for an advanced self-resilient prosumer which is not sending energy to the grid, thus becoming "UniRCon" (HLUC-1-PUC-2). 2. A storage control algorithm for prosumer based on PV production forecast in deciding the local battery schedule. 3. A storage control algorithm for prosumer with PV and local battery having available a 24 hours forecast for both the PV production and for the consumption. **GESSCon:** 1. Minimize energy cost (charge the distributed ESS when the market price of electricity is low due to high shares of renewables). 2. Prevent systems discharging to the neighbouring systems which charging is high and thereby prevent that it counteracts the grid stabilization. 3. Relief congestion in the grid by not pull/push power from/to the grid during peak demand hours. 4. Include battery cycle into consideration in order to prolong the battery operational lifetime. **PROFEV:** 1. Predictive stochastic algorithm for minimizing power exchange with the grid. 2. Predictive stochastic algorithm for minimizing energy cost.

Obj. #	Indicator	End of phase 3 Target	Phase 3 Status	Achievements/Description
				3. Predictive stochastic algorithm for maximizing self-consumption. 4. Predictive stochastic algorithm for minimizing power exchange with the grid including global control. 5. Predictive stochastic algorithm for minimizing energy cost including global control. 6. Predictive stochastic algorithm for maximizing self-consumption including global control.
TO2	Systems embedding S4G predictive control algorithms	3	Achieved (4)	1. PROFESS 2. PROFEV 3. GESSCon 4. LESSAg
TO2	Systems considered by the S4G predictive control algorithms	• Residential storage • DSO-side storage • EV charging stations	Achieved	• **Residential storage** (PROFESS, PROFEV): Bolzano, Fur/Skive • **DSO-side storage** (GESSCon): Bolzano, Fur/Skive **EV charging stations** (PROFEV): Bolzano
TO3	Test deployment of Unbundled Smart Meter prototypes	• Bucharest • Bolzano • Fur	Achieved	• Bucharest • Bolzano • Fur/Skive
TO3	Systems fully integrated with the unbundled smart meter	• Home (production and consumption) meters • Energy Router • Residential storage • EV home charging stations	Achieved	• **Home** (production and consumption) meters: Bolzano, Fur/Skive • **Energy Router**: Bucharest, Fur/Skive • **Residential storage**: Bolzano, Fur/Skive • **EV home charging stations**: Bolzano • EV charging stations in the commercial site: Bolzano
TO4	Test deployments of Energy Router prototypes	2	Achieved	• The three-phase ER was deployed in the Fur/Skive test site, as described in D4.11 [S4G-D4.11]. • The single-phase ER was deployed in the Bucharest test site, as described in D4.12 [S4G-D4.12].
TO5	Availability of DSF components	100 % of related specifications implemented	Achieved	The DSF was fully implemented, and their components described in the following deliverables:

Obj. #	Indicator	End of phase 3 Target	Phase 3 Status	Achievements/Description
				• **D5.2** [S4G-D5.2]: DFS-SE, DSF-EE, DSF-Hybrid simulator • **D5.5** [S4G-D5.5]: DSF-Connectors, DSF-DWH, OGC Wrapper, Data dispatcher • **D5.7** [S4G-D5.7]: DSF Predictive models, lifetime estimation algorithms
TO5	DSF Features supported	• Analysis by simulation • Optimization • Planning	Achieved	• **Analysis by simulation**: D5.2 [S4G-D5.2], D5.5 [S4G-D5.5], and D5.7 [S4G-D5.7]. • **Optimization**: PROFESS, PROFEV, GESSCon • **Planning**: DSF-SE, DSF-EE

TO6	Number of different cases evaluated in test sites Bucharest/Bolzano/Fur	6	Achieved (10)	**Bucharest**
				1. HLUC-1-PUC-1: Grid strengthening and ancillary services simulation
				  • S1: Handle over-generation of renewable energy sources on DSO-level (avoid curtailment)
				  • S2: Serving peak demands on DSO-level
				  • S3: Provide ancillary services (black-start) at DSO-level
				2. HLUC-1-PUC-2: Advanced self-resilient prosumer
				3. HLUC-1-PUC-3: Resilient hybrid cooperative ecosystem
				
				Bolzano
				1. HLUC-2-PUC-1: Residential prosumer with PV production and storage behind the meter
				2. HLUC-2-PUC-2: Parking place of a commercial test site with PV and EV charging stations
				3. HLUC-2-PUC-3: Simulating EV charging and storage behaviour, considering both public and residential charging stations
				
				Fur/Skive
				1. HLUC-3-PUC-1: Support for analysing storage dimensioning and positioning in the low-voltage grid
				2. HLUC-3-PUC-2: Autonomous control of storage installed at user premises and distributed in the grid

Obj. #	Indicator	End of phase 3 Target	Phase 3 Status	Achievements/Description
				3. HLUC-3-PUC-3: Voltage and flux control at grid side storage 4. HLUC-3-PUC-4: Coordinated Distributed storage in the grid Evaluation documented in D6.12.
SO1	Number of residential/professional users engaged in test sites	• 6 residential • 10 professional	Achieved (11+13)	• 11 residential users (granted to remain anonymous) • 10 professional users were involved in the overall process, 7 out of them were involved in the final evaluation of the professional GUI • Other 3 professional users were engaged in evaluation of resilient solutions of advanced prosumers
SO2	Number of Business cases proposed/evaluated	4	Achieved (14)	14 business cases were proposed, as described in D2.4 [S4G-D2.4]. 1. HLUC-1-PUC-1-S1: Handle over-generation of renewable energy sources on DSO-level (avoid curtailment) 2. HLUC-1-PUC-1-S2: Serving peak demands on DSO-level 3. HLUC-1-PUC-1-S3: Provide ancillary services (black-start) at DSO-level 4. HLUC-1-PUC-2: Advanced self-resilient prosumer 5. HLUC-1-PUC-3: Resilient hybrid cooperative ecosystem 6. HLUC-2-PUC-1-BM-1: Prosumer with ESS "stand-alone" (baseline) 7. HLUC-2-PUC-1-BM-2: Prosumer with grid integration 8. HLUC-2-PUC-2-BM-1: Cooperative Charging at Commercial or Fleet level 9. HLUC-2-PUC-3: Simulation of high penetration of EV chargers and of prosumers with storage and residential EV charging 10. HLUC-3-PUC-1-BM-1: Support for analysing storage dimensioning and positioning in the low-voltage grid 11. HLUC-3-PUC-2-BM-1: Autonomous voltage control at household battery 12. HLUC-3-PUC-3-BM-1: Voltage control at grid side battery

Obj. #	Indicator	End of phase 3 Target	Phase 3 Status	Achievements/Description
				13. HLUC-3-PUC-4-BM-2: Voltage control at both household and grid side battery and Energy Flux control at grid side battery 14. HLUC-3-PUC-4-BM-3: Flux control and load shaving at households with PV and battery
SO3	Number of complete techno-economic planning cases analysed using the DSF	4	Achieved (4)	Four scenarios were analysed and evaluated within the economic model implemented by the DSF-EE: 1. Scenario 0 (baseline): Grid strengthening without any storage system deployed along the grid. (HLUC-3-PUC-1-BM-1 was considered as the baseline scenario). 2. Scenario 1: Grid strengthening with different degree of decentralized household storage penetration (HLUC-3-PUC-2-BM-1 was considered as example). 3. Scenario 2: Grid strengthening with a storage system deployed by DSO at sub-station level (HLUC-3-PUC-3-BM-1 was considered as example). 4. Scenario 3: Grid strengthening with both decentralized household storage penetration and storage system deployed by DSO at sub-station level (HLUC-3-PUC-4-BM-2 was considered as example). Note that HLUC-3-PUC-1 and HLUC-2-PUC-3 allow to simulate all the scenarios. The complete detail about analysis and results are described in D7.8 [S4G-D7.8].
SO4	Number of inputs proposed to EU or regional policy-related, traditional or open standardization initiatives	4	Achieved (5)	1. IEC SyC LVDC/WG 1 - LVDC Standards for Electricity Access 2. IEC TC8/SC8B - Microgrids Part 3-3: Technical requirements 3. IEC TC8/JWG12 - Power frequency measurement for DER management 4. Romanian national legislation related to prosumer's connection to the main grid 5. Portuguese IEC TC57 collaboration Described in D7.6.

Obj. #	Indicator	End of phase 3 Target	Phase 3 Status	Achievements/Description
SO5	Number of inputs Lessons Learned, and recommendations published towards security- and privacy-related initiatives	2	Achieved	1. Cyber-security guidelines and policies for operating storage systems involving users data and preferences D8.1 [S4G-D8.1]. 2. Jira requirements (explained in D2.7 [S4G-D2.7]). 3. Lessons Learned for phase 1, 2, and 3 (D6.10 [S4G-D6.10], D6.11 [S4G-D6.11], D6.12), and in D2.7 [S4G-D2.7]). 4. Contribution to the knowledge base of ETIP SNET, by highlighting the security in future grids feature and privacy-related initiatives, also included in the publication (co-authored) 5. Data destruction indications documented in confluence

8 Summary of Phase 3 Lessons Learned

8.1 Summary of the LL collection and evolution process

The S4G Lessons Learned (LL) are being collected throughout the whole project to ensure a consistent enhancement of the overall project development. In general, the collection process consists of 6 steps:

1. **Collection**: Collection of LL is done with respect to both internal and external sources. Collection is organized per work package.
2. **Verification**: LL are verified regarding their correctness, significance, validity, and applicability by the respecting WP leader.
3. **Storage**: LL will be stored on the Confluence wiki page https://confluence.fit.fraunhofer.de/confluence/display/S4G/Lessons+Learned+Repository.
4. **Dissemination**: LL are reported in D2.5 [S4G-D2.5], D2.6 [S4G-D2.6], and D2.7 [S4G-D2.7]. All project partners are encouraged to consult the repository.
5. **Reuse**: WP leaders are responsible to consult the LL repository to take them into account at least before any major decision has to be made.
6. **Identification of improvement opportunity**: relevant LL will lead to new and/or updated requirements, which will be taken into account during the development cycle. Final requirements as well as LL are to be reported in D2.7 – "Final Lessons Learned and Requirements Report" (M30).

More detail about the LL collection and improvement process can be found in D6.10 [S4G-D6.10] as well as D2.5 [S4G-D2.5] and D2.6 [S4G-D2.6].

8.2 Brief Summary of LL from Phase 3

In the phase 3 of the project, the project's attention was on revisiting (WP2) business models and requirements and progress on (WP6) integration and evaluation of different systems produced by all partners. Therefore, the lessons learned in these WPs are higher in volume than others. This section briefly summarizes all the experience gathered in different WPs during the crucial final phase of the S4G project.

Upon retrospective analysis of business models and requirements, the software development model used in S4G is a mixed model: a traditional waterfall process with use-cases and scenarios; and an agile (SCRUM) method. Although such an approach is appropriate for interdisciplinary teams, it could cause concerns when all project partners do not adhere to follow the processes rigorously. Especially in the agile method, regular meetings and status updates are vital; however, when partners are uncomfortable in attending regular meetings and keep documentation of user need modifications, the development process gets hindered. An appropriate solution would be to choose one standard software development model and vigorously enforce the partners to follow it. Also, as every user need has to be documented, this creates a documentation overhead; instead, the documentation of issues should be short and meaningful while the issues must be discussed and monitored via agile discussions. Another important lesson learned during the phase of S4G is that when a project produces multiple technical assets, focussing on the end-users of such products in the earlier project phase would contribute to the success of the project. User needs and requirement gathering based on the target user group is vital before designing the technical requirements. Further, the user needs must be revisited and updated throughout the phase of the project. Another task-specific lesson learned in S4G is that futuristic scenarios, such as economic modelling, require specialized analyses of various scenarios, solid knowledge over technical aspects, legislation, and policies. Extensive studies of these futuristic scenarios would help to define efficient and reasonable hypothetical scenarios/proposals.

Regarding the S4G technical architecture, in phase 3, new microgrid architectures have been discovered and understood, which can complement the project's original AP architecture. In technical development (TRL 4-6), it is crucial to keep an open mind on new solutions. Based on theoretical analysis and simulation, microgrids by design were possible to be considered with added Solid-State Transformers, to allow high RES deployment and resilience. In S4G, these microgrids have been developed and reported in papers. Another lesson learned in the system architecture is that it is essential to provide in-depth details about vague/general concepts to provide accurate component specifications. Otherwise, components specifications might not match the real scenario as expected.

A lesson learned during the integration of ESS Control is that the REST API connectors must be standardized and agreed upon before implementation. During integration, different API endpoint format increases the complexity of the workflow.

During the research and testing phase of the DSF, the important lesson learned was the performance of the predictive models highly depends on the available data. Therefore, it is crucial to define the requirements for data availability, quality, etc. concerning the deployment to select the best strategy for data analysis. Also, the quality of predictions cannot be guaranteed if the research relies only on the project's dataset. A combination of available public or private dataset helps to improve the performance of predictions. Another lesson learned was that different components of the same module (DSF-SE and DSF-EE) might have different target users: DSF-EE users were responsible for investments. In contrast, DSF-SE users are interested in technical issues in the grid simulation. These discrepancies in interest must be noted in the earlier phase of the project so it can be tested appropriately.

In one of the vital phases of the project's, Integration and Evaluation, there were several valuable lessons learned. Due to the network issues faced at the end of the project, a valuable lesson learned is that the internet connection necessities must be forecasted and tested. In real-world settings, the data traffic might exceed the contractually expected limit (25 GB per month in S4G). Also, the internet connection might not be stable, especially in rural areas or areas with bad weather. Another location-based issue is that in winter, not enough sunlight is typical for northern countries; so, the test period should be planned better to have appropriate evaluation result. In project coordination, a lesson learned is that there must be close communication between the partners that use the same devices for different purposes. Different partners, the intentions, and the needs must be discussed before setting up tasks. Also, temporary workarounds must be averted in the initial project phase. Although these workarounds will lead to depend on temporary developments, finally it might complicate the process during integration. During the measurement of data from meters, a lesson learned is that accessing the main meter is legally hard, as it is not appropriate to interact with the main billing meter. A workaround would be installing another meter in series along with the main meter; however, this workaround is expensive and time-consuming; therefore, such installations must be planned accordingly in advance.

During the standardization, exploitation, and dissemination of S4G, a lesson learned is that several assets can be produced during the project phase, which can be exploited even after the end of the project. Some assets could be interesting for industries which undergoes profound changes due to technological advancements. Also, from the project phase, the two-digit long-term growth trend is forecasted, coupled with promising cost structure dynamics that may positively influence the future profitability of business operations. Exploiting this future trend of storage systems is advisable for economic opportunities. Besides, there are a few regulatory lessons learned in S4G. The changes in the regulatory environment are necessary for devising future developments; in some EU countries, the regulation does not permit for DSO to invest in the storage system. Also, the increasing role of the distributed storage system is crucial for developing a sustainable long-term strategy of storage deployment in the grid. These regulations must be further discussed in the future.

In the upcoming section, all the lessons learned from the phase 3 of S4G project are listed in tabular format.

8.3 LL from Phase 3

LL in S4G consist of the following information:

- **Category**: For categorizing the LL learned, classification codes are being used:
  - *RTD*: Research oriented
  - *PRO*: Process oriented
  - *SWD*: Software development experience
  - *ARC*: Architecture oriented
  - *NET*: Network oriented
  - *SEC*: Security oriented
  - *TST*: Testing result
  - *INT*: Integration experience
  - *VAL*: Validation experience
  - *REG*: Regulatory
  - *IWU*: Interaction with (end) user
  - *DIS*: Dissemination and Exploitation
- **S4G Partner**: abbreviation of the partner who experienced the LL.
- **Experience and Knowledge gained**: short description of the gained experience and knowledge that led to the final LL.
- **Lesson Learned**: One sentence describing what to do to not encounter a similar problem.
- **Analysis of Lesson Learned**: Further explanation of what went wrong and how to compensate or countermeasure the negative impact.
- **Requirement(s) affected**: Keys for affected requirements as they are collected in Jira.

The resulting LL are documented in tabular form as seen in Table 36.

Table 36. Reported LL for Phase 3 per WP.

Category	S4G-partner	Experience and knowledge gained	Lesson Learned	Analysis of Lesson Learned	Requirement(s) affected
WP 2					
PRO	LINKS	The requirements definition highly depends on components descriptions	It is important to keep updated the components description according to the latest architecture	Few requirements were not defined representing the actual status due to lack of components descriptions in the Jira tool	
PRO	LINKS	Agile method application for such dynamic research project may not be always an efficient approach	The defined user-stories should be splitted into very small but certain tasks.	Nature of such research projects that is interdisciplinary jobs and exploring new strategies and models, these	

Category	S4G-partner	Experience and knowledge gained	Lesson Learned	Analysis of Lesson Learned	Requirement(s) affected
				cause Agile less efficient.	
RTD	LINKS	Economic modelling for futuristic scenarios requires specialized analyses for various scenarios, and solid knowledge over technical aspects as well as legislations and policies	Many inputs for economic models and scenarios are not already considered by policy makers nor market	Broad studies help to define efficient while reasonable hypothetical scenarios and proposals.	
PRO	FIT	The maintenance of requirements/user needs to be less documentation-heavy and more practical / agile	Maintenance and elicitation should take few times and be as flexible as possible, following only a hand full of rules.	Partners were in denial of following the requirements elicitation and maintenance process since it was loaded with documentation rules	
PRO	FIT	SWE development and requirements elicitation process should be either agile (SCRUM) or waterfall, but not mixed	It is important to agree on a single process or mindset for both, requirements and software development	Volere requirements and SCRUM-like approaches are difficult to be matched which produces organizational overhead and inconsistencies in the documentation chain	
PRO	FIT	Technology-driven research projects should adopt the user-centric methodology as good as possible - at least on a high level of user needs and system features	User-centred approaches for technology improvement and research are a modern way of ensuring the applicability and usability of developed hard-	It is important that the necessity of involving users as one of the main drivers of system features is explained to and understood by all project partners - users	

Category	S4G-partner	Experience and knowledge gained	Lesson Learned	Analysis of Lesson Learned	Requirement(s) affected
			and software systems	are not a limiting factor for evolving ideas and advancing technology, but a very important source for motivation and requirements for future systems	
PRO	FIT	Agile software development is only beneficial if every partner is able to adopt and apply the necessary mindset and actively participating in the project and regular meetings	It is easy to restrain agile software development in interdisciplinary, international (EU research) projects	The development process can be blocked if partners are feeling uncomfortable with agile methods, are not willing to participate in regular meetings and are in general not keen in working in a fast and agile way	
PRO	FIT	The waterfall process and waterfall-ish methods like Volere Requirements are not flexible enough to adapt to unforeseen changes (law, technical limitations)	The chosen process needs to be able to support changes due to technical limitations or other reasons discovered later in the project.	Available infrastructure and hardware kept changing during the project; requirements could be adapted to reflect the new circumstances in the project goals because a mixed approach of Volere and SCRUM was used; however, this was not optimal.	

Category	S4G-partner	Experience and knowledge gained	Lesson Learned	Analysis of Lesson Learned	Requirement(s) affected
PRO	FIT	The user needs research in the beginning of the project needs more time than originally reserved for this task and needs to be kept alive over the project run time	The time needed for user research was underestimated	Several requirements kept being reworked throughout the project because there was no clear user need / reasoning for the feature described by the Volere Requirement. It was not possible to properly research	
PRO	FIT	High fluctuation in team members causes trouble because undocumented knowledge and targets get lost	A plan to tackle team member fluctuation needs to be established; knowledge needs to be documented in a format that sits all project members	High fluctuation in team members causes knowledge loss. This is especially painful if Requirements were formulated and the person taking the requirement over has no option to contact the original author to ask about his/her intentions	
WP 3					
ARC	UPB	New microgrid architectures have been discovered and understood, which can complement the project initial	In TRL 4 to 6 projects it is needed to have an open mind on new solutions.	Microgrids by design were possible to be considered with added Solid-State transformers, to	The initial advanced prosumer architecture is not affected but complemented with microgrid resilience features.

Category	S4G-partner	Experience and knowledge gained	Lesson Learned	Analysis of Lesson Learned	Requirement(s) affected
		advanced prosumer architecture.		allow high RES deployment and resilience. Theoretical analysis and simulation have been made and reported in papers.	
ARC	LINKS	An accurate definition of a system architecture and components specification depends on a clear identification of the provided services	It is important to provide more detail about vague/general concepts to provide accurate component specifications	Few components specification was not matching the real scenario	
ARC	UPB	There is no clear standard for the low voltage DC distribution, but more practice for different applications.	A flexible solution for the low voltage level needs to be possible, such that certain variations on the nominal voltage can be obtained through parameterisation of boost converters	It was shown that is possible to have more flexibility by design for boost converters, e.g. to support as nominal voltage on higher stage values between 350 and 400 V DC, thus covering a broader range of practical implementations.	
ARC	UPB	Islanded microgrids do not show the need of mechanical inertia of only inverter-based generators are used	The capacitor on the DC bus behind the inverters is responsible for dynamic stability in such grids	Extensive simulations were made, showing that the principle of electrostatic-energy based inertia is stabilizing such grids	No existing requirements were affected, however the findings, published in two peer-reviewed papers in Energies journal (reported in D7.3) may bring impactful new designs for microgrids, with specific requirements.

Category	S4G-partner	Experience and knowledge gained	Lesson Learned	Analysis of Lesson Learned	Requirement(s) affected
			WP 4		
INT	LiBal	REST API connector endpoints should have a standard to follow.	It is important to define and agree on a standard for the API endpoint format.	During integration, different API endpoint format increases the complexity of the work.	
			WP 5		
RTD	LINKS	The performance of the predictive models highly depends on the available data	It is important to define the requirements about data availability, quality, etc. with respect to the deployment in order to select the best strategy for data analysis	Few predictive models have not been evaluated using the data collected with the S4G project because data requirements were too high with respect to the deployment plans	
RTD	LINKS	external software could have hidden restrictions	The API of the load-flow solver software selected for Hybrid Simulation Plug-in, is still under development and does not cover all needed functionalities, while in windowing mode offers those one	For missing APIs, suitable and efficient implementation was possible thanks to COM interface and representative model definitions.	
RTD	LINKS	Choice of appropriate predictive models depends on the final destination of forecasts	Changes in forecasts' features, even though slightly, may require changing machine learning models completely.	Sticking to standard features helps to converge different actors and entities with various tasks.	
RTD	LINKS	Quality of predictions cannot be guaranteed	Particular predictive methods especially those applied to	combination of available public or private dataset helps to	

Category	S4G-partner	Experience and knowledge gained	Lesson Learned	Analysis of Lesson Learned	Requirement(s) affected
		relying only on project dataset	sequence models require far richer datasets, for wider time span, otherwise hardly reaches the minimum acceptable precision	improve performance of predictions.	
PRO	EDYNA	The SCADA system does not always provide the desired measurements	The SCADA system provides only MV measures, but the test site is located in LV grid. Furthermore, these measures are inaccurate, because they come from a protection system and not from a measurement system	An existing system not always provides the desired data. For specific purpose is better to a have a dedicated system.	
TST	LINKS	DSF-EE target users	DSF-EE and DSF-SE have different target users	DSF-EE results are addressed to decision makers (responsible for investments), while DSF-SE results are addressed to grid planning managers (interested in technical issues)	
TST	LINKS	DSF-EE optimal simulation time horizon	DSF-EE and DSF-SE have different optimal simulation time horizons	DSF-EE results allow to evaluate the profitability of an investment in ESS. In this case, it is reasonable to select an optimal simulation time horizon equal to the ESS lifetime (one or two	

Category	S4G-partner	Experience and knowledge gained	Lesson Learned	Analysis of Lesson Learned	Requirement(s) affected
				decades). DSF-SE results regard the technical grid features, have to be analysed with a maximum time horizon of 1 year.	
WP 6					
INT	UPB	It should be a close communication between the partners that use the same devices for different purposes.	Mention the intentions and the needs that we have before acting.	Putting different software on the same device can cause problems, if the situation is not closely monitored and controlled. For example, SMXs created some internal files that in very short time occupied almost the entire memory of the SD card, making impossible to store the recorded data.	
NET	UPB/EDYNA/ALPERIA	When you are working with real-time data collection, you have to test before the internet connection for such kind of applications.	That a simple internet router/ internet connection/ internet provider can be very important for the project deployment.	Because the accessibility to the residential test site was limited, some project tools cannot be tested in time (PROFES) and data collection became difficult. A partial mitigation is based on local daily records on the SMX SD card, which can be	

Category	S4G-partner	Experience and knowledge gained	Lesson Learned	Analysis of Lesson Learned	Requirement(s) affected
				used for tests with real data.	
PRO	UPB	In a research project it cannot be guaranteed full time acquisition, as the equipment is a flexible solution for research, upgrades and restart are frequently needed, remote communication problems are usual and unforeseen is also a disturbing factor	We should be willing to find & implement tolerant, thus also robust solutions which allow to run applications in a partial acquisition environment.	For example, UPB needed to create MEDAS & PROSIT software in order to fill the gaps in data collection (missed by various reasons) with predicted values, based on similarities with acquired daily records.	
TST	UPB	Following the ER deployment in UPB test site we realized that more useful measures can be needed from ER device.	It is recommended to look for all the outcomes of a deployment and not only for the planned ones in order to deliver better results.	Uninova made available for SMX some internally read by Arduino measures. Then the partner tested the update remote, assisted by UPB.	
RTD / SWD	UPB	Estimating SoC is a challenging task	Estimating SoC for small lead-acid batteries is challenging by using Coulomb and voltage-based calculation	Additional criteria may be needed for commercial purposes, using also in future more data, e.g. obtained from impedance spectroscopy	
SEC / SWD	UPB	OpenVPN used for cyber-security reasons is crushing sometime	OpenVPN is not stable in some situations	Scripts for supervising VPN may be needed, with the purpose to restart OpenVPN when it crushes	

Category	S4G-partner	Experience and knowledge gained	Lesson Learned	Analysis of Lesson Learned	Requirement(s) affected
SEC / SWD	UPB	Use in SMXcore of different MQTT clients makes possible security and privacy measurements	SMXcore has a proper approach for controlling MQTT messages for implementing security measures	For increasing security and privacy it is possible to implement various MQTT broker solutions.	
INT / VAL	UPB	Protection of DC grid is a challenging task	A special focus on protection and in-rush currents in the DC grid is needed in future works	Additional coils for reducing di/dt at boost converter level shown to be useful for scope.	
SWD	LINKS	Temporary solution must be avoided or replaced during initial project phases	It is important to adopt a solution that does not depend on temporary developments	Few solutions were approached assuming the highest risk	
PRO	LINKS	An efficient pilot management depends on a precise deployment plan	It is important to consider a draft analysis of the software behaviour with respect to available hardware	Few software was requiring too many resources with respect to the available hardware	
NET	EDYNA	Before activating an internet connection, it is necessary to evaluate the data traffic that will be necessary	It is not nice to activate an internet connection and discover that this is a data traffic of over 25 GB per month, much higher than contractually expected	The correct evaluation of the resources necessary for a project or a new work is a necessary requirement for the success of the same	
NET	EDYNA	In the real world the internet connection is not always stable, especially in rural areas and with bad weather	Sometimes in the residential test site, located in a rural area, internet access is not available, especially in bad weather	The stability of the internet connection cannot be a requirement for the success of the project. A stand-alone operation must	

Category	S4G-partner	Experience and knowledge gained	Lesson Learned	Analysis of Lesson Learned	Requirement(s) affected
				be provided for situations where the data connection is not available	
PRO	EDYNA	When installing equipment, it is necessary to have all the necessary tools and ask first if there is what is necessary at the place of installation	The works may be delayed due to setbacks that could have been foreseen (for example, lack of internet connection)	Better work planning can avoid annoying setbacks	
IWU / PRO / VAL	FIT	Software and hardware evaluation based solely on the requirements as well as technical functionality is not sufficient for a product involving end-users	Software and hardware components should always be tested in collaboration with actual end-users if applicable results are expected	Functional tests or software driven tests do not replace user-based testing and evaluation of the overall system. If a system does work from the technical point of view but is difficult to use and understand for end-users, it will not be used at all.	
IWU	Eniig	Getting data from the main (billing) meter is not possible with direct access.	We were not allowed to interact with the billing meter, because it would give us access to setting up / changing the meter	We decided instead to install another meter in series with the billing meter	
IWU	Eniig	Installing another meter in series with the billing meter	This solution raised other problems. a) There was not room in the board. b) we needed to interrupt the entire building, which was	The solution was to install a meter in the sub-board where the ER is installed and receiving setpoints from this board, which	

Category	S4G-partner	Experience and knowledge gained	Lesson Learned	Analysis of Lesson Learned	Requirement(s) affected
			not allowed due to main servers for fibre broadband customers. c) the billing meter is a transformer meter, which was very expensive to install, due to the above issues.	will not be very different from the main board.	
TST/RTD	LiBal	Not enough sunlight (solar production) to charge the battery energy storage system in order to perform voltage support in the grid	Not enough sunlight in the wintertime is typical for Northern country. Test period should be planned better in order to have result for evaluation.	The functionality of the voltage support algorithm could be evaluated by using the grid power. However, this cannot last long, since it does not benefit the battery owner.	
IWU/REG	LiBal	No regulation on research project use-case.	There is no regulation on voltage support in LV grid. It is necessary to agree with the battery owner to perform the use-case when the outcome may impact one's profit.	It was agreed to perform a shorter test in order to extract result.	
WP 7					
EXPL	LINKS	Several exploitable outputs with different TRLs and time-to-markets strategies were developed	Outputs can be exploitable after the end of the project	Dataset, DSF, Energy Router, GESSCon, Professional User	
DIS	LINKS	Open source licences of some assets	A further deep evaluation of these licenses should be done in the next upcoming months	The assets generated will be released mostly through open source licenses in order to	

Category	S4G-partner	Experience and knowledge gained	Lesson Learned	Analysis of Lesson Learned	Requirement(s) affected
				maximise the reuse potential and to reflect the role that public funding played in their development	
DIS	LINKS	Development of a DSF-EE (economic engine)	Decision maker support system for long term investment analysis	The DSF-EE (economic engine) asset was developed and it should be considered by Partners for the final exploitation strategy as a strategic asset useful for decision makers economic analysis	
DIS	LINKS	Industrial interest of S4G assets	S4G addresses an industry and an international context undergoing profound changes	Such change represents a great opportunity that VCs and incumbents alike are trying to seize through conspicuous innovation investments	
DIS	LINKS	Expected future growth for storage systems	Exploit the future trend of storage systems is advisable for economic opportunities	Two-digit long-term growth trend is forecasted coupled with promising cost structure dynamics that may positively influence the future profitability of business operations	

Category	S4G-partner	Experience and knowledge gained	Lesson Learned	Analysis of Lesson Learned	Requirement(s) affected
DIS	LINKS	Future trend of storage pricing	Decreasing of future storage prices represents a necessary condition for higher profitability and investment opportunity	It can generate a great opportunity for stakeholders with interest in investing in storage system that today are not so profitable. Danish and the Italian markets show a short-term situation of limited economic sustainability mainly due to current regulatory incentives and constraints coupled with significant costs of storage equipment	
REG	LINKS	Regulatory open issues	Changing in regulatory environments is needed	In some EU countries the regulation does not permit for DSO to invest in storage system	
REG	LINKS	Increasing added value of the distributed storage	Increasing role of the distributed storage system is crucial for developing a sustainable long-term strategy of storage deployment in the grid	The role of distributed storage appears to be pivotal in solving some of the key challenges that the transition to a new energy paradigm is going to pose due to the diffusion of renewable sources of energy generation as well as self-	

Category	S4G-partner	Experience and knowledge gained	Lesson Learned	Analysis of Lesson Learned	Requirement(s) affected
				consumption patterns	

9 Conclusions

This deliverable summarizes the phase 3 evaluation in all the three S4G test sites (Bucharest, Bolzano, and Fur/Skive), resulting from the evaluation activities performed during phase 3, as defined in the planned evaluation framework and its KPIs (D6.3 [S4G-D6.3]).

Each HLUC evaluation results are presented in their sections, were good results were achieved and some lessons learned identified. The S4G environmental impacts were presented, with S4G HLUCs targeting a higher RES production and its local mitigation, supporting also a higher EV penetration with minimum impact on the grid. Policy and regulations play a crucial role in the future energy sector, however national policies and legislations are different from country to country, and there is lack of standardisation and regulatory policy. The government is a key factor in financial incentives to overcome the high ESS costs.

The final S4G objectives were successfully evaluated and their description is detailed. The phasal lessons learned are also presented and were a very important tool since they enabled the learning iterative process that supported the S4G phase planning.

This is final issue of this deliverable, considering the final evaluation framework and KPIs and taking into account both technical and economic aspects of the HLUCs and business cases defined in the project.

Acronyms

Acronym	Explanation
AC	Alternating Current
AP	Advanced Prosumer
API	Application Programming Interface
ASRP	Advanced Self-Resilient Prosumer
BC	Business Case
BESS	Battery Energy Storage System
BM	Business Model
BMS	Battery Management System
C&I	Commercial and Industrial
CAISO	California Independent System Operator
CaPex	Capital Expenditure
CEP	Clean Energy Package
DC	Direct Current
DoA	Description of Action
DOD	Definition of Done
DSF	Decision Support Framework
DSF-DWH	Decision Support Framework Data Warehouse
DSF-EE	Decision Support Framework – Economic Engine
DSF-SE	Decision Support Framework Simulation Engine
DSO	Distribution System Operator
EPRI	Electric Power Research Institute
ER	Energy Router
ESS	Energy Storage System
EU	European Union
EV	Electric Vehicle
GDPR	General Data Protection Regulation
GESSCon	Grid-side Energy Storage System Control
GUI	Graphical User Interface
HIL	Hardware-in-the-Loop
HLUC	High-Level Use-Case

Acronym	Explanation
KPI	Key Performance Indicator
LESSAg	Local Energy Storage System Agent
LL	Lessons Learned
LV	Low Voltage
MPPT	Maximum Power Point Tracking
MQTT	Message Queuing Telemetry Transport
MS	Milestone
MV	Medium Voltage
OpEx	Operating Cost
PCC	Point of Common Coupling
PROFESS	Professional Real-time Optimization Framework for Energy Storage Systems
PROFEV	Professional Real-time Optimization Framework for Electric Vehicles
ProSiT	Profiles Similarity Tool
PUC	Primary Use-Case
PV	Photovoltaic
RES	Renewable Energy Sources
REST	Representational State Transfer
RMS	Root Mean Square
ROI	Return of Investment
RPi	Raspberry Pi
S4G	Storage4Grid
SaaS	Storage as a Service
SMX	Smart Meter eXtension
SO	Strategic Objectives
SoC	State of Charge
SUS	System Usability Scale
TO	Technical Objectives
TRL	Technology Readiness Levels
UniRCon	Unidirectional Resilient Consumer
USM	Unbundled Smart Meter
UX	User Experience

Acronym	Explanation
VPN	Virtual Private Network
WP	Work Package

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References

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Appendix A S4G qualitative evaluation

This qualitative evaluation is a summary of the information available on D7.5 [S4G-D7.5].

S4G business cases clusters

The business case clusters were defined with the objective of synthetically representing S4G business cases considering their scopes. These clusters were identified by LINKS analysts and discussed with the Consortium during the project physical meeting on October 24th, 2019. The main goals of S4G business cases can be described as follows:

A. ESS positioning and dimensioning.
B. Services for the prosumers.
C. Voltage / load flow optimisation.
D. Energy community.

Figure 79 provides a brief overview on the four clusters.

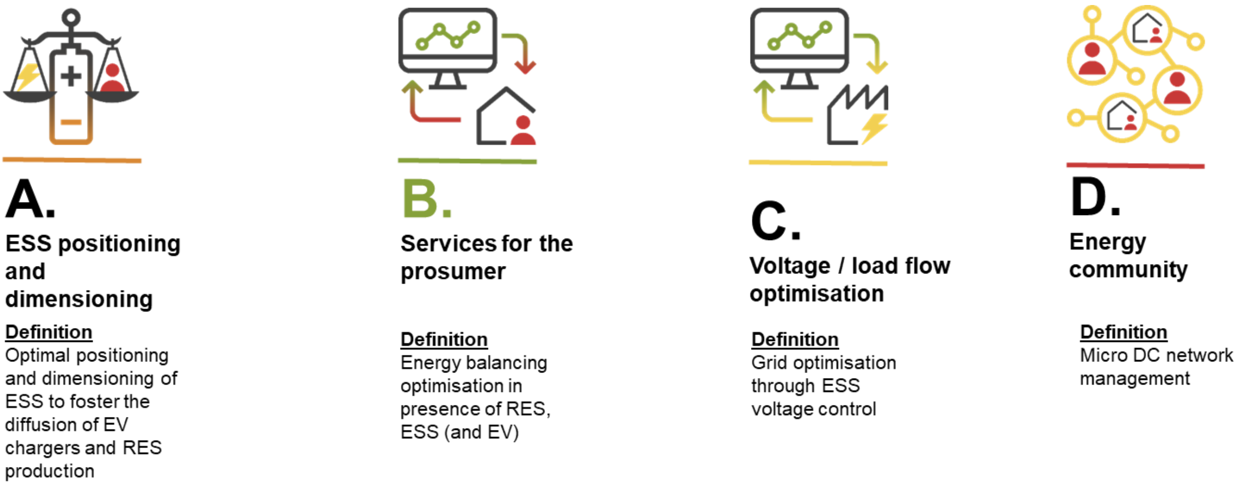

Figure 79. S4G business cases clusters.

Hereafter a more detailed description of the clusters and the cases is provided.

Cluster: ESS positioning and dimensioning - *Optimal positioning and dimensioning of ESS to foster the diffusion of EV chargers and RES production*

The first cluster includes the business cases that offer to the DSO the possibility to understand the optimal positioning and dimensioning of ESS to be placed in the grid to foster the diffusion of EV chargers and RES production. Two situations are considered: (a) the presence of ESS at prosumer and / or at grid level; (b) the possibility for the DSO to place ESS in the grid and its ideal location.

Cases to be included:
1. ESS placed at prosumer and / or grid level
- HLUC-2-PUC-3.
- HLUC-3-PUC-1-BM-1 (Figure 80 shows its value proposition canvas).

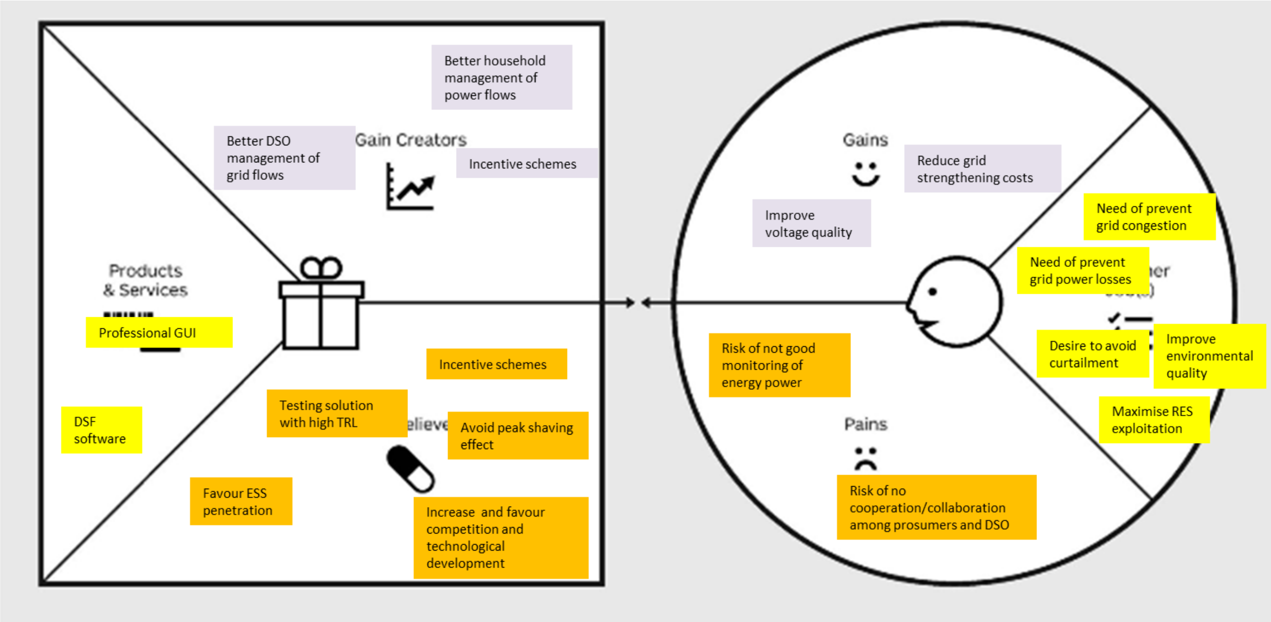

Figure 80. HLUC-3-PUC-1-BM-1: Value proposition canvas (DSO point of view).

2. ESS placed at grid level, owned by the DSO
- HLUC-3-PUC-3-BM-1 (Figure 81 shows its value proposition canvas).

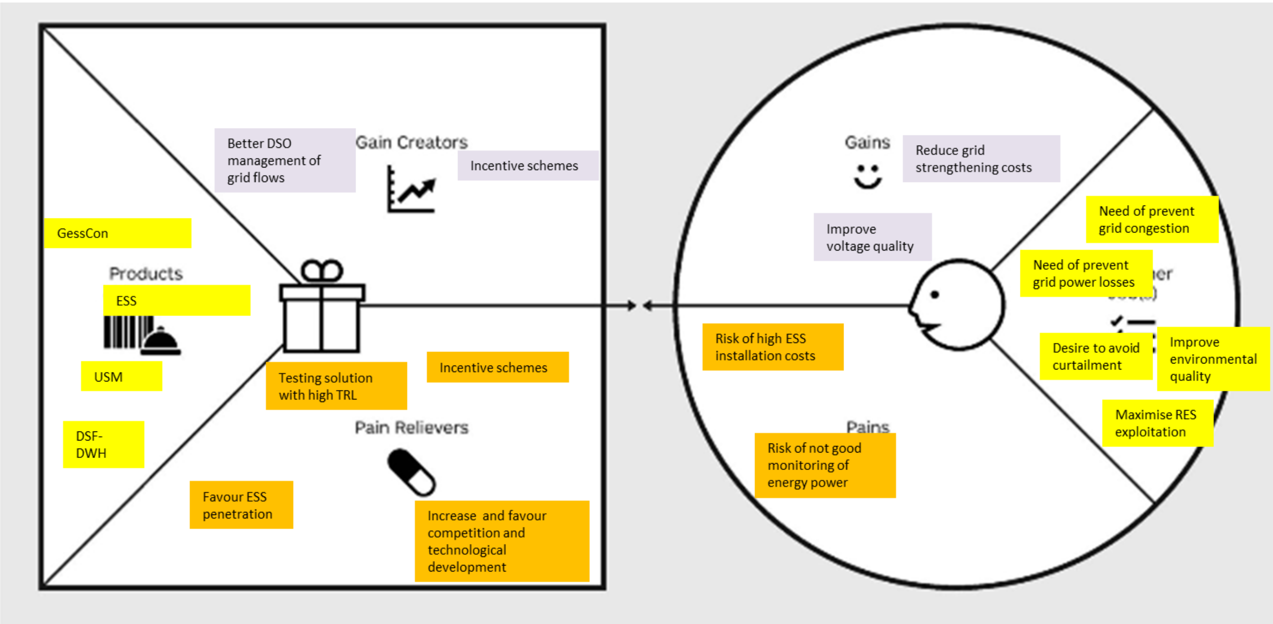

Figure 81. HLUC-3-PUC-3-BM-1: Value proposition canvas (DSO point of view).

Cluster: Services for the prosumer - *Energy balancing optimisation in presence of RES, ESS (and EV)*

The second cluster focuses on the prosumer and includes the BCs that allow the prosumers to optimise their energy consumption and production in presence of RES, ESS (and EV). These business cases demonstrate if it is profitable for prosumers to install ESS in connection to their local PV production and/or EV charging.
The DSO can indirectly benefit from the installation of ESS at prosumer level, because he can defer traditional grid strengthening.

Cases to be included:

- HLUC-1-PUC-2-BM-1
- HLUC-2-PUC-1-BM-1
- HLUC-2-PUC-2-BM-1 (Figure 82 shows its value proposition canvas).

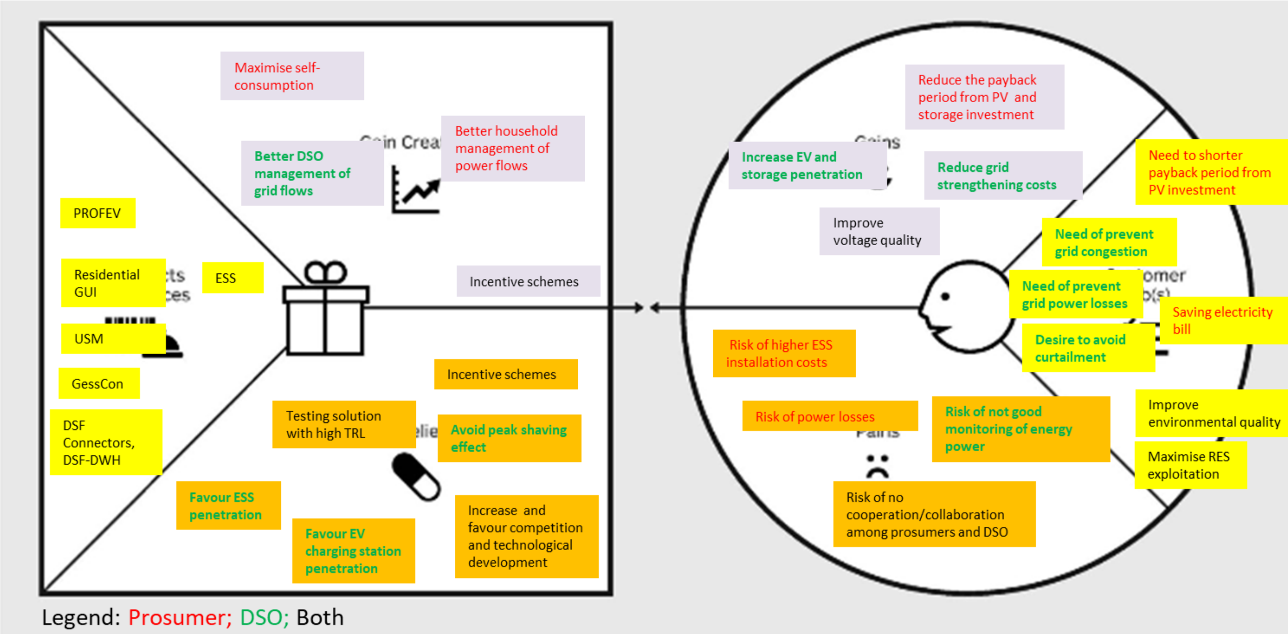

Figure 82. HLUC-2-PUC-1-BM-1: Value proposition canvas (prosumer and DSO point of view).

Cluster: Voltage / load flow optimisation - *Grid optimisation through ESS voltage control*

The third cluster considers solutions of grid optimisation through ESS voltage control. In these business cases ESS at prosumer level are controlled by the DSO that can better manage ESS charging, voltage issues and load flow. Prosumers can make business by offering ancillary services to the DSO. In these cases, an external aggregator can manage ancillary services.

Cases to be included:

1. ESS placed at prosumer and grid level
   - HLUC-1-PUC-1-S1.
   - HLUC-3-PUC-4-BM-2 (Figure 83 shows its value proposition canvas).

2. ESS placed at prosumer level
   - HLUC-1-PUC-1-S2.
   - HLUC-2-PUC-1-BM-2.
   - HLUC-3-PUC-2-BM-1 (Figure 83 shows is value proposition canvas).
   - HLUC-3-PUC-4-BM-3.

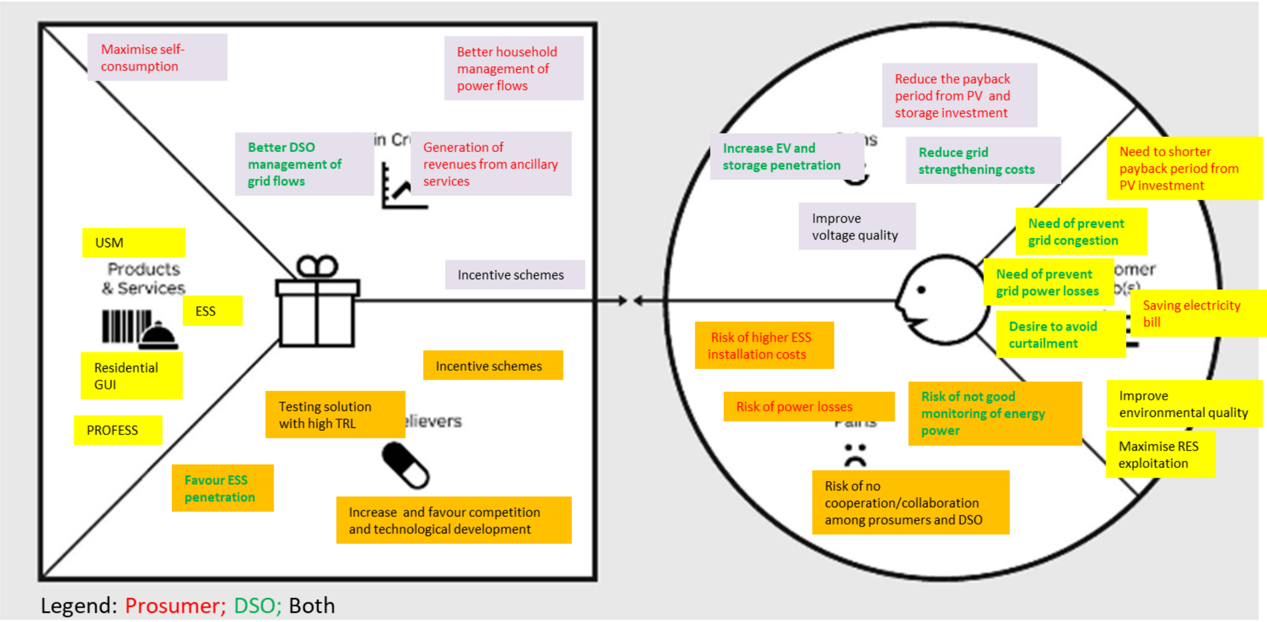

Figure 83. HLUC-3-PUC-4-BM-2 and HLUC-3-PUC-2-BM-1: Value proposition canvas (prosumer and DSO point of view).

Cluster: energy community - *Micro DC network management*

The last cluster is an example of micro DC network management. This case considers a local grid in which prosumers can consume their RES production and / or together with their neighbours, by using a cooperative energy control.

Cases to be included:

- HLUC-1-PUC-3-BM-1 (Figure 84shows is value proposition canvas).
- HLUC-1-PUC-1-S3

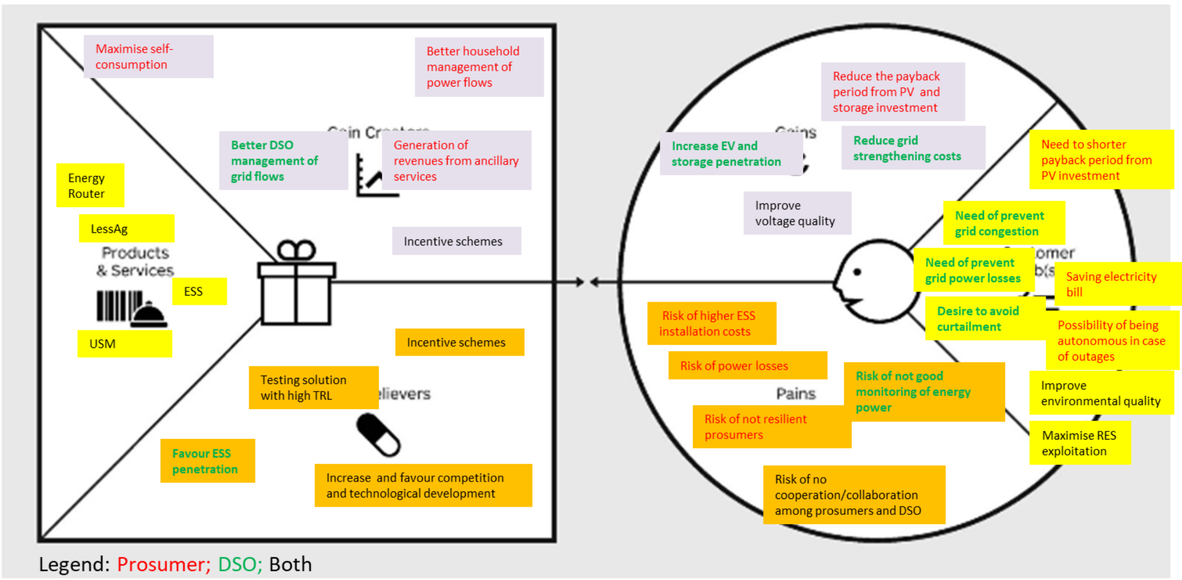

Figure 84. HLUC-1-PUC-3-BM-1: Value proposition canvas (prosumer and DSO point of view).

Underlying business models

The analysis of the business cases that was conducted in D2.4 [S4G-D2.4] and refined in D7.5 [S4G-D7.5] through the definition of the business cases clusters allowed to discover that **business cases within the same cluster have similar business models**. Moreover, from the analysis of existing studies on business models for DER it was possible to define six general business model archetypes for distributed energy sector. They can be taken in consideration by any subject interested in developing new initiatives in the sector, and, consequently, are also aligned with S4G business cases. Specifically, S4G business cases can be described by three of the six archetypes (Figure 85):

1. ESS at prosumer level integrated in the grid.
2. ESS at prosumer level standalone.
3. ESS owned by the DSO.

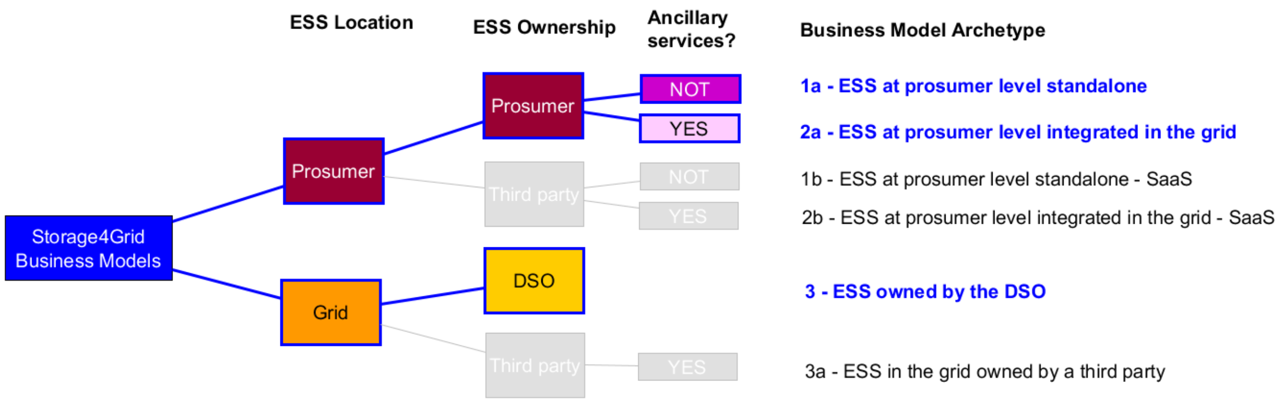

Figure 85. Business models archetypes for S4G business cases.

The main features of the business models' archetypes underlying S4G business cases are followed described.

BM archetype 1a

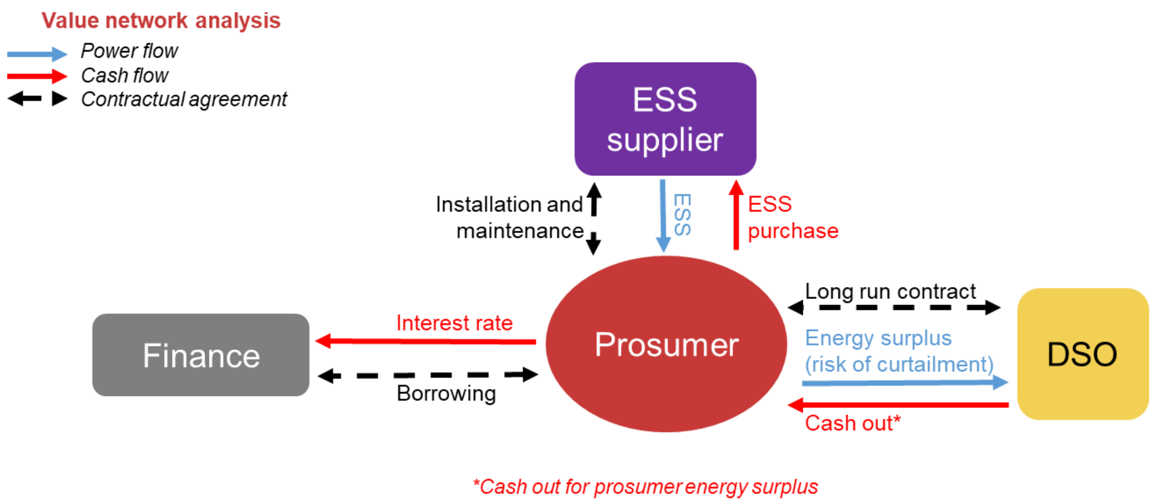

Figure 86. BM archetype 1a: Value network analysis[9].

[9] Cash out for energy surplus can be managed by the TSO, like in the case of Denmark

Table 37 summarises the main revenues and costs for the key stakeholders.

Table 37. BM archetype 1a: Main revenues and costs for key stakeholders.

Stakeholder	Revenues	Costs
ESS supplier	ESS sale (from prosumer) ESS installation + maintenance (from prosumer)	
Prosumer	Cash out for energy surplus (from DSO) Savings in the electricity bill from optimal energy consumption / production management	ESS purchase ESS maintenance
DSO	Savings from avoiding grid strengthening and reduced curtailment risk	Cash out for prosumer energy surplus (to prosumer)

BM archetype 2a

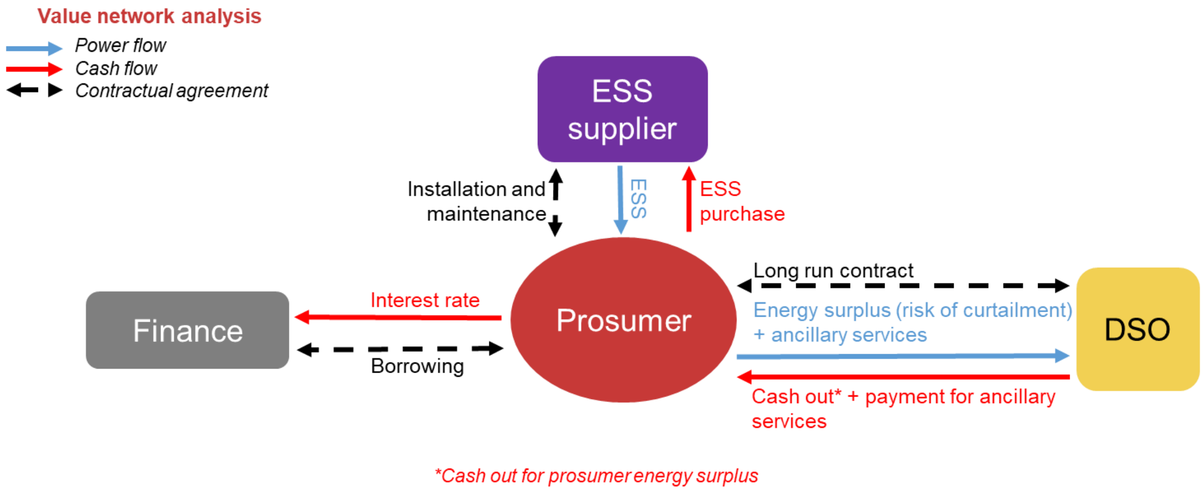

Figure 87. BM archetype 2a: Value network analysis.

Table 38 summarises the main revenues and costs for the key stakeholders.

Table 38. BM archetype 2a: Main revenues and costs for key stakeholders.

Stakeholder	Revenues	Costs
ESS supplier	ESS sale (from prosumer) ESS installation + maintenance (from prosumer)	
Prosumer	Revenues from ancillary services (from DSO) Cash out for energy surplus (from DSO)	ESS purchase ESS maintenance
DSO	Savings from avoiding grid strengthening and reduced curtailment risk	Payment for ancillary services (to prosumer) Cash out for prosumer energy surplus (to prosumer)

BM archetype 3a

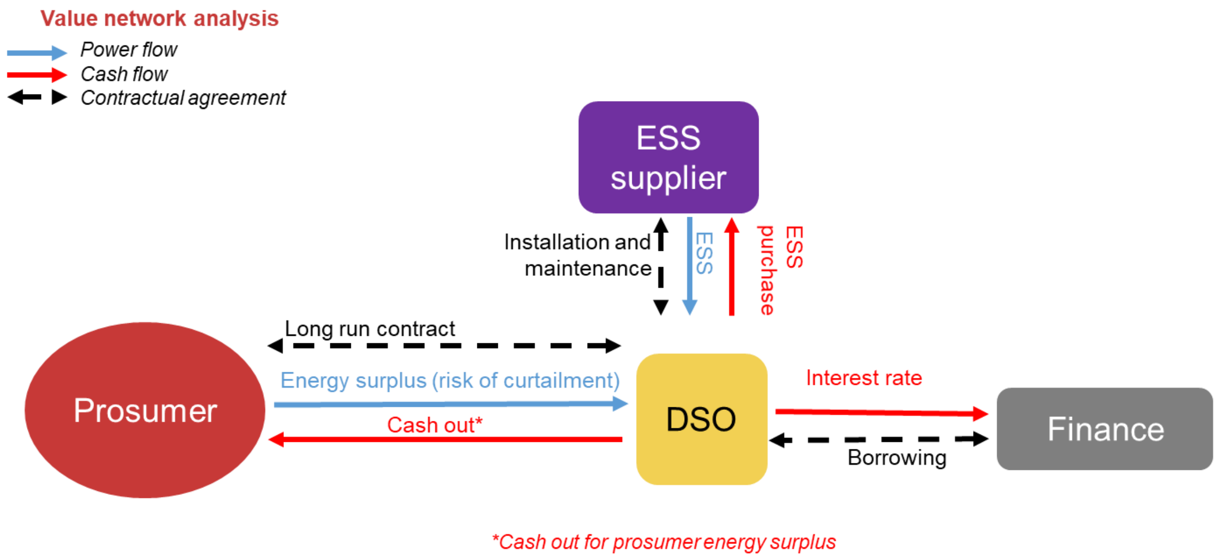

Figure 88. BM archetype 3a: Value network analysis.

Table 39 summarises the main revenues and costs for the key stakeholders.

Table 39. BM archetype 3a: Main revenues and costs for key stakeholders.

Stakeholder	Revenues	Costs
ESS supplier	ESS sale (from DSO) ESS installation + maintenance (from DSO)	
Prosumer	Cash out for energy surplus (from DSO)	
DSO	Savings from avoiding grid strengthening and reduced curtailment risk	Cash out for prosumer energy surplus (to prosumer) ESS purchase ESS maintenance

To summarise, the analysis showed that:

- For the business cases that consider the presence of ESS at prosumer level, BM archetypes 1 and 2 can be appropriate, with a distinction:
    - The BCs within the cluster "services for the prosumer" focus exclusively on the end-user self-sustainability, and do not consider an integration in the grid (no ancillary services). As a consequence, the most appropriate BM archetype for these business cases is 1a.
    - The BCs within the clusters "energy community" and "voltage load flow optimisation" envisage the possibility to offer ancillary services to the DSO. In these cases, the most adequate BM archetype is 2a.
- BM archetype 3a, is suitable for the unique case that considers the ESS ownership by the DSO (HLUC-3-PUC-3-BM-1).
- HLUC-3-PUC-1-BM-1 and HLUC-3-PUC-4-BM-2 are simulation tools that offer to the grid planning manager the possibility to evaluate different grid configurations. In these two situations, the grid planning manager is able to determine an optimal grid configuration and, afterwards, can consider the most appropriate business model archetype accordingly with the grid configuration designed.

The alignment between the business cases within each BC cluster and the business model archetypes is reported in Table 40.

Table 40. Business model archetypes underlying S4G business cases clusters.

Cluster	ESS location category	Ancillary services	Exemplary business case	BM archetype	Notes
ESS positioning and dimensioning	Prosumer and / or grid	Not relevant	HLUC-3-PUC-1-BM-1	Any[10]	Simulation[11]
	Grid level	/	HLUC-3-PUC-3-BM-1	3a	ESS owned by DSO
Services for the prosumer	Prosumer	No	HLUC-2-PUC-1-BM-1	1a	Or 1b if ESS is owned by third party
Voltage / load flow optimisation	Prosumer and grid	Yes	HLUC-3-PUC-4-BM-2	2a, 3a	Simulation[11]
	Prosumer	Yes	HLUC-3-PUC-2-BM-1	2a	Or 2b if ESS is owned by third party
Energy community	Prosumer	Yes	HLUC-1-PUC-3	2a	Or 2b if ESS is owned by third party

[10] This BC allows the DSO to understand where to place ESS in the grid. Depending on the optimal solution any business model archetype can be taken in consideration.

[11] Simulation that consider different grid configurations. Different options of ESS ownership and ESS location can be evaluated afterwards.