Energy Local Storage Advanced system

D6.3 Results of service evaluation

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Executive Summary

The ELSA project has worked at developing a 2nd life storage system solution using electric vehicle battery. This solution has been developed and have led to three storage system version (DT3, DT4 and DT5).

On the frame of the ELSA project, Storage solution, ICT platform have been developed and installed on 6 pilot sites in Terni (IT), Ampère building (FR), NISSAN office (FR), Aachen University (GER), Kempten (GER) and SASMI building (UK). Each of those test site have experimented different use cases defined during the project. Those different test site condition offer a various set up for use case evaluation, a strong point of the overall project. Through this diversity, a particular attention have been done on site description to give as much reference as possible to the reader.

The aim of the ELSA project is to test those use cases on real conditions with a storage system, an Energy Management System, Renewable energy sources and eventually flexibility sources. Each of the test site have tested various services, from service to the DSO, service to the building to service to district. Experiments aim at evaluate service performance on different test condition. This is done through the document by using a Key Performance Indicator method and described on annex of this report. Along the ELSA project, common KPI through the test site have been selected, Power KPI, Energy KPI, Cost KPI, and CO2 KPI.

For each couple use case and KPI, a target value is calculated in order give a reference to each value obtained and enable a critical eye on the results obtained. This value is not necessary reachable and can be ideal value depending on the use case, that is the reason why, a particular attention is given to this target value calculation.

Through the document, each pilot site present his experiment results and service evaluation, describing method and analysis. One key point of the document is analysis of results obtained and a particular attention on the lesson learned by each site. Real condition operation can lead to various kind of results which make those test strongly valuable.

At the end of this report, the overall ELSA environment performance has been demonstrated through the valuable results obtained on use cases experimented. Those results show the consistency of the overall solution and the potential of those kind of solution on environment improvement. The economic and environmental impact of the ELSA solution is fully described on another deliverable of the project (WP5).

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List of Acronyms and Abbreviations

ELSA	Energy Local Storage Advance
WP	Work package
DT	Technical definition
KPI	Key Performance Indicator
UC	Use case
DSO	Distribution System Operator
EBMS	ELSA Building Management System
EEMS	ELSA Energy Management System
ESMS	ELSA Storage Management System
EV	Electric Vehicle
PV	Photovoltaic
EDEMS	ELSA District Energy Management System
BoEU	Block of Energy Unit
HQE	High Quality Energy
BREEAM	Building Research Establishment Environmental Assessment Method
HEX	Heat Exchanger
VEP	Visually Envoked Potential
FCU	Fan Coil Unit
VSD	Variable Speed Drive
DHW	Domestic Hot Water
BMS	Building Management System
DR	Demand Response
EPTS	Energy Purchase Time Shifting
SOC	State Of Charge

Preface

The ELSA project aim at developing innovative energy solution integrating 2nd life batteries storage system. It consists in 6 pilot sites over Europe experimenting those solutions.

Over the ELSA project, The ELSA storage system has been developed on the WP2 frame. Starting from one existing version (DT3), two higher versions have been developed and installed on the different pilot site (DT4 and DT5). The work done on the design of storage solution end on TRL9 storage system solution (DT5).

Test site		Terni	Ampere	NISSAN	Aachen	Kempten	Sunderland
Test site type		District	Office	Office	Commercial district	Residential district	Office
Consumption		665 MWh/y	1460 MWh/y	3300MWh/y	1577 MWh/y	124 MWh/y	876 MWh/y
Generation	Power installed	240 kWp	60 kWp	-	500kW	37.1 kWp	50 kWp
	Annual production	305 MWh	65.5 MWh	-		40.5 MWh	54.6 MWh
ELSA Battery	Storage version	DT4	DT3	DT5	DT3	DT3	DT3
	Available energy	66 kWh	22 kWh	132 kWh	66 kWh	66 kWh	33 kWh
	Charging power	72 kW	6 kW	144 kW	18 kW	18 kW	9 kW
	Discharging power	72 kW	24 kW	144 kW	72 kW	72 kW	36 kW

Table 1: Test site information

The Table 1 summarizes the different storage system installed. It has to be noticed that in Ampère and Aachen, A final storage system version has been installed and the final capacity are:

- 88kWh and 96kW on both side for Ampere
- 66kWh and 72kW on both side for Aachen

This table summarizes as well the test site information like production or the consumption of the test site. These information are important to understand the different KPI values details and target values established on the following sections.

The different use case experimented on test site have been defined during Work package 1. Each use case is evaluated by a set of common KPI that are further tailored for the specific context. It is summarized on Table 2. This KPI work is fully described on annexe of this document.

Project KPI	City of Terni						Ampere Building					Nissan Office		RWTH Aachen				City of Kempten						SASMI Building				
	UC 1	UC 2	UC3	UC 4	UC5	UC6	UC 1	UC 2	UC 3	UC 4	UC5	UC1	UC 2	UC 1	UC 2	UC 3	UC 4	UC 1	UC 2	UC 3	UC 4	UC 5	UC 6	UC 1	UC 2	UC 3	UC 4	UC 5
	Power Quality – Power Balance	Primary Reserve	Dynamic Reactive Power Control	Reactive Power Compensation	Peak Shaving Consumption to Reduce Peak Loads in Peak Hour	PV power smoothing	Peak Shaving for Power Subscription Cost Optimization	Provide DR Auto Consumption on Building Level	Energy Purchase Time Shifting	Provide DR Cost Minimization on Building Level	Provide DR - Flexibility for Building and District	Peak Shaving for Power Subscription Cost Optimization	Energy Purchase Time Shifting	Provide DR CO_2 Minimization for District Optimization	Provide DR Auto Consumption for District Optimization	Provide DR Cost Minimization for District Optimization	Provide DR - Flexibility for Building and District	Provide DR Auto Consumption for District Optimization	PV Self-consumption Maximization by Power Smoothing	Balance Group Optimization	Participation to the Energy Trade Market	District Provides Primary Reserve	DSO Manages the Reactive Power Compensation	Peak Shaving for Power Subscription Cost Optimization	Provide DR Auto Consumption on Building Level	Energy Purchase Time Shifting	Provide DR Cost Minimization on Building Level	Provide DR - Flexibility for Building and District
Power	√	√	√	√	√	√	√					√					√		√					√				
Energy			√	√			√	√	√	√	√	√	√		√		√	√		√			√	√	√	√	√	√
Costs		√						√	√	√		√	√			√		√		√	√	√	√		√	√	√	
CO_2 Emis-								√		√				√											√		√	

Table 2: Use case and KPI use on pilot site

The different pilot site have installed a set of equipment that will interact using the ICT platform to perform the use cases listed on Table 2. Four general KPI has been selected on the ELSA project to evaluate the service, the power, energy, cost and C02 KPI. Each pilot select the KPI needed to evaluate the different use cases that will be experimented.

On top of that, a target value on each KPI of each use cases is calculated and enable the evaluation of the KPI obtained during experimental test. The target value is not necessary reachable and can be optimum value, the aim is to enable comparison with the figures obtained.

1 Pilot site evaluation

1.1 City of Terni

1.1.1 Pilot site description

Terni is a small sized city at the heart of Italy with 105 000 inhabitants. The local multi-utility operator (ASM) is fully owned by the municipality. As DSO, ASM Terni directly owns and operates the power distribution grid and distributes electricity from the MV-LV and HV-MV substations to the end consumers (65.000 Smart Meters).

ASM Terni is running the ELSA pilot site at its own headquarters. The ASM TERNI pilot site is a district and its objectives are to mitigate and smooth the fluctuating power output generated by the nearby PV farm in order to follow, ultimately, the requests from the DSO in terms of district power profile that can help them in improve grid efficiency. The district is composed of 4 Blocks of energy units (BoEU):

- 2 PV arrays - 180 kWp and 60 kWp, connected to the LV section of the network. The two PV plants are aggregated in order to manage these as one unique block.
- ELSA energy storage system composed of 6 Renault Kangoo 2nd life EV batteries for a total capability of 66KWh / 72KW. The ELSA storage system is a DT4 version which corresponds to an intermediate design able to provide fast services to the grid and to the DSO.
- 3 ASM Terni buildings comprising 1) a 4,050 m^2 three-storey office building, 2) a 2,790 m^2 single-storey building consisting of technical offices, a computer center and an operation control center and 3) a 1,350 m^2 warehouse. The Buildings block is passive since does not have any controllable system.
- 3 EV charging stations, two of which can absorb a maximum power of 44 kW (22 kW for each) and a fast charging station which can absorb a power of 45 kW. The interaction with the charging stations is simulated due to the limited availability of an e-car fleet for the real testing condition.

Figure 1 shows a graphic representation of the Terni pilot site district.

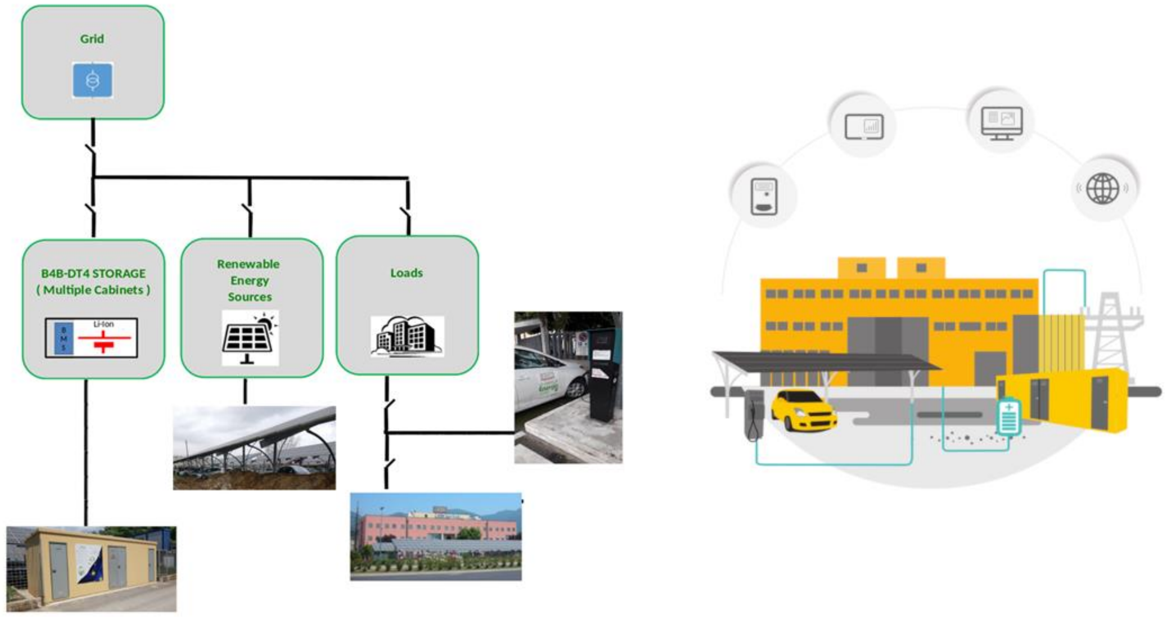


Figure 1: Graphic representation of Terni district

All the infrastructures are located close to the secondary substation (and immediately downward of the secondary substation) and connected with the ASM Terni Office building. In Figure 2 it is possible to have a more detailed picture of physical location of Terni pilot site blocks around the ASM Terni headquarters.

Figure 2: Terni pilot site blocks of energy units

The ICT platform developed by ENG for the district energy services is hosted in two virtual servers in the ASM Server Farm physically located at the ASM Terni headquarters. The ICT platform consists of the ELSA modules belonging to the control of the district blocks. Figure 2 shows the overall architecture of the system. Architecture components represent the main actors of Terni district, respectively:

- The **District Management System (EDEMS)** that represents the central module of the district optimization processes. This module, part of EDEMS, interacts with the DSO on one side, for the requests of Power profile that can help the DSO to stabilize the local district; on the other side it interacts with the different Blocks of Management systems for the negotiation of block power profiles, in turn leveraging on block flexibility.
- The **Flexibility dashboard (DSO Dashboard)** for the main beneficiary of the platform services, the DSO. It defines the interface between the DSO and the District Management system leveraging on OpenADR interoperable standard. It provides to the DSO a twofold functionality: provide the aggregated forecast of the district power profile

(production and consumption of the different blocks in an aggregated way) and allow the DSO to formulate power profile requests –with related tolerance region- to be accomplished by the local district as a whole.

- The **blocks management system (EV EEMS, ESMS, PV EEMS, EBEMS)** that manages the different aspects of the block power profile negotiation exploiting the block flexibility. It includes also the monitoring of production and consumption data to collect historical data and knowledge for future forecasts.

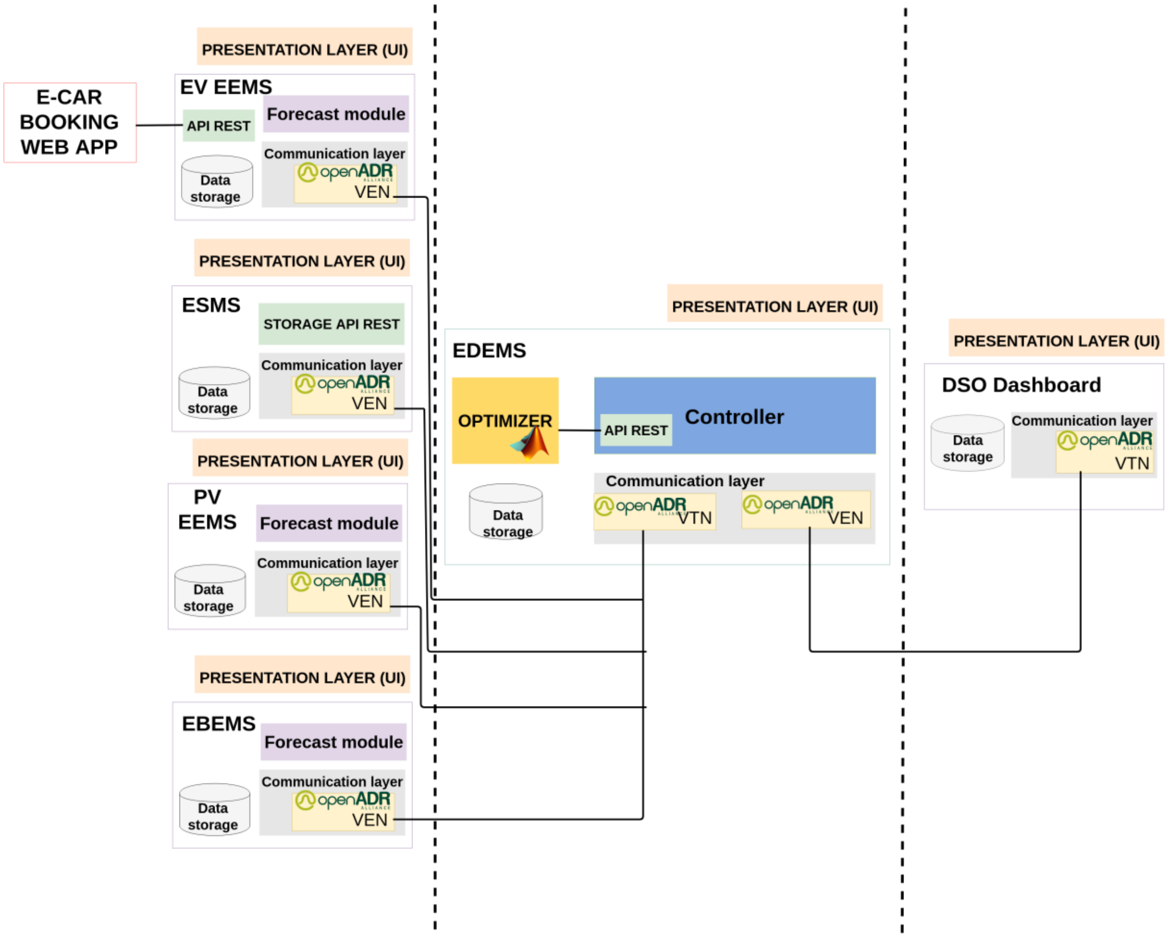


Figure 3: Terni district. ICT platform architecture

Additionally it has been developed an **e-car booking application** which operates as ASM Terni Fleet Management system, the employees are allowed to book an e-car specifying the delivery time and estimated distance of usage. The system give the entire e-cars daily scheduling request as input to the Optimizer; this performs the optimization and negotiate with the **e-car booking application** the e-cars charging scheduling exploiting the potential load shifts.

1.1.1.1 Terni pilot site characteristics

For a better overview of Terni pilot site in the following table are summarized the main characteristics of the site.

Test site type	District
Consumption	• Three ASM Terni buildings • Load shifting charging stations (simulated) • Usual daily peak demand of 150kWp • Annual consumption: ○ Three buildings: 665 MWh / a

Generation	• 2 PV arrays above the parking lots
	• 240 kWp installed
	• Annual generation
	  ○ PV 1 (180 kWp): 225 MWh / a
	  ○ PV 2 (60 kWp): 80 MWh / a

ELSA Battery	• DT.4 prototype system
	• Six battery modules with each one power module
	• Total energy: 66 kWh
	• Total Power
	  ○ Charging: max. 72 kW
	  ○ Discharging: max. 72 kW

Battery purpose	District Management: • PV power smoothing • Peak shaving consumption to reduce peak loads in peak hour DSO Services • Ancillary services (primary reserve, dynamic reactive power control, reactive power compensation, power balance)

Table 3: Terni test site information

1.1.2 Use case evaluation

This section provides the evaluation of the Key Performance Indicators (KPIs) for each energy service related to the District Management. The set of services evaluated in Terni pilot site is the following:

- Pv Power smoothing

- Peak shaving consumption to reduce peak loads in peak hours

The EDEMS has been designed with the purpose of coordinating –in negotiation way- the district BoEU to achieve the optimal solution responding to power profiles requests from the DSO. Optimal solution has to be intended as exploitation of BoEU flexibilities to achieve power profile requested maintaining a sustainable usage of renewable resources. Five Power KPIs are defined to evaluate the system. In addition to the evaluation of reduction of peaks in power production and the reduction of peaks in power consumption we are interested in two aspects: the deviation between DSO power profile request and the aggregated power profile realized by the district; second aspect the violation of acceptance area defined by the DSO as zone for suboptimal solutions. More information on KPI methodology and calculation is given in the annex of this document.

Table 4 reports the target values established for each use case. These were estimated referring to some simulations of the district potentialities performed considering the usage DT4 battery system with a full capability of 66kWh/72kW.

DT4 deployed in Terni is working since September, due to some issues the batteries have worked with limited capability of 66kWh/72kW. Main part of the experimentation was performed relying on DT4 battery system with a limited capability of 33 kWh/36kW. Since the end of October 2018 the experimentation is using the DT4 battery system with a capability of 44 kWh/48kW. The limited capability of the test plant affected the evaluation results, we exploited the gathered data and extrapolated these in order to asses what could have been the result with the full capacity battery, details are reported in the conclusion of this chapter.

Project KPI	City of Terni	
	UC5	UC6
	Peak Shaving Consumption to Reduce Peak Loads in Peak Hour	PV power smoothing
Power	-17,5%	18,5%
Energy	n.a.	n.a.
Costs	n.a.	n.a.
CO_2 Emissions	n.a.	n.a.

Table 4: Terni target use case KPI

1.1.2.1 UC5 Peak shaving consumption to reduce peak loads in peak hour

Peak shaving is the process of reducing the amount of energy at district level during peak demand hours. The service is requested by the DSO -as part of the overall power profile request- and managed at district level following a combined coordination of load shifting charging stations and discharging of batteries action. It worth noting that the behaviour of e-car filling stations BoEU is simulated.

Estimation of the target value

In order to evaluate the reduction of peak consumption service the Minimum power gap KPI is used.

$$\frac{\min\limits_{i=1,..,T}\left(P_{\text{ELSA District}}(t_i) - P_{Dsorequest}(t_i)\right)}{\left|P_{Dsorequest}(t_y)\right|} \cdot 100\%$$

Where:

$P_{\text{ELSA District}}(t_i)$ is the average power demanded / injected by the district to the grid in every time slot t_i

$P_{DSOrequest}(t_i)$ is the reference value of the power profile requested by the DSO in every time slot t_i

T is the number of intervals in the time horizon of the optimization process

y is the value of *i* for which the min occurs

It calculates the minimum of all deviations between the power profile achieved from the district and power profile requested from the DSO. The convention adopted in the system considers the positive power flows as power generation and the negative ones as power consumption. For this use case results are relevant only for negative values otherwise means that the system had not consumption peaks over the DSO power request so only these negative values are considered. If this value is < 0 it means that the district achieved an extra power consumption in reference to DSO request, the minimum among these negative values actually represents the maximum absolute value of consumption peak. This value is compared then with the power request performed by the DSO in that specific time slot where the min occurs in order to understand its influence percentage.

The target value according to this KPI is -17,5%. Smaller is the absolute value better is the optimization performed, optimum corresponds to value 0. The power profile is provided by DSO to the EDEMS as a triplet, one for each time interval, it represents the expected profile value and a tolerance region around this value expressed as maximum and minimum value. We expect that the target value is considered acceptable if, in the specific time slot where the min occurs, it is inside the tolerance region, otherwise the tolerance zone requested from DSO is considered as most restrictive condition for the system.

Tests performed with DT4

A test of peak shaving service was performed over a certain period of time, in this chapter we are presenting three consecutive days from October 3rd to October 5th, 2018 that reflect a typical service execution. Figure 4 shows the charts of different power profiles over the three days. At the top of image, for each day there is the power profile requested from the DSO (in red) in reference to the district forecast profile (in blue). In the middle, for each day there is the real power profile achieved by the district (in green) in reference to the power profile requested by the DSO (in red). It is also reported the Minimum power Gap KPI value and the timestamp where it occurs. At the bottom, for each test day there is the power profile actuation of the batteries (light blue) using a convention of positive values for charging and negative for discharging. In the period of test only three batteries are working, having a total capacity of 33kWh / 36kW.

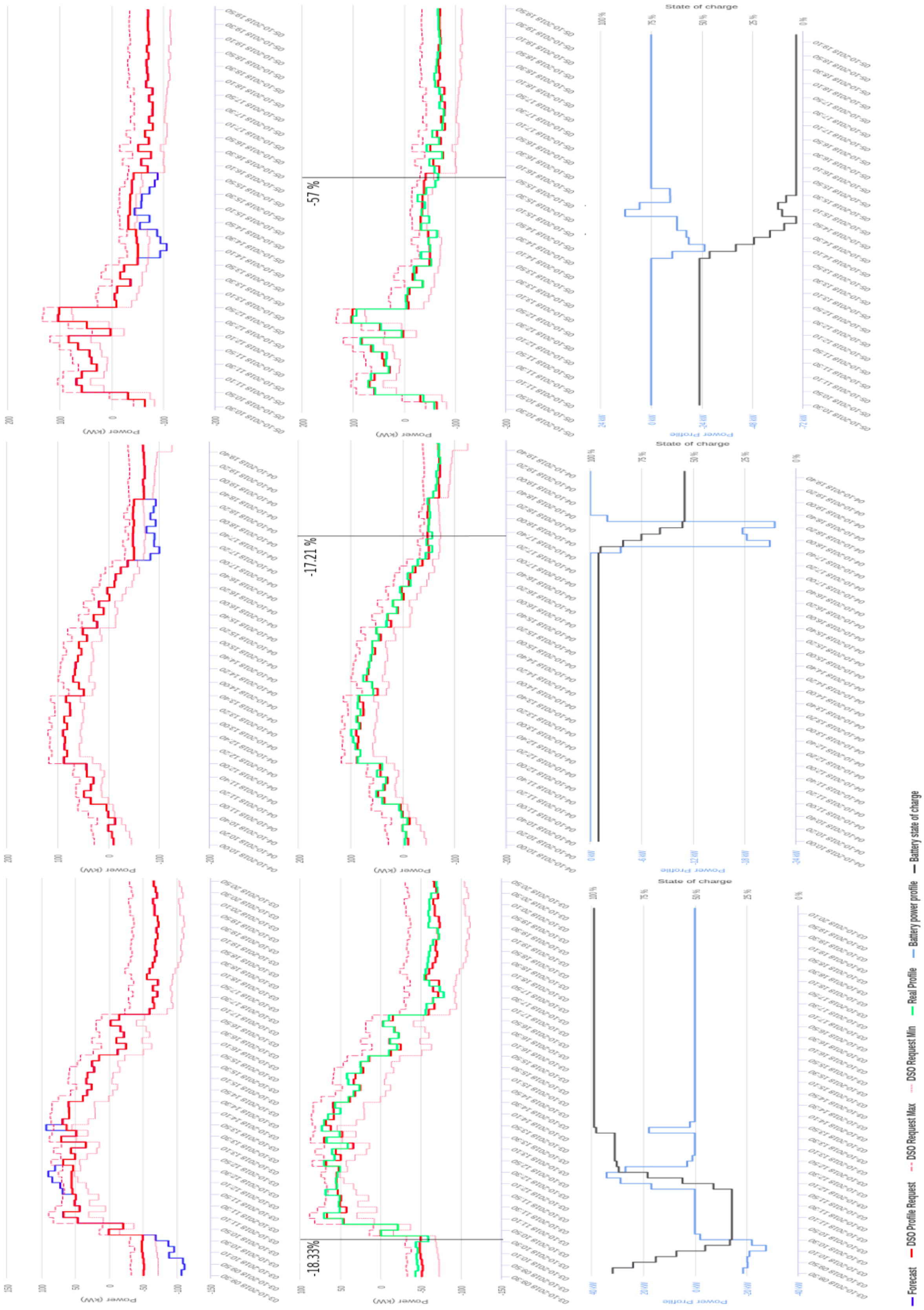


Figure 4: A test of peak shaving service from October 3rd to October 5th,2018

In the first day the peak shaving service was requested from 09:30 to 10:40. The Minimum power Gap KPI is near the target reaching the value of -18,33% at 10:30 and the real profile in that timeslot is inside the tolerance region; this result is very close to the target value so we can consider this as a nearly positive experiment. In the second test day the peak shaving was requested from 17:00 to 18:30 and the power KPI reaches the value of -17,21% at 17:30 and the real profile in that timeslot was inside the tolerance region, so this result is positive. In the last day the peak shaving service was requested from 14:00 to 16:00 and the Minimun power Gap value is -57% at 15:50. In this last day the system does not reach the target KPI of -17,5%, the storage system was charged at 50% the beginning of the request (at 14:00 the SOC is 50%) the system exploited the whole remaining 50% of charge not being able to achieve the requested result. Moreover, the power achieved from the district violates the tolerance region in that timeslot. The availability of the full nominal capacity of the battery system (66 kWh) would have produced a better result probably allowing to achieve at 100% the target value.

Date	Target value	Achieved value	Differences
October 3rd,2018	-17,5%	-18,33%	• 0,83% deviation /in tolerance region
October 4th,2018	-17,5%	-17,21%	Target achieved / in tolerance region
October 5th,2018	-17,5%	-57%	• 39,5% deviation / outside the tolerance region

Table 5: Minimum power Gap KPI values over a three period of test

A good performance of the system can be evaluated using further indicators. One of this is the Total profile deviation (see KPI Calculation methodology table, Section 3.1 of KPI document) which measures the deviation between demand (DSO request) and actual power provision (actual power profile achieved by the district). Smaller is this deviation better is the optimization performed. Table 6 shows the Total profile deviation values for the test period. The average value of this KPI is 6,3 kW . The target value is 11 kW.

	October 3rd	October 4th	October 5th	Mean	Target value
Total profile deviation	6,1 kW	5,3 kW	7,6 kW	6,3 kW	11kW

Table 6: Total profile deviation KPI values over a three period of test

The request from DSO is to stay as much as close possible to the reference power but other values are considered acceptable if they remain inside the tolerance region. Two further KPIs evaluate this constraint: Number of timestamps we have power downward and power upward on respect of the total optimization time window, reported in percentage (for formulae details see KPI Calculation methodology table, Section 3.1 of KPI document). Smaller are these values better are the optimization performed. Table 7 shows the results of the two KPIs for the period test.

	October 3rd	October 4th	October 5th	Mean	Target value
N upward	1,4%	0%	0%	0,5%	2,8%
N downward	0%	0%	3,5%	1,2%	2%

Table 7: Number of power downward and number of power upward KPI values over a three period of test

For the use case of peak shaving we are more interested in the Number of power downward KPI, since it represents the number of intervals in which the district exceeded the lower value delimiting the acceptance area on respect of the total number of intervals (in percentage). For this KPI the target value is 2%.

In main part of the test cases the values achieved are smaller than the target value established. There is only one case it is not achieved with a downward, the system didn't achieve the level of peak shaving value requested due to the limited capability of the battery as above described. It is important to underline that the mean values are in the limit fixed as KPI target value.

1.1.2.2 UC6 PV power smoothing

The PV Power smoothing service represents the possibility to smooth the PV production peak storing it in the ELSA storage or consuming the energy for EV charging with re-arranged scheduling (load shifting) to mitigate fluctuating power injection from the district to the grid. The service is requested by the DSO as part of the overall power profile request and handled at district level increasing the load or activating the battery charging.

Estimation of the target value

In order to evaluate the PV power smoothing service the Maximum power gap KPI is used.

$$\frac{\max_{i=1,..,T}\left(P_{\text{ELSA District}}(t_i) - P_{Dsorequest}(t_i)\right)}{\left|P_{Dsorequest}(t_y)\right|} \cdot 100\%$$

Where:
$t_i$is the average power demanded / injected by the district to the grid in every time slot t_i
$P_{DSOrequest}(t_i)$ is the reference value of the power profile requested by the DSO in every time slot t_i
T is the number of intervals in the time horizon of the optimization process
k is the value of *i* for which the max occurs

It calculates the maximum of all deviations between the power profile achieved from the district and power profile requested from the DSO. Results are relevant only for positive values otherwise it means that the system had not PV production peaks on respect of the DSO power request. If this value is > 0 it means that the district achieved an extra power production in reference to DSO request. This value is compared then with the power request performed by the DSO in that specific timestamp which the max occurs in order to understand its influence percentage.

The target value according to this KPI is 18,5%. Lower is the value better is the performance. We expect that the target value is considered acceptable if in the specific timeslot where the max occurs the district power profile is inside the tolerance region.

Tests performed with DT4

In analogue way to the peak shaving the tests were performed over a certain period of time, in this chapter we are presenting tests executions over three consecutive days from September 26th to September 28th, 2018 as shown in Figure 5, that reflect a typical service execution . The template of Figure 5 is the same as reported for the test of peak shaving service (Figure 4). In the period of test only three batteries were working, having a total capacity of 33kWh / 36kW.

During the three days the PV power smoothing service was requested during the time frame 11:00-13:30, that is when the pv power production is high. The first test day the Maximum power Gap KPI reached the value of 17,17% at 11:40. The second day the KPI was 53,15% at 12:30 and it did exceed the target value of 18,5%. This was due to the fact that the batteries are only three and they are fully charged at 12.30, while the request of service ended at 13.30. The last day the KPI target reached the value of 15,65% at 20:20.

Date	Target value	Achieved value	Differences
September 26th,2018	18,5%	17,17%	• Target achieved /inside the tolerance region
September 27th,2018	18,5%	53,15%	34,65% deviation/ outside the tolerance region
September 28th,2018	18,5%	15,65%	• Target achieved /inside the tolerance region

Table 8: Maximum power gap KPI values over a three period of test

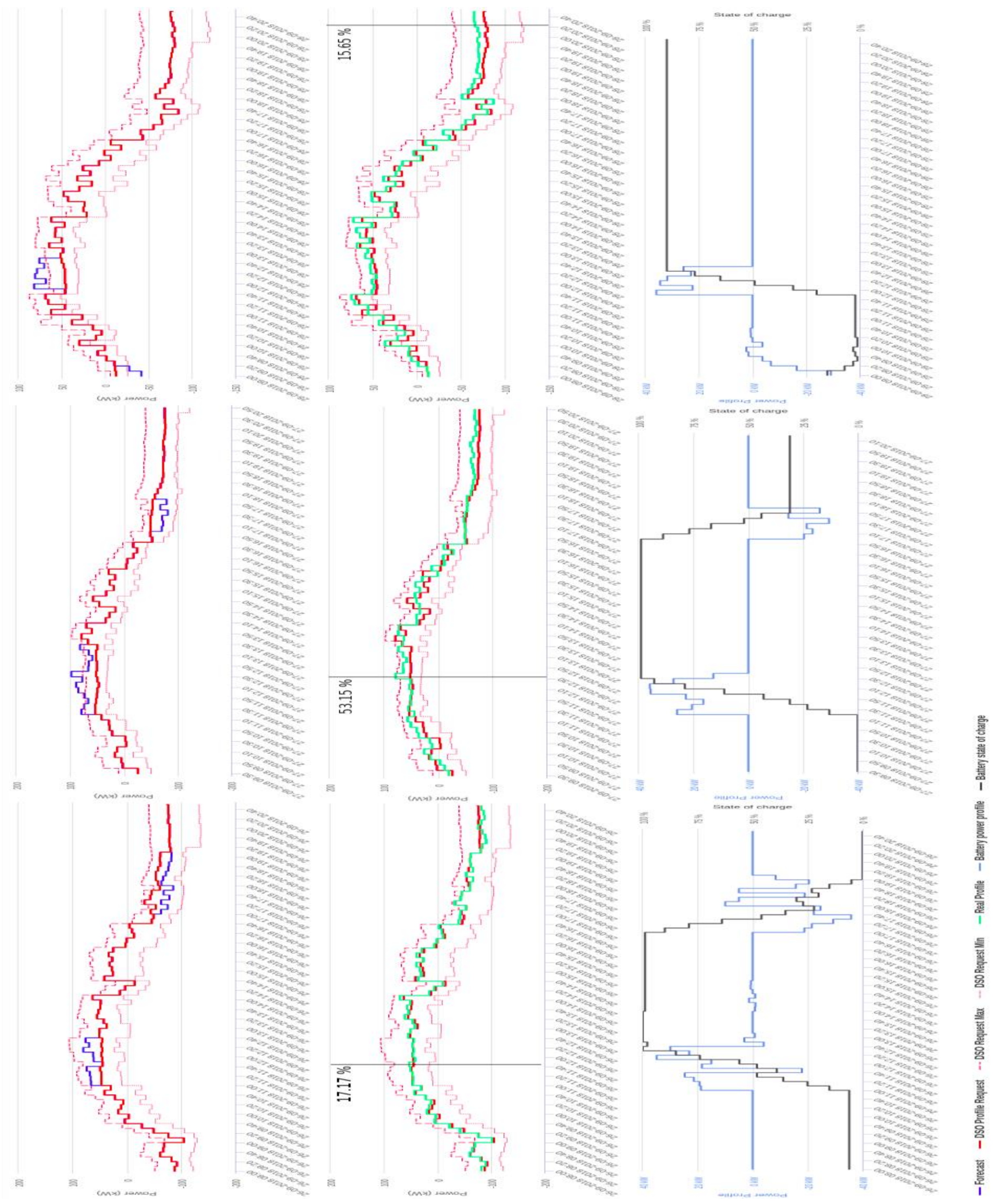


Figure 5: A test of pv power smoothing service from September 26th,2018 to September 28th,2018

Table 9 shows the Total profile deviation results over the three day period of test. The average value of this KPI is 7,8 kW ., the target value is 11 kW.

	September 26th	September 27th	September 28th	Mean	Target value
Total profile deviation	4,8 kW	11,4 kW	7,2 kW	7,8 kW	11kW

Table 9: Total profile deviation KPI values from September 26th to September 28th

Table 10 shows the results of Number of power downward and Number of power upward KPIs for the period test. In general the power profile achieved by the district does not violate the tolerance region requested by the DSO. The average value for Number of power downward KPI is 0%. The average value for Number of power upward KPI is 0,5%.

	September 26th	September 27th	September 28th	Mean	Target value
N upward	0%	1,5%	0%	0,5%	2,8%
N downward	0%	0%	0%	0%	2%

Table 10: Number of power downward and Number of power upward KPIs values from September 26th to September 28th

For the use case of pv power smoothing we are more interested in the Number of power upward KPI, since it represents the number of intervals in which the district exceeded the higher value delimiting the acceptance area on respect of the total number of intervals (in percentage). For this KPI the target value is 2,8%.

The KPI target value is bigger than the one established for peak shaving because the for the system it is more easy to compensate a load peak than a pv production peak, at least considering only the max peak values that are 240KW and 166KW respectively.

In all the test cases the values achieved are smaller than the target value established.

1.1.3 Ancillary services

This section provides the evaluation of the ancillary service that the Storage System can provide to the DSO.

The set of ancillary services evaluated in Terni pilot site is the following:

- Power Quality – Power Balance
- Primary Reserve
- Dynamic Reactive Power Control
- Reactive Power Compensation

Providing of Ancillary services has been done through interfacing of the Storage system and the Scada System of the DSO's network. A gateway converts the modbus of the storage system in IEC 61850. The Scada system collect main electrical parameters of the storage system.

Main electrical parameters collected on the interface are:

- Signal:
- Q set feedback
- Cos phi set feedback
- P set feedback
- Safety mode feedback

Measurements:

- State of Charge (SOC)
- Active Power
- Reactive Power
- Max P in Abs
- Max P in Gen
- Max Q Capacitive
- Max Q Inductive
- Frequency

Commands/SetPoint:

- InverterMode
- Activation Regulation PQ
- UnbalanceCompensation
- SafetyDisconnect
- Set Point of Q
- Set point of cos phi
- Set Point of P

Figure 6 shows interface available of the DSO operator. Five different window has been implemented as HMI interface for the DSO operator (Secondary substation MV, Storage Plant alarms monitoring, Storage Plant management, Storage Measurement details). In a P-Q graph DSO is possible to see in real time the electrical operational point of the storage system. The connection between the Scada system and the storage system use an existing hyperlan connection.

Figure 6: SCADA HMI Storage Interface

A test of ancillary service has be done from the month of September, of the 6 inverters of the plant only one has the configuration to provide ancillary services. Anyway there is no hardware limit to extend this functionalities to all 6 the inverters. A kit current sensors has been installed in a specific point of the grid to provide to the inverter the feedback for the power quality from the network and realize a closed loop regulation.

1.1.3.1 Time response of the storage

Time response of the system has been evaluated by a wave form recorder after a step request of Power Injection, as shown in the Figure 7 the "inverter+batteries" system requires 0,4 second to reach the Set Point. This value is fully adequate for: Power Balance, Reactive Power Compensation. To reach better performances of Dynamic Reactive Power and Primary Reserve it requires to speed up the inverter ramp up.

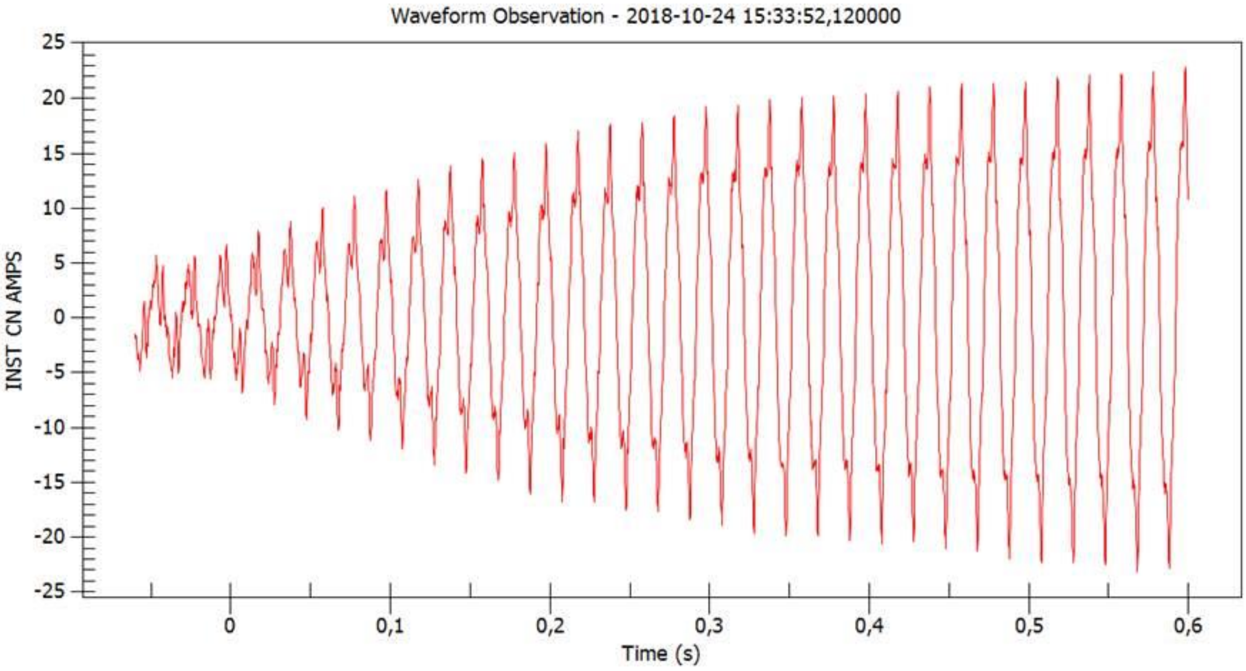
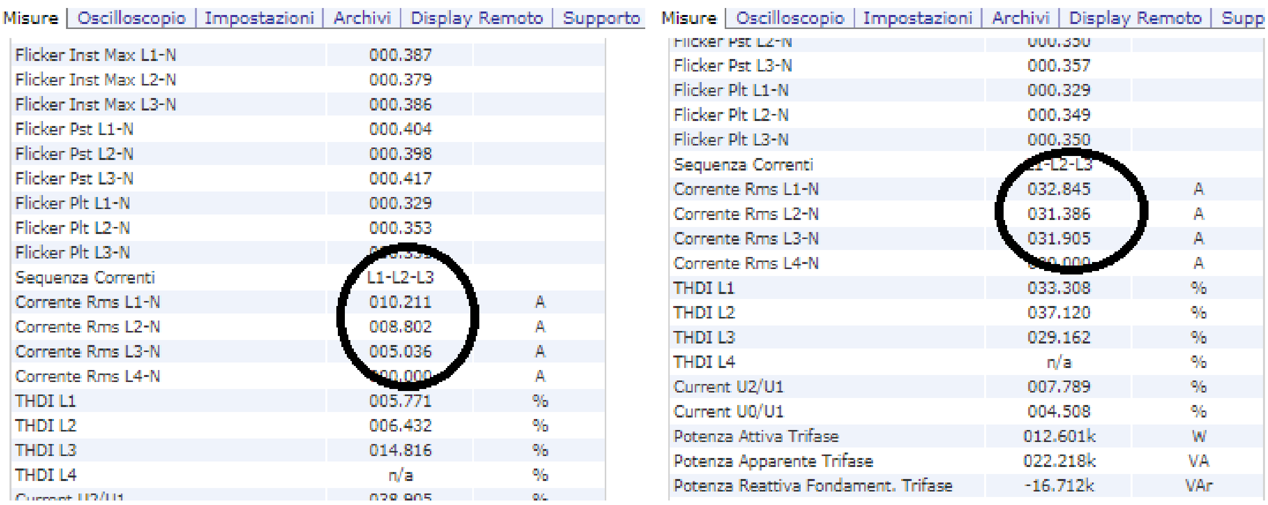


Figure 7: Example of response time of the system wave form

1.1.3.2 Power Balance

During the Power Balance Regulation, sensors provide the single phase current values in a specific point of the grid, the inverter #1 provide the current injection to compensate any difference between the phases. The current single phase A, B and C have a different value as reported in the figure #___ reports. In this configuration test, 5/6 of the capability of the storage was used for the active power injection and 1/6 for the phases unbalance compensation (maximum 1/6 of the total capability). In the point of the installation of the CTs the difference between the phases is less of the 5%, and this is adequate for the DSO's need.



Misure | Oscilloscopio | Impostazioni | Archivi | Display Remoto | Supporto

Flicker Inst Max L1-N	000.387	
Flicker Inst Max L2-N	000.379	
Flicker Inst Max L3-N	000.386	
Flicker Pst L1-N	000.404	
Flicker Pst L2-N	000.398	
Flicker Pst L3-N	000.417	
Flicker Plt L1-N	000.329	
Flicker Plt L2-N	000.353	
Flicker Plt L3-N	[illegible]	
Sequenza Correnti	L1-L2-L3	
Corrente Rms L1-N	010.211	A
Corrente Rms L2-N	008.802	A
Corrente Rms L3-N	005.036	A
Corrente Rms L4-N	000.000	A
THDI L1	005.771	%
THDI L2	006.432	%
THDI L3	014.816	%
THDI L4	n/a	%
Current U2/U1	[illegible]	%

Storage Current Injection

Misure | Oscilloscopio | Impostazioni | Archivi | Display Remoto | Supp

Flicker Pst L2-N	[illegible]	
Flicker Pst L3-N	000.357	
Flicker Plt L1-N	000.329	
Flicker Plt L2-N	000.349	
Flicker Plt L3-N	000.350	
Sequenza Correnti	L1-L2-L3	
Corrente Rms L1-N	032.845	A
Corrente Rms L2-N	031.386	A
Corrente Rms L3-N	031.905	A
Corrente Rms L4-N	000.000	A
THDI L1	033.308	%
THDI L2	037.120	%
THDI L3	029.162	%
THDI L4	n/a	%
Current U2/U1	007.789	%
Current U0/U1	004.508	%
Potenza Attiva Trifase	012.601k	W
Potenza Apparente Trifase	022.218k	VA
Potenza Reattiva Fondament. Trifase	-16.712k	VAr

CTs installation point Balancing

Figure 8: Power balance in Terni

The power balance aims at reaching a power equilibrium between each phase. In this sense the KPI is looking at the power flexibility it offers between phases. One of the phase (arbitrary phase one) will be taken as a reference to compare the two other phases.

$$\Delta P12 = P1 - P2$$

$$\Delta P13 = P1 - P3$$

$$\Delta P = \Delta P12 + \Delta P13$$

$$\Delta P\% = \Delta P / P1$$

Where P1, P2, P3 are the active power of the single phase.

Figure 9 highlight KPI the power balance calculation during 10 minutes of activation of the function. From 15:10:00 to 15:20:00 the function is on and the power Unbalance go from 15% to 3%, after the deactivation the value rise to 10% and after go to 18%.

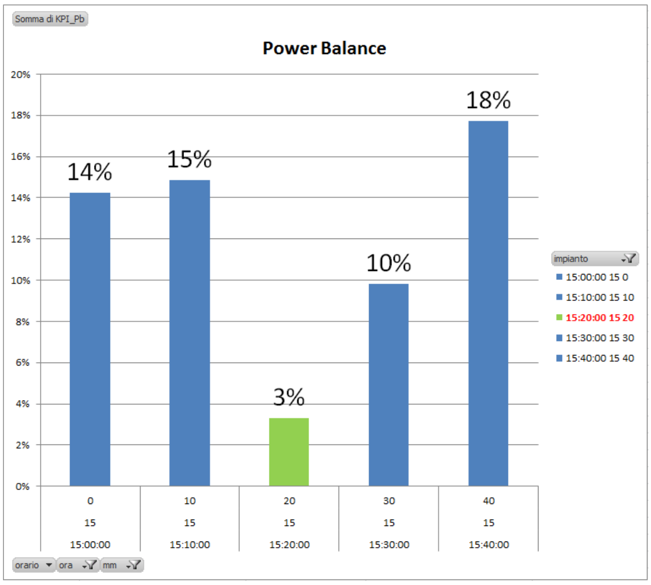


Figure 9: Power balance KPI value

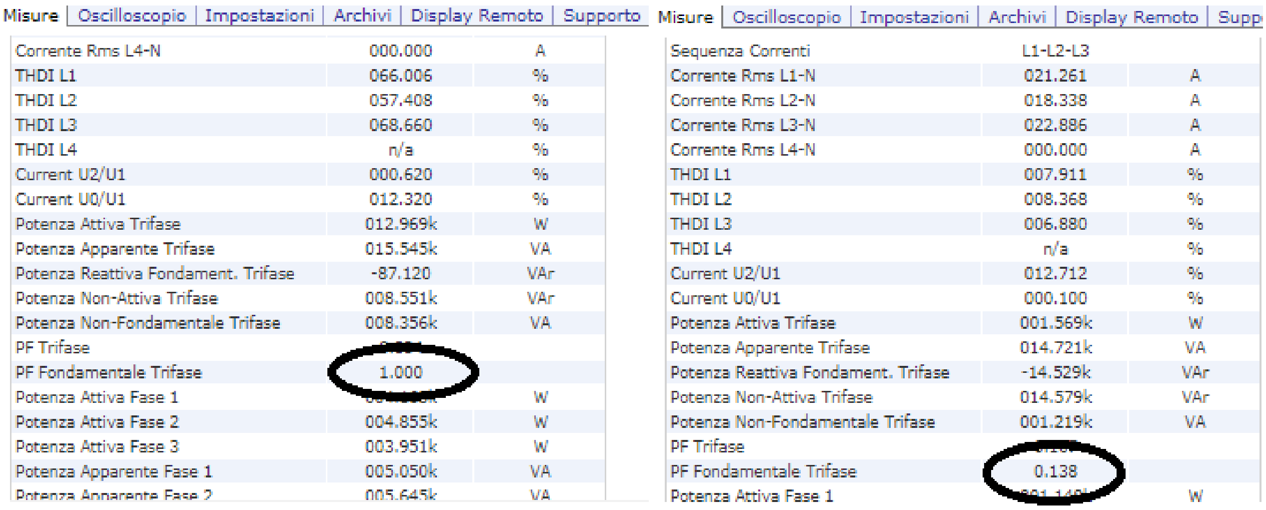
1.1.3.3 Dynamic Reactive Power Control

During the Dynamic Reactive Power Control, DSO provide a (P,Q) request to the Storage system and the Storage follow the (P,Q) set point. In the Figure 10 shows the operational point provided by the storage system. Fixed the (P,Q) set point, the inverter charge and discharge the system to fix this point, there are not fluctuations appreciable in SCADA HMI interface. The SET is fixed in a very very adequate way.

Figure 10: SCADA HMI interface during a (P,Q) request

1.1.3.4 Reactive Power Compensation

During the Reactive Power Compensation, DSO provide a (cos(φ)) request to the Storage system and the Storage follow the cosfi set point. In the Figure 11 shows the cos(φ) result in the CTs installation point, (cos(φ) = 1), and the value of the cos(φ) =1 in the output of the storage cos(φ) =0,138. The SET is fixed in a very very adequate way also in the face of load flow changing.



Misure		
Corrente Rms L4-N	000.000	A
THDI L1	066.006	%
THDI L2	057.408	%
THDI L3	068.660	%
THDI L4	n/a	%
Current U2/U1	000.620	%
Current U0/U1	012.320	%
Potenza Attiva Trifase	012.969k	W
Potenza Apparente Trifase	015.545k	VA
Potenza Reattiva Fondament. Trifase	-87.120	VAr
Potenza Non-Attiva Trifase	008.551k	VAr
Potenza Non-Fondamentale Trifase	008.356k	VA
PF Trifase	[illegible]	
PF Fondamentale Trifase	1.000	
Potenza Attiva Fase 1	[illegible]	W
Potenza Attiva Fase 2	004.855k	W
Potenza Attiva Fase 3	003.951k	W
Potenza Apparente Fase 1	005.050k	VA
Potenza Apparente Fase 2	005.645k	VA

Misure		
Sequenza Correnti	L1-L2-L3	
Corrente Rms L1-N	021.261	A
Corrente Rms L2-N	018.338	A
Corrente Rms L3-N	022.886	A
Corrente Rms L4-N	000.000	A
THDI L1	007.911	%
THDI L2	008.368	%
THDI L3	006.880	%
THDI L4	n/a	%
Current U2/U1	012.712	%
Current U0/U1	000.100	%
Potenza Attiva Trifase	001.569k	W
Potenza Apparente Trifase	014.721k	VA
Potenza Reattiva Fondament. Trifase	-14.529k	VAr
Potenza Non-Attiva Trifase	014.579k	VAr
Potenza Non-Fondamentale Trifase	001.219k	VA
PF Trifase	[illegible]	
PF Fondamentale Trifase	0.138	
Potenza Attiva Fase 1	[illegible]	W

Power factor in the CTs installation point **Power Factor in out of the Storage System**

Figure 11: Reactive power compensation - power factor

Figure 12 highlight KPI the Reactive Power Compensation effect on the Grid, during the running of this functionality the value of D Reactive Power is practically 0% (period from 14:40:00 to 14:50:00). Before the activation the value is 32%, after the deactivation the value rise to 23%.

The KPI used is

$\Delta Preactif,\%=(Preactif,REF-Preactif,ELSA)/Preactif,REF$

where $Preactif,REF$ is the reactive power on the point of the CTs installation, $Preactif,ELSA$ is the reactive power of the storage plant and $\Delta Preactif,\%$ is the difference between the need and the providing of reactive power in percentage.

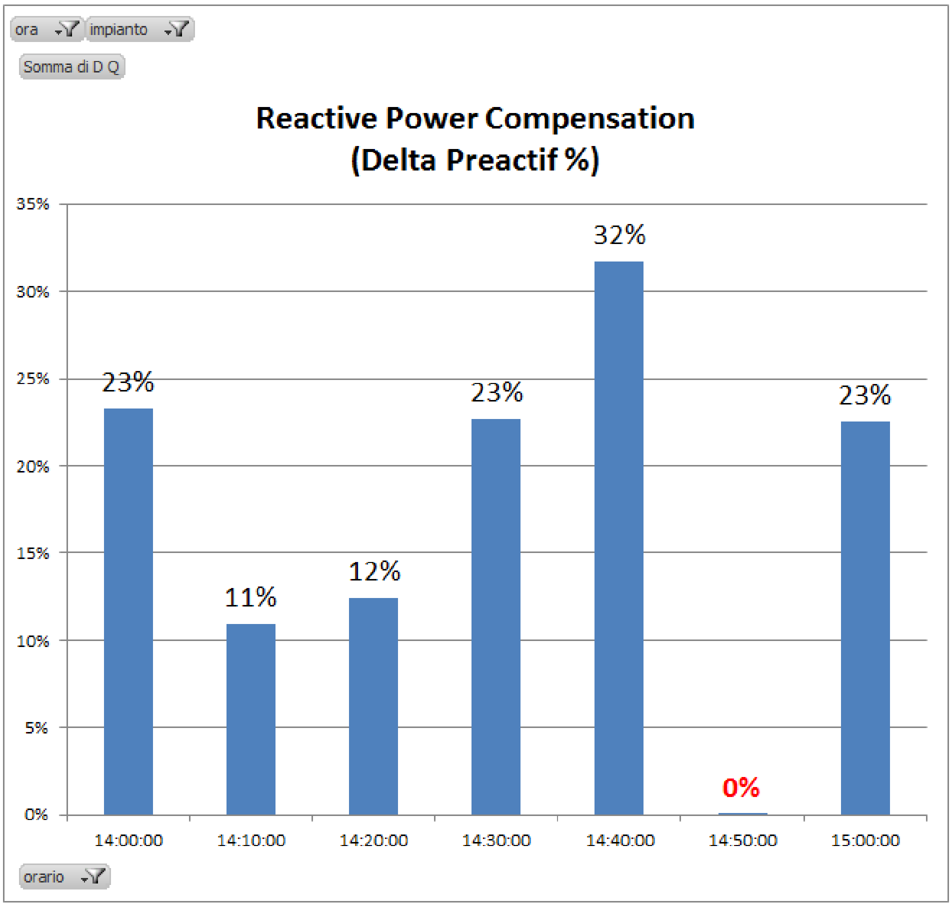


Figure 12: Reactive power compensation - KPI

1.1.3.5 **Primary Reserve**

During the Primary Reserve the DSO, change a set point of P based on the value of the frequency, in this way it can support the frequency stability of global network. The request of the P injection or absorption should be provided by a TSO parameterization in a local device. Test has be done by a simulation of a TSO request of power Injection and a power absorption as shown in the Figure 13

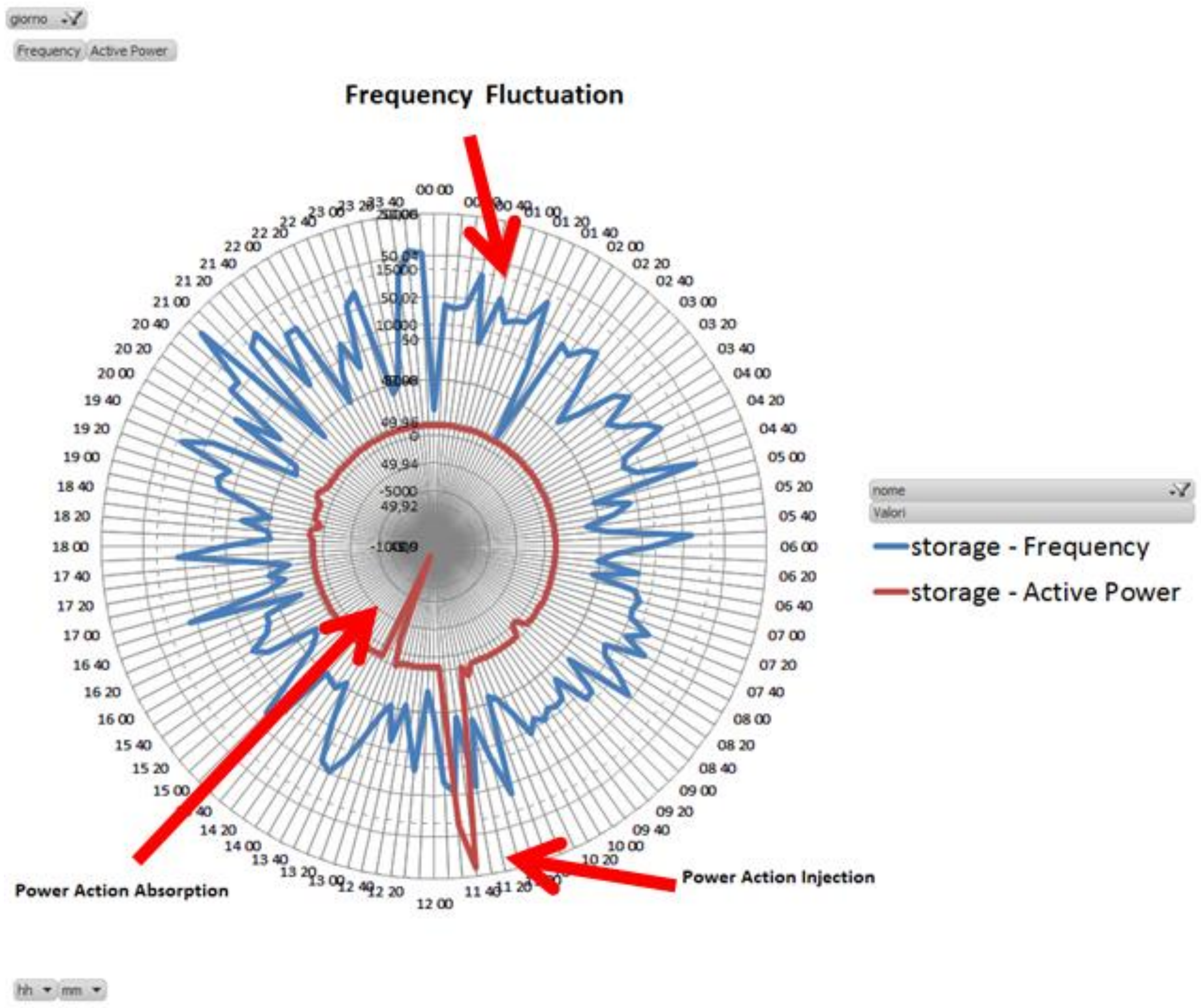


Figure 13: Primary reserve test

1.1.4 Conclusions

All ELSA use cases have been evaluated for the ICT platform running in Terni pilot site. The set of KPI has been defined for the evaluation process. A few key achievements and lessons learned were met in the evaluation of the EDEMS at district level. From results of the experimentations performed with the storage system in Terni we can conclude that the optimization process performed by the EDEMS in most of the cases was working as expected. It means that the deviations between DSO requests and power profiles achieved by the district (which follow the optimized power profiles) have reached the prefixed targets. In some cases the services are not achieved as requested by the DSO. This is due to the fact that the system has been worked with a limited capacity of batteries.

October 5th, DSO –expressly not caring about the forecast provided by EDEMS- put a request of power profile aimed at compensate the abnormal load due to e-cars dense scheduling. That allowed us to stress the system for peak shaving, the result had the worst timeslot with 57%

of deviation on respect of the request, the system behaviour analysis underlined that the EDEMS properly exploited the maximum flexibility available even not being able to achieve the request from DSO. We performed a simulation of what would have been the scenario having a battery with the full capability as planned and the result was -16,28%, This result achieve the target value established at 17,5%. This experimentation gave us some reference in order of lesson learnt for the most proper dimension of battery and overall flexibility that a district like the one under evaluation is able to provide. This kind of information is particularly relevant for the DSO because give them the basic element for scaling up extrapolation in a general context where the DSO would interact with many districts like the one exploited.

In analogue way for PV power smooting on September 27th we had a result of 53,15% of deviation between the DSO power request and the actual district power profile achieved. The EDEMS properly exploited as much as possible the available flexibility of the battery even not being able to achieve the request from DSO. As for the peak shaving case. A simulation of what would have been the scenario having a battery with the full capability as planned was performed and the result was 17,65%, this result achieve the target value established at 18,15%. This gave us some other reference that contributed to the overall lesson learnt for the most proper dimension of battery and overall flexibility that a district like the one under evaluation is able to provide.

1.2 Ampère building

1.2.1 Pilot site description

The Ampere Building is an office building built in 1985 in the business district La Défense in Paris. This L-shaped building presents a net floor area of 14,200 square meters of offices over 10 floors. It has been completely renovated from 2014 to 2016 to become a sustainable construction and complain with the high environmental quality certification (HQE) as well as BREEAM certification.

Figure 14: Ampere building located in Paris, France

The building is equipped with an electrical storage of two Kangoo 2nd life batteries for a total capacity of 22 kWh. The ELSA system is a DT3 version which corresponds to the original TRL6 system. The local electric storage capacity was upgraded to 88 kWh with DT5 version in August 2018, where the DT5 version corresponds to the final industrialized version of the storage system.

The building also presents local sources of energy generation: photovoltaic panels with a peak power of 60 kWp and "Gen 2 Switch" elevators developed by Otis (generating energy). The building heating and cooling requirements are provided by the district heat distribution system for La Defense (Enerthem).

A high indoor air quality is achieved with supply airflow rates of 36 m^3/h per person instead of 25 m^3/h. The ventilation to the offices is provided by two air handling units (AHUs) located on the roof of the building. The AHUs include rotary heat exchangers with a recovery rate greater than 80%.

The Ampere E+ building presents a high performance envelope with a U-value of $1{,}06\ W.m^{-2}.K^{-1}$ [1]. The building envelope presents high-performance windows with clear

[1] Detailed information on Ampere building available at https://www.construction21.org/case-studies/fr/ampere-e.html

light emissive double-glazing on the inner side (VEP cover technology) and single extra-clear outer glazing, on the exterior side. The whole envelope constitutes a breathable thin double skin.

The Ampere E+ building presents the following services:

- Heating: all heating is provided indirectly via a plate and frame Heat Exchanger (HEX) from the local district heating network for La Defense operated by Enertherm. The room setpoints are maintained via a network of radiant panels and 4 pipe fan coil units (FCUs) for exterior zones and unique spaces.
- Cooling: Provided indirectly via a plate and frame HEX from the local district cooling network for La Defense operated by Enertherm, or by a water cooled scroll chiller which is also connected to the building via a plate and frame HEX. The chiller condenser has a glycol circuit which is connected to a drycooler on the roof and also the hot water return of the Enertherm district heating network connection for heat recovery via a plate and frame HEX. The room setpoints are maintained via a network of radiant panel and 4 pipe FCUs for exterior zones and unique spaces.
- Ventilation: 6 AHUs with VSDs on all fans and rotary energy recovery wheels.
- DHW: electric water heaters
- Lighting: Internal lighting controlled from the BMS and by building occupants via an application on their smartphone.
- Other loads: Floor heating in lobby via underfloor heating at garden and ground levels, electric heaters for small select areas on ground and garden floors and heated door curtain.
- Renault 2nd life batteries with a capacity of 2 x 11 kWh
- Photovoltaics array on the roof with a peak power of 60 kWp

Test site type	Office building
Consumption	• Office building • Usual daily peak demand of 250 kW • Usual daily consumption of 4000 kWh
Generation	• PV panels installed on the roof • 60 kWp installed

ELSA Battery	• DT.3 prototype system:
	    o Two battery modules of 11 kWh capacity each
	    o Total energy: 22 kWh
	    o Total Power:
	        ▪ Charging: max. 6 kW
	        ▪ Discharging: max. 24 kW
	• DT.5 system (since late September 2018):
	    o Eight battery modules of 11 kWh capacity each
	    o Total energy: 88 kWh
	    o Total Power:
	        ▪ Charging: max. 80 kW
	        ▪ Discharging: max. 80 kW

Battery purpose	• Peak shaving • Auto-consumption • Energy purchase time shifting • Cost-minimization • Flexibility

Table 11: Ampère test site information

The ICT platform deployed in Ampere building for supporting the operation and management of second life batteries is presented in Figure 15. The building scale ICT platform, EBEMS, presents the ability to communicate with: the existing Schneider Building Management System, the 2nd life battery energy management system, and the renewable energy sources. The EBEMS is also able to implement smart grid communications to provide energy services to the grid.

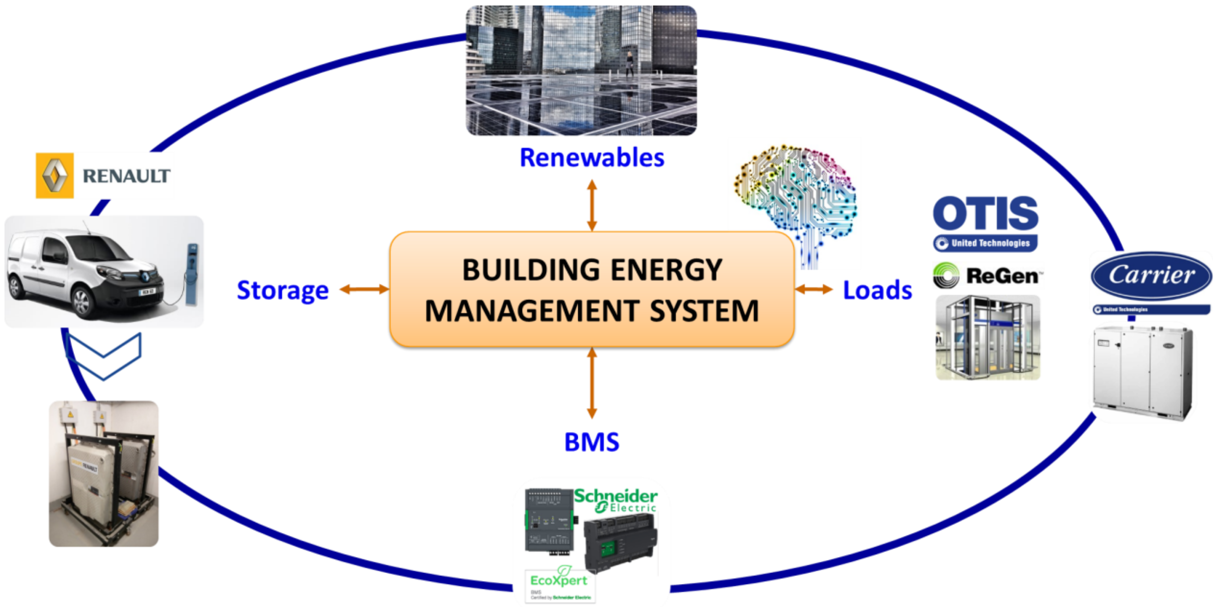


Figure 15: Ampère ICT system deployed

1.2.1 Use case evaluation

This section describes the evaluation of the Key Performance Indicators (KPIs) for each energy service. Five energy services, referred to as use cases, are evaluated based on some KPIs. The following energy services are evaluated: peak shaving, energy purchase time shifting (energy arbitrage) and three Demand Response (DR) services: auto-consumption, cost-minimization and flexibility.

The EBEMS has been designed with the ability to provide Demand Response services to the Distribution System Operator (DSO), electric supplier or demand response aggregator depending on the contractual agreement. The DR events are generated by the electricity provider and might occur at any time of the day with a short-term notification. The EBEMS is able to deal with the following DR services in real time: auto-consumption, cost minimization and flexibility. When the EBEMS receives the notification from the grid about the type of DR service, the starting time of the event and its duration, it plans for an optimal use of the resources available in the building (storage, renewables, HVAC system, …). The DR services are simulated in this project: the notification from the grid is emulated giving the type of DR event the starting time and duration.

Table 12 presents the target values (T) for each use case and each KPI corresponding to Ampere pilot site. The achieved values (A) of the KPIs are filled in as well; the achieved values were computed over different experiments performed on the pilot site. Table 12 summarizes the achieved results; a more detailed description of the estimation of the target values and the tests is given for each use case in the following sub-sections.

All the experiments presented in this document were performed using DT.3 prototype system. The installation and initial commissioning of the DT.5 system were finalized late September

2018. The EBEMS was tested and its functionalities demonstrated also against the DT.5 system, thus highlighting the replicability nature of the energy management solution. Despite this, at the time of writing of this document, it was not possible to perform long lasting experiments due to the existence of operating issues over the new DT.5 system. However, the DT.5 system is expected to improve the results achieved for the energy services in the tests presented in this deliverable, by a factor which is proportional to the capacity increase from 22kWh to 88kWh.

Project KPI	Ampere Building									
	UC1		UC2		UC3		UC4		UC5	
	Peak Shaving for Power Subscription Cost Optimization		Provide DR Auto Consumption on Building Level		Energy Purchase Time Shifting		Provide DR Cost Minimization on Building Level		Provide DR – Flexibility for Building and District	
	T	A	T	A	T	A	T	A	T	A
Power	**8.8%**	7.0%								
Energy	**0.6%**	0.3%	**4.4%**	2.9%	**0.6%**	0.4%	**-4.4%**	-3.0%	**4.4%**	3.8%
Costs			**4.4%**	2.9%	**0.6%**	0.4%	**-4.4%**	-3.0%		
CO_2 Emissions			**4.4%**	2.9%			**-4.4%**	-3.0%		

Table 12: Targeted KPIs and achieved values per use case for Ampère building.

1.2.1.1 UC1: Peak shaving

This energy service aims at flattening and reducing the power consumption of a building load. Benefitting from an electric storage, the peak demand of the building can be shifted to a different time period of the day.

Two KPIs are considered to evaluate this use case. The power KPI estimates by how much the peak demand of the day can be reduced by using the electric storage. The energy KPI quantifies by how much the energy consumption of the building from the grid can be reduced during the peak demand period of the day.

Power KPI: estimation of the target value

The target value for the power KPI is estimated as the maximum ratio of the difference between the usual daily peak demand and the daily peak demand when using the electric storage, by the usual daily peak demand of the building (equation [1]). In the case of the Ampere building, the target for the power KPI is of 8.8%, using the information in Table 11.

$$Power_{\%} = \max_{t=1,\dots,t_{end}} \left(\frac{P_{Ref_t} - P_{ELSA_t}}{P_{Ref_t}}\right) \cdot 100\% \quad [1]$$

Where P_{Ref_t} is the usual daily peak demand of the building and P_{ELSA_t} is the reduced peak demand when using the electric storage.

Energy KPI: Estimation of the target value

The target for the energy KPI is estimated as the amount of energy that can be shifted from the peak demand period to a low demand period. In this case, we consider daytime (from 7:00 to 23:00) to be the peak demand period and low demand at night.

The target energy KPI corresponds to the ratio of the difference between the usual daily energy demand over daytime and the daily energy demand when using the electric storage, by the usual daily energy demand over daytime (equation [2]).

$$Energy_{\%} = \frac{E_{Ref} - E_{ELSA}}{E_{Ref}} \cdot 100\% \quad [2]$$

Where E_{Ref} is the usual daily energy demand of the building during daytime and E_{ELSA} is the reduced daily energy demand when using the electric storage. The target is of 0.6%, using the information inTable 11.

KPI evaluation over a test period

An example of peak shaving test performed in Ampere building is displayed in Figure 16. In this example, the test was performed over three consecutive days. The ELSA Building Energy Management System (EBEMS) forecasts when the peak demand of the building will happen during the day and charges the electric storage before the event if needed.

In Figure 16, the top part of the graph presents the reference power demand of the building (P_REF) in blue and the ELSA power demand in orange (P_ELSA) when the building presents an electric storage capability. The power demand of the building is normalized for data privacy reasons. The vertical red dashed lines present the max peak demand reduction for each day.

The bottom part of the graph presents the status of the electric storage system during the same time period. The actuation of the batteries are presented in blue using a convention of positive values for charging and negative for discharging. The red line corresponds to the stated of charge of the electric storage.

The same graphical template is used to present the experiments for the different energy services in both building pilot sites: Ampere building and SASMI building.

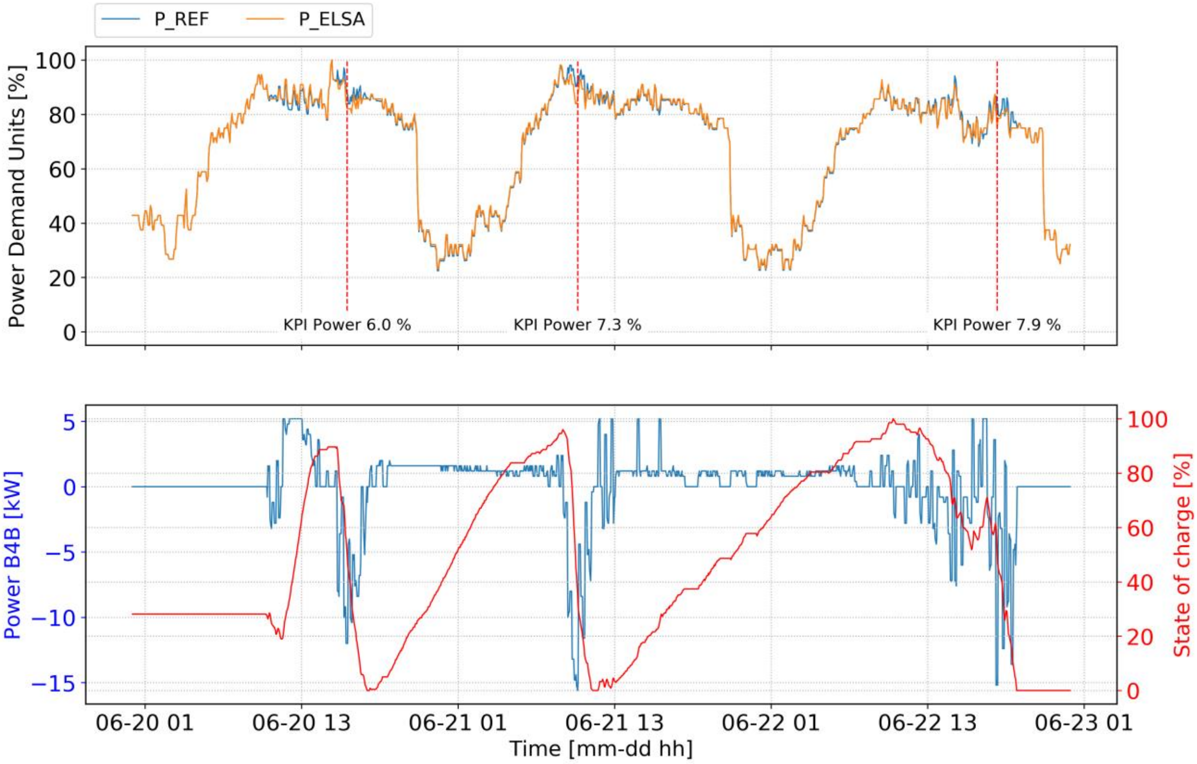


Figure 16. UC1: Example of peak shaving experiment over a three-day period.

The power KPI reaches a maximum value of 7.9% over the three-day period; the average value of the power KPI of the three days is of 7.0%. Figure 17 presents the peak shaving energy service over the third day, June 22nd, 2018. The electric storage is charged overnight and reaches about 85% of its capacity at 6:00. The EBEMS plans to use the battery capacity during daytime to reduce the peak demand.

The system never reaches the target KPI of 8.8% for the Power over that experiment. This is partially due to the fact that in some of the cases the electric storage was not completely full before performing the peak shaving. In addition, the actual discharge rate during the peak shaving event gets to a maximum of about -15 kW over the last two days and about -12 kW on the first day of the experiment. The maximum discharge rate is supposed to be of -22 kW, in the normal conditions of operation. It should be noted that the Battery Energy Management System (BEMS) continually sends bounds for the charge and discharge rates to the EBEMS according to the status of the battery system. This explains the maximum discharge rates obtained in this experiment.

The Energy KPI reaches a value of 0.3% over the three-day period by benefitting from the stored energy to reduce the energy demand during peak demand periods.

Regarding the Energy KPI, a target value of 0.6% was set and the achieved value is of 0.3%. In this case also, the fact that the electric storage did not reach its full capacity before the event has an impact on the achieved KPI. It should be noted that in the definition of the energy KPI, the calculation is performed considering the energy consumed during the day time (from 7:00 to 23:00). In the experiment, the electric storage is being charged until the start of the peak shaving event even during the day.

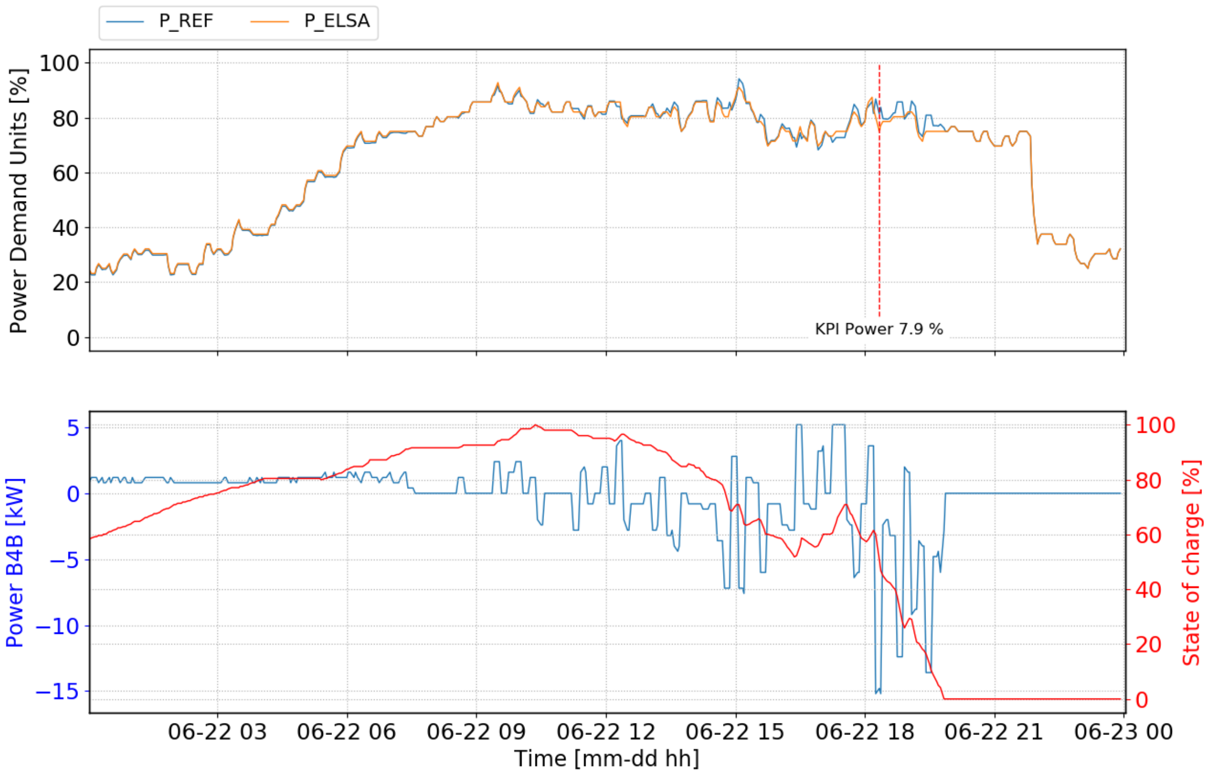


Figure 17. UC1: Example of peak shaving experiment over June, 22nd 2018.

1.2.1.2 UC2: Auto-consumption DR Service

This DR Service aims at minimizing the amount of energy consumed from the electric utility over a pre-defined time horizon. This can be done by using as much renewable energy as possible but also by using the energy stored in the B4B (Batteries for Buildings) system.

Energy KPI: estimation of the target

The target value for the energy KPI is calculated similarly to the one for the Peak shaving use case (equation [2]). The difference in this case is the time period considered: a usual time length of two hours is considered for the DR event, instead of sixteen hours for the daytime in the Peak shaving service. A target value of 4.4% is estimated using the information in Table 11.

Costs KPI: estimation of the target

The target value for the Costs KPI is estimated as the ratio of the difference between the cost of the energy demand of the building in the reference case and when the building presents an electric storage capacity, by the cost of the energy demand of the building (equation [3]). The energy terms in equation [3] refer to the energy consumed by the building during the DR event. During an auto-consumption DR event, the rate of energy is constant so the Costs KPI described in equation [3] is equivalent to the energy KPI in equation [2]. Similarly, a target value of 4.4% is estimated using the information in Table 11.

$$Costs_{\%} = \frac{rate*\left(E_{Ref}(t)-E_{ELSA}(t)\right)}{rate*E_{Ref}(t)}.100\% \quad [3]$$

Where $E_{Ref}(t)$ corresponds to the energy demand of the building during the DR event, $E_{ELSA}(t)$ is the energy demand of the building when using an electric storage and $rate$ is the price of the electricity during the DR event.

CO2 emissions KPI: estimation of the target

The CO2 emissions KPI is estimated as the ratio of the difference between the CO2 emissions corresponding the energy demand of the building in the reference case and when the building presents an electric storage capacity, by the CO2 emissions in the reference case (equation [4]). The conversion factor from the energy demand of the building to the corresponding CO2 emissions is considered constant during the DR event. The CO2 emissions KPI calculation is described in equation [4]. Similarly to the Costs KPI, it is equivalent to the energy KPI and a target value of 4.4% is estimated.

$$CO2_{\%} = \frac{Conv._{factor}*\left(E_{Ref}(t)-E_{ELSA}(t)\right)}{Conv._{factor}*E_{Ref}(t)}.100\% \quad [4]$$

Where $Conv._{factor}$ is the conversion factor from energy demand to CO2 emissions.

KPI evaluation over a test period

An auto-consumption DR Service was tested in Ampere building; an example over a five-day period is presented in Figure 18. The template of the figure is the same as the one presented in section 1.2.1.1 for the Peak shaving service. The only additional feature is the green area corresponding to the time period when a DR event is occurring.

From the lower part of the graph in Figure 18, one can see that the electric storage system is operated such that the energy demand of the building during the DR periods (green areas) is reduced. The batteries are completely charged over the night, completely discharged during the first DR event and then partially charged before reaching the next DR event. The PV production is not presented on Figure 18 because the PV panels were malfunctioning during the time period of the experiment and were not producing renewable power.

Figure 19 presents an example of auto-consumption DR Service over one day: July 18th, 2018. Four DR events occur during the day: #1 from 10:15 to 12:45, #2 from 14:00 to 15:00, #3 from 16:20 to 17:50 and #4 from 19:30 to 22:00. The EBEMS charges the electric storage over night to reach full capacity before 7:00 when the energy rate increases; the EBEMS completely discharges the B4B system during the first DR event. The storage is then partially charged before reaching the next DR event and this successively during the day. The same behaviour was observed over several days in Figure 18. An average value of 2.9% was reached in this test for the Energy, Costs and CO2 emissions KPIs while the target KPI is 4.4%.

Table 13 summarizes the KPI values for the Energy, Costs and Co2 emissions for each DR event that occur over the four-day experiment. The first DR event of each day presents the highest KPI value because of the electric storage was full at the start of the event after charging at night. The target KPI of 4.4% is even exceeded in the case of the first DR event on the July, 17th. For this specific event, its duration is of one hour while a two-hour DR event is considered in the calculation of the target value. In the majority of the events, the target is not reached because of the available energy stored in the batteries. Due to the multiple events occurring during one day, the system does not have time to fully charge between the events. Note that during the last two days of experiment, only one battery module was in operation (maximum discharge rate of about -11kW) which impacts the achieved KPI.

Date	July 17th			July 18th				July 19th				July 20th			
DR event	#1	#2	#3	#1	#2	#3	#4	#1	#2	#3	#4	#1	#2	#3	#4
KPI value	7.5	4.7	2.0	4.7	2.6	2.1	1.9	2.2	1.1	2.2	1.9	3.7	2.7	2.6	2.1

Table 13: Energy, Costs and CO2 emissions KPIs values of the auto-consumption DR events over a four-day period.

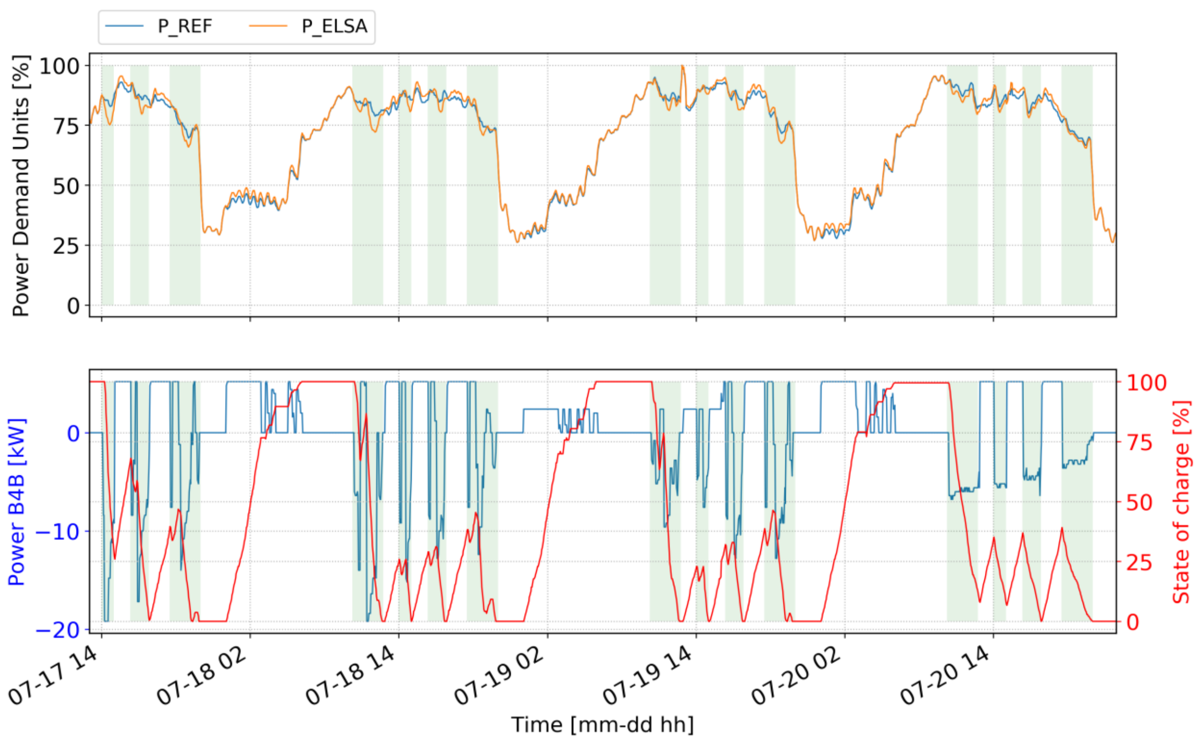


Figure 18. UC2: Example of auto-consumption DR Service experimented over a five-day period.

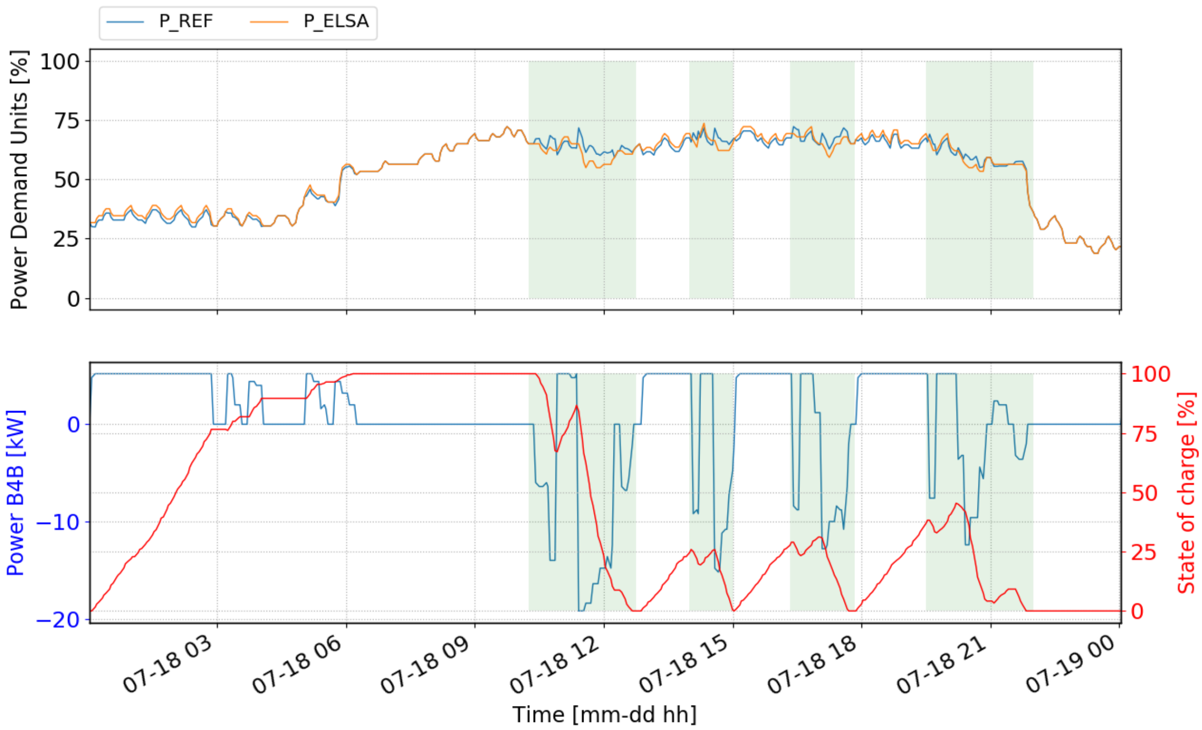


Figure 19. UC2: Example of auto-consumption DR Service experimented over July, 18th 2018.

1.2.1.3 UC3: Energy Purchase Time Shifting

In the Energy Purchase Time Shifting (EPTS) Service, the electric grid tries to balance the demand during day-time and night-time by implementing a cheaper electricity rate at night. In the context of this energy service, the EBEMS will use the electric storage available to shift part of the building grid demand from an expensive time of use of energy to a cheaper time of use. The EBEMS will flatten the demand of the building over the day. The EPTS service is based on given tariff profiles that are agreed a priori with the electric supplier on long term contracts of a minimum period of one year.

Energy KPI: estimation of the target

The target value for the Energy KPI is the same as the one defined in section 1.2.1.1 for the Peak shaving service. The energy demand of the building during daytime (set from 7:00 to 23:00) is compared to the energy demand over the same time period when using an electric storage (see equation [2]). The target value is of 0.6%.

Costs KPI: estimation of the target

For the Costs KPI, the target value is estimated using equation [3] defined in section 1.2.1.2. The KPI is estimated over the daytime period such as for the Energy KPI in the previous subsection. The energy rate stays constant during daytime and the Costs is identical to the energy KPI. The target value is also of 0.6%.

KPI evaluation over a test period

An example of EPTS service over a three-day period is presented on Figure 20. The figure follows the same template as previously; one piece of information is added: the energy rate. The energy rate is presented in red on the top part of the graph. Note that the energy rate, in this example, is set to a value of 0.11 euros/kWh from 07:00 to 00:00, and 0.055 euros/kWh the rest of the time. The EBEMS foresees the increase of price from night-time to day-time and plans to charge the B4B system to its full capacity over the cheapest period. The lower part of the graph in Figure 20 shows the operation of the storage system: the EBEMS charges the batteries at night when the price is lower to reduce the costs of operation during daytime.

Figure 21 focuses on one day of test of the EPTS Service: May 22nd, 2018. With a 9-hour forecasting horizon, the EBEMS starts charging the electric storage about 9 hours before it foresees the increase in energy rate; and it would respectively start discharging the storage 9 hours before the decrease in energy rate. One can observe this behaviour on the bottom part of Figure 21: the B4B system starts discharging around 14:00 while the energy rate will increase at 23:00. A forecasting horizon of 9 hours was set in this example but it can be increased up to 24 hours.

The Energy and Costs KPIs reach a value of 0.4% on the experiment considered compared to the target value of 0.6%. During this experiment, only one of the two modules was in operation. The available capacity for energy storage at night influences significantly the achieved KPI. Note that the SOC of the system displayed on Figure 20 and Figure 21 is derived from the available battery capacity during the experiment; it is not representative of the number of battery modules in operation.

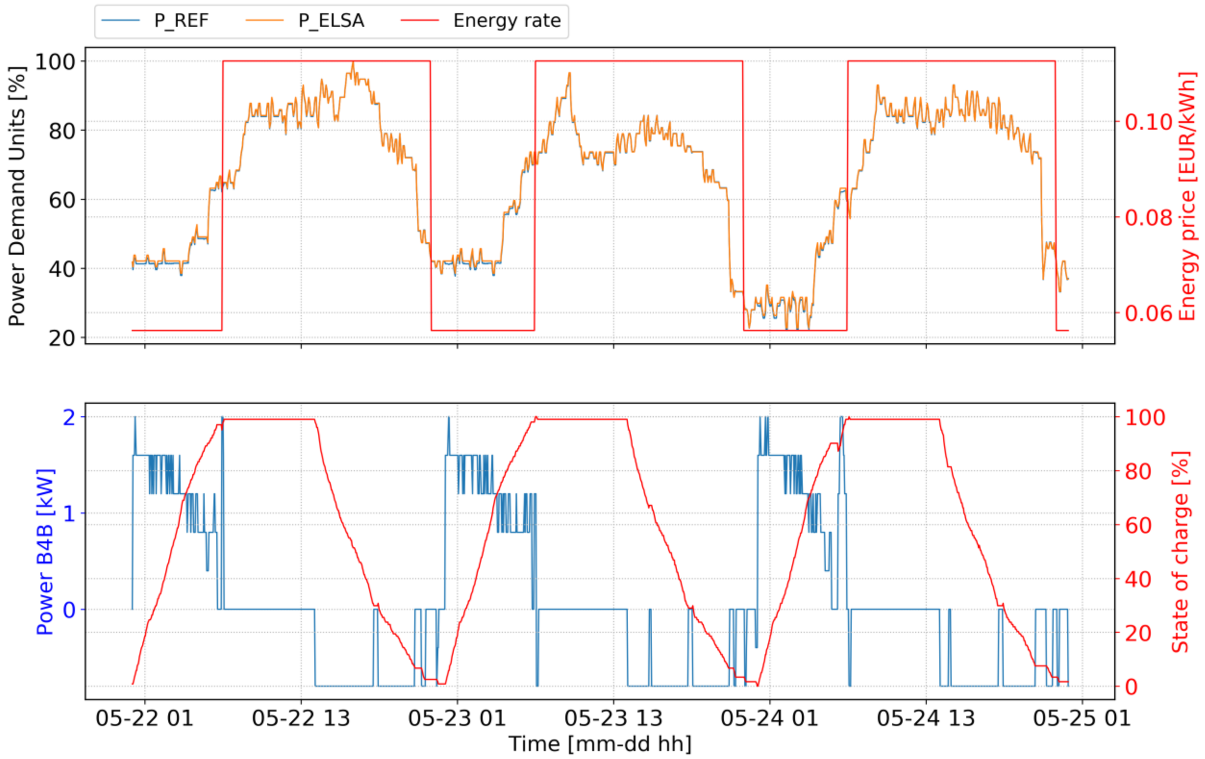


Figure 20. UC3: Example of Energy Purchase Time Shifting Service experimented over a three-day period.

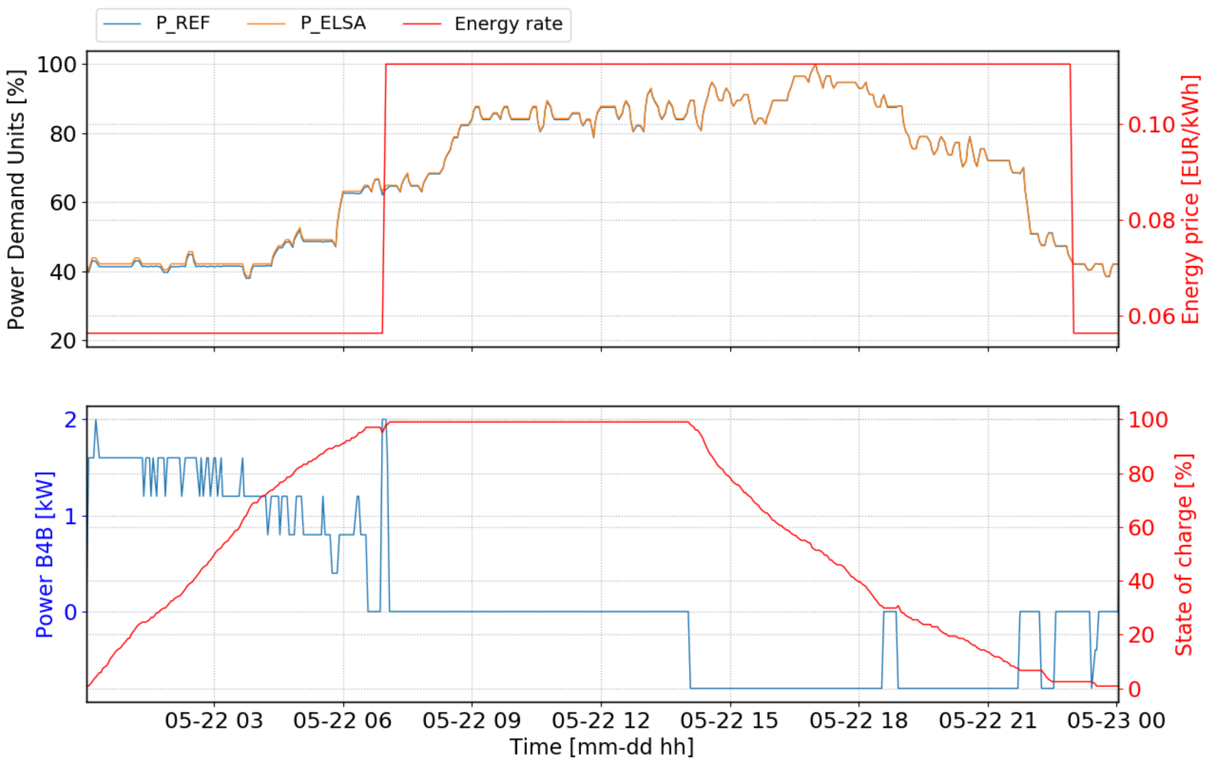


Figure 21. UC3: Example of Energy Purchase Time Shifting Service experimented over May 22nd, 2018.

1.2.1.4 UC4: Cost-minimization DR Service

During a cost-minimization DR event, the electric utility varies the energy cost to deal with a variation of price on the market for instance. The EBEMS is provided with the start time of the DR event, its duration, as well as the profile of the energy cost along the time period of the event. The EBEMS will act on the building energy demand profile to benefit from the period when the energy is cheaper, such that the total energy cost over the DR event is minimized.

Energy, Costs and CO2 emissions KPIs: estimation of the target

The evaluation of the target values for the Energy, Costs and CO2 KPIs in case of a cost-minimization DR Service is similar to an auto-consumption DR Service (see section 1.2.1.2). The time period considered for the usual time length of a DR event is of two hours. The target for the Energy KPI is evaluated using equation [2], respectively equation [3] for the Costs KPI and equation [4] for the CO2 emissions KPI.

In the case of a cost-minimization DR Service, if the energy rate during the DR event is lower than the usual energy rate, the EBEMS will plan to charge the batteries to benefit from this lower price later during the day after the DR event when the rate will increase. In this case, a negative value appears in the evaluation of the target KPIs because the demand of the building with the ELSA system will be higher than the usual demand of the building during that DR event. A target value of – 4.4% is estimated.

These are the case experimented and presented in the next subsection but if the energy rate was higher than the usual rate during the DR event the sign of the target value would be the opposite.

KPI evaluation over a test period

A test of the cost-minimization DR Service is performed over a four-day period from July 30th to August 2nd, 2018 (Figure 22). The DR events are highlighted by the light green areas and the energy rate is also displayed in red on the top part of the figure. It is assumed in the test of a DR event that the system runs normally under an EPTS Service. A DR event generated by the electricity provider, might occur at any time of the day with a short-term notification. The EBEMS is able to deal with the DR Service in real time; it plans for an optimal use of the resources available in the building.

In this example, the energy rate is set to a value of 0.11 euros/kWh from 07:00 to 00:00, and 0.055 euros/kWh the rest of the time; this corresponds to the EPTS energy rates. When a cost-minimization DR event occurs, the energy rate is set to a constant lower value of 0.05 euros/kWh, in this test. The energy rate presented in red on top of Figure 22 can take three different values: 0.11 euros/kWh during when no DR event occurs, 0.055 euros/kWh during night time and 0.05 euros/kWh during DR event.

The EBEMS takes advantage of the time periods when the energy rate is lower: the electric storage is charged at night (from 23:00 to 7:00) or during the DR events (see Figure 22).

Figure 23 focuses on a 24-hour period on August 2nd, 2018. Four DR events occur during the day: #1 from 10:15 to 12:45, #2 from 14:00 to 15:00, #3 from 16:20 to 17:50 and #4 from 19:30 to 22:00. The EBEMS charges the electric storage over night to reach full capacity before 7:00 when the rate increases. Then, it discharges the batteries during periods of higher rates and charges them during the DR events while the rate is the cheapest.

In the test presented, the Energy, Costs and CO2 KPIs reach an average value of -3.0% compared to a target KPI of -4.4%. Table 14 summarizes the KPI values for the Energy, Costs and Co2 emissions for each DR event that occur over the four-day experiment. Similarly to UC3, the time duration of the DR events in the test differs from the two-hour duration used to estimate the target value. For the test performed in the context of this energy service, the charging rate of the electric storage shows an important effect. A maximum charging rate of 5 kW appears in the test which constrains the amount of energy that can be stored in the batteries during the DR event.

Date	July 30th			July 31st				August 1st				August 2nd			
DR event	#1	#2	#3	#1	#2	#3	#4	#1	#2	#3	#4	#1	#2	#3	#4
KPI value	-1.9	-2.6	-3.0	-2.7	-5.8	-2.4	-3.1	-2.7	-2.8	-2.8	-3.1	-2.8	-2.9	-2.7	-3.1

Table 14: Energy, Costs and CO2 emissions KPIs values of the cost–minimization DR events over a four-day period.

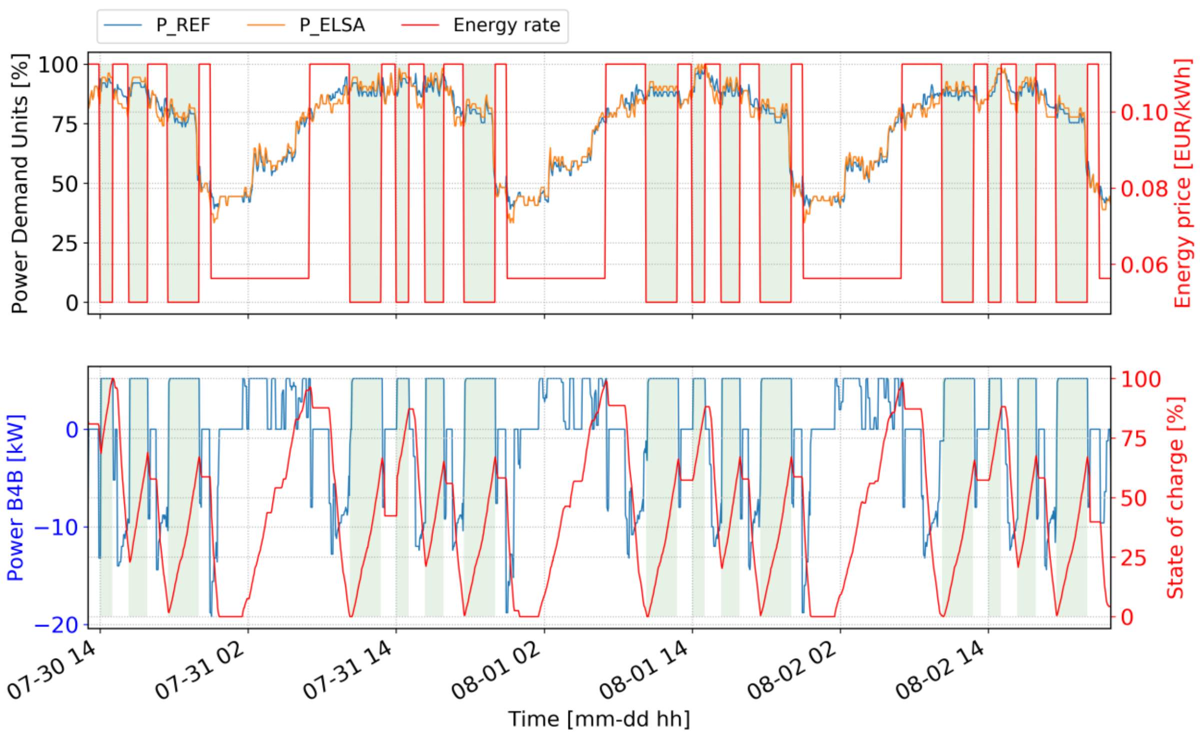


Figure 22. UC4: Example of Cost-minimization DR Service experimented over a four-day period.

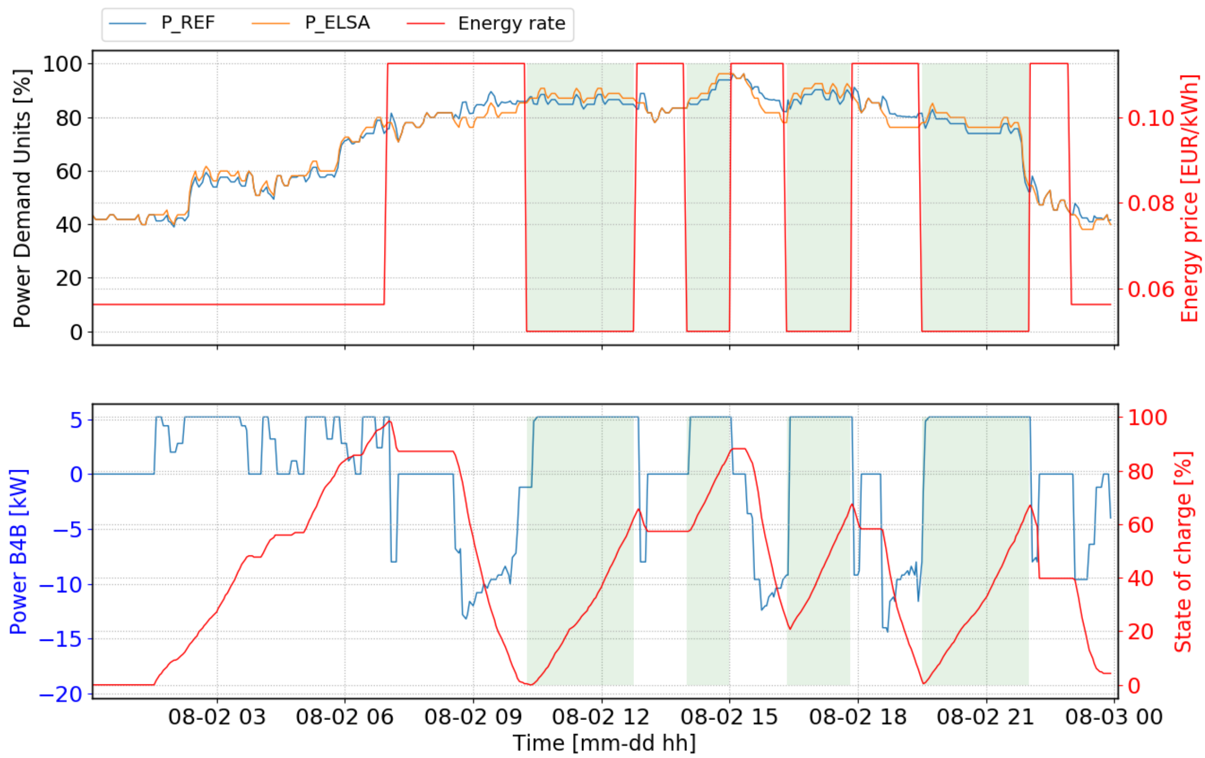


Figure 23. UC4: Example of Cost-minimization DR Service experimented over July 31st, 2018.

1.2.1.5 UC5: Flexibility DR Service

This DR Service determines the amount of building energy demand from the grid which can be reduced in a given time interval exploiting the contribution of all the flexible resources including the storage. During the DR event, the electric utility requires the building to track (if possible) within certain tolerances a specific demand that can be higher or lower than the usual electric demand of the building.

Energy KPI: estimation of the target

The evaluation of the target value for the Energy KPI in case of a flexibility DR Service is the same as for an auto-consumption DR Service (see section 1.2.1.2). The time period considered for the usual time length of a DR event is of two hours. The target for the Energy KPI is evaluated using equation [2]; a target value of 4.4% is estimated.

KPI evaluation over a test period

A test of a flexibility DR Service was performed on August 10th, 2018. Figure 24 presents the experiment where the DR event occurs from 19:30 to 22:00 (green area). A specific demand profile is required from the electric utility to be tracked by the building (P_target). This profile is represented by the continuous red line on the top part of Figure 24; the dashed redline corresponds to the tolerance bandwidth given by the electric utility in which the building demand should remain.

During the test, the EBEMS was not able to reach the demand specified by the grid and stay within the tolerances. The EBEMS tried to reach the specified demand (P_target) that is higher than the reference demand of the building (P_REF) by charging the electric storage during the DR event and increasing the demand of the building. In this example, the difference between the reference demand of the building and the specified demand was too large for the EBEMS to cope with given the available capacity of the electric storage.

An Energy KPI value of -3.8% is achieved on this test, while the target value is of 4.4%. The negative value is because, in this experiment, the specific power demand required by the grid is higher than the actual one so the building is required to consume more than usual. The absolute value 3.8% can be compared to the target value.

Similarly to the cost-minimization DR Service, an upper limit of 5 kW is met during the experiment. The limit on the charging rate as well as the existing storage capacity compared to the specific demand required by the electric utility makes it difficult to reach the target value of the KPI.

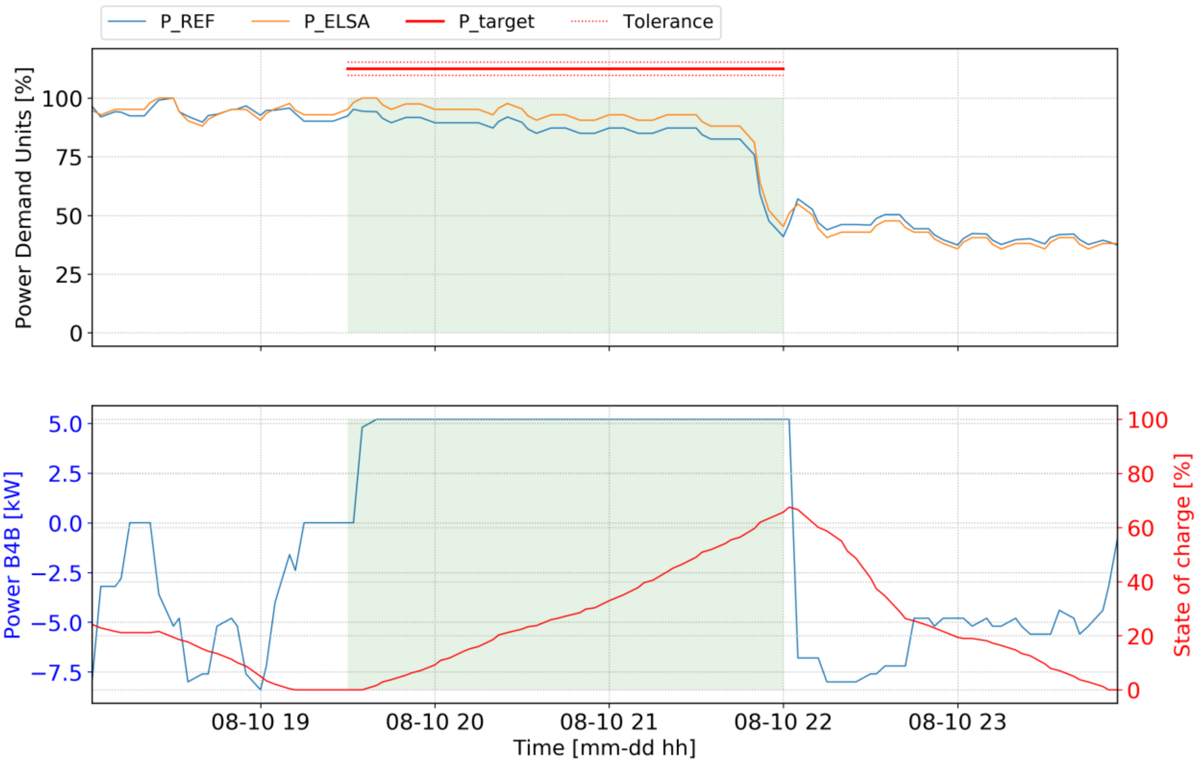


Figure 24. UC5: Example of Flexibility DR Service experimented on August 10th, 2018 from 19:30 to 22:00.

1.2.2 Conclusion

Three energy services were demonstrated in the Ampère building pilot site: peak shaving, energy arbitrage and demand response services (including auto-consumption, cost-minimization and flexibility). KPIs were evaluated to assess the performance of the system on providing those services to the grid in terms of power, energy, costs and CO2 emission indices.

The energy services were tested several times and the average value of the KPIs is reported in Table 12. The targeted KPIs were reached with a discrepancy of about 30%, except for the energy KPI in the case of the peak shaving service which reached a KPI of 0.3% compared to a target of 0.6%. When performing several demonstrations consecutively, the evaluation of the KPIs is impacted: the system is not in the same state at the beginning of each test, the battery modules are not always at full capacity when starting an experiment. The KPIs achieved over the demonstrations were also impacted by the operation of the storage system; the total capacity of the system was not always available.

The experiments presented in this document were performed using the DT.3 prototype system. The installation and initial commissioning of the DT.5 system were finalized late September 2018. The EBEMS was tested and its functionalities demonstrated also against the DT.5 system, thus highlighting the replicability nature of the energy management solution. At the time of writing this document, long-lasting experiments were not performed due to the existence of operating issues in the DT.5 system. However, the DT.5 system is expected to improve the energy services provide: the achieved KPIs should be improved by a factor proportional to the capacity increase from 22kWh to 88kWh.

The overall ELSA system demonstrated the capability, for Ampère pilot site, to provide the defined energy services to the electric grid. The limited capacity of the storage system compared to the building load significantly impacts the energy services that can be provided.

1.3 RWTH Aachen

1.3.1 Pilot site description

The Aachen pilot site represents a district in the ELSA project framework. It belongs to the E.ON Energy Research Center of the RWTH Aachen University Melaten campus in Aachen, Germany. The district consists of three buildings, each building with a monitoring system and in case of the main building and test hall an energy management system. The main building is a large office building with 7222 m² of floor space, containing offices and laboratories for around 200 employees as well as student working places and seminar rooms. The test hall houses large scale experiments on around 1000 m² lab space. The sense building is another office building with around 90 offices with approximately 18 m² per room. The ELSA battery system is installed inside of a container placed next to the test hall. Additionally, the Aachen pilot considers a virtual' wind turbine with 500kW peak power as part of a simulation integrated into the district.

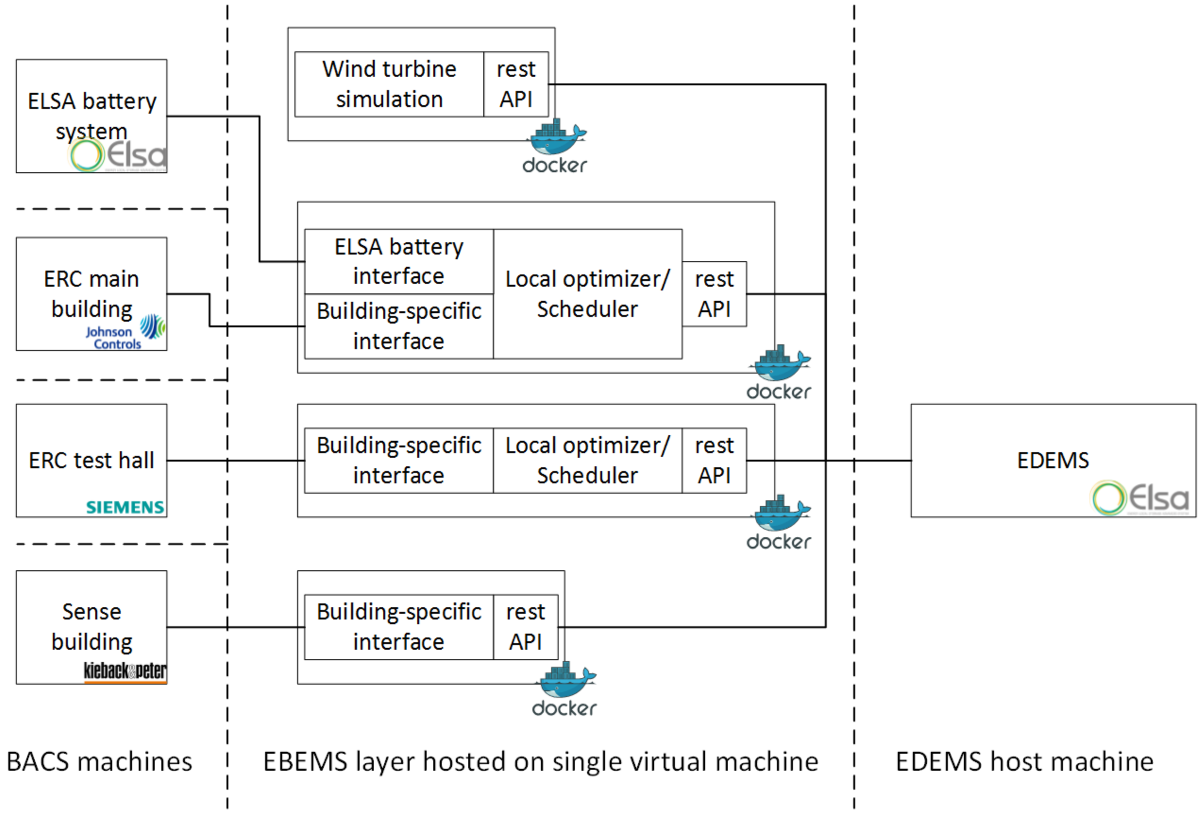


Figure 25: Aachen ICT platform deployed

The flexibility resources included in this test site evaluation are not connected to other electrical appliances in the building. Therefore, they can be controlled independently.

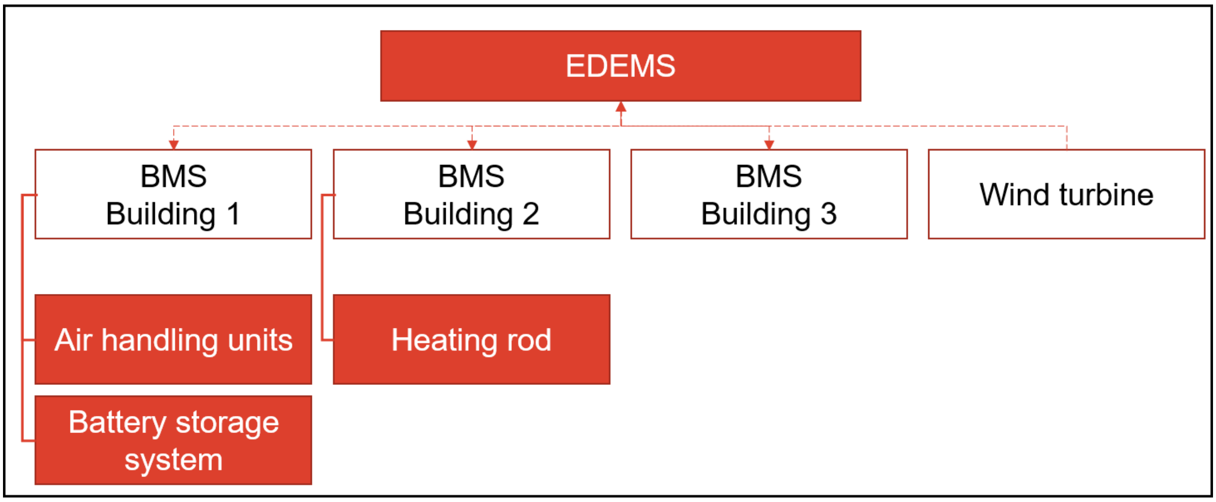


Figure 26: Structure of district with flexibility sources

Test site type	**Commercial district**
Consumption	• Commercial district with three buildings • Usual daily peak demand of 250 kW • Usual daily consumption of 4320 kWh
Generation	• A 500kW simulated wind turbine is considered as part of the experimental setup
ELSA Battery	• DT.3 prototype system: ○ Six battery modules of 11 kWh capacity each ○ Total energy: 66 kWh ○ Total Power: ▪ Charging: max. 18 kW ▪ Discharging: max. 72 kW • DT.5 system (since November 2018): ○ Six battery modules of 11 kWh capacity each ○ Total energy: 66 kWh ○ Total Power: ▪ Charging: max. 72 kW ▪ Discharging: max. 72 kW
Battery purpose	• Auto-consumption • CO2-minimization • Cost-minimization • Flexibility

Table 15 RWTH test site information

Battery storage

The battery storage is composed of six second life batteries with a capacity of 11 kWh each. The maximum charge power is 18 kW and the maximum discharge power is 72 kW.

The primary purpose of the battery storage is to provide power for peak shaving within the main building. The main building disposes of a heat pump with an electrical peak power of 47.8 kW which is the main influence on peak power of the building. Therefore, the battery is used to compensate the heat pump's load.

For the heat pump peak shaving, the control algorithm works as follows: The battery will discharge while the heat pump is in operation to compensate its load. This discharge behaviour will continue until the battery state of charge falls below 40%. At this point, the heat pump's load will no longer be compensated. Instead, the battery will be recharged. This can be seen in the figure below. The battery discharges according to the heat pump load. From 22:38 on, s district-wide schedule asks for 10 kW discharge power. Therefore, the local and district-wide use cases are superposed. At about 22:49, the battery's SoC falls below 40%. Consequently, the local use case pauses until the heat pump operates no longer. Only the district schedule of 10 kW is put into practice. As soon as the heat pump operates no longer, the battery charging process at 18 kW initiated by the local heat pump peak shaving use case begins.

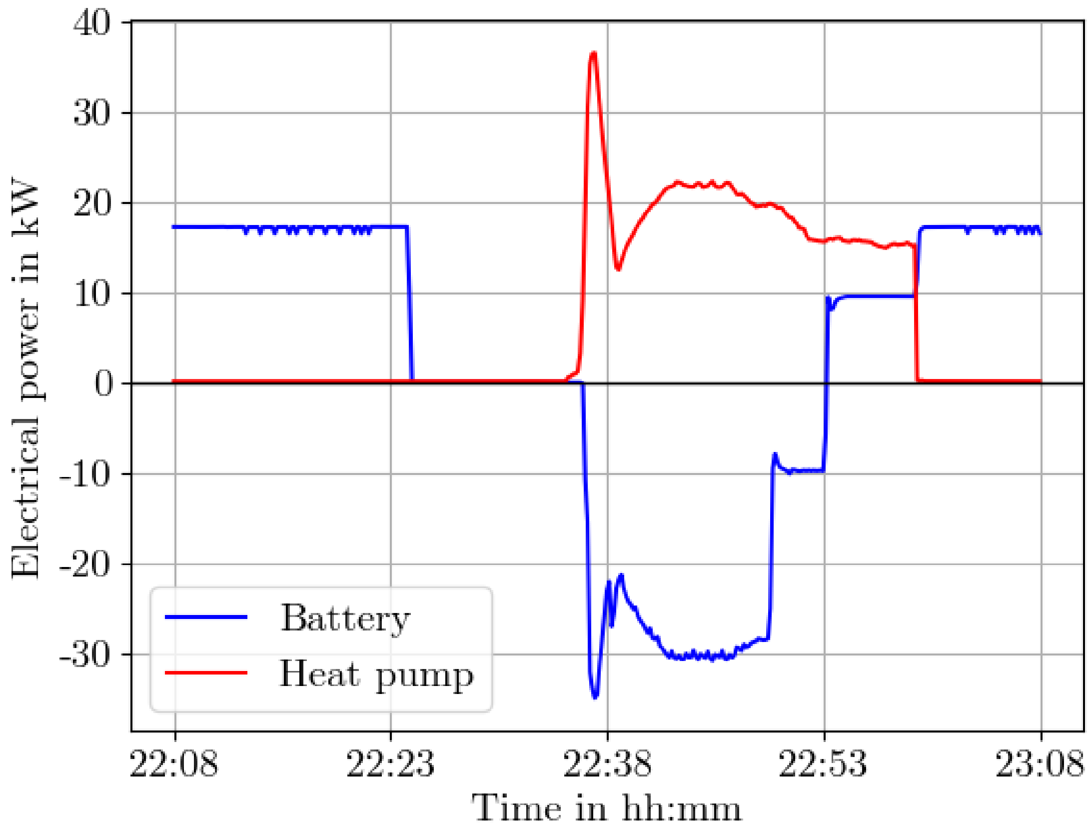


Figure 27: Local use case vs. global use case

Assuming that the goal of this heat pump peak shaving is to decrease the building's peak power, heat pump peak shaving is primarily relevant during the day.

On average, between 8 a.m. and 6 p.m. the heat pump consumes 97 kWh. Thus, the battery storage's capacity of 66 kWh does not suffice to sustain the chosen heat pump peak shaving concept over a whole day. To allow the use of the battery in the district-wide use case, tests are only conducted over one or a few hours while the battery is available.
Therefore, test results are evaluated hour-wise. Further testing will include tests over a more representative time period, i. e. 24 hours.
The KPI target values described above are based on the assumption that the system is used continuously over 24 hours. Consequently, recovery times of the flexibility sources are included. Therefore, they indicate the theoretical maximum impact the EDEMS can have on the district. In order to evaluate individual experiment hours, the following target values will be considered.
The remaining battery capacity can be provided to the district energy management system. The remaining maximum charge and discharge power provided to the EDEMS is 10 kW with the DT3 system.

The duration of battery operations is limited by the need to maintain the SoC. At the end of the optimization horizon, the SoC needs to be the same as at the beginning. This constraint ensures that necessary recharging is taken into account in the coordination process. Otherwise, for example during cost minimization, the battery would only be discharged because this behaviour would results in the lowest costs. Therefore, after a certain period of time of discharging/charging energy from the battery storage, the corresponding amount of energy has to be charged/discharged. As the optimization horizon assessed is 60 minutes, the maximum duration of a charging or discharging action is 30 minutes.

Air handling units

The air handling units that are part of the main building's ventilation system can be utilized as a means of load shedding. They are vital to the building's user comfort which constrains the shedding capabilities. Their power consumption depends on the pressure set point and is characterized by fluctuations over the course of the day. Complete interruption is limited to a duration of 15 minutes. Partial load shedding is limited to a duration of 60 minutes. In this case, the pressure set points of an air handling unit is decreased in order to reduce its electricity consumption. Due to inertia in this type of control via pressure set points this shedding action is performed over one hour to significantly lower the electricity consumption. In between any shedding action, a recovery time of 30 minutes must be respected.

The electricity consumption during normal operation fluctuates, but usually, each air handling unit can reduce their consumption by about 4 kW when interrupted and by 2 kW to 3.6 kW when the pressure set point is adjusted.

Heating rod

The heating rod converts electrical energy to thermal energy. This thermal energy is stored in a storage with a volume of 1500 l and supplies heat for experiments conducted in the test hall. The device can be operated from 0 kW to 9 kW and can be set in 3 kW steps. It can be activated as long as the constraints of the thermal storage are respected. The thermal storage's temperature needs to be maintained between 40°C and 80°C.

1.3.2 Use case evaluation

On the KPI document that you can find in the annexe, you will be able to find the KPI approach of the ELSA project. Moreover, it also defines the KPI used and the target expected for each test site. For the Aachen test side, the target values were deviated from the estimated available flexibility potential per hour and day.

The further remarks are estimated on base of the DT3 battery system limitations exclusivly. The DT5 system was commissioned and installed in summer 2018. The third quarter of 2018 was used to debug the system and to fix problems of the battery controller and the communication between battery PLC, converter and battery packs. Since mid November, the DT5 system is operationable robustly. Our EDEMS was tested and demonstrated against the DT5 system. Unfortunately, the intensive debugging period prevented us to run long lasting experiments with the DT5 system. The presented results are a subset of representative experimental runtime of the overall system, which underline our key findings of the expermients performed in Aachen.

1.3.2.1 Estimation of flexibility potential

Flexibility potential per day

- Charging battery storage including inverter losses assuming that two battery cycles can be used:

$$\frac{2 \cdot 66\ kWh}{0.9} = 146.67\ kWh$$

- Discharging battery storage including inverter losses:

$$-2 \cdot 66\ kWh\ \ \cdot 0.9 = -118.8\ kWh$$

- Heating rod, operated within temperature boundaries of the thermal storage:

$$\Delta T \cdot c_{p\,water} \cdot m_{water} = (80°C - 40°C) \cdot 4.182 \frac{kJ}{kg} \cdot K \cdot 1500\ kg \cdot \frac{1\ h}{3600\ s} = 69.7\ kWh$$

- Shedding air handling units:

Each of the two air handling units' consumption can be reduced by 6 kWh every 3 h:

$$2 \cdot \frac{-6\ kWh}{3\ h} \cdot 24\ h = -96\ kWh$$

The average daily energy consumption of the first seven months of 2018 of the district's buildings is $4294\ kWh$.

Flexibility potential per hour

For single experiment hours, the flexibility sources are assumed to be readily available. The thermal storage is capable of absorbing thermal energy and the battery storage can both charge and discharge energy. Recovery times are not taken into account. The power modifications possible within one hour of every flexibility source depend on the duration of the action:

Table 16: Aachen flexibility characterisation

Flexibility source	Power	Energy
Air handling units (aggregated) Power decrease	Option A: 8 kW Power decrease for 15 min	2 kWh
	Option B: 6 kW Power decrease for 60 min	6 KWh
Battery storage system Power increase/decrease	Option A: Shift 10 kW for 15 min	2,5 kWh
	Option B: Shift 10 kW for 30 min	5 kWh
Heating rod Power decrease	Option A: 9 kW Power increase for 15 min	2,25 kWh
	Option B: 9 kW Power increase for 30 min	4,5 kWh
	Option C: 9 kW Power increase for 60 min	9 kWh

Table 17: Flexibility sources in Aachen

UC1 CO_2 minimization target value

The objective of this use case is to shift electrical energy consumption into time slots characterized by low CO_2 emissions on the national power grid level.

Therefore, a CO_2 emission signal is considered for every time step. This signal indicates the amount of CO_2 emitted by generation units in the German power grid. It is calculated by

weighting the current energy generation mix extracted from ENTSO-E[2] with the respective CO_2 emissions caused[3].
In our application, CO_2 emissions can be minimized by reducing consumption as far as possible and shifting consumption from time slots with relatively high CO_2 emissions into time slots with relatively low CO_2 emissions.

In order to evaluate the best-case result for an hour, the KPI is calculated based on maximum emission signal spreads. Emission signal spreads indicate the difference in the emissions signal that occur within one coordination horizon.

Assumptions regarding the CO_2 emissions – according to data analysis from the year 2017:

- Average emission per kWh: $416.58\ \mathrm{g/kWh}$
- Maximum emission spread within one hour: $11.261\ \mathrm{g/kWh}$

Operating the battery in order to reduce C02 emissions is only beneficial if the converter loses do not exceed the shifted energy. We subtract the maximum emissions avoided by discharging the battery from the emissions caused by charging the battery.

$$146.67\ kWh \cdot 416.58 \frac{g}{kWh} - 118.8\ kWh \cdot \left(416.58 \frac{g}{kWh} + 11.261 \frac{g}{kWh}\right) = 10272.28\ g$$

Concluding, we see that the battery increases the overall CO2 emissions. Since the emissions caused by energy generation do not fluctuate strongly within one hour, the consumption shifting cannot outweigh the supplementary consumption because of converter losses. Therefore, the battery storage is not used for this use case.

Nevertheless, load shedding can be used as a means to avoid CO_2 emissions. In this way,

$$6\ kW \cdot 1h \cdot 416.58 \frac{g}{kWh} = 2\ 498.88\ g$$

of CO_2 emissions could be saved per hour.

Accordingly, KPI target for CO_2 is $\frac{2\ 498.88\ g}{\frac{4294\ kWh}{24} \cdot 416.58\ \mathrm{g/kWh}} = 3.35\%$.

UC2 Auto-consumption target value

For the use case Auto-consumption, the consumption needs to be adjusted with the objective to utilize as much on-site generated renewable energy as possible. In order to reach the goal of raising the auto-consumption, the heating rod can be used as a supplementary load in times

[2] *ENTSO-E Transparency Platform.* [Online] Available: https://transparency.entsoe.eu/.

[3] H.-J. Wagner *et al.,* "CO2-Emissionen der Stromerzeugung: Ein ganzheitlicher Vergleich verschiedener Techniken," in *BWK 59 (2007) Nr. 10*

of high local wind energy generation. Moreover, the battery storage serves to shift the consumption over time. Additionally, the air handling units' load can be shed to optimize the amount of energy consumed.

Adding the available modifications by means of heating rod and battery storage loses, $E_{flex,1h}$ can add up to $9\ kWh \cdot\ 1h + 10\ kW \cdot \frac{1}{2} h - 8.1\ kW \cdot \frac{1}{2}\ h = 9.95\ kWh$. This represents the maximum improvement during one hour. The maximum improvement by percentage is achieved, when $\frac{E_{buildings,min}}{E_{wind,opt}}$ is minimized. A challenging target value can be estimated on base of the minimum district building consumption $E_{buildings,min}$ is 84 kWh over 1 hour. Since the wind energy needs to be greater than the original building consumption, we assume $E_{wind,opt} = E_{buildings,min} + E_{flex} = 93,95\ kWh$.

Consequently, the self-consumption can be increased from $\frac{E_{buildings,min}}{E_{wind,opt}} = \frac{84\ kWh}{84\ kWh + 9.95\ kWh} =$ 89.41% to $\frac{E_{buildings,min} + E_{flex}}{E_{wind,opt}} = \frac{84\ kWh + 9.95\ kWh}{84\ kWh + 9.95\ kWh} = 100\%$.

Thus, the target of KPI self-consumption is $9.95\ kWh$ or $\frac{100\% - 89.41\%}{89.41\%} = 11.84\%$.

UC3 Cost minimization target value

The objective of this use case is to shift electrical energy consumption into time slots characterized by low electricity prices on the Intraday electricity market.
In this case, costs can be reduced by shedding flexible loads as far as possible and shifting consumption into time slots with relatively low electricity prices.
By using the battery storage, 4.05 kWh of the district's consumption can be shifted per hour. Inverter losses add up to $5kWh - 4.05\ kWh = 0.95\ kWh$ per hour.
By shedding the air handling units, approximately 6 kWh can be saved per hour.
In order to evaluate the best case result for an hour, the KPI is calculated based on maximum intraday price spreads. Price spreads indicate the difference in price signal within one coordination horizon.

Assumptions regarding the electricity price – according to analysis of Intraday prices 03/2017-03/2018[4]:
Taking into account energy savings by load shedding, the result is

$$6\ kW \cdot 1h \cdot 0.032687 \frac{€}{kWh} = 0.1961\ € \text{ per hour.}$$

Additionally, costs can be avoided by shifting the consumption using the battery storage.

$$8.1\ kW \cdot \frac{1}{2} h\ \cdot \left(0.032687 \frac{€}{kWh} + 0.01542\ \frac{€}{kWh}\right) - 10\ kW \cdot \frac{1}{2} h\ \cdot 0.032687 \frac{€}{kWh} = 0.0314\ €$$

Thus, costs can be reduced by 0.2275 € per hour or $\frac{0.2275\ €}{\frac{4294\ kWh}{24} \cdot 0.032687\ €/\text{kWh}} = 3.89\%$.

[4] http://www.epexspot.com/en/market-data/intradaycontinuous

KPI target for cost is 3.89%.

UC4 Flexibility target value

For UC 4 Flexibility a technical aggregator requests a power / energy profile for the districts' residual consumption. In our tests, we assume that the duration of the flexibility action is limited to a few hours of the day as it is requested only when the local grid is congested.

The flexibility request could ask for both load reductions and load increases. Therefore, all flexibility sources can contribute to this use case.

The amount of requested power (or energy) adjustment must be within the feasible range of district consumption.

The maximum value for reducing the deviation of the districts' consumption from the requested consumption is yielded if the power gap between requested and actual power profile is decreased by the maximum amount of flexible power from the battery and heating rod. Note, that this holds for both directions and includes the power of the battery, heating rod and air handling uni. Out of simplicity reasons, we consider a symmetric flexibility power potential of 19 kW, which corresponds to the maximum increase in consumption by aggregating the battery and heating rod for 15 minutes.

Project KPI	RWTH Aachen			
	UC1	UC2	UC3	UC4
	Provide DR CO_2 Minimization for District Optimization	Provide DR Auto Consumption for District Optimization	Provide DR Cost Minimization for District Optimization	Provide DR - Flexibility for Building and District
Power	-	-	-	ΔP_{MaxGap}:±19 kW ΔP_{MinGap}:±19 kW
Energy	-	$\Delta E_{Self-Consumption_{\%}}$:11.74%	-	-
Costs	-	-	$\Delta Cost_{\%}$: −3.89%	-

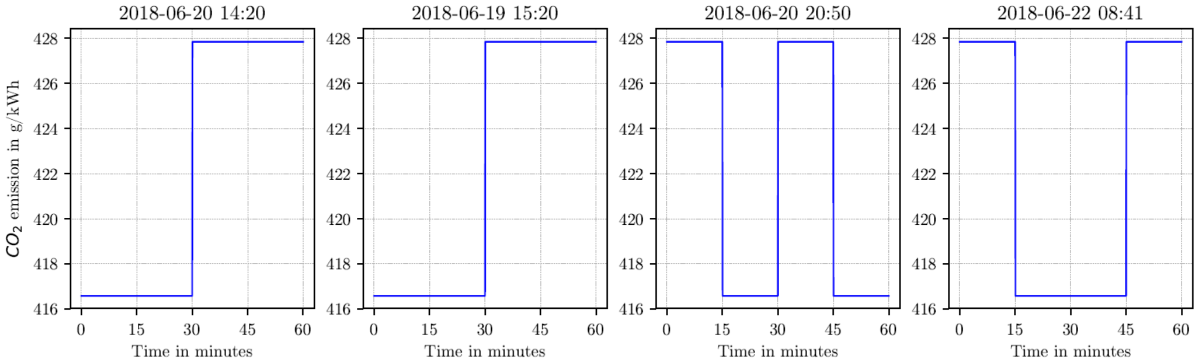
CO_2 Emissions	$\Delta CO2_{\%}: -3.35\%$	-	-	-

Table 18: Aachen 1 h target use case KPI

1.3.2.2 **Tests DT3**

In the following, the results of the ELSA District Energy Management System (EDEMS) at RWTH Aachen are presented. Every KPI indicates the difference in the measured values when ELSA District Energy Management System is deployed compared to operation without EDEMS.

UC1 Provide DR CO_2 Minimization for District Optimization



As the input to tests, different combinations of the CO_2 signal are used in order to assess the EDEMS behaviour. To incite the use of the flexibility sources, the maximum spread in the CO_2 signal is used as input.

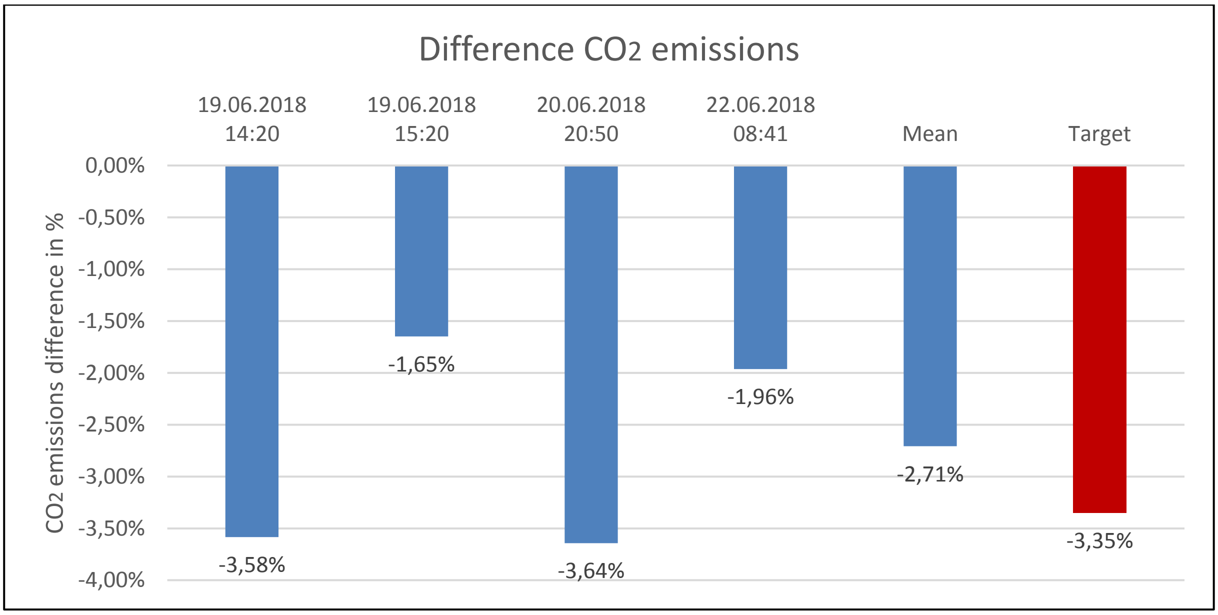


Figure 28: KPI CO_2 emissions

For this use case, the air handling unit load is shed. According to the tests conducted, the mean CO_2 emission reduction is close to the target value. There are particular tests where this KPI exceeds the target value. This is because the sheddable load is estimated as the

mean air handling unit load. As a result, more load than expected can be shed if the current power of AHU is higher than the mean. However, considering this test sample and comparing the measured mean and estimated target value, the estimation of available sheddable load seems adequate.
The first two experiments are conducted continuously. As can be seen in Figure 28: KPI CO_2 emissions, the impact of the EDEMS on the KPI decreases with the number of consecutive optimization horizons. The primary reason is that the sheddable air handling units need recovery time in between actions.

UC2 Provide DR Auto Consumption for District Optimization

To evaluate this use case, different wind generation profiles are simulated as local wind generation in the district.

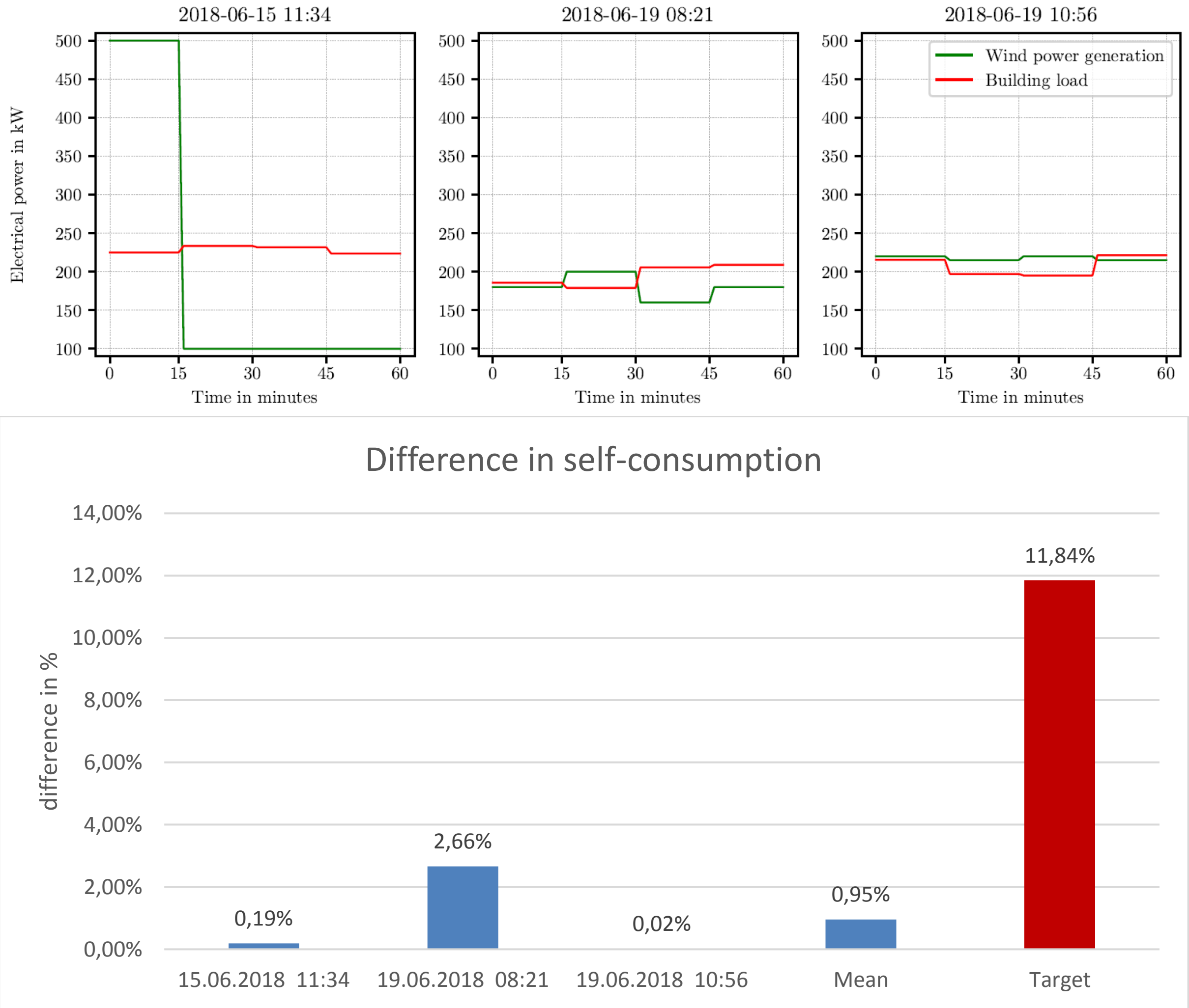
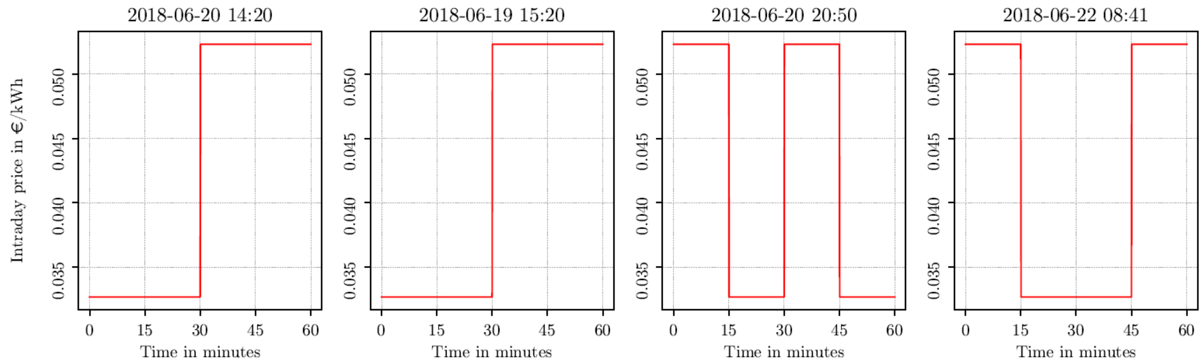


Figure 29: KPI self-consumption

Comparing the actual KPI to its target value, it is much less than theoretically possible. This is on the one hand because the load forecast is not accurate. This makes it difficult to adjust the consumption to use more of the wind generation exactly. On the other hand, the outcome of these tests depends on the wind generation data used as input. The self-consumption can be increased only if wind generation is greater than building consumption at least for a certain period of time. If the wind power fluctuates and its value is close to building demand, the building demand forecast is particularly important. Increasing the self-consumption for example in the third experiment is more challenging. It requires to coordinate battery charging and discharging correctly despite forecast errors. The higher the wind generation, the less impact load forecast errors have and the more wind energy is consumed.

UC3 Provide DR Cost Minimization for District Optimization

As input to the tests, different combinations of the electricity Intraday price are used in order to assess the EDEMS behaviour.



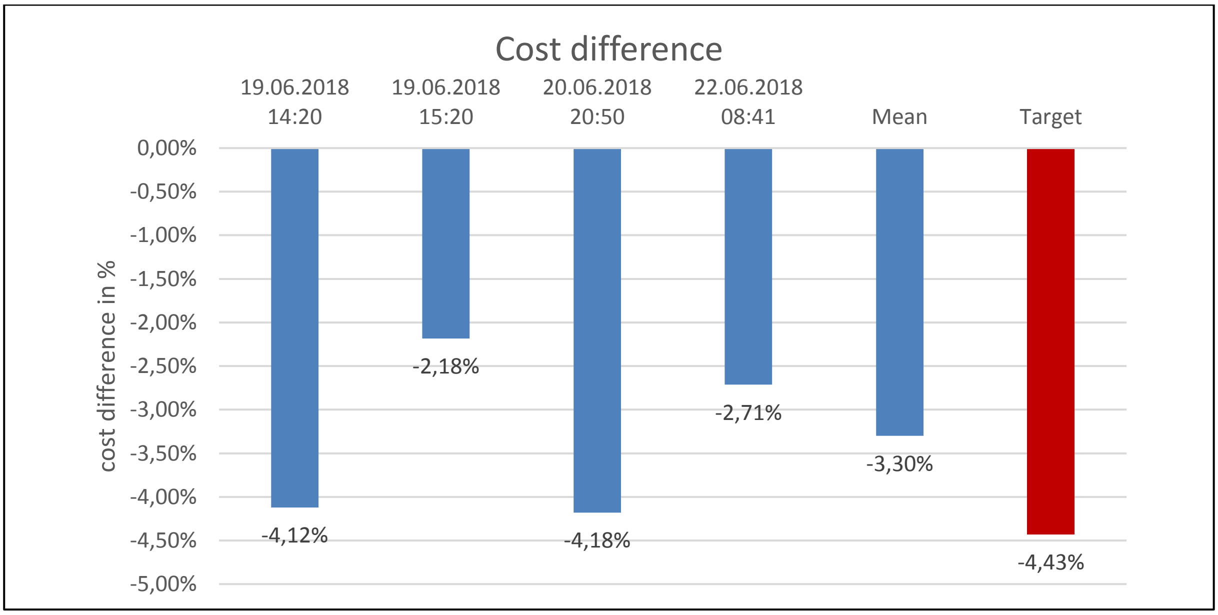


Figure 30: KPI cost

In this use case, as in the use case CO_2 minimization, load shedding is the primary means to optimize the district's consumption. As the optimization approach is the same as in use case CO_2 minimization, the same findings on the load shedding are valid. As in this case the spreads of the input data - the electricity price - are high enough, in addition to load shedding the battery is used to shift the consumption. Consequently, the impact on the KPI is higher than for use case CO_2 minimization.

UC4 Provide DR - Flexibility for Building and District

Only one test hour was dedicated to UC4.
The requested district consumption profile is shown in Figure 31: Use case Flexibility. It is calculated based on the district load forecast. The utility asks to reduce the peak-to-valley distance of the district load by 50%. This reduction of the peak-to-valley distance serves to counteract possible local grid congestions.

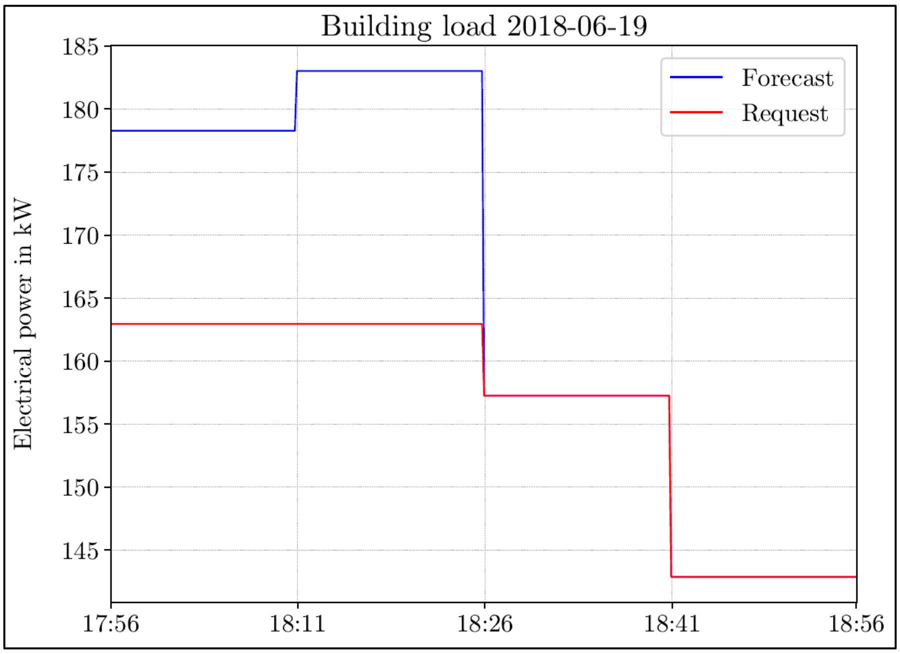


Figure 31: Use case Flexibility: load request

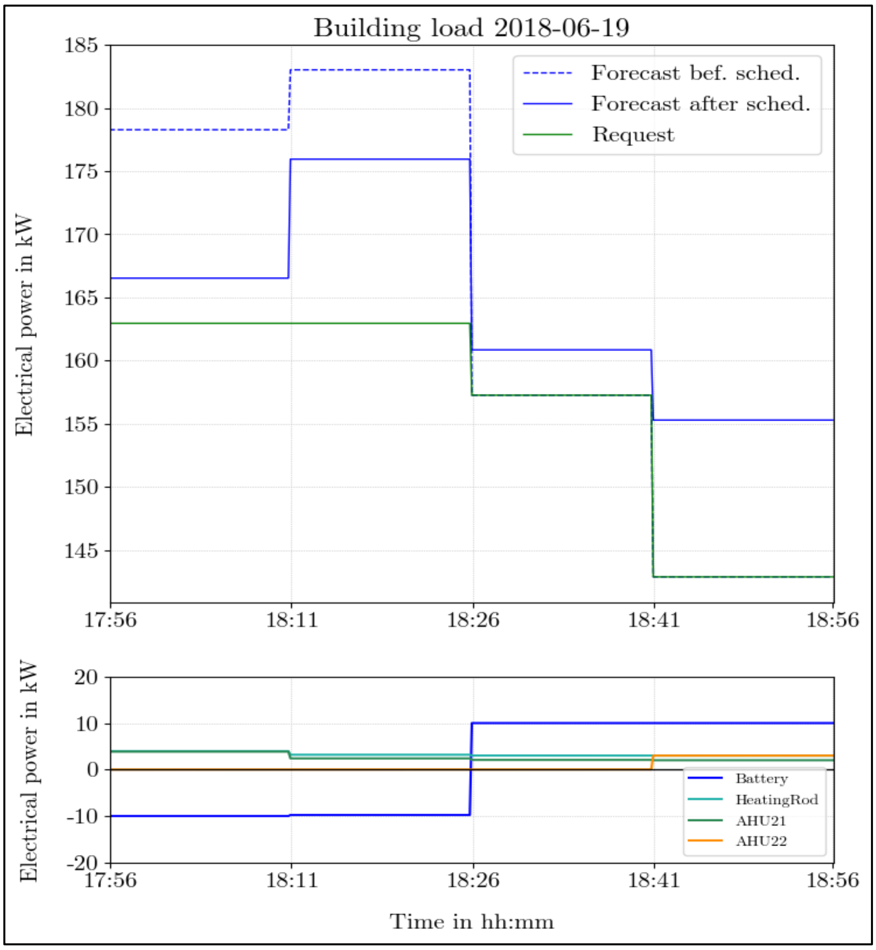


Figure 32: Use case Flexibility experiment

Resulting KPIs:

Total profile deviation from requested profile

$\Delta TpD = TpD_{\text{ELSA District}} - TpD_{\text{Ref}} = 188.26\ \text{kW} - 192.47\ \text{kW} = -4.21\ \text{kW}$

Maximum power gap to requested profile

$\Delta P_{MaxGap} = P_{MaxGap\ ELSA\ District} - P_{MaxGap\ Ref} = 194.45\ \text{kW} - 202.21\ \text{kW} = -7.76\ \text{kW}$

Minimum power gap to requested profile

$\Delta P_{MinGap} = P_{MinGap\ ELSA\ District} - P_{MinGap\ Ref} = 180.05\ \text{kW} - 181.88\ \text{kW} = -1.83\ \text{kW}$

Although the results of this one test need to be treated with caution, it becomes obvious in Figure 32 that the district cannot follow an exact power consumption request. The flexibility sources must operate under their constraints and at discrete power steps. Consequently, not every desired load value can be scheduled. Adjusting the consumption forecasted by making use of the flexibility, brings it closer to the request but cannot exactly reproduce it.

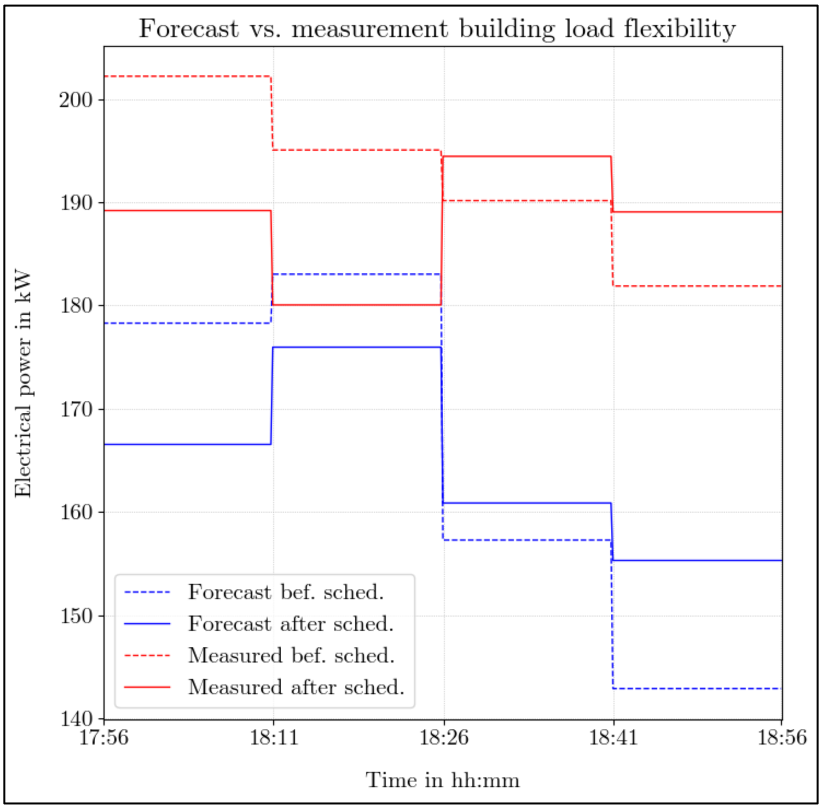


Figure 33: Forecasts vs. actual measurements in flexibility experiment

Figure 33 shows exemplary test data of use case flexibility and visualizes that the actually measured consumption differs strongly from the forecasted consumption including flexibility actions. The primary reason is the forecast quality.

1.3.3 Conclusions

In general, the KPI results of use cases CO_2 minimization and cost minimization are close to the target value. Their most important input is the CO_2 and electricity price data respectively. As this data is assumed to be certain, the KPI result is only dependent on the availability of the flexibility sources. Conversely, for use cases auto-consumption and flexibility, the KPI results differ more from the target values. One important factor is the quality of the load forecasts. As the flexibility sources' schedules are optimized based on load forecasts, the theoretical optimum is reached only when the forecast is perfect. But as the mean absolute error of the building load forecasts is 12.97 kW, achieving the targets for auto-consumption and flexibility is not possible.

We draw the following conclusions:

- Our calculations and measurements of the DT3 battery system indicates that the CO2 saving potential by shifting loads to periods of low CO2 emission power generation are used up by the higher energy consumption caused by converter loses. Therefore, we conclude that the DT3 battery system cannot be utilized for the CO2 minimization use case.

- The two UCs C02 minimization and cost minimization provide relatively good results because they are only influenced by the availability of flexibility.
- The two UCs Auto-Consumption and Flexibility provided worse results compared to the other two UCs because they are heavily influenced by the quality of the forecast of each district stakeholder.
- The DT3's large deviation of available charging and discharging power limits the provided limitation of the battery system. We had to limit our control to the lower power boundary because otherwise we would discharge the battery more than we should charge it.

1.4 City of Kempten

The ELSA test site Kempten is located in the grid area of the local DSO "AllgäuNetz GmbH & Co. KG" who is part of the Allgäuer Überland Werk GmbH (AÜW). The test site is run by the AÜW and the subsidiary the egrid applications & consulting GmbH.[5]

1.4.1 Pilot site description of Kempten

1.4.1.1 Test site location in Kempten

The test site is located in a residential district with multiple apartment buildings. Six of these apartment buildings are included in the test site district with total 81 apartments. Whereby five buildings with 45 apartments are connected via the same power cable and therefore taken into account for the tests (see Figure 34). The electrical loads in the test site are the households in the buildings (home appliances and lightning). There are no controllable loads in the district. The heating and warm water preparation is done with a natural gas heater per building.

Three of the houses are equipped with PV modules on the rooftop. The PV generator has a total size of 37.1 kWp and is oriented towards south. These PV generators cannot be controlled within the ELSA project.

Figure 34: Kempten test site with ELSA battery and apartment buildings

[5] Further information are available on
https://elsa-h2020.eu/City_of_Kempten.html www.auew.de www.egrid.de

1.4.1.2 ELSA battery in Kempten

The battery storage system is integrated in a nearby transformer station which is providing the energy for the whole district (see Figure 35).

Figure 35: ELSA battery inside the transformer station

Inside the transformer station the six second life batteries from electric cars and the power electronics as well as the hardware necessary to control the battery are installed. The structure can be seen in Figure 36. The battery is connected to the main bus bar where also the five buildings are connected electrically.

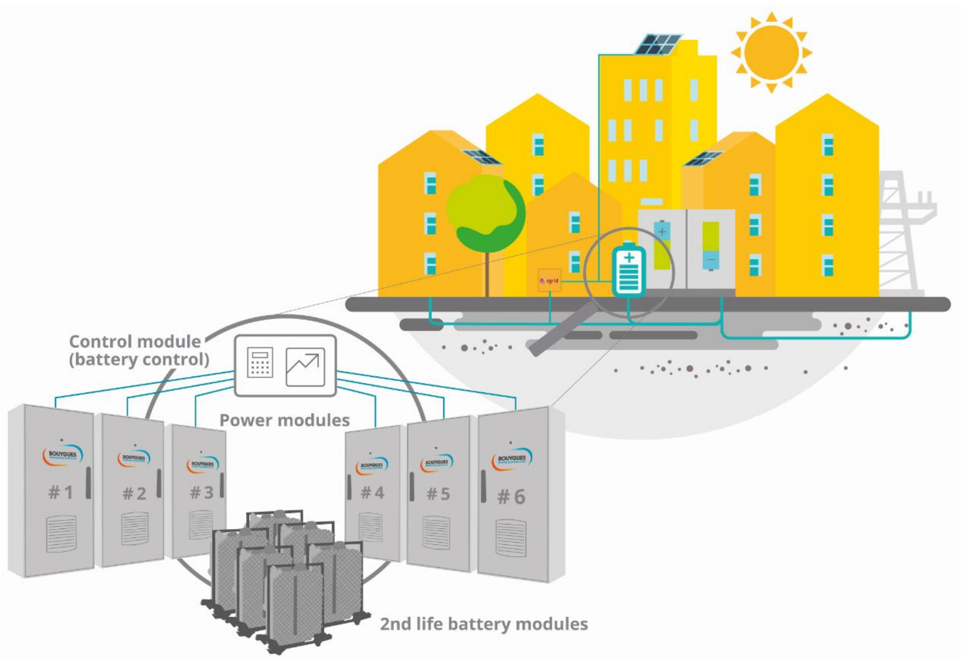


Figure 36: Structure of the ELSA battery system with control inside the transformer station

In the beginning of the ELSA project the first prototype (internal product code DT.3) was duplicated and built up multiple times to be tested in the different test sites in Europe. This prototype has the same structure and mechanical size in all test sites. The battery systems in this project have a standard size and there was no adaption to the Kempten district needs in power and capacity.

The gained results of the analyses with the DT.3 system in the project consortium led to the intermediate system DT.4 and finally to the system DT.5. This final system is marked ready and categorized to level nine of the technology readiness scale (TRL 9).

The installed battery in Kempten test site is of the first type DT.3 and therefore classified as a prototype. In the following sections the results which led to the improvements of the DT.5 system are pointed out.

1.4.1.3 Battery Control System in Kempten

The battery is the only controllable component in the system therefore the ELSA test site in Kempten differs from the other test sites. There is no need for a Building Energy Management System (controlling the heating or cooling) nor a District Energy Management System (controlling further loads or generation) as all needed services will be delivered directly by the ELSA Residential Energy Management System (EREMS).

For providing the EREMS with the required information each participating house is equipped with an egrid measurement box that collects the houses electrical demand and if there is a PV-generator installed the renewable production is also measured (seen in Figure 37). The boxes inside the houses gather data, which is then retrieved by another measurement box inside the transformer station. This device meters the energy flow of the battery and further forwards all the measured load flow data to the EREMS.

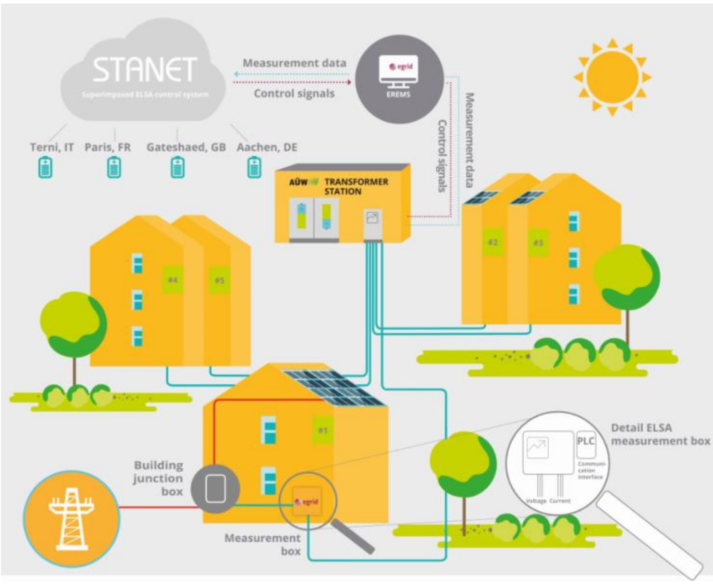


Figure 37: ELSA district in Kempten with measurement system and EREMS control system

The EREMS has a connection to the ELSA Storage Management System (ESMS) which is the battery controller located in the control module seen in Figure 36. In the following demonstrated energy services will be provided by the EREMS by setting a power request to the battery controller ESMS.

For controlling all ELSA test sites in Europa there is the superimposed controller called STANET. The system design provides a possible connection between the STANET and the ESMS via the EREMS. This control option is important for future applications where all ELSA batteries are operated collectively. One possible business case is the participation at the primary control market.

1.4.1.4 Pilot site Kempten characteristics

For better overview the Kempten test site is described in a few basic points:

Test site type	Residential district
Consumption	• Multifamily apartment buildings • No controllable loads • Annual consumption: o Three PV buildings: approx. 44.000 kWh / a o Five test buildings: approx. 80.000 kWh / a
Generation	• PV generator distributed on three buildings • 37.1 kWp installed via three inverters • Annual generation: approx. 40.500 kWh / a
ELSA Battery	• DT.3 prototype system • Six battery modules with each one power module • Total usable energy: 66 kWh • Total Power o Charging: max. 18 kW o Discharging: max. 72 kW
Battery purpose	• Auto Consumption for District Optimization • PV Self-consumption Maximization by Power Smoothing

Table 19: Kempten test site characteristics

1.4.2 Use case evaluation in Kempten

In order to evaluate the ELSA system and the use cases of each test site four global Key Performance Indicators (KPI) have been defined[6]. Beside the consideration of power, energy and costs the CO2 emission reduction is analysed.

In the Kempten test site six use cases are evaluated, but only the use cases UC1 and UC2 are realized in the EREMS and tested with the battery. For the use cases UC3 to UC6 the installed prototype system DT.3 is not suitable. These use cases are evaluated simulative. Therefore the focus in this document is on the in reality tested use cases and only UC1 and UC2 are described in the following.

In the following Table 20 the Kempten use cases are matched to the global KPI. The KPIs are split up into two values, because the PV system is the sole generation in the district and subject to seasonal fluctuations.[7] For use case UC1 the amount of energy shifted from times with PV generation to times with high demand is the most important criterion. The cost savings are also considered, but at the moment there is no monetary advantage expected. Further there is at the moment no monetary compensation - e.g. by a DSO - for batteries reducing the impact of load on the grid (use case UC2). Therefore only the average power reduction and no economic impact is analysed.

Project KPI	Test site Kempten use cases			
	UC1		UC2	
	Provide DR Auto Consumption for District Optimization		PV Self-consumption Maximization by Power Smoothing	
Time period	Transition	Summer	Transition	Summer
Power			3.5 kW	5.7 kW
Energy	45.1 kWh / day	60.0 kWh / day		
Costs	0.54 € / day	0.72 € / day		
CO_2 Emissions				

Table 20: Kempten target values for use case KPIs

More detailed information can be found in the following sections.

[6] The complete document with overarching and test site specific KPIs can be found in the annex.

[7] Further information about the chosen seasons can be found in section 1.4.2.2.

1.4.2.1 **EREMS functionality for use cases in Kempten**

The EREMS is operating the ELSA battery autonomously by using the measurement data of the participating buildings and of the PV generation. The surplus of PV energy that is not directly consumed by the households is charged according to the set use case into the ELSA battery system. Whenever the current consumption of the participating households is higher than the PV generation the EREMS discharges the battery in accordance to the actual SOC and the power limits of the inverters.

For the unlikely case of grid instability the DSOs in Germany are allowed to reduce the infeed of generators and batteries. This functionality is integrated directly in the battery control module (ESMS) and not in the EREMS. For that reason this aspect is not further covered in this document.

The EREMS has a graphical user interface as seen in Figure 38. The six battery modules with SOC and current requested power per module are displayed. Further information of the battery and measurements of the transformer station can be unhidden. Beside the automatically use case mode a manual mode for demonstration purposes is available.

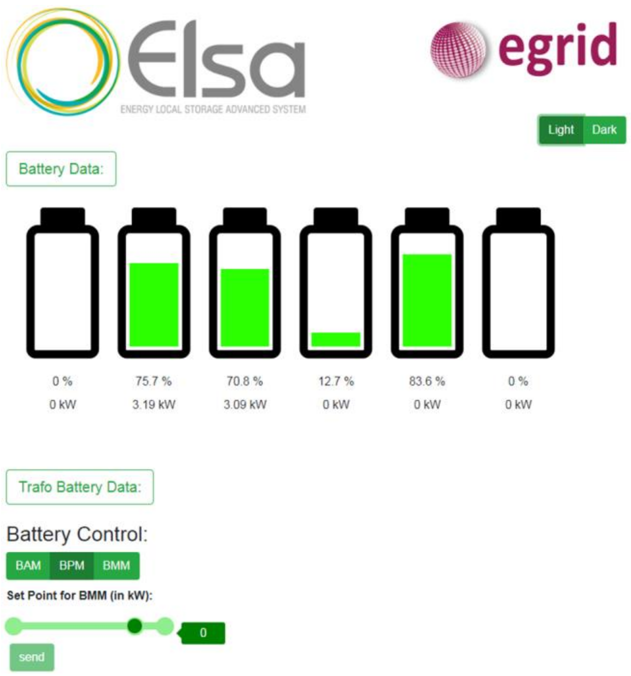


Figure 38: EREMS GUI in Kempten

UC 1: Auto Consumption for District Optimization

The objective of this use case is the maximization of usage of the decentralized produced PV energy to optimize the districts power balance. Therefore the EREMS operates the battery in a way that as much as possible of the surplus of solar energy from the time during PV generation is stored and then discharged in times without generation e.g. the night time.

EREMS Charging power request (positive set value):

$$while\ |P_{PV}| \geq P_{HH}\ and\ SOC\ \leq 100\%$$

$$P_{ELSA}(t) = \begin{cases} |P_{PV}(t)| - P_{HH}(t) & for\ \ |P_{PV}(t)| - P_{HH}(t)\ \leq 18kW \\ 18kW & for\ \ |P_{PV}(t)| - P_{HH}(t)\ > 18kW \end{cases}$$

EREMS Discharging power request (negative set value):

$$while\ |P_{PV}| < P_{HH}\ \ and\ SOC\ \geq 0\%$$

$$P_{ELSA}(t) = \begin{cases} |P_{PV}(t)| - P_{HH}(t) & for\ \ |P_{PV}(t)| - P_{HH}(t)\ \geq -72kW \\ -72kW & for\ \ |P_{PV}(t)| - P_{HH}(t)\ < -72kW \end{cases}$$

For this use case UC1 the EREMS is not taking any forecast (load or generation) into account. The objective is to shift as much as possible surplus PV energy from the sunny periods to times with no generation.

Further the SOC is only the upper or lower limit of the operation. In-between the operational SOC limits there is no effect of the SOC on the set power e.g. a reduction of set power when close to SOC 100%.

A malfunction of one or more battery modules (e.g. a downtime) of the ELSA DT3 prototype system is not influencing the functionality of the EREMS. The only impact is a reduction of the possible shifted energy amount.

UC 2: PV Self-consumption maximization by Power Smoothing

The objective of this use case is to reduce the load on the grid during periods of high feed-in or high power demand for a time per day as long as possible. This is obtained by charging or discharging the battery with a certain power according to the measurements and forecasts.

The EREMS sets the power request (P_{ELSA}) for the ELSA battery system in accordance with a power smoothing factor (PSF) and a factor for the current battery SOC (SOCF).

The total PV energy production of the day ahead according to the forecast is split into equal time frames. Corresponding to the potential energy surplus of each time frame a factor for power smoothing between 0 and 1 is determined. This power smoothing factor (PSF) is in correlation to the intensity of load or feed-in. For each time frame the EREMS is comparing the current battery SOC with the forecasted target value and sets the SOCF.

EREMS Charging power request (positive set value):

$$while\ |P_{PV}| \geq P_{HH}\ and\ SOC\ \leq 100\%$$

$$P_{ELSA}(t) = \begin{cases} PSF \times SOCF \times (|P_{PV}(t)| - P_{HH}(t)) & for\ \ |P_{PV}(t)| - P_{HH}(t)\ \leq 18kW \\ SOCF\ \times 18kW & for\ \ |P_{PV}(t)| - P_{HH}(t)\ > 18kW \end{cases}$$

EREMS Discharging power request (negative set value):

$$while\ |P_{PV}| < P_{HH}\ \ and\ SOC\ \geq 0\%$$

$$P_{ELSA}(t) = \begin{cases} PSF\ \times SOCF \times\ |P_{PV}(t)| - P_{HH}(t) & for\ \ |P_{PV}(t)| - P_{HH}(t)\ \geq -72kW \\ SOCF\ \times\ -72kW & for\ \ |P_{PV}(t)| - P_{HH}(t)\ < -72kW \end{cases}$$

For this use case UC2 the EREMS is highly depending on the quality of the forecasts and of data provided by the battery control system (ESMS) for example the SOC.

A malfunction or downtime of one or more battery modules shut the operation of these modules down. The ESMS is wrongly calculating the overall battery SOC by still including all battery modules. The EREMS is processing the wrong SOC without any information about the real battery module status. Therefore the SOCF is calculated incorrect in times when battery modules are having a malfunction.

For better understanding an example is given in the following. As seen in Figure 39 some battery modules are in the “capacity check mode” where manual supervision is needed. This can be identified due to the red cross marking all modules except of module #2. The overall capacity provided by the ESMS is SOC = 29.44% while the real available capacity is 1.6% (module 2). The EREMS is processing the wrong SOC and requests P_{ELSA} = -4.93 kW for providing energy to the households which the battery system cannot supply in reality. Due to the specification of the interface between the EREMS and the ESMS there is no option to provide more information about the battery status to the EREMS to avoid misoperation.

These malfunctions did influence a lot of tests done with the ELSA DT3 prototype system.

Figure 39: EREMS GUI of Kempten with capacity check example

1.4.2.2 Calculation of Kempten KPI reference cases and target values

For the KPI evaluation a reference case has to be defined. This reference case is the investigated district without the impact of the ELSA battery. In Kempten test site the ELSA battery is the only device controllable by the EREMS. Therefore the regular power grid operational state used by the participating buildings / households and the connected PV generator is the reference case.

The reference case can be specified by considering only the measurements of the demand and generation in the participating buildings. This is feasible due to the fact, that the measurements of the households and the PV generator are taken directly at the junction box of each building and the ELSA battery is connected in the transformer station at the beginning of the relevant power cable.

For the KPI analysis the aggregated measurement data of the district buildings are analysed in comparison to the measurements at the bus bar of the transformer station where the ELSA battery is taken into account.

To be able to evaluate the ELSA system performance, in the following the target values of the KPIs for each tested use case are estimated. The target values are objectives under ideal conditions and therefore it is not expected to easily achieve them. Furthermore as already noted the characteristic of the installed DT.3 system is not exactly matched to the needs of the Kempten district. Therefore further deviations from the target values are expected in reality.

Due to the varying energy consumption and generation the year is partitioned into the following seasons (see Table 21). It has to be noted that the PV system is the only generation in the district and during the winter season there is only few or even no generation due to the seasonal sun position and snow on the PV panels. Therefore the winter season is not taken into account in the analysis.

season	time period
Winter (W)	November – February
Transition (T)	March – May and September – October
Summer (S)	June - August

Table 21: seasons in the year at Kempten test site

<u>Target value for UC 1: Auto Consumption for District Optimization</u>

Using reference measurements of the residential buildings in the district and of the PV generation the average daily energy consumption and production for the analysis time periods T and S are determined. By taking the major losses of the energy storing process (inverters) and the real battery capacity into account the consumable surplus energy is identified. The surplus of usable PV energy is set into relation with the cost reduction for power purchasing of the district.

- Efficiency of the charger η = 0.95
- Efficiency of the inverter η = 0.92
- Real capacity of ELSA DT3 system 66 kWh
- Regular power price in district 0.269 € / kWh
- Price for local produced energy[8] 0.257 € / kWh

[8] Price for local produced energy includes plant investment, taxes and fees.

	T	S
average daily consumption	204.7 kWh	194.0 kWh
average daily generation	143,9 kWh	170.9 kWh
average daily consumable surplus energy (due to mismatch of load and generation)	51.6 kWh	68.6 kWh

Table 22: Consumption and Generation in test site Kempten (according to meters)

According to these estimations and the systems frame conditions (efficiency and capacity) the expected increase of self-consumption and the reduction of power purchasing costs due to the ELSA battery system in the auto consumption mode are determined:

Target value	T	S
increased average usable energy per day $\Delta \boldsymbol{E}_{\boldsymbol{AutoC}} =$	45.1 kWh	60.0 kWh
average cost reduction per day $\boldsymbol{\Delta C}_{\boldsymbol{AutoC}} =$	0.54 €	0.72 €

Table 23: Target values for UC1 in test site Kempten

Target value for UC 2: PV Self-consumption Maximization by Power Smoothing

The objective of this use case is to reduce the load on the grid. At the moment there is no monetary compensation for this operation e.g. by the DSO. But in the future of the energy system this decentralized power reduction might be helpful and probably will be refunded. In this analysis the target value of UC2 is focused on the possible load reduction by the ELSA system without taking any economic factors into account. Table 24 shows the average power values (consumption and generation) to estimate the average power reduction potential.

	T	S
average household load power per day	8.5 kW	8.1 kW
average PV power during the day	12.0 kW	14.2 kW
average power reduction potential for ELSA battery system	3.5 kW	6.1 kW

Table 24: average load and average power of the PV generator (according to meter)

For fulfilling the power smoothing over the whole day the maximum charging power of 18 kW and the maximum capacity of the ELSA battery system has to be taken into account. The power smoothing has to be active over the full time of PV generation at the day.

	T	S
surplus energy (see **Table 22**)	51.6 kWh	68.6 kWh
approx. time of generation	8am – 5pm	7am – 7pm
estimated maximum of average battery power	5.7 kW	5.7 kW

Table 25: assumptions for possible average battery power

The target values are defined for an average power reduction during the PV generation time per day according to the data in Table 24 and Table 25. Beside the assumptions experience in similar projects of local generated energy are taken into account.

Target value	T	S
average power reduction per day $\emptyset P_{smoothing} =$	3.5 kW	5.7 kW

Table 26: target values for UC2 in test site Kempten

1.4.2.3 Test evaluation of the Kempten system

This section focuses on the evaluation of the ELSA system using the defined KPIs. For the KPI analysis in the year 2018 several time sections of a few days were chosen. The selection of the time frames took into account that the DT3 system in Kempten test site is a prototype and the battery system was not working properly with all battery modules at all times. Malfunctions occurred (e.g. as described in section 1.4.2.1) and blocked one or more modules, causing a reduction of the total capacity of the system. In average three of six modules of the prototype DT3 system were active. These errors required usually a manually restart of the battery ESMS. Therefore the time frames were chosen on behalf of their duration and number of active battery modules.

UC 1: Auto Consumption for District Optimization

The increased average usable surplus PV energy *per day* was identified by analyzing the discharged energy in the specific time period. Further the possible savings *per day* were calculated and also displayed in Table 27.

Transition				Summer			
Time period	Modules	ΔE_{AutoC} $[kWh]$	ΔC_{AutoC} $[€]$	Time period	Modules	ΔE_{AutoC} $[kWh]$	ΔC_{AutoC} $[€]$
target transition		45.1	0,54	target summer		60.0	0.72
full transition period		21.6	0.26	full summer period		21.3	0.26
21st – 26th Apr	4M	35.5	0.43	28th Mai – 9th Jun	3M	34.0	0.41
27th – 28th Apr	5M	36.7	0.44	28th Jun – 6th Jul	4M	27.9	0.33
4th – 20th Sep	4M	39.6	0.47	7th– 17th Jul	4M	35.6	0.43
24th Sep – 10th Oct	3M	27.5	0.33	17th – 25th Aug	3M	34.7	0.42

Table 27: Results of UC1 KPI analysis with number of active battery modules (test site Kempten)

The results are graphically displayed in Figure 40. As mentioned above a continuously operation of the battery with all modules was not possible, therefore the average over each full period is quite low.

In comparison to the summer period during the transition period more time frames with a higher number of active battery modules were identified. Furthermore the consumption - generation relation was better during this time period. Therefore the ELSA battery functionality approximated the target value quite good up to approx. 88%.

During the summer period the number of continuously active modules and therefore the total system capacity was lower. Therefore no advantage was taken out of the higher amount of available PV surplus energy. The shifted energy amount is approximately similar but in relation to the target value of 60.0 kWh shifted energy per day the results are only between 45% up to approx. 60%.

Results for the calculated savings are proportional to the energy.

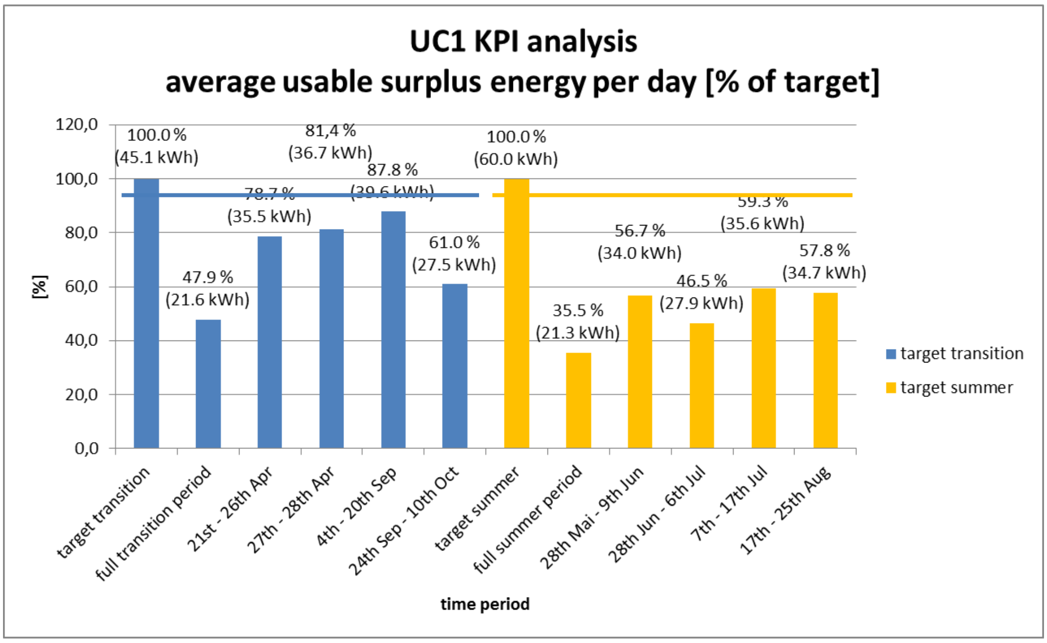


Figure 40: UC1 KPI analysis – average usable surplus energy per day in percent of the target value

For better understanding the load measurement and the battery operation at the 10th of October 2018 are shown in Figure 41. Three battery modules were active in this time frame. The other three modules are loaded at a specific SOC but are due to a malfunction not in operation; therefore the total SOC is not at 0% by night and not 100% in the afternoon (lower graph green line).

The yellow graph shows the load of all households and the surplus of the PV generation. During the whole day the EREMS set the requested power according to the load measurement and the battery SOC given by the ESMS. But in early morning and by night no *active* module can supply energy, therefore the real battery power (purple curve) is at the zero line.

During the day the EREMS set the operation according to the measurement and the systems limits (maximum charging power is 18 kW). Due to the limitations with only three modules the real charging power is lower and it is not possible to charge the full amount of surplus energy. Furthermore by night the battery has not enough stored energy to provide to the households for a full night. The peaks in the requested power (blue line) are the “kick start”, a functionality of the EREMS to operate the ESMS and the battery at low power.

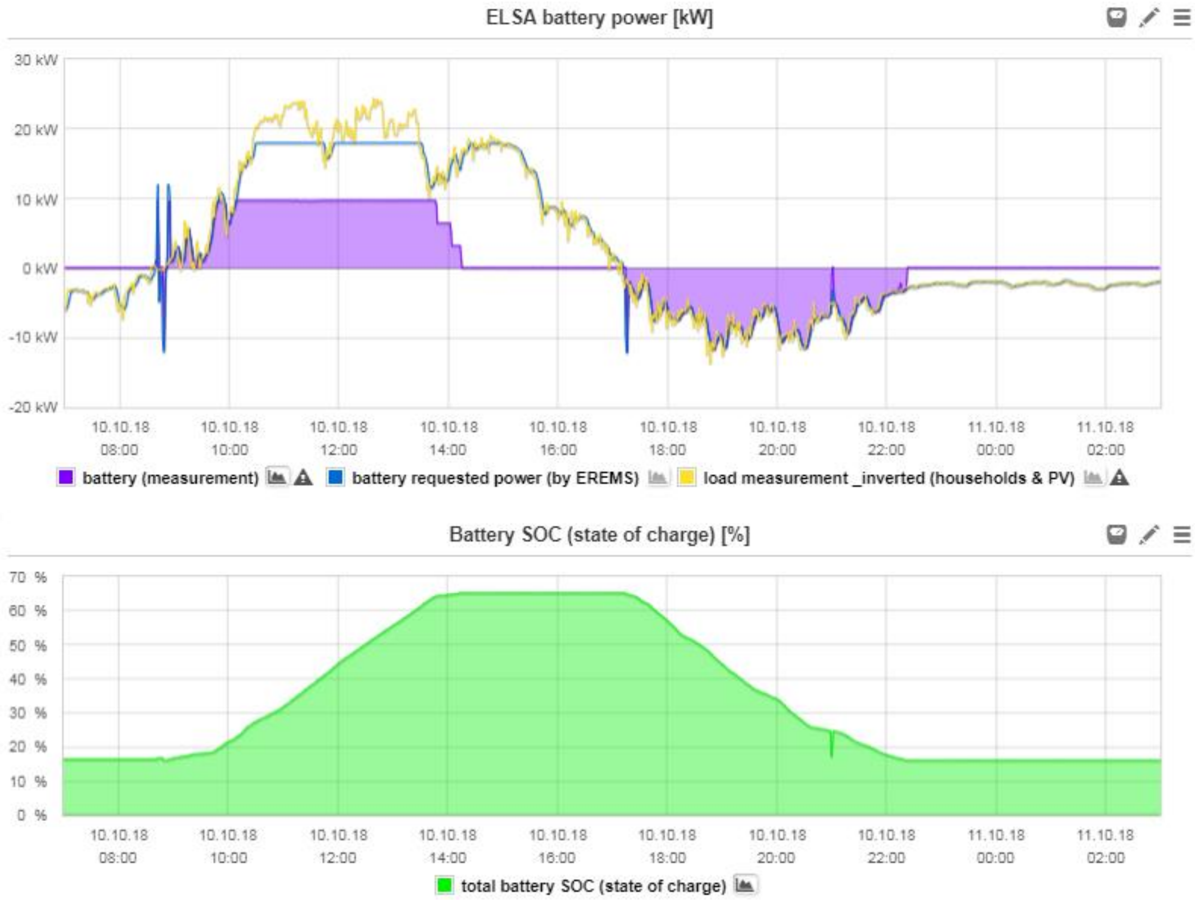


Figure 41: ELSA battery operation by EREMS at October 10th 2018

<u>UC 2: PV Self-consumption Maximization by Power Smoothing</u>

The average power reduction during the day by the ELSA battery system was identified by analyzing the load profiles of the battery in specific time frames. Further the relative power reduction in relation to the *total power load* was calculated. The results are shown in the Table 28. The maximum of the power reduction in the specific time frame highly depends on the number of active battery modules. For example during the time between 27th and 28th of April up to 14.3 kW were reduced by the ELSA battery system in smoothing mode.

Transition				Summer			
Time period	Modules	$\varnothing P_{smooth}$ $[kW]$	$\varnothing P_{smooth}$ $[\%]$	Time period	Modules	$\varnothing P_{smooth}$ $[kW]$	$\varnothing P_{smooth}$ $[\%]$
target transition		3.5		target summer		5.7	
full transition period		1.7	19.4	full summer period		1.8	19.1
21st – 26th Apr	4M	3.2	31.2	28th Mai – 9th Jun	3M	2.7	30.7
27th – 28th Apr	5M	3.4	54.8	28th Jun – 6th Jul	4M	2.4	23.7
4th – 20th Sep	4M	3.3	33.3	7th– 17th Jul	4M	3.1	28.1
24th Sep – 10th Oct	3M	2.3	22.2	17th – 25th Aug	3M	2.5	26.0

Table 28: Results of UC2 KPI analysis with number of active battery modules (test site Kempten)

The results in relation to the *target value* are graphically displayed in Figure 42. Similar as for use case one the average power reduction over each full period is quite low, because the battery system did not had access to all battery modules.

For the investigated time frames in the transition period the target value was almost achieved due to the relatively high number of active battery modules. During the summer period the number of continuously active modules and therefore the total system charging power was lower. Therefore the maximum achievable average power reduction was only at approx. 54%.

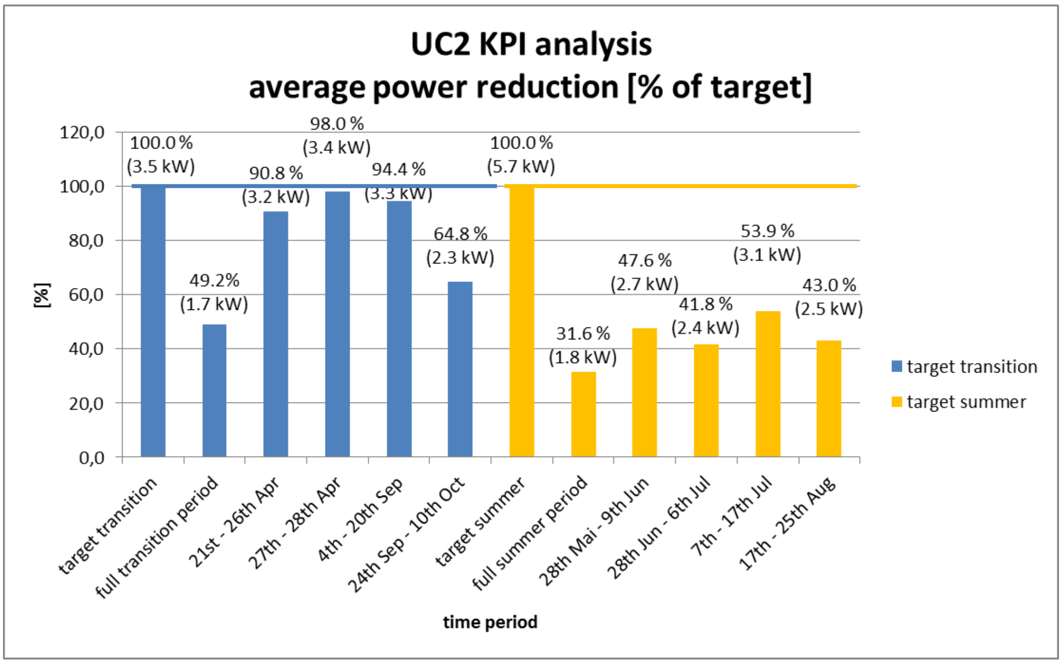


Figure 42: UC2 KPI analysis – average power reduction over the day in percent of target value

1.4.3 Conclusions

The operation of the ELSA battery system and the measurement infrastructure for more than 1.5 years was successful. During this phase several suggestions for improvement were identified and shared in the consortium. Thereby design changes in the new developed DT.4 and DT.5 system were made, leading to a better performance of the ELSA system.

For the prototype DT.3 system the data showed, that the target values can be achieved as long as the majority of battery modules are functional. Furthermore the following results were obtained:

- An energy amount of up to approx. 40 kWh per day can be shifted from times during the day with high PV generation to times by night with demand by households
- For the district habitants a surplus of up to approx. 40 kWh of local produced energy can be provided per day
- The load on the power grid by PV infeed during the day can be reduced by charging the ELSA battery in average by 30% - meaning a total reduction up to 3.4 kW of load.

For the future of energy decentralized batteries e.g. in districts are a major component for the success. Providing the consumption with a higher share of renewable energy and supporting utilities by operating their grid.

1.5 SASMI building

1.5.1 Pilot site description

The Gateshead College Skills Academy for Sustainable Manufacturing and Innovation (SASMI) is a 5,713 m^2 building consisting of classrooms, offices and workshops. It is located adjacent to the Nissan manufacturing facility in Sunderland, UK. A relatively new building, construction was completed in 2011 and it has an Energy Performance Certificate (EPC) rating of 'C'. While this rating may seem low for a new building, it does contain comfort cooling and mechanical ventilation, both of which add to the energy load. These systems are a potential source of load flexibility and so are beneficial for participation in demand side services.

The electrical load in the building has a 140 kW peak load with 40 to 20 kW base load. The SASMI building presents the following services:

- Heating: Mainly gas direct burners, VRF split units (heat pumps) in classrooms & offices.
- Ventilation: 5 AHUs with Variable Speed Drives (VSDs) on all fans.
- Cooling: VRF split units (heat pumps), Direct Expansion (DX) chiller units in AHU-01.
- Domestic Hot Water (DHW): Gas fired direct hot water cylinders
- Lighting: Indoor lighting (locally switched), External lighting (from the BMS: Lux, time and on/off control).
- Other loads: door curtain, air compressor.

Installations which took place in the building as part of the ELSA project included:

- 3 x 16 kWh Nissan Leaf 2nd life batteries
- 50 kWp PV array
- Additional sensors, meters and BMS programming changes
- UTRC-I ICT system.

Test site type	
Consumption	• College facility: classrooms, offices and workshops • Usual daily peak demand of 150 kW • Usual daily consumption of 2400 kWh
Generation	• PV panels • 50 kWp installed

ELSA Battery	• DT.3 prototype system:
	  ○ Three battery modules of 16 kWh capacity each
	  ○ Total energy: 48 kWh
	  ○ Total Power:
	    ▪ Charging: max. 10 kW
	    ▪ Discharging: max. 36 kW

Battery purpose	• Peak shaving • Auto-consumption • Energy purchase time shifting • Cost-minimization • Flexibility

Table 29: SASMI test site information

Figure 43: SASMI building located in Sunderland, UK


Figure 44: Gateshead College located in Newcastle, UK

The ICT platform deployed in SASMI building for supporting the operation and management of second life batteries is presented in Figure 45. The building scale ICT platform Deployed in SASMI building is the same as the one in Ampere building. The EBEMS has been adapted to communicate with the Cylon Building Management System for this building; the remaining capabilities of the EBEMS were described in section 1.2.1.

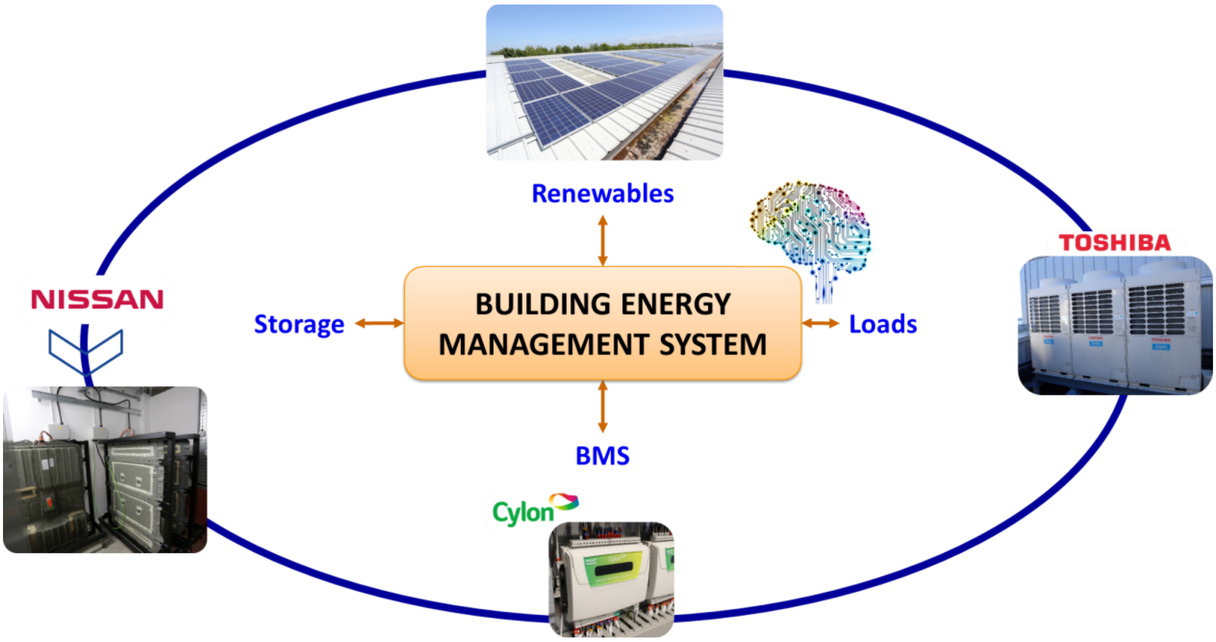


Figure 45: Sunderland ICT system deployed

1.5.2 Use case evaluation

The following table presents the target values (T) for each use case and each KPI corresponding to SASMI building. The achieved values (A) of the KPIs are filled in as well; the achieved values were computed over different experiments performed on the pilot site. **Erreur ! Source du renvoi introuvable.** summarizes the achieved results; a more detailed description of the estimation of the target values and the tests is given for each use case in the following sub-sections. More information is given in the annexe on the methodology applied to calculate the KPIs; each KPI is described in details.

The achieved values of the KPIs for the DR services exceed the targeted values in Table 30. This is due to the assumption made when calculating the target KPIs for the DR services: a usual time period of two hours was considered. The actual length of the DR events varies in the experiments; the average value over all the experiments is reported in Table 30. The value of the KPI for each DR event is reported in each corresponding sub section.

Project KPI	SASMI Building									
	UC1		UC2		UC3		UC4		UC5	
	Peak Shaving for Power Subscription Cost Optimization		Provide DR Auto Consumption on Building Level		Energy Purchase Time Shifting		Provide DR Cost Minimization on Building Level		Provide DR - Flexibility for Building and District	
	T	A	T	A	T	A	T	A	T	A
Power	**32%**	30%								
Energy	**2%**	1%	**16%**	27%	**2%**	1.1%	**-16%**	-21%	**16%**	1%
Costs			**16%**	27%	**2%**	1.1%	**-16%**	-21%		
CO_2 Emissions			**16%**	27%			**-16%**	-21%		

Table 30: Target KPIs and achieved values per use case for SASMI building

1.5.2.1 UC1: Peak shaving

Power and Energy KPIs: estimation of the target value

The target values for the Power and Energy KPIs for UC1 are calculated in the same way as for the Ampere building (see section 1.2.1.1). The target values differ due to a different energy demand of the building and electric storage capacity installed (see Table 29). A target value of 32% is calculated for the Power KPI and, respectively, 2% for the Energy KPI, using the information presented in Table 29.

KPI evaluation over a test period

An example of peak shaving experiment is presented in Figure 46. The experiment is conducted over one day in this example. . A Power KPI of 30% is reached around 7:30 in the morning by discharging the modules at a full rate of -22 kW; this impacts the Energy KPI which reaches a value of 1% over the short period of time of peak shaving when the batteries are discharging (about one hour).

The target value of 32% of the Power KPI is almost reached on that experiment. Even though the discharge rate of the electric storage is quite smaller than the maximum considered in the calculation of the target (about -25 kW instead of -36 kW due to the status of the battery system), the value of the KPI is close to the target. The actual power demand from the building at the time of the experiment is lower than the one used in the calculation of the target value.

Regarding the Energy KPI, it is half of the target value of 2%. Firstly, one of the three battery modules was not working during the experiment, so the total storage capacity considered in the estimation of the target was not available. Secondly, the EBEMS started charging the electric storage after 15:00 in planning for the next event in the set of experiment. This behaviour impacts the calculation of the KPI since the power demand of the building is higher than the usual one over this time period.

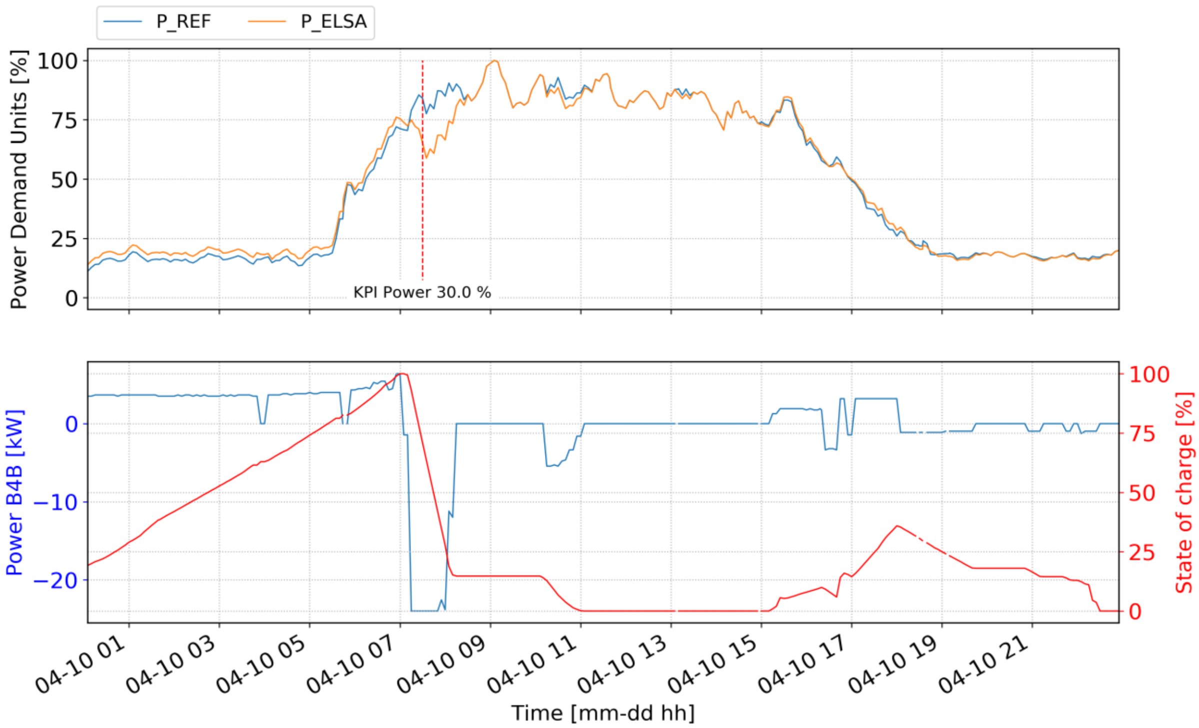


Figure 46. UC1: Example of peak shaving experiment over April 10th, 2018.

1.5.2.2 **UC2: Auto-consumption DR Service**

Energy, Costs and CO2 KPIs: estimation of the target value

The target values for the Energy, Costs and CO2 KPIs for UC2 are calculated in the same way as for the Ampere building (see section 1.2.1.2). Due to a different energy demand of the building and electric storage capacity installed in SASMI building, a target value of 16% is calculated for the Energy, Costs and CO2 KPIs, using the information presented in Table 29.

KPI evaluation over a test period

The test of an auto-consumption DR Service is displayed in Figure 47. Two DR events were planned on that day: first from 15:00 to 16:00 and second from 18:00 to 19:50. During those DR events the EBEMS reduces as much as possible the demand of the building trying to be autonomous from the grid by using the energy stored the batteries. The full capacity of the electric storage is used over the first DR event; the EBEMS charges the system to about 25% before reaching the second event. The Energy, Cost and CO2 KPIs reach an average value of 27% over the two DR events, respectively 43% for the first DR event and 12% for the second. The first DR event has a time length of one hour and the full battery capacity has been consumed compared to the second event which started with a SOC of 25% over about 2 hours event.

The target value of 16% for the Energy, Costs and CO2 KPIs has been largely exceeded in the case of the first DR event. Again this can be partly explained because the DR event is one-hour long instead of two hours used in the target calculation. Also in this experiment, at the time of the first DR event, the power demand of the building is about a third of the value considered in the calculation of the target value.

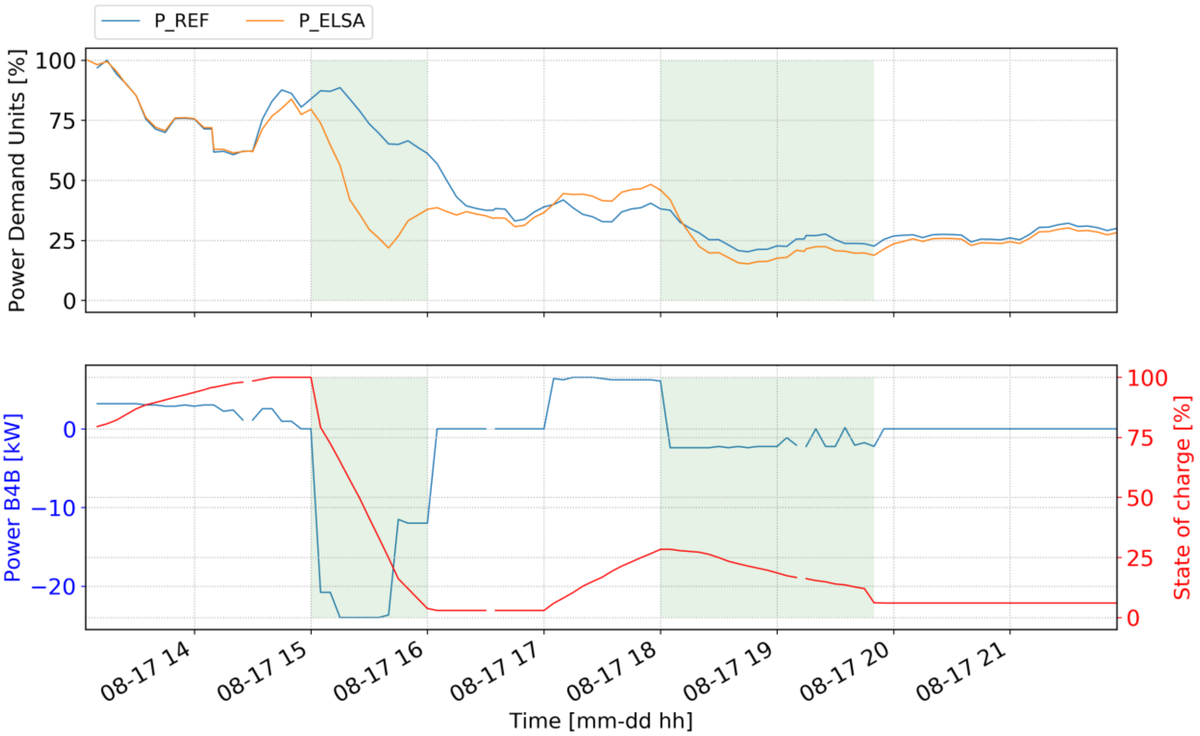


Figure 47. UC2: Example of auto-consumption DR experiment over August 17th, 2018.

1.5.2.3 UC3: Energy Purchase Time Shifting

Energy and Costs KPIs: estimation of the target value

The target values of the Energy and Costs KPIs are estimated using the same methodology as explained in section 1.2.1.3. A target value of 2% is calculated for the Energy and Costs KPIs, using the information presented in Table 29.

KPI evaluation over a test period

An EPTS service was tested over a half-day period on April 10th, 2018. The experiment started around 19:00 with a state of charge of the electric storage of about 40%. The EBEMS uses the amount of energy left in the batteries by the end of the day before the energy rate decreases. The EBEMS charges the battery system as soon as the rate decreases to benefit from the cheaper rate. The Energy and Costs KPIs reach a value of 1.1% on that example for a target value of 2%. The KPI value estimated over that experiment is low partly because the charging rate is very small (less than 4 kW, two modules out of three were in operation) and combined to the fact that the experiment is not long enough to have time to fully charge the batteries.

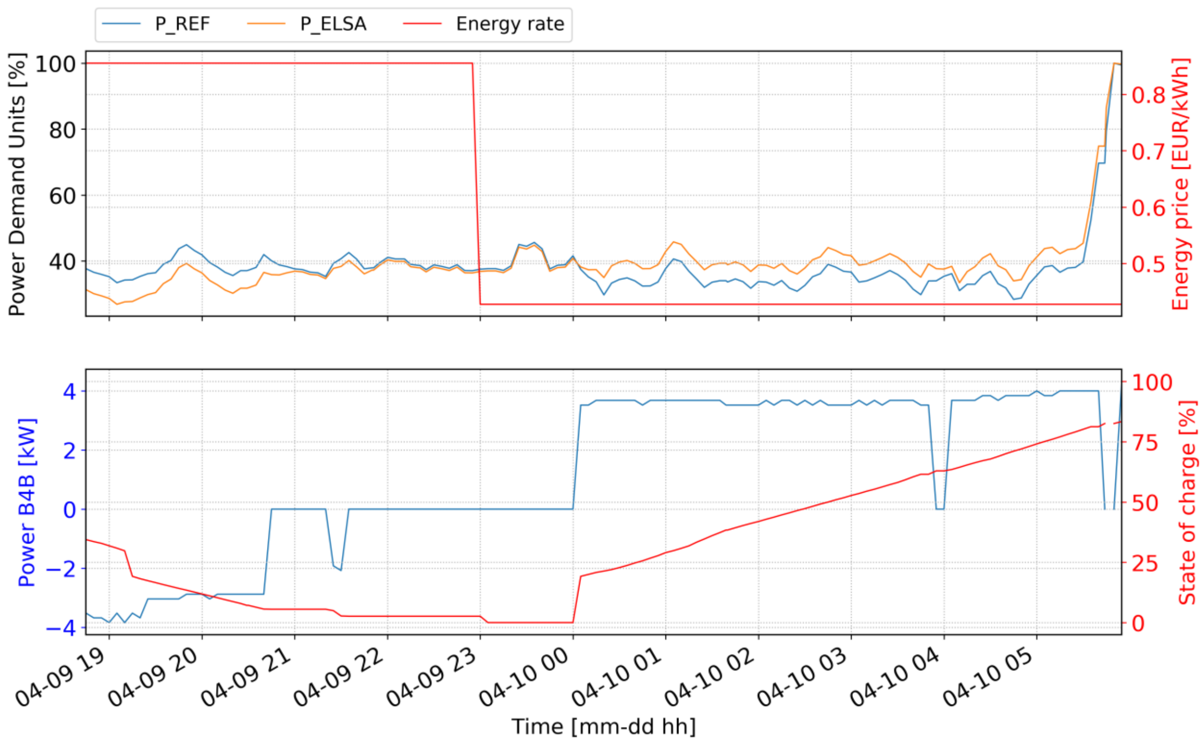


Figure 48. UC3: Example of EPTS experiment over April 10th, 2018.

1.5.2.4 UC4: Cost-minimization DR Service

Energy, Costs and CO2 KPIs: estimation of the target value

Similarly to UC2, the target KPIs are calculated in the same way as for the Ampere building (see section 1.2.1.2). The rate during the cost-minimization DR Service is also lower than the usual rate: a negative target value is calculated. A target value of -16% is calculated for the Energy, Costs and CO2 KPIs, using the information presented in Table 29.

KPI evaluation over a test period

The experiment presented in Figure 49 is an example of a cost-minimization DR Service. In the context of this experiment, the system is normally running an EPTS energy service. At some point in the experiment the EBEMS receives a notification from the electric utility for a DR Service (Cost-minimization in this case), with information about the starting time, the duration and the energy rate during the DR event. The EBEMS is able to plan accordingly in real time.

In the example, two DR events appear on the first day (August 17th, 2018) and one DR event on the last day (August 20th, 2018). The two days between the DR events correspond to the weekend (August 18th and 19th), the EBEMS runs an EPTS energy service with a lower energy rate at night. The EBEMS charges the electric storage at night when the energy rate is of 0.42 euros/kWh instead of 0.85 euros/kWh during the day.

Figure 50 focuses on the first day of the experiment with two cost-minimization DR events: the first one from 13:00 to 15:00 with an energy rate of 0.24 euros/kWh and the second one from 17:00 to 18:00 with a cheaper energy rate of 0.08 euros/kWh. The EBEMS takes advantage of the lower rate during those two DR events to charge the batteries. The power demand of the building is then higher during the DR events than the usual power demand of the building. A value of -21% is reached for the Energy, Costs and CO2 KPIs over that experiment, with a value of -18.5% for DR event #1, -32.3% for #2 and -12.1% for #3. The difference in the KPI values between the successive DR events is due to the difference in the duration and charging rate over each event. The target value of -16% was exceeded over the first two events even if the charging rate was not as high as considered in the calculation of the target. The power demand of the building at the time of the first two DR events is about a third (even less for the second DR event) of the one considered in the estimation of the target value. Also the second DR event lasts over one hour compared to two hours for the target. The target value is not reached in the third DR event mainly because of the low charging rate (less than 4 kW).

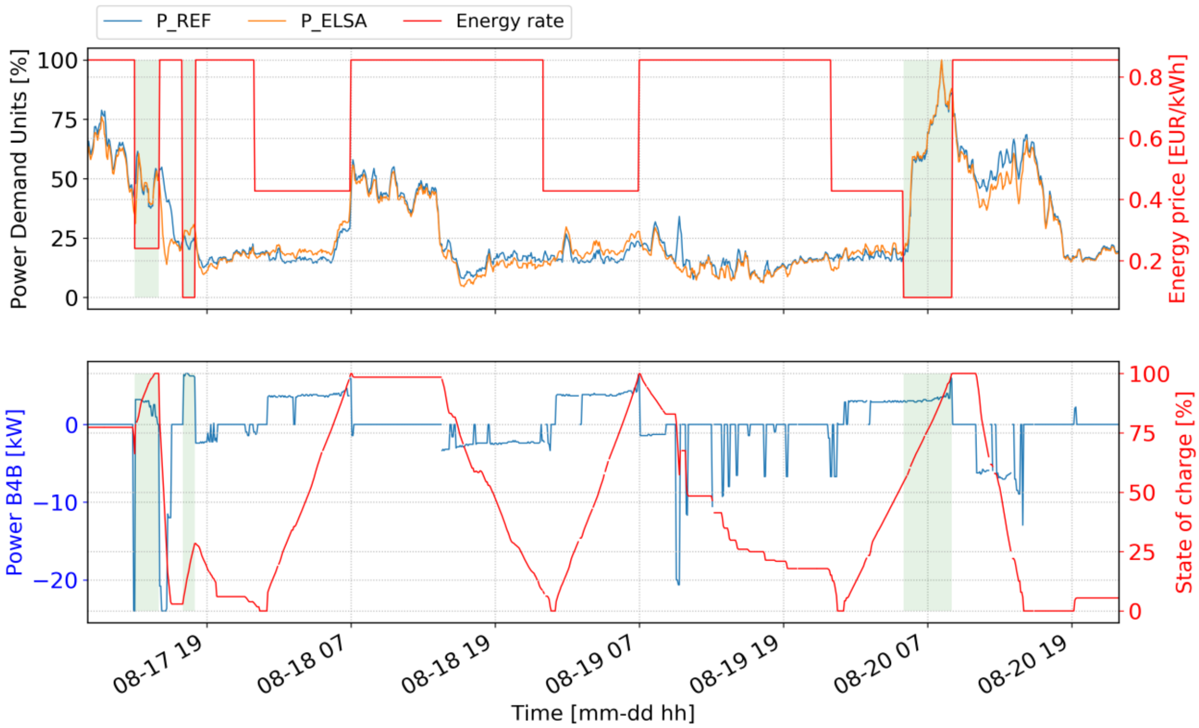


Figure 49. UC4: Example of cost-minimization DR experiment over a four-day period.

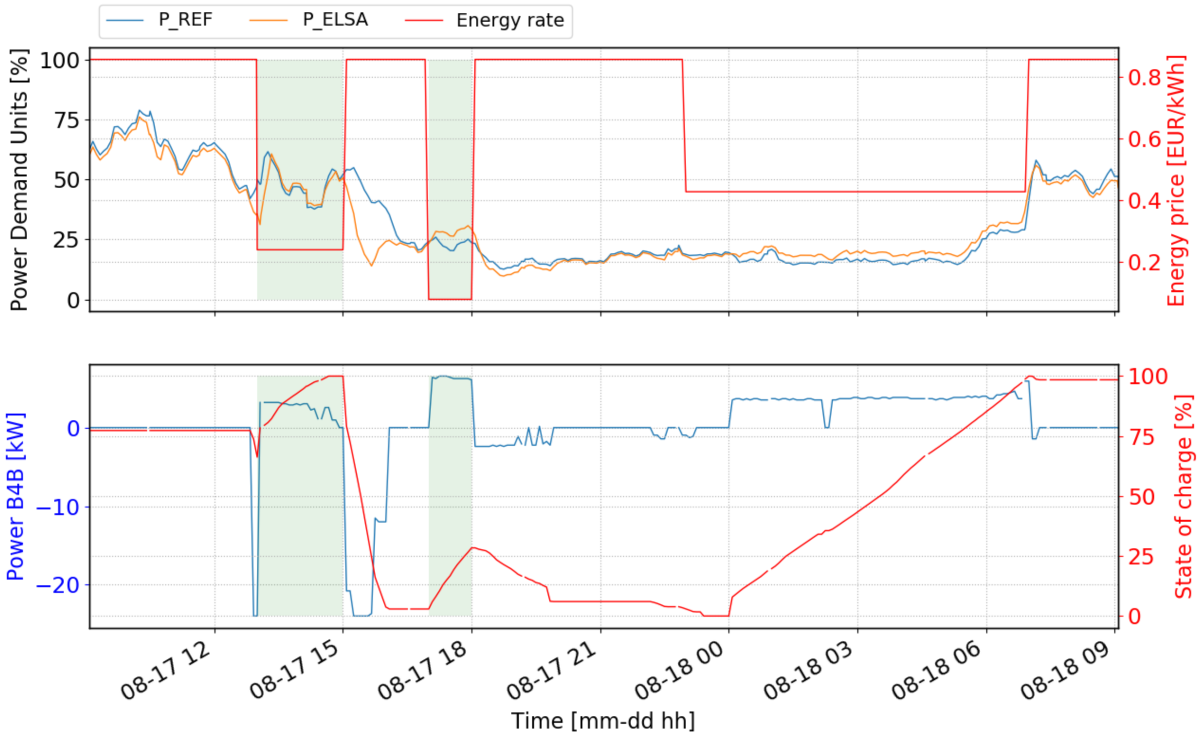


Figure 50. UC4: Example of cost-minimization DR experiment over August 17th, 2018.

1.5.2.5 UC5: Flexibility DR Service

Energy KPI: estimation of the target value

A target value of 16% is estimated for the Energy KPI in UC5, using the information presented in Table 29. The target value is calculated following the same methodology as for an auto-consumption DR Service (see section 1.2.1.2).

KPI evaluation over a test period

A flexibility DR Service was tested over a three-day period in April 2018 in SASMI building (Figure 51). Similarly to other DR services, before the DR event is triggered by the electric utility, the EBEMS runs an EPTS energy service. When the electric utility notifies the EBEMS of a future flexibility DR event, it specifies a "target" power demand that the building should require from the grid within a specified tolerance bounds.

In the example presented in Figure 51, three DR events occur; one per day. During the first event, the target power demand requested by the electric utility is close to the actual demand of the building so the electric storage was not heavily used. For the second DR event (April 10th, from 17:00 to 18:00) the target power demand is very high compared to the actual demand of the building (more than twice). The EBEMS charged the electric storage at full rate during the DR event to increase the demand of the building. The available capacity in the electric storage is not sufficient to reach the target power. On the last DR event (April 11th, from 9:30 to 10:30), the target power demand is lower than the actual demand of the building. The EBEMS discharges the batteries at a rate of about -10 kW to reduce the power demand of the building and get closer to the target. The EBEMS managed to reach the tolerance bandwidth of the target towards the second half of the DR event.

The Energy KPI evaluated for each DR event are the following: 2% for DR event #1, -5.8% for #2 and 6.9% for #3. An average value of 1% is calculated over the three DR events, significantly smaller than the expected value of 16%. As explained in the previous paragraph, in the first DR event the electric storage is not required to reach the requested power demand. The power demand of the building is close to the usual one so the Energy KPI is small. For the second and third DR events, the charging and discharging rates were too little (less than 5 kW in charge and -10 kW in discharge according to the bounds for charge and discharge rates sent by the BEMS to the EBEMS). The requested power demand has not been met.

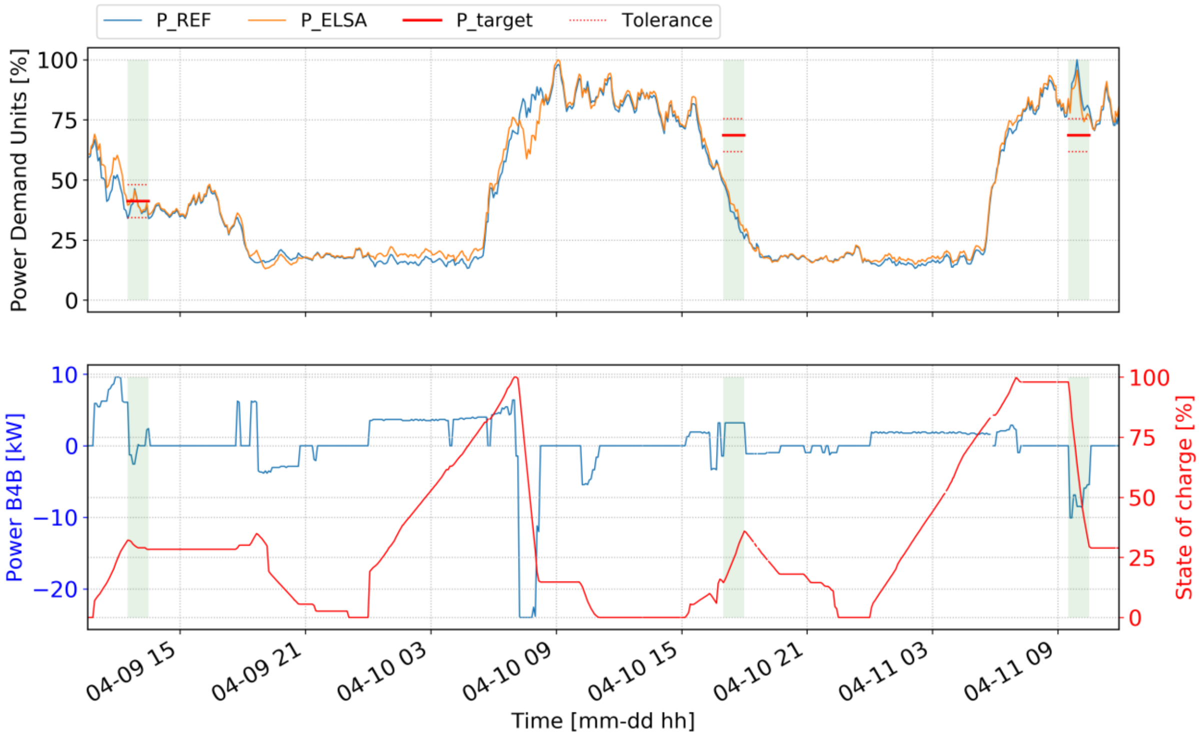


Figure 51. UC5: Example of flexibility DR experiment over a three-day period in April, 2018.

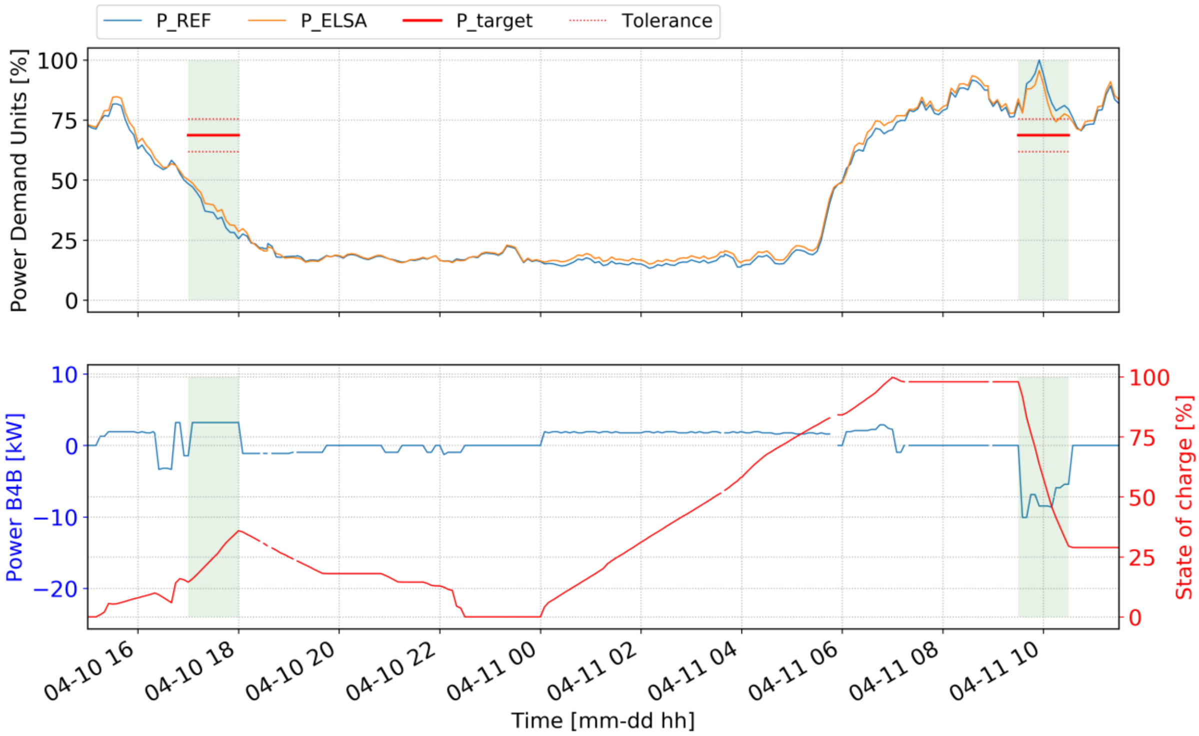


Figure 52. UC5: Example of flexibility DR experiment over April 10th, 2018.

1.5.3 Conclusion

Three energy services were demonstrated in the SASMI building pilot site: peak shaving, energy arbitrage and demand response services (including auto-consumption, cost-minimization and flexibility). KPIs were evaluated to assess the performance of the system on providing those services to the grid in terms of power, energy, costs and CO2 emission indices. The energy services were demonstrated and evaluated using the DT.3 prototype system.

The energy services were tested several times for most of the use cases and the average value of the KPIs is reported in Table 30. The KPIs targeted were exceeded for the DR services: auto-consumption and cost-minimization. The target values were estimated assuming a usual time-length of two hours for each DR event. The DR services were tested over different durations varying from one to two hours. The achieved KPI for the flexibility DR Service was significantly lower than the target value in average over the tests. In this case, the KPI evaluated is dependent on the "target" power demand specified by the electric utility to be tracked by the building. For instance, in some test, the "target" power demand was close to the actual power demand of the building and the electric storage was not used. When performing several demonstrations consecutively, the evaluation of the KPIs is impacted: the storage system is not in the same state at the beginning of each test. The KPIs achieved over the demonstrations were also impacted by the operation of the storage system; the total capacity of the system was not always available.

At SASMI building the demonstrations were run over reduced time periods. This particular situation was determined by the instability in the communications between the EBEMS and the Cylon BMS installed at the site. In particular, in line with the challenges already presented during the second review with the EU Commission, problems related to the OPC protocol were at the basis of continuous data loss and disconnections. Despite this, the results presented in the above section were obtained in typical days that represent the average operating condition of the building. However, as presented in Section 1.2 for the Ampere E+ site, it is expected that these kinds of problems will tend to vanish as the number of IoT connected devices will increase and and through the ever increasing adoption of standard protocols (e.g., BACNET) used in conjunction with APIs.The overall ELSA system demonstrated the capability, for the pilot site, to provide the defined energy services to the electric grid. The capacity of the storage system compared to the building load drives the impact of the energy services that can be provided; it is a crucial point to consider in the design phase knowing the energy services of interest.

2 Conclusion

As part of ELSA project, storage system solution has been developed on WP2, the ICT has been designed on WP3 and the overall system installed on WP4. Each partner has implemented on site different ICT solution and equipment. One main part of the ELSA project was to experiment those solutions on real conditions and evaluate performances of the ELSA solution over different use cases. This have been successfully done for all test site which has been able to run experiment. For NISSAN test site, every component are ready and operational to run experiment. Unfortunately, the late finalization of the test site has led to the impossibility to provide service evaluation.

The overall experiments done on site gives pretty good results and are encouraging for ELSA solution. KPI are closed to their target values and show the ELSA solution offer values to an integrated solution with storage. Even some results shows a different view, this is mainly due to real conditions experimentation. Indeed, there were some reliability trouble of the first version of the storage system that have been implemented on site and lead to power and energy lack on service experimentation. Some use case have also shown versatile results due to complexity of forecast component. However most of experiments show the good potential of the ELSA solution and the benefit for the grid, for battery owner or economic interest of the solution. Specific lessons were collected together with valuable reference data, such as for Terni site one relevant result was that understanding that a smaller battery could provide even interesting results in a large part of the cases where the e-car charging system is not stressed at maximum capacity.

The renewable energy will provide more and more uncertainty on energy production and the ELSA solution offer flexibility to answer this problem. On top of that, it offers service to the grid, by enabling to answer DSO request but also by offering less stress on the load of the grid but also offering some ancillary service to the DSO. Storage solution is placed as one of the best answer to renewable energy, the ELSA solution demonstrate this fact and its capability of taking unusable car battery, increasing the environmental impact of the overall solution.

Integration of all equipment and implementation of the overall ELSA solution on every test site make a main part of the ELSA project a success. Demonstrating the uses cases and showing encouraging results on those services is a great achievement for the overall project.

3 Appendix

3.1 Executive Summary

KPI Deliverable is an input from WP1 - Requirement Analysis and System Level Specification. The aim of this document is to provide the Definition of the Key Performance Indicators of the ELSA project, which allow measuring the success of the project in relation to its overall objectives.

A template has been created to define Key Performance Indicators. The template is organized into four main sections:

1. Basic KPI Information - General Project KPI Info (common to different DEMOs)
2. KPI Calculation Methodology – Methodology for calculating KPI (DEMO specific)
3. KPI Data Collection – Data required for calculating indicator (DEMO specific)
4. KPI Baseline – Baseline for calculating KPI (DEMO specific)

All KPIs can be grouped in four categories: Power, Energy, Costs, and CO2 emissions. The objective of KPIs defined in this document is to evaluate services offered for the different use cases in the specific pilot site.

The list of ELSA project KPIs is provided below:

ELSA project KPI	KPI ID	KPI Description
Power	WP1_KPI_1	Amount of power involved in the specific use case.
Energy	WP1_KPI_2	Amount of energy and reactive energy involved in the specific use case.
Costs	WP1_KPI_3	Reduction of energy costs by optimizing energy consumption and energy generation.
CO2 emissions	WP1_KPI_4	CO2 reduction due to the RES usage as result of the specific process optimization implemented via ELSA solution.

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3.2 List of Figures

3.3 List of Tables

3.4 List of Acronyms and Abbreviations

ELSA	Energy Local Storage Advanced system
BoEU	Block of Energy Units
CA	Commercial Aggregator
DR	Demand Response
DSO	Distribution System Operator
EDEMS	ELSA District Energy Management System
EEMS	ELSA Energy Management System
EV	Electric Vehicle
PV	Photovoltaic
TSO	Transmission System Operator

3.5 Introduction

In ELSA project, Use Cases were defined in Deliverable 1.5 for the different pilot sites.

In order to evaluate, in T6.3, the quality of the offered services a proper methodology has been defined. This document aims at describing the methodology and the KPIs defined for the systems evaluation.

The KPIs are defined at level of DSO, Districts -residential and prosumers districts- and Buildings. Subject of the KPI evaluation are the services offered for the different use cases in the specific pilot site.

The ELSA project identified four overarching KPI, those represent the main metrics categories that are used to group the Specific Pilot KPI: Power, Energy, Costs, CO2 emissions. The detailed Elsa approach to KPIs is described in Section 2.

Each group of Key Performance Indicators is organized into four main sections:

- Basic KPI Information: describes the overarching KPI common to different pilot sites
- KPI Calculation Methodology: specific formulas applicable to each KPI
- KPI Data Collection: collection of required data to calculate formulas, vary from demo to demo
- KPI Baseline: reference baseline condition for calculating KPI, vary from demo to demo

Section 3 describes the list of proposed ELSA project KPIs, with the detailed measurement methodologies and precise formulas applicable to each KPI.

3.6 ELSA approach to KPIs

The overall ELSA approach to the KPI is structured in two layers:

1. some overarching KPI that are defining the set of indicators which trace clear progress toward overarching goals;
2. specific Pilot KPI that are a set of indicators, proposed for each Pilot site, in order to detail further the contribution of each Pilot to first group of KPI.

In the study of scenarios implemented, for the calculation of the related KPI, it is necessary to take in consideration the current situation. The latter is considered the Reference Scenario, it represent the situation as the business was operated before the application of ELSA results solution (EMS, ICT Platform, Second Life battery, etc.).

Once the scenarios are defined KPI calculation is addressed following a multistep approach:

- STEP 1: Determination of the reference scenario or initial situation, the problems to solve, needs to satisfy, and the drivers that trigger a network/system improvement.
- Step 2: Analysis of the situation when ELSA pilot solutions are deployed. For this aspect the use cases defined in WP1 and reported in D1.5 are considered.
- STEP 3: Calculation of the correspondent KPI to evaluate the R&I situation. In this step the specific calculation formula need is identified.

In the ELSA project each pilot site tailors the specific Pilot KPI referring to the use cases that are implemented. This offers the actual formulas that are used for the validation of all the use cases. Table 1 shows the overarching KPIs relationship to each pilot site. Furthermore Table 2 summarizes the close relationship with the ELSA Use Cases and the defined project Key Performance Indicators.

An important aspect related to the defined KPIs is their target value. The target value represents an estimation of result that the KPI should achieve. The mapping of the KPI target values in relation to each use case per demo site can be shown in Table 3.

Project KPI	City of Terni Italy	Ampere Building France	Nissan Office France	RWTH Aachen Germany	City of Kempten Germany	SASMI Building United Kingdom
Power	√	√	√	√	√	√
Energy	√	√	√	√	√	√
Costs	√	√	√	√	√	√
CO_2 Emissions		√		√		√

Table 1: Mapping the KPIs to each pilot site

Project KPI	City of Terni						Ampere Building					Nissan Office		RWTH Aachen				City of Kempten						SASMI Building				
	UC1	UC2	UC3	UC4	UC5	UC6	UC1	UC2	UC3	UC4	UC5	UC1	UC2	UC1	UC2	UC3	UC4	UC1	UC2	UC3	UC4	UC5	UC6	UC1	UC2	UC3	UC4	UC5
	Power Quality – Power Balance	Primary Reserve	Dynamic Reactive Power Control	Reactive Power Compensation	Peak Shaving Consumption to Reduce Peak Loads in Peak Hour	PV power smoothing	Peak Shaving for Power Subscription Cost Optimization	Provide DR Auto Consumption on Building Level	Energy Purchase Time Shifting	Provide DR Cost Minimization on Building Level	Provide DR - Flexibility for Building and District	Peak Shaving for Power Subscription Cost Optimization	Energy Purchase Time Shifting	Provide DR CO_2 Minimization for District Optimization	Provide DR Auto Consumption for District Optimization	Provide DR Cost Minimization for District Optimization	Provide DR - Flexibility for Building and District	Provide DR Auto Consumption for District Optimization	PV Self-consumption Maximization by Power Smoothing	Balance Group Optimization	Participation to the Energy Trade Market	District Provides Primary Reserve	DSO Manages the Reactive Power Compensation	Peak Shaving for Power Subscription Cost Optimization	Provide DR Auto Consumption on Building Level	Energy Purchase Time Shifting	Provide DR Cost Minimization on Building Level	Provide DR - Flexibility for Building and District
Power	√	√	√	√	√	√	√					√					√		√					√				
Energy			√	√			√	√	√	√	√	√	√		√		√	√		√			√	√	√	√	√	√
Costs		√						√	√	√		√	√			√		√		√	√	√	√		√	√	√	
CO_2 Emissions								√		√				√											√		√	

Table 2: Mapping the KPIs to each use case per pilot site

Project KPI	City of Terni						Ampere Building					Nissan Office		RWTH Aachen				City of Kempten						SASMI Building				
	UC1	UC2	UC3	UC4	UC5	UC6	UC1	UC2	UC3	UC4	UC5	UC1	UC2	UC1	UC2	UC3	UC 4	UC1	UC2	UC3	UC4	UC5	UC6	UC1	UC2	UC3	UC4	UC5
	Power Quality – Power Balance	Primary Reserve	Dynamic Reactive Power Control	Reactive Power Compensation	Peak Shaving Consumption to Reduce Peak Loads in Peak Hour	PV power smoothing	Peak Shaving for Power Subscription Cost Optimization	Provide DR Auto Consumption on Building Level	Energy Purchase Time Shifting	Provide DR Cost Minimization on Building Level	Provide DR - Flexibility for Building and District	Peak Shaving for Power Subscription Cost Optimization	Energy Purchase Time Shifting	Provide DR CO_2 Minimization for District Optimization	Provide DR Auto Consumption for District Optimization	Provide DR Cost Minimization for District Optimization	Provide DR - Flexibility for Building and District	Provide DR Auto Consumption for District Optimization	PV Self-consumption Maximization by Power Smoothing	Balance Group Optimization	Participation to the Energy Trade Market	District Provides Primary Reserve	DSO Manages the Reactive Power Compensation	Peak Shaving for Power Subscription Cost Optimization	Provide DR Auto Consumption on Building Level	Energy Purchase Time Shifting	Provide DR Cost Minimization on Building Level	Provide DR - Flexibility for Building and District
Power	/	/	/	/	-17,5%	18,5%	8,8%					/	/				+19 kW -19 kW		4.6kW	/	/	/	/	32%				
Energy	/	/	/	/			0,6%	4,4%	0,6%	-4,4%	4,4%	/	/		11,74%			52.55 kWh/ day		/	/	/	/	2%	16%	2%	-16%	16%
Costs	/	/	/	/				4,4%	0,6%	-4,4%		/	/			-3,89%		0.63€ /day		/	/	/	/		16%	2%	-16%	
CO_2 Emissions	/	/	/	/				4,4%		-4,4%		/	/	- 3,35%						/	/	/	/		16%		-16%	

Table 3: Mapping the KPIs Expectations to each use case per pilot site

3.7 ELSA KPIs in detail

3.7.1 Power

<table>
<tr><th colspan="7">BASIC KPI INFORMATION</th></tr>
<tr><td>KPI Name</td><td colspan="3">Power</td><td colspan="2">KPI ID</td><td>WP1_KPI_1</td></tr>
<tr><td>Strategic objective</td><td colspan="6">This indicator represents the amount of power involved in the specific use case. Power has to be intended as both power consumed and power produced, typical scenario of power usage is the peak shaving or pv power smoothing.</td></tr>
<tr><td rowspan="2">DEMO where KPI applies</td><td>City of Terni</td><td>Ampere Building</td><td>Nissan Office</td><td>RWTH Aachen</td><td>City of Kempten</td><td>SASMI Building</td></tr>
<tr><td>√</td><td>√</td><td>√</td><td>√</td><td>√</td><td>√</td></tr>
<tr><td>KPI description</td><td colspan="6">This indicator represents the available power flexibility in a defined period</td></tr>
<tr><td>KPI formula</td><td colspan="6">$\Delta P = P_{Ref} - P_{ELSA}$[unit: kW]
$\Delta P_{\%} = \frac{P_{Ref} - P_{ELSA}}{P_{Ref}} \cdot 100\%$
[unit: %]</td></tr>
<tr><td>Unit of measurement</td><td colspan="6">% of reference power</td></tr>
<tr><td>Reporting period</td><td colspan="6">At the end of each use case demonstration</td></tr>
<tr><td>Relevant standards</td><td colspan="6">None</td></tr>
<tr><td>Connection / link with other relevant defined KPIs</td><td colspan="6"></td></tr>
</table>

<table>
<tr><th colspan="3">KPI CALCULATION METHODOLOGY</th></tr>
<tr><th colspan="3">City of Terni</th></tr>
<tr><th>KPI step methodology ID</th><th>Step</th><th>Responsible</th></tr>
<tr><td>Total profile deviation (TpD)</td><td>DSO District Power profile request is accomplished mixing Peak shaving and PV Power smoothing. This is considered a level of flexibility that the District Management can offer. In Terni pilot site the reference</td><td>Eng</td></tr>
</table>

	scenario is represented by the blocks not offering any kind of flexibility and by EV-charging station considering the re-charging schedule without any load postponement (load-shift); the Building is a passive consumer and the PV is a producer not offering curtailment for production modulation. The Battery system completes the ELSA scenario for the provision of flexibility, together with EEMS of EV-charging stations. Those provide to the district a set of flexibilities that can be combined to accomplish DSO power profile request for the whole district. In a demand and supply setting, it is important to measure the deviation between demand and actual power provision. In case of Terni pilot the demand is represented by DSO request of district power profile, the actual power profile achieved by the district exploiting the aggregated flexibility represent the supply. A key performance index for this deviation can be the calculated as follows: $$TpD = \sqrt{\frac{\sum_{i=1}^{T}\left(P_{\text{ELSA District}}(t_i) - P_{Dsorequest}(t_i)\right)^2}{T}}$$ where: $P_{\text{ELSA District}}(t_i)$ is the average power demanded / injected by the district to the grid in every time slot t_i $P_{DSOrequest}(t_i)$is the reference value of the power profile requested by the DSO in every time slot t_i, even this provided as average value for the whole timeslot. $T$is the number of intervals in the time horizon of the optimization process. The smaller this deviation is, the better is the prediction.	
Number of power downward	DSO provides the reference power to the District manager in terms of a reference segmented curve and an acceptance area. The request from DSO is to stay as much as close possible to the reference power but other values are considered acceptable if they remain inside the acceptance area. So, for each interval, three values are provided by DSO: $P_{DSOrequest}$that represents the power average request value for the interval; $P_{DSOrequestDown}$that represents the lower value delimiting the acceptance area;	Eng

	$P_{DSOrequestUp}$ that represents the higher value delimiting the acceptance area. This KPI represents the number of intervals in which the $P_{\text{ELSA District}}$ exceeded the $P_{DSOrequestDown}$ on respect of the total number of intervals, expressed in percentage: $$N_{Down} = \frac{Card(Downward)}{T} \cdot 100\%$$ where: *Downward* is the set of intervals for which $P_{\text{ELSA District}}(t_i) < P_{DSOrequestDown}(t_i)$ *Card* is the cardinality function	
Number of power upward	Following the same approach of previous KPI : $$N_{Up} = \frac{Card(Upward)}{T} \cdot 100\%$$ where: *Upward* is the set of intervals for which $P_{\text{ELSA District}}(t_i) > P_{DSOrequestUp}(t_i)$ *Card* is the cardinality function	Eng
Maximum power gap	This KPI evaluates the reduction of peak of power production. It is calculated taking in consideration the maximum of all deviations between the power profile achieved from the district and the power profile requested from the DSO. $$P_{MaxGap} = \max_{i=1,..,T}\left(P_{\text{ELSA District}}(t_i) - P_{Dsorequest}(t_i)\right)$$ where: $P_{\text{ELSA District}}(t_i)$ is the average power demanded / injected by the district to the grid in every time slot t_i $P_{DSOrequest}(t_i)$ is the reference value of the power profile requested by the DSO in every time slot t_i T is the number of intervals in the time horizon of the optimization process. To understand its influence percentage the Max Gap value is then compared with the power request performed by the DSO:	Eng

	$$\frac{P_{MaxGap}}{\lvert P_{Dsorequest}(t_k) \rvert} \cdot 100\%$$ where: *k* is the value of *i* for which the maximum occurs It will be reported if the $P_{\text{ELSA District}}(t_k)$ is part of the *Upward*	
Minimum power gap	It evaluates the reduction of peak consumption shaving. It is calculated taking in consideration the minimum of all deviations between the power profile achieved from the district and the power profile requested from the DSO. $$P_{MinGap} = \min_{i=1,..,T}\left(P_{\text{ELSA District}}(t_i) - P_{Dsorequest}(t_i)\right)$$ where: $P_{\text{ELSA District}}(t_i)$is the average power demanded / injected by the district to the grid in every time slot t_i $P_{DSOrequest}(t_i)$is the reference value of the power profile requested by the DSO in every time slot t_i $T$is the number of intervals in the time horizon of the optimization process. To understand its influence percentage the Min Gap value is then compared with the power request performed by the DSO: $$\frac{P_{MinGap}}{\lvert P_{Dsorequest}(t_y) \rvert} \cdot 100\%$$ where: *y* is the value of *i* for which the min occurs It will be reported if the $P_{\text{ELSA District}}(t_y)$ is part of the *Downward*	Eng
Primary reserve	Primary reserve aim at the frequency regulation, or balancing the power consumption and production on the grid. So in this case, injection and absorption has the exact same importance and has seen the same way as a power made available for the grid.	ASM

Primary reserve KPI description	$$meanP = \frac{1}{T}\int_{T} \lvert P_{storage}\rvert dt$$ $$\Delta P = meanP_{Ref} - meanP_{ELSA}$$ In this particular case, mean P_{ref} is 0 since there is no participation to primary reserve without the storage system.	ASM
Power balance	The power balance aims at reaching a power equilibrium between each phase. In this sense the KPI is looking at the power flexibility it offers between phases. One of the phase (arbitrary phase one) will be taken as a reference to compare the two other phases.	ASM
Power balance KPI description	$$\Delta P_{12} = P_1 - P_2$$ $$\Delta P_{13} = P_1 - P_3$$ $$\Delta P = \Delta P_{12} + \Delta P_{13}$$ $$\Delta P_{\%} = \frac{\Delta P}{P_1}$$	ASM
Reactive power compensation	The use case aim at limiting the amount of reactive energy going through the distribution line since the reactive energy is creating losses on the grid. The amount of reactive power will be tracked at the delivery point through the power factor or the cos phi.	ASM
Reactive power compensation KPI description	$$\Delta P_{reactif} = P_{reactif,REF} - P_{reactif,ELSA}$$ $$\Delta P_{reactif,\%} = \frac{P_{reactif,REF} - P_{reactif,ELSA}}{P_{reactif,REF}}$$ The amount of reactive power is usually tracted by the power factor or the cos phi: $$Powerfactor = \frac{P_{recatif}}{P_{actif}}$$	ASM

	$$cos(\phi) = \frac{P_{actif}}{S}$$ S is the apparent power $$\Delta powerfactor = powerfactor_{REF} - Powerfactor_{ELSA}$$ $$\Delta cos(\phi) = cos(\phi)_{REF} - cos(\phi)_{ELSA}$$ $$\Delta Powerfactor_{\%} = \frac{powerfactor_{REF} - powerfactor_{ELSA}}{powerfactor_{REF}}$$ $$\Delta cos(\phi)_{\%} = \frac{cos(\phi)_{REF} - cos(\phi)_{ELSA}}{cos(\phi)_{REF}}$$	
Ampere Building		
KPI step methodology ID	**Step**	**Responsible**
KPI description power	This indicator represents the maximum difference between the power demand of the building with the ELSA electric storage and the reference case without electric storage over a selected period of time.	UTRCI
KPI estimation power	$$Power = \max_{t=1,\dots,t_{end}} \left(\frac{P_{ELSA_t} - P_{Ref_t}}{P_{Ref_t}} \right) \cdot 100\%$$	UTRCI
Nissan Office		
KPI step methodology ID	**Step**	**Responsible**
KPI description Power peak shaving	For peak shaving, we are interested in the power above the Power limit (which simulate the power subscription). We want to estimate the global reduction of power excess. Therefore, we will use the mean value of Power excess.	Nissan
KPI estimation power peak shaving	$$\Delta P_{excess} = \langle P_{excessref} \rangle - \langle P_{excess} \rangle$$	Nissan

	$$\Delta P_{excess}\% = \frac{\langle P_{excessref}\rangle - \langle P_{excess}\rangle}{\langle P_{excessref}\rangle}$$	
KPI estimation power peak shaving calculation	We already had the balance equation in the power (see deliverable 3.2 for more details) applies at each time step: $$P_{demand}(t) = P_{grid}(t) - P_{storage}(t) \qquad [1]$$ Where $P_{demand}(t)$ is the power demand of the building, $P_{grid}(t)$ is the power imported from/exported to the grid, and $P_{storage}(t)$ is the power associated to energy storage. The power profile corresponds to the power demand of the building stated in equation [1]. Then to measure the Power excess we just have to remove the Power limit. $$P_{excess}(t) = P_{grid}(t) - P_{limit}$$ $$P_{excess}(t) = \frac{1}{T_{excess}} \int max\left(0, P_{grid}(t) - P_{limit}\right)$$ $T_{excess}$is the total duration when the power exceed the power limit.	Nissan
	RWTH Aachen	
KPI step methodology ID	**Step**	**Responsible**
Specific KPI description Gap in power	The maximum gap between the actual power profile and the power profile requested by a commercial aggregator - in relation to the requested value - is calculated over time. Measured in %. Also, the minimum and mean absolute gap between the actual power profile and power profile requested by a CA - in relation to the requested value - is calculated over time. Measured in %. $P_{Request_{el,t}}$denotes the power profile requested by a commercial aggregator.	RWTH Aachen
Maximum gap in power	$$P_{\mathrm{max\_Gap\_up}_{\%}} = \frac{\max\limits_{t=1,..,t_{end}}\left(\left\lvert P_{ELSA_{el,t}} - P_{Request_{el,t}}\right\rvert\right)}{P_{Request_{el,t}}} \cdot 100\%$$	RWTH Aachen

Mean gap in power	$P_{\text{mean\_Gap}_{\%}} = \frac{\underset{t=1,..,t_{end}}{mean}\left(\left\|P_{ELSA_{el,t}} - P_{Request_{el,t}}\right\|\right)}{P_{Request_{el,t}}} \cdot 100\%$	RWTH Aachen
Specific KPI description Flexible power	The maximum modification in power upward and downward after deployment of the ELSA scheduling in relation to the reference power. Measured in %. $P_{Request_{el,t}}$ denotes the power profile requested by a commercial aggregator.	RWTH Aachen
Flexible power down-ward	$P_{\text{max\_down}_{\%}} = \frac{\left\|\underset{t=1,..,t_{end}}{min}\left(P_{ELSA_{el,t}} - P_{Ref_{el,t}}\right)\right\|}{P_{Ref_{el,t}}} \cdot 100\%$	RWTH Aachen
Flexible power up-ward	$P_{\text{max\_up}_{\%}} = \frac{\underset{t=1,..,t_{end}}{max}\left(P_{ELSA_{el,t}} - P_{Ref_{el,t}}\right)}{P_{Ref_{el,t}}} \cdot 100\%$	RWTH Aachen
City of Kempten		
KPI step methodology ID	**Step**	**Responsible**
PV Power Smoothing	The KPI Power is used to identify to what extend the excess PV power at the point of common coupling of the district could be reduced with an ELSA system. The KPI ΔP is a theoretical sum of power which could be reduced over a certain time period e.g. a day. $$P_{mean-Ref} = \frac{1}{n}\sum_{i=1}^{n} P_{HH,i}$$ n = 15 min P_{HH}: combined Power measurement of House hold consumption and PV power production at the certain time $$P_{mean-ELSA} = \frac{1}{n}\sum_{i=1}^{n} P_{CC,i}$$ n = 15 min	AÜW / egrid

	P_{PCC}: power at the point of common coupling of the district at the certain time $$\Delta P = \sum_{i=1}^{n}(\lvert P_{mean-Ref,i} - P_{mean-ELSA,i}\rvert) \quad for P_{\text{mean-Ref,i}} > 0$$ n = the time period e.g. 96 ¼h values in 24 hours ΔP [kW]	
SASMI Building		
KPI step methodology ID	**Step**	**Responsible**
KPI description power	See KPI in **Ampere Building** site.	UTRCI
KPI estimation power	See KPI in **Ampere Building** site.	UTRCI

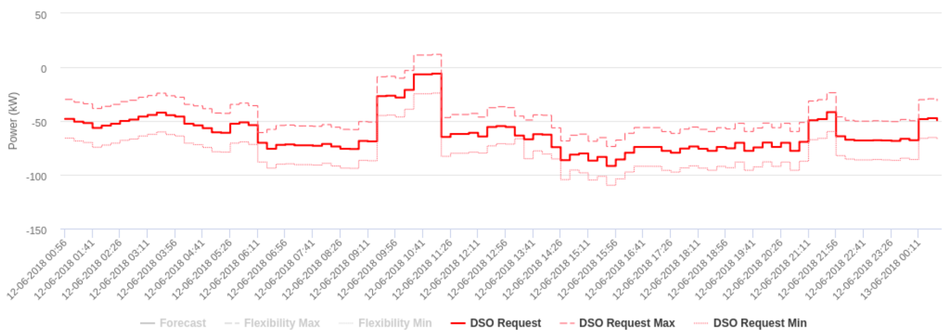
KPI DATA COLLECTION							
City of Terni							
Data	**Data ID**	**Methodology for data collection**	**Source/tools/instruments for data collection**	**Location of data collection**	**Frequency of data collection**	**Minimum monitoring period**	**Responsible**
Building consumption power	P_building	Measurement	Measurement equipment	Site	10 min		Eng
PV production power	P_pv	Measurement	Measurement equipment	Site	10 min		Eng
Battery storage power	P_storage	Measurement	Measurement equipment	Storage system	10 min		Eng
EV-charging	P_evChargingStations	Measurement	Measurement equipment	Site	10 min		Eng

stations power							
EV recharge schedules	P_rechargeSchedules	Simulation	E-car booking web application		User books a car		Eng
Reactive power at the delivary point	P_reactif	Measurement	Sensor	Site	5 min		ASM
Reactive power injected by the storage system	P_reactif, storage	Measurement	Sensor	Storage system	5 min		ASM
Frequency of the grid	F_grid	Measurement	Sensor	Site	5 sec		ASM
Power absorbed by the storage	P_abs	Measurement	Sensor	Site	5 sec		ASM
Power injected by the storage	P_inj	Measurement	Sensor	Site	5 sec		ASM
Ampere Building							
Data	**Data ID**	**Methodology for data collection**	**Source/tools/instruments for data collection**	**Location of data collection**	**Frequency of data collection**	**Minimum monitoring period**	**Responsible**
Energy consumed by the building	E_cons	Measurement	Sensor	Building site	5 min		UTRCI
Energy generated by the PV	E_gen_PV	Measurement	Sensor	Building site	5 min		UTRCI
Energy charged in the B4B	E_ch_B4B	Measurement	Sensor	Building site	5 min		UTRCI

Energy discharged from the B4B	E_dis_B4B	Measurement	Sensor	Building site	5 min		UTRCI
Nissan Office							
Data	**Data ID**	**Methodology for data collection**	**Source/tools/instruments for data collection**	**Location of data collection**	**Frequency of data collection**	**Minimum monitoring period**	**Responsible**
Energy consumed by the building	E_cons	Measurement	Sensor	Building site	5 min		Nissan
Energy charged in the B4B	E_ch_B4B	Measurement	Sensor	Building site	5 min		Nissan
Energy discharged from the B4B	E_dis_B4B	Measurement	Sensor	Building site	5 min		Nissan
RWTH Aachen							
Data	**Data ID**	**Methodology for data collection**	**Source/tools/instruments for data collection**	**Location of data collection**	**Frequency of data collection**	**Minimum monitoring period**	**Responsible**
System Load	P_system	Measurement	Measurement equipment	Substation	15 min		RWTH Aachen
RES power in the system	P_RES	Simulation	Data sheet of system		15 min		RWTH Aachen
Battery storage power	P_storage	Measurement	Measurement equipment	Storage system	15 min		RWTH Aachen
Flexible devices power	P_flexDevice	Measurement	Measurement equipment	Device	15 min		RWTH Aachen
City of Kempten							

Data	Data ID	Methodology for data collection	Source/tools/instruments for data collection	Location of data collection	Frequency of data collection	Minimum monitoring period	Responsible
PV Infeed	P_HH	Measurement	Measurement equipment	Households	30 seconds		AÜW / egrid
Combined Power	P_PCC	Measurement	Measurement equipment	Households & Substation	30 seconds		AÜW / egrid
SASMI Building							
Data	**Data ID**	**Methodology for data collection**	**Source/tools/instruments for data collection**	**Location of data collection**	**Frequency of data collection**	**Minimum monitoring period**	**Responsible**
See KPI Data Collection in **Ampere Building** site.							

KPI BASELINE			
City of Terni			
Source of Baseline condition	**Literature values**	**Company historical values**	**Values measured at start of project**
		√	√
Details of peak shaving and pv power smoothing Baseline	In the case of Terni district pilot it is not possible to compare P_{ELSA} with P_{Ref} where the latest is intended as in the overarching definition as the situation existing previous to the ELSA equipment and ICT installation. This is due to the fact that the reference power requested by the DSO – the $P_{DSOrequest}$ - couldn't have been defined without aggregated value of district forecast and flexibility that are exploited by DSO. DSO defines its power request -the $P_{Dsorequest}$ considering a more global goal affected by the district conditions and the nearby other prosumers conditions in a more general context, so not always the $P_{Dsorequest}$ is driven by peak load reduction and pv power smoothing but could have different requests affected by condition of nearby prosumers belonging the same transformation cabin. So KPIs are calculated taking in consideration as reference the power profile the DSO requests according its awareness of both forecast and flexibility available. A power profile is provided to the EDEMS as triplet, one for each time interval, including the expected profile and a tolerance region around this value. In general the aim of the EDEMS is to coordinate the district BoEU to achieve the optimal solution responding to DSO power profiles requests.		

	An example of DSO request can be shown in .  **Figure 53: Terni pilot site - Example of DSO request**		
Details of primary reserve Baseline	In the case of the primary reserve baseline, the reference scenario is the non-participation on the primary reserve market. mean $P_{REF} = 0$		
Details of power balance Baseline	The reference scenario will be based on the same KPI without the battery storage intervention. The use case is solved by the battery by an on/off activation of the services. The reference will be taken before activate the service by: $\Delta P_{12} = P_1 - P_2$ $\Delta P_{13} = P_1 - P_3$ $\Delta P = \Delta P_{12} + \Delta P_{13}$ $\Delta P_{\%} = \frac{\Delta P}{P_1}$		
Details of reactive power compensation Baseline	The amount of reactive power transported by the distribution line is obtained by measurement The reference case is the amount of reactive power transported without storage system. This can be obtain by removing the reactive power compensated by the storage system. $P_{reactif,REF} = P_{reactif,ELSA} - P_{reactif,storage}$		
Ampere Building			
Source of Baseline condition	**Literature values**	**Company historical values**	**Values measured at start of project**
			√

Details of Baseline	The energy consumed by the building in the reference case ($E_{consref}$) without any B4B system installed can always be calculated using the measured energy stored in the batteries. The following balance equation in the power (see deliverable 3.2 for more details) applies at each time step: $$P_{demand}(t) = P_{grid}(t) + P_{storage}(t) + P_{res}(t) \quad [1]$$ Where $P_{demand}(t)$ is the power demand of the building, $P_{grid}(t)$ is the power imported from/exported to the grid, and $P_{storage}(t)$ and $P_{res}(t)$ are the powers associated respectively to energy storage and renewable resources. The reference power profile corresponds to the power demand of the building stated in equation [1]. The reference energy can then be estimated as follows: $$E_{ref}(t) = \left[P_{grid}(t) + P_{storage}(t) + P_{res}(t)\right].\Delta t \quad [2]$$		
Nissan Office			
Source of Baseline condition	**Literature values**	**Company historical values**	**Values measured at start of project**
			√
Details of Baseline	We already had the balance equation in the power (see deliverable 3.2 for more details) applies at each time step: $$P_{demand}(t) = P_{grid}(t) - P_{storage}(t) \quad [1]$$ Where $P_{demand}(t)$ is the power demand of the building, $P_{grid}(t)$ is the power imported from/exported to the grid, and $P_{storage}(t)$ is the power associated to energy storage (Convention : $P_{storage}(t) > 0$when the battery is charging and $P_{storage}(t) < 0$ when the battery is discharging).. The reference power profile corresponds to the power demand of the building stated in equation [1]. Then to measure the Power excess we just have to remove the Power limit. $$P_{excess,ref}(t) = P_{grid}(t) - P_{storage}(t) - P_{limit}$$ $$P_{excess}(t) = \frac{1}{T_{excess}} \int max\left(0, P_{grid}(t) - P_{storage}(t) - P_{limit}\right)$$ $T_{excess}$is the total duration when the power exceed the power limit.		
RWTH Aachen			
	Literature values	**Company historical values**	**Values measured at start of project**

Source of Baseline condition			√
Details of Baseline	*The reference load profile $P_{Ref_{el,t}}$ compared to the load profile $P_{ELSA_{el,t}}$ which itself results from the application of the ELSA energy management, represents the load profile the pilot site would show without any intervention by the ELSA energy management. On the RWTH Aachen pilot site, the flexible devices are the battery storage, a heat pump, two air handling units and a heating rod. The battery storage, heat pump and air handling units are part of one BoEU named main building. The heating rod belongs to BoEU test hall.* *The heat pump's and part of the battery storage's operation is optimized with the local objective of peak shaving. To remove the impact of the battery storage on the residual load, its power profile $P_{StorageDifference_{el,t}}$ is subtracted from $P_{ELSA_{el,t}}$. Thus, the charging power is subtracted and the discharging power is added. The heat pump's power consumption is assumed to be the same in the reference case as after the implementation of the ELSA scheduling. The default mode for the air handling units is the operation at full capacity. So, in order to obtain the reference load, the curtailment of the air handling unit power $P_{AHU_{el,t}}$ is added to $P_{ELSA_{el,t}}$. The factor* $Curtailment_{el,t}$ indicates to what extent the air handling units' power is reduced by the ELSA energy management. The factor $Activation_{el,t}$ indicates at which level the heating rod is operated. The reference power profile can thus be determined by: $$P_{Ref_{el,t}} = P_{ELSA_{el,t}} - P_{StorageDifference_{el,t}} + P_{AHU_{el,t}} \cdot Curtailment_{el,t} - P_{HeatingRod_{el,t}} \cdot Activation_{el,t}$$ Consequently, the reference energy can be stated as: $$E_{Ref_{el,t}} = [P_{ELSA_{el,t}} - P_{StorageDifference_{el,t}} + P_{AHU_{el,t}} \cdot Curtailment_{el,t} - P_{HeatingRod_{el,t}} \cdot Activation_{el,t}] \cdot \Delta t$$		
City of Kempten			
Source of Baseline condition	**Literature values**	**Company historical values**	**Values measured at start of project**
		√	√
Details of Baseline	**<u>PV Power Smoothing</u>** The reference data is created by using the measurement data of the households (P_{HH}). The installed ELSA system is not interfering.		
SASMI Building			

Source of Baseline condition	**Literature values**	**Company historical values**	**Values measured at start of project**
			√
Details of Baseline	See **Details of Baseline** in **Ampere Building** site.		

3.7.2 Energy

BASIC KPI INFORMATION						
KPI Name	Energy			**KPI ID**	WP1_KPI_2	
Strategic objective	This indicator represents the amount of energy (and reactive energy) involved in the specific use case. Energy has to be intended as both consumed and produced, typical scenario of energy usage is involving the flexibility of a certain BoEU. Other possible scenarios are Energy Purchase Time Shifting and Peak shaving service.					
DEMO where KPI applies	**City of Terni**	**Ampere Building**	**Nissan Office**	**RWTH Aachen**	**City of Kempten**	**SASMI Building**
	√	√	√	√	√	√
KPI description	The available energy flexibility both in consumption and generation within a defined period in relation to reference energy.					
KPI formula	$\Delta E = E_{Ref} - E_{ELSA}$[unit: kWh] $\Delta E_{\%} = \frac{E_{Ref} - E_{ELSA}}{E_{Ref}} \cdot 100\%$ [unit: %]			[unit: kvarh$\Delta E_Q = E_{Q\ Ref} - E_{Q\ ELSA}$] $\Delta E_{Q_{\%}} = \frac{E_{Q\ Ref} - E_{Q\ ELSA}}{E_{Q\ Ref}} \cdot 100\%$ [unit: %]		
Unit of measurement	% of reference energy					
Reporting period	At the end of each use case demonstration					
Relevant standards	None					
Connection / link with other relevant defined KPIs						

KPI CALCULATION METHODOLOGY		
City of Terni		
KPI step methodology ID	**Step**	**Responsible**
Reactive power compensation	The use case aim at limiting the amount of reactive energy going through the distribution line since the reactive energy is creating losses on the grid. The amount of reactive energy will be tracked at the delivery point.	ASM

Reactive energy	$$E_{reactif} = \int_{t_1}^{t_2} P_{reactif}\,dt$$ $P_{reactif}$ is the reactive power at the delivery point	ASM
Reactive power compensation $\Delta E_{reactif} = E_{reactif,Ref} - E_{reactif,ELSA}$ **KPI**		ASM
Ampere Building		
KPI step methodology ID	**Step**	**Responsible**
Specific KPI description auto-consumption	• The auto-consumption indicator refers to the capability of the building of using renewable energy sources, or pre-stored power capacity, to reduce the power bought from the main grid. The auto-consumption KPI is calculated as the ratio of energy used from the batteries and photovoltaics panels over the total energy consumed by the building over the period of the experiment.	UTRCI
Auto-consumption evaluation	• $Auto(t) = \frac{E_{B4B}(t)+E_{PV}(t)}{E_{cons}(t)}$ • •	UTRCI
Specific KPI estimation auto-consumption	• The global KPIs used to track the auto-consumption maximisation are calculated with the following equations: • • $\Delta RES_{Auto} = \frac{E_{B4B}(t)+E_{PV}(t)}{E_{cons}(t)} - \frac{E_{PV}(t)}{E_{cons}(t)}$ • • $\Delta RES_{Auto_{\%}} = \big(E_{B4B}(t) + E_{PV}(t) - E_{PV}(t)\big)/E_{PV}\,(t)$ •	UTRCI
Specific KPI description flexibility	The flexibility of the system is a performance indicator referring to the capability of the system to provide a certain level of flexibility (i.e. building load modulation and variation) to the grid. To this aim, the presence of electric storage and renewable sources can be properly coordinated and managed through the adoption of an advanced control strategy. The system flexibility (SF) is defined as the amount of energy consumed by the building that can be reduced or	UTRCI

	shifted when coordinating resources like the electric storage system and the renewable sources.	
Flexibility evaluation	$SF(t) = E_{cons\,ref}(t) - E_{cons}(t)$	UTRCI
Specific KPI estimation flexibility	The following equations estimate the global KPIs for the flexibility of the building. The second term of the first equation is null to describe the fact that the building does not present any flexibility in the baseline case. $\Delta SF = \left(E_{consref}(t) - E_{cons}(t)\right) - \left(E_{consref}(t) - E_{consref}(t)\right)$ $\Delta SF_{\%} = \left(E_{consref}(t) - E_{cons}(t)\right) / E_{consref}(t)$	UTRCI
Nissan Office		
KPI step methodology ID	**Step**	**Responsible**
Specific KPI time shifting	• Time shifting enable to move consumption to another time where the prices are more interesting. To estimate if all the capacity of the battery could be used at high price time we will measure the energy avoided during those periods. We have 5 different flat prices during 5 periods and 3 of them are high price periods: critical peak hours, summer and winter peak hours.	Nissan
Time shifting evaluation	• $\Delta E_{peakhours} = E_{refpeakhours} - E_{peakhours}$ • $\Delta E_{peakhours}\% = \frac{E_{refpeakhours} - E_{peakhours}}{E_{refpeakhours}}$ •	Nissan
Specific KPI time shifting calculation	• Actually, the Energy avoided during peak is the energy provided by the battery (we assume that during peak hours, the battery will never charge only discharge). Therefore, the difference between the energy consumed during peak hours between the reference scenario and the testing, will be equal to the energy injected by the battery. • Over the 3 periods, $\Delta E_{peakhours} = E_{discharge}$ • Over the 3 periods, $E_{avoided}\% = \frac{E_{discharge}}{E_{consref}}$ • •	Nissan

Specific KPI description peak shaving	Similarly to time shifting, with peak shaving we want to know how much energy has avoided during the own building peak demand. We will measure the Energy consumed above the power consumption (remember that the real power subscription will not used in the tests for peak shaving, it will be a parameter to be decided P_{limit}).	Nissan
Peak shaving evaluation	$\Delta E_{excess} = E_{excess,ref} - E_{excess}$ $\Delta E_{excess_{\%}} = \left(E_{excessref}(t) - E_{excess}(t)\right)/E_{excessref}(t)$	Nissan
Specific KPI estimation peak shaving calculation	The energy excess will not be measured directly, we calculate this value through the measurement of power demand : $E_{excess}(t) = max\left(0, \int_{t_o}^{t_{end}} P_{grid} - P_{subcription}\right)$ $E_{excess}(t) = max\left(0, \Delta t * \sum_{i}^{n} P_{grid,i} - P_{subcription,i}\right)$	Nissan
RWTH Aachen		
KPI step methodology ID	**Step**	**Responsible**
Self-consumption rate after deployment of ELSA scheduling	This metric represents the mean percentage of consumption of locally generated power after the deployment of the ELSA scheduling. $E_{Renewable_{el,t}}$ denotes the energy generated on-site. Measured in %. $E_{\text{Self-Consumption\_ELSA}_{\%}} = mean\left(\frac{\min_{t=1,\dots,t_{end}} \{E_{ELSA_{el,t}}, E_{Renewable_{el,t}}\}}{E_{Renewable_{el,t}}}\right)$	RWTH Aachen
Self-consumption rate in reference scenario	This metric represents the mean percentage of consumption of locally generated power in a reference scenario, i.e., without the deployment of the ELSA scheduling. Measured in %.	RWTH Aachen

	$E_{\text{Self-Consumption\_Ref}_{\%}} = mean\left(\frac{\min_{t=1,\dots,t_{end}} \{E_{Ref_{el,t}}, E_{Renewable_{el,t}}\}}{E_{Renewable_{el,t}}}\right)$ $\Delta E_{Self-Consumption_{\%}} = E_{\text{Self-Consumption\_ELSA}_{\%}} - E_{\text{Self-Consumption\_Ref}_{\%}}$	
Difference in self-consumption rate	The difference of the percentage before and after the deployment of the ELSA scheduling is determined.	RWTH Aachen
Shifted energy	$E_{shifted_{\%}} = \frac{\int_{t=1}^{t_{end}} P_{StorDischarge_{el,t}}}{\sum_{t=1}^{t_{end}} E_{Ref_{el,t}}}$ With $P_{StorDischarge_{el,t}}$ denoting the current battery storage system output power when discharging.	RWTH Aachen
City of Kempten		
KPI step methodology ID	**Step**	**Responsible**
Auto Consumption for District optimization	The maximization of the auto consumption/ self-consumption of the locally produced PV power is to optimize the districts energy balance. The KPI Energy ΔE_{AutoC} is the sum of stored energy which could be consumed beyond the regular self-consumed PV Energy. $E_{PV} = \int_{t1}^{t2} P_{PV}(t)$ P_{PV} is the measured PV power t1 start of investigation period t2 end of time period e.g. a day or a year $E_{\text{HH\_excess}} = \int_{t1}^{t2} P_{HH}(t) \quad for P_{HH} > 0$	egrid

	P_{HH} is the combined power measurement of household consumption and PV power production E_{HH_excess} is the excess PV power which is not used by the Households $$E_{\text{PCC\_excess}} = \int_{t1}^{t2} P_{CC}(t) \quad for P_{CC} > 0$$ P_{PCC} is the power load measured at the point of common coupling of the district E_{PCC_excess} is the PV energy fed back into the grid after taking the self-consumption and the ELSA battery charge into account $$\Delta E_{AutoC-Ref} = E_{PV} - E_{\text{HH\_excess}}$$ Regular Auto consumption $$\Delta E_{AutoC-ELSA} = E_{PV} - E_{\text{PCC\_excess}}$$ Auto Consumption with ELSA battery system $$\Delta E_{AutoC} = \left\| \Delta E_{AutoC-Ref} - \Delta E_{AutoC-ELSA} \right\|$$ Increased auto consumption by ELSA battery system	
Reactive Power Compensation	Simulative the ELSA System is placed at an industrial or commercial site. According to the measured load profile of the site it is identified to what extend reactive power could be compensated by the ELSA system to avoid billing by the DSO. The KPI Energy ΔE_Q is the sum of compensated reactive energy. *<u>Source of Data</u>* <u>Option 1:</u> Real Case - Measurement of reactive power are locally available $$Q_{ELSA} = \begin{cases} Q_{site} & for Q_{site} < Q_{\text{ELSA\_max}} \\ Q_{\text{ELSA\_max}} & for Q_{site} \geq Q_{\text{ELSA\_max}} \end{cases}$$ Q_{site} : measured reactive power at the site [kvar] Q_{ELSA_max}: maximum of reactive power compensation defined by limits of ELSA system	egrid

	$E_{\text{Q ELSA\_15min}} = \int_{t1}^{t2} Q_{ELSA}\,(t)$ t1 start of time period t2 end of 15min time period <u>Option 2:</u> Simulation – 15min Load profile from DSO $E_{\text{Q ELSA 15min}} = \begin{cases} E_{\text{Q site 15min}} & for E_{\text{Q site 15min}} < E_{\text{Q ELSA\_max 15min}} \\ E_{\text{Q ELSA\_max 15min}} & for E_{\text{Q site 15min}} \geq E_{\text{Q ELSA\_max 15min}} \end{cases}$ $E_{\text{Q Site 15min}}$: reactive Energy of site in 15min time slot $E_{\text{Q ELSA\_max 15min}}$: maximum reactive Energy ELSA battery can compensate in 15 min time *<u>KPI Calculation</u>* $E_{QELSA} = \sum_{i=1}^{n} E_{\text{Q ELSA\_min i}}$ n = the time period e.g. 96 ¼h values in 24 hours $\Delta E_Q = \left\| E_{\text{Q Ref}} - E_{\text{Q ELSA}} \right\|$ [unit: kvarh] $E_{\text{Q Ref}}$ = 0 due to the fact there is no compensation of reactive power without the ELSA system	
Balance group optimization	Imbalance energy for given 1/4h time period of the AÜW balance group in kWh $E_{imbalance_{Ref}} \quad [kWh]$ Imbalance energy for given 1/4h time period with ELSA installation for AÜW balance group in kWh $E_{imbalance_{ELSA}} \quad [kWh]$ KPI for difference of needed imbalance energy between reference and ELSA scenario in kWh for given 1/4h time period $\Delta E_{imbalance} = E_{imbalance_{Ref}} - E_{imbalance_{ELSA}} \quad [kWh]$	egrid

Participation to the energy trade market	Total amount of energy from different sources used by the BoEU in kWh $$E_{partecipation_{ELSA}} = E_{grid} + E_{stock/buy} + E_{production} - E_{stock/sell} - E_{EEG}$$ Energy, BoEU bought from the energy supplier via the public grid $E_{grid_{ELSA}} = \sum_{t=1}^{t_{end}} E_{grid_{ELSA\,t}}$ Energy bought by the BoEU from the stock market via the public grid $$E_{stock/buy_{ELSA}} = \sum_{t=1}^{t_{end}} E_{stock/buy_{ELSA\,t}}$$ Energy sold by BoEU to the stock market via the public grid $$E_{stock/sell_{ELSA}} = \sum_{t=1}^{t_{end}} E_{stock/sell_{ELSA\,t}}$$ Energy produced and directly used in the BoEU $$E_{\text{self-consumption\_ELSA}} = E_{\text{production\_ELSA}} - E_{\text{feedin\_ELSA}}$$ Energy produced by the BoEU $$E_{production_{ELSA}} = \sum_{t=1}^{t_{end}} E_{production_{ELSA\,t}}$$ Energy produced by the BoEU and feed into the public grid $$E_{feedin_{ELSA}} = \sum_{t=1}^{t_{end}} E_{production_{ELSA\,t}}$$	egrid

SASMI Building		
KPI step methodology ID	**Step**	**Responsible**
Specific KPI description auto-consumption	• See KPI in **Ampere Building** site.	UTRCI
Auto-consumption evaluation	• See KPI in **Ampere Building** site.	UTRCI
Specific KPI estimation auto-consumption	• See KPI in **Ampere Building** site.	UTRCI
Specific KPI description flexibility	• See KPI in **Ampere Building** site.	UTRCI
Flexibility evaluation	• See KPI in **Ampere Building** site.	UTRCI
Specific KPI estimation flexibility	• See KPI in **Ampere Building** site.	UTRCI

KPI DATA COLLECTION							
City of Terni							
Data	**Data ID**	**Methodology for data collection**	**Source/tools/instruments for data collection**	**Location of data collection**	**Frequency of data collection**	**Minimum monitoring period**	**Responsible**
Reactive power at the delivary point	P_reactif	Measurement	Sensor	Site	5 min		ASM
Reactive power injected by	P_reactif, storage	Measurement	Sensor	Storage system	5 min		ASM

the storage system							
Ampere Building							
Data	**Data ID**	**Methodology for data collection**	**Source/tools/instruments for data collection**	**Location of data collection**	**Frequency of data collection**	**Minimum monitoring period**	**Responsible**
See KPI Data Collection in **Power KPI** section.							
Nissan Office							
Data	**Data ID**	**Methodology for data collection**	**Source/tools/instruments for data collection**	**Location of data collection**	**Frequency of data collection**	**Minimum monitoring period**	**Responsible**
Energy consumed by the building	E_cons	Measurement	Sensor	Building site	5 min		Nissan
Energy charged in the B4B	E_ch_B4B	Measurement	Sensor	Building site	5 min		Nissan
Energy discharged from the B4B	E_dis_B4B	Measurement	Sensor	Building site	5 min		Nissan
Power excess	P_excess	Measurement	Sensor	Building site	5 min		Nissan
RWTH Aachen							
Data	**Data ID**	**Methodology for data collection**	**Source/tools/instruments for data collection**	**Location of data collection**	**Frequency of data collection**	**Minimum monitoring period**	**Responsible**
See KPI Data Collection in **Power KPI** section.							
City of Kempten							
Data	**Data ID**	**Methodology for data collection**	**Source/tools/instruments for data collection**	**Location of data collection**	**Frequency of data collection**	**Minimum monitoring period**	**Responsible**
PV power	P_PV	Measurement	Measurement equipment on site	Site	30 sec		AÜW / egrid
Combined power HH and PV	P_HH	Measurement	Measurement equipment on site	Site	30 sec		AÜW / egrid

Power at point of common coupling of district	P_PCC	Measurement	Measurement equipment on site	Site	30 sec		AÜW / egrid
Option 1 Reactive Power	Q site	Measurement	Measurement equipment on site	Site	1 sec		Site
Option 2 Reactive energy	E_Q Site 15min	Measurement	Measurement equipment of DSO	Site	15 min		AÜW
Energy produced by PV system	Eproduction	Measurement	Measurement equipment of DSO	Site	15min	Since June 2016	AÜW
Energy feed into public grid	Efeedin	Measurement	Measurement equipment of DSO	Site	15min	Since June 2016	AÜW
Self-consumed energy	Eself-consumption	Measurement + calculation	Measurement equipment of DSO	Site	15min	Since June 2016	AÜW
Consumption from grid	Egrid	Measurment	Measurement equipment of DSO	Site	15min	Since June 2016	AÜW
SASMI Building							
Data	**Data ID**	**Methodology for data collection**	**Source/tools/instruments for data collection**	**Location of data collection**	**Frequency of data collection**	**Minimum monitoring period**	**Responsible**
See KPI Data Collection in **Power KPI** section.							

KPI BASELINE			
City of Terni			
Source of Baseline condition	**Literature values**	**Company historical values**	**Values measured at start of project**
			√

Details of Baseline	The amount of reactive energy transported by the distribution line is obtained through the reactive power measured. The reference case is the amount of reactive energy transported without storage system. This can be obtain by removing the reactive energy compensated by the storage system. $$E_{reactif,REF} = E_{reactif,ELSA} - E_{reactif,storage}$$		
Ampere Building			
Source of Baseline condition	**Literature values**	**Company historical values**	**Values measured at start of project**
			√
Details of Baseline	*See Details of Baseline in **Power KPI** section.*		
Nissan Office			
Source of Baseline condition	**Literature values**	**Company historical values**	**Values measured at start of project**
			√
Details of Baseline	The energy consumed by the building in the reference case ($E_{consref}$) without any B4B system installed can always be calculated using the measured energy stored in the batteries. The following balance equation in the power (see deliverable 3.2 for more details) applies at each time step: $$P_{grid}(t) = P_{demand}(t) + P_{storage}(t) \quad [1]$$ Where $P_{demand}(t)$ is the power demand of the building, $P_{grid}(t)$ is the power imported from/exported to the grid, and $P_{storage}(t)$ is the power associated to energy storage (Convention : $P_{storage}(t) > 0$when the battery is charging and $P_{storage}(t) < 0$ when the battery is discharging).. The reference power profile corresponds to the power demand of the building stated in equation [1]. The reference energy can then be estimated as follows: $$E_{ref}(t) = [P_{demand}(t)].\Delta t$$ $$E_{ref}(t) = [P_{grid}(t) - P_{storage}(t)].\Delta t \quad [2]$$ In the case of $E_{refpeakhours}$ we will measure the same thing but during specific period only. The peak hours periods for the grid are : Critical peak hours : December, January and February from 8:00 to 10:00 and 17:00 to 19:00 every day except Sunday and national holiday Winter peak hours : from November to March from 6:00 to 22:00 except critical peak hours, Sundays and national holidays.		

<table>
<tr><td></td><td colspan="3">Summer peak hours : from april to October from 6:00 to 22:00 except Sundays and national holidays.

For the energy excess in the reference case ($E_{excessref}$), we use the Power to get the energy above the power limit.
$$E_{excess,ref}(t) = max\left(0, \Delta t * \sum_{i}^{n} P_{demand,i} - P_{limit,i}\right)$$
$$E_{excess,ref}(t) = max\left(0, \Delta t * \sum_{i}^{n} P_{grid,i} - P_{storage,i} - P_{limit,i}\right)$$</td></tr>
<tr><td colspan="4">RWTH Aachen</td></tr>
<tr><td rowspan="2">Source of Baseline condition</td><td>Literature values</td><td>Company historical values</td><td>Values measured at start of project</td></tr>
<tr><td></td><td></td><td>√</td></tr>
<tr><td>Details of Baseline</td><td colspan="3">See Details of Baseline in Power KPI section.</td></tr>
<tr><td colspan="4">City of Kempten</td></tr>
<tr><td rowspan="2">Source of Baseline condition</td><td>Literature values</td><td>Company historical values</td><td>Values measured at start of project</td></tr>
<tr><td></td><td>√</td><td></td></tr>
<tr><td>Details of Baseline</td><td colspan="3">Use case auto consumption:
The reference scenario consists of a PV production unit and consumers. The consumers can use the energy production from the PV system directly, but there is no possibility to store overproduction for later use in the BoEU. The overproduction is feed into the public grid.
The KPI will be calculated with data measured at the start of the project and actual data after installation of ELSA system.

Use case reactive power compensation:
The reference case without interference of the ELSA system is the load profile measured by the DSO. The values Q_{site} bzw. $E_{Q\ Site\ 15min}$ are without any compensation. Therefore the variable $E_{Q\ Ref}$ used for the KPI ΔE_Q is zero.
The KPI will be calculated with historical values from AUEW.

Use case: Balance group optimization
As energy supplier we need to forecast the overall consumption of our customers in our balance group. For the deviation between forecast and real</td></tr>
</table>

	consumption the balance group operator needs to purchase imbalance energy. Due to the fact that the real consumption is actually calculated afterwards this use case can show only a theoretical value of the technical capability a ELSA system could contribute to minimize the imbalance energy which needs to be bought. The data used for balance group optimization in the reference scenario consist of real historical data from the balance group operator and consists of 15 minute imbalance energy values for the year 2016. The KPI therefore shows the amount of needed imbalance energy over a defined period of time. $$E_{imbalance_{REF}} = \sum_{t=1}^{t_{end}} E_{imbalance_{REF\,t}} \quad [kWh]$$ The needed imbalance energy in the reference scenario is therefore defined as 100%. $$E_{imbalance_{REF}\%} = 100\%$$ **Use case: Participation to the energy trade market** In the reference scenario the BoEU does not have the possibility to participate to the energy trade (stock) market, due to the fact that the production and consumption in each 1/4h is too small to buy or sell the minimum value at the stock market. Therefore the electricity has to be used from one of the following sources Energy, BoEU bought from the energy supplier via the public grid $$E_{grid_{REF}} = \sum_{t=1}^{t_{end}} E_{grid_{REF\,t}}$$ Energy produced and directly used in the BoEU $$E_{\text{self-consumption\_Ref}} = E_{\text{production\_Ref}} - E_{\text{feedin\_Ref}}$$ Furthermore the following energies are needed later to calculate the cost KPI for this use case.

	Energy produced by the BoEU and feed into the public grid $$E_{\text{feedin\_Ref}} = \sum_{t=1}^{t_{end}} E_{production_{REF\ t}}$$ Energy produced by the BoEU $$E_{\text{production\_Ref}} = \sum_{t=1}^{t_{end}} E_{production_{REF\ t}}$$

SASMI Building			
Source of Baseline condition	**Literature values**	**Company historical values**	**Values measured at start of project**
			√
Details of Baseline	*See Details of Baseline in **Power KPI** section.*		

3.7.3 Costs

BASIC KPI INFORMATION						
KPI Name	Costs			**KPI ID**	WP1_KPI_3	
Strategic objective	Reduction of energy costs by optimizing energy consumption and energy generation over a specific period of time.					
DEMO where KPI applies	**City of Terni**	**Ampere Building**	**Nissan Office**	**RWTH Aachen**	**City of Kempten**	**SASMI Building**
	√	√	√	√	√	√
KPI description	This indicator evaluates the increase/decrease in cost C for all stakeholders participating in the process (including both generation and demand) whenever it is necessary.					
KPI formula	$\Delta C = C_{Ref} - C_{ELSA}$[unit: €] $$\Delta C_{\%} = \frac{C_{Ref} - C_{ELSA}}{C_{Ref}} \cdot 100\%$$ [unit: %]					
Unit of measurement	% of reference cost					
Reporting period	At the end of each use case demonstration					
Relevant standards	None					
Connection / link with other relevant defined KPIs						

KPI CALCULATION METHODOLOGY		
City of Terni		
KPI step methodology ID	**Step**	**Responsible**
KPI Cost description	Participating to the primary reserve required to respond to frequency signal in order inject or absorb active power. This mechanism is sold to the TSO.	ASM

	$$C_{\text{ELSA PR}} = \sum_{i=1}^{n} (P_{\text{ELSA\_PR,i}} \times C_{PR,i})$$ n: the period of times e.g. 52 weeks (for the weeks where the PR pool does not win the tender $P_{\text{ELSA\_PR i}} = 0$) C_{PR}: the price for the prequalified primary reserve power offered by the PR pool operator	
Ampere Building		
KPI step methodology ID	**Step**	**Responsible**
KPI Cost description	For the Ampère building, a flat rate of 0.112542 €/kWh for the electricity cost is also specified in the contract with the utility company. For the use case of energy purchase time shifting, a variable rate based on time of use will be considered.	UTRCI
Utility cost assessment	$$\Delta C = rate * \left(E_{consref}(t) - E_{cons}(t)\right) Cost(t) = rate * E_{cons}(t)$$	UTRCI
KPI Cost calculation	$$\Delta C_{\%} = \frac{rate * \left(E_{consref}(t) - E_{cons}(t)\right)}{rate * E_{consref}(t)}$$	UTRCI
Nissan Office		
KPI step methodology ID	**Step**	**Responsible**
KPI Cost description	The utility cost of Nissan site is calculated based on the energy bought from the grid by the building. We don't have information on the electricity prices, they will have 5 periods of price (winter peak hour, winter off peak hour, critical peak hour, summer peak hours and off-peak hours). Therefore, in summer, there will be a night price and a day price.	Nissan
Utility cost assessment	$$Cost(t) = price(t) * E_{cons}(t)$$	Nissan
KPI Cost calculation	$$\Delta C = price(t) * \left(E_{consref}(t) - E_{cons}(t)\right)$$	Nissan

	$$\Delta C_{\%} = \frac{price(t) * \left(E_{consref}(t) - E_{cons}(t)\right)}{price(t) * E_{consref}(t)}$$	
Specific KPI peak shaving benefit	The benefit from peak shaving are directly calculated using the penalties paid if the peak demand excess the peak subscription. The power demand never excess the power subscription, we cannot ask Nissan to rene-gociate the electricity contract. Therefore, we will put P_{limit} as a parameter to be decided which will simu-late Power subscription to ensure that we will have peak shaving activity in the site. As it is connected in HV, Nissan is charge for each kWh that exceed the sub-scription with a deterrent price.	Nissan
Peak shaving benefit as-sessment	$$Penalties(t) = price_{deterrent} * E_{excess}(t)$$ $$\Delta Penalties = price_{deterrent} * \left(E_{\text{excess ref}}(t) - E_{excess}(t)\right)$$ $$\Delta Penalties_{\%} = \frac{price_{deterrent} * \left(E_{\text{excess ref}}(t) - E_{excess}(t)\right)}{price_{deterrent} * E_{\text{excess ref}}(t)}$$	Nissan
KPI peak shav-ing benefit Calculation	The energy excess will not be measured directly, we calculate this value through the measurement of power demand : $$E_{excess}(t) = max\left(0, \int_{t_o}^{t_{end}} P_{grid} - P_{subcription}\right)$$ $$E_{excess}(t) = max\left(0, \Delta t * \sum_{i}^{n} P_{grid,i} - P_{subcription,i}\right)$$ Note : P_{grid} is the power demand of the building from the grid point of view (measured by the grid meter, it is the Power that will be recorded for the electricity bill)	Nissan
RWTH Aachen		

KPI step methodology ID	Step	Responsible
KPI description Cost	The electricity cost is calculated over time. Measured in €. The difference in electricity cost after and before deployment of the ELSA scheduling is determined in relation to costs before ELSA. Measured in %.	RWTH Aachen
Electricity cost after deployment of the ELSA scheduling and in reference scenario	$Cost_{ELSA_{el}} = \sum_{t=1}^{t_{end}} (P_{ELSA_{el,t}} \cdot \Delta t \cdot Tariff_{el,t})$ $Cost_{Ref_{el}} = \sum_{t=1}^{t_{end}} (P_{Ref_{el,t}} \cdot \Delta t \cdot Tariff_{el,t})$	RWTH Aachen
Difference in cost	$\Delta Cost_{ELSA_{el}} = Cost_{ELSA_{el}} - Cost_{Ref_{el}}$ $\Delta Cost_{ELSA_{el}\%} = \frac{\Delta Cost_{ELSA_{el}}}{Cost_{Ref_{el}}} \cdot 100\%$	RWTH Aachen
City of Kempten		
KPI step methodology ID	**Step**	**Responsible**
Contribution margin due to auto consumption maximization	$\Delta C_{AutoC} = \Delta E_{AutoC} \times \eta_{\text{ELSA system}} \times C_{advantage}$ ΔE_{AutoC} as calculated in KPI Energy $\eta_{\text{ELSA System}}$ over all efficiency of charging and discharging $C_{advantage}$ Cost advantage by using stored PV power (price for regular energy - cost for PV produced energy)	AÜW / egrid
Contribution margin/ cost reduction due to participation at primary reserve marked	$C_{\text{ELSA PR}} = \sum_{i=1}^{n} (P_{\text{ELSA\_PR,i}} \times C_{PR,i})$ n: the period of times e.g. 52 weeks (for the weeks where the PR pool does not win the tender $P_{\text{ELSA\_PR i}} = 0$) C_{PR}: the price for the prequalified primary reserve power offered by the PR pool operator	egrid

	$$\Delta C_{PR} = \lvert C_{\text{Ref PR}} - C_{\text{ELSA PR}} \rvert \qquad [unit: €]$$ $C_{ELSA,PR}$: contribution margin generated by participating at the primary reserve marked $C_{Ref,PR}$: profit made with primary reserve without the ELSA system ($C_{Ref,PR}$ = 0 because no participation at the market)	
Contribution margin/ cost reduction due to reactive power compensation	$$C_{\text{ELSA Q}} = \Delta E_Q \times C_{kvarh}$$ ΔE_Q as calculated in KPI Energy [kvarh] C_{kvarh} as provided by the DSO [€/kvarh] $$\Delta C_Q = \lvert C_{\text{Ref Q}} - C_{\text{ELSA Q}} \rvert \qquad [unit: €]$$ $C_{ELSA\ Q}$: contribution margin generated by compensating the otherwise billed amount of reactive power $C_{Ref\ Q}$: Cost reduction without the ELSA system ($C_{Ref\ Q}$ = 0 because no compensation)	egrid
Contribution margin/ cost reduction due to balance group optimization	$$C_{\text{ELSA\_imbalance}} = \sum_{i=1}^{n} \left(\Delta E_{imbalance,i} \times C_{imbalance,i}\right)$$ n: the period of times e.g. 262800 (1/4 for 1 year) $C_{imbalance}$: the price for the imbalance energy for each corresponding 15 min block [€]	AUEW
Contribution margin/ cost reduction due to participation to the energy trade market	$$\Delta C_{participation} = C_{\text{Ref\_participation}} - C_{\text{ELSA\_participation}} \quad [€]$$ $$C_{ELSA_{participation}} = \sum_{i=1}^{n} \left(E_{grid,i}\right) * C_{grid} + \sum_{i=1}^{n} \left(E_{\text{self-consumption,i}}\right) * C_{self-consumption} + \sum_{i=1}^{n} \left(E_{stock_{buy,i}} * C_{stock_{buy,i}}\right) + \sum_{i=1}^{n} \left(E_{stock_{sell,i}} * C_{stock_{sell,i}}\right)$$	AUEW

	n: the period of times e.g. 262800 (1/4 for 1 year) C_{grid}: constant price for the energy purchased via public grid [€/kWh] $C_{self\text{-}consumption}$: the constant incremental costs for producing the energy in the BoEU with the PV system [€/kWh] C_{stock_buy}: the costs for buying energy at the stock market for each corresponding 15min period [€/kWh] C_{stock_sell}: the refund for selling energy to the stock market for each corresponding 15min period [€/kWh]	
SASMI Building		
KPI step methodology ID	**Step**	**Responsible**
KPI Cost description	The utility cost of SASMI site is calculated based on the energy bought from the grid by the building. The contract with the utility specifies a flat energy rate of 0.08552 £/kWh (about 0.09747 €/kWh). This flat rate goes against the concept of energy purchase time shifting. For the use case of energy purchase time shifting, a variable rate based on time of use will be considered.	UTRCI
Utility cost assessment	See KPI in **Ampere Building** site.	UTRCI
KPI Cost calculation	See KPI in **Ampere Building** site.	UTRCI

KPI DATA COLLECTION							
City of Terni							
Data	**Data ID**	**Methodology for data collection**	**Source/tools/instruments for data collection**	**Location of data collection**	**Frequency of data collection**	**Minimum monitoring period**	**Responsible**

Frequency of the grid	F_grid	Measurement	Sensor	Site	5 sec		ASM
Power absorbed by the storage	P_abs	Measurement	Sensor	Site	5 sec		ASM
Power injected by the storage	P_inj	Measurement	Sensor	Site	5 sec		ASM
Ampere Building							
Data	**Data ID**	**Methodology for data collection**	**Source/tools/instruments for data collection**	**Location of data collection**	**Frequency of data collection**	**Minimum monitoring period**	**Responsible**
Energy consumed by the building	E_cons	Measurement	Sensor	Building site	5 min		UTRCI
Energy generated by the PV	E_gen_PV	Measurement	Sensor	Building site	5 min		UTRCI
Energy charged in the B4B	E_ch_B4B	Measurement	Sensor	Building site	5 min		UTRCI
Energy discharged from the B4B	E_dis_B4B	Measurement	Sensor	Building site	5 min		UTRCI
Electricity tariff	rate	Simulation / Virtual			5 min		UTRCI
Nissan Office							
Data	**Data ID**	**Methodology for data collection**	**Source/tools/instruments for data collection**	**Location of data collection**	**Frequency of data collection**	**Minimum monitoring period**	**Responsible**

Energy consumed by the building	E_cons	Measurement	Sensor	Building site	5 min		Nissan
Energy charged in the B4B	E_ch_B4B	Measurement	Sensor	Building site	5 min		Nissan
Energy discharged from the B4B	E_dis_B4B	Measurement	Sensor	Building site	5 min		Nissan
Electricity tariff	price	Provided (electricity bill)					Nissan
Electricity tariff penalties	penalties	Provided (electricity bill)					Nissan
Power excess	P_excess	Measurement	Sensor	Building site	5 min		Nissan
RWTH Aachen							
Data	**Data ID**	**Methodology for data collection**	**Source/tools/instruments for data collection**	**Location of data collection**	**Frequency of data collection**	**Minimum monitoring period**	**Responsible**
System Load	P_system	Measurement	Measurement equipment	Substation	15 min		RWTH Aachen
RES power in the system	P_RES	Simulation	Data sheet of system		15 min		RWTH Aachen
Battery storage power	P_storage	Measurement	Measurement equipment	Storage system	15 min		RWTH Aachen
Flexible devices power	P_flexDevice	Measurement	Measurement equipment	Device	15 min		RWTH Aachen
Current electricity tariff	Tariff	Simulation/Virtual			15 min		RWTH Aachen
City of Kempten							

Data	Data ID	Methodology for data collection	Source/tools/instruments for data collection	Location of data collection	Frequency of data collection	Minimum monitoring period	Responsible
Over all Efficiency	η	Data sheet	Data sheet				Bouygues
Cost advantage by using PV power	C_advantage	Calculation	Calculation				AÜW / egrid
Primary Reserve Refund	C_PR	Historical data	Historical data of primary reserve auctions	Regelleistung.net	Weekly		egrid
Reactive power	E_Q Site 15min	Measurement	Measurement equipment of DSO	Site	15 min		AÜW
Price for imbalance energy	Cimbalance	Historical data	Historical date from balance group operator	TSO	15min		AÜW
Price for energy purchase via grid	Cgrid	Historical data	Actual energy tariffs from AÜW	AÜW	constant value		AÜW
Price for energy from PV system	Cself-consumption	Historical value	Inremental costs energy from PV system	AÜW	constant value		AÜW
Feed in tariff for energy from PV system	Cfeedin	Literature value	German law EEG 2017		constant value		AÜW
Price for energy at stock market	Cstock_buy & Cstock_sell	Literature value	Energy purchase department AÜW	epex-spot.com/	15min		AÜW
SASMI Building							
Data	**Data ID**	**Methodology for data collection**	**Source/tools/instruments for data collection**	**Location of data collection**	**Frequency of data collection**	**Minimum monitoring period**	**Responsible**
See KPI Data Collection in **Ampere Building** site.							

<table>
<tr><th colspan="4">KPI BASELINE</th></tr>
<tr><th colspan="4">City of Terni</th></tr>
<tr><td rowspan="2">Source of Baseline condition</td><td>Literature values</td><td>Company historical values</td><td>Values measured at start of project</td></tr>
<tr><td></td><td></td><td>√</td></tr>
<tr><td>Details of Baseline</td><td colspan="3">Since there is no primary reserve mechanism before the ELSA project. The reference value of the remunerative value is zero.
In this particular case we will consider:
$$\Delta C_{PR} = C_{ELSA,PR}[\text{unit:€}]$$
$C_{ELSA,PR}$: contribution margin generated by participating at the primary reserve marked</td></tr>
<tr><th colspan="4">Ampere Building</th></tr>
<tr><td rowspan="2">Source of Baseline condition</td><td>Literature values</td><td>Company historical values</td><td>Values measured at start of project</td></tr>
<tr><td></td><td></td><td>√</td></tr>
<tr><td>Details of Baseline</td><td colspan="3">See Details of Baseline in Power KPI section.</td></tr>
<tr><th colspan="4">Nissan Office</th></tr>
<tr><td rowspan="2">Source of Baseline condition</td><td>Literature values</td><td>Company historical values</td><td>Values measured at start of project</td></tr>
<tr><td></td><td></td><td>√</td></tr>
<tr><td>Details of Baseline</td><td colspan="3">The energy consumed by the building in the reference case ($E_{consref}$) without any B4B system installed can always be calculated using the measured energy stored in the batteries.
The following balance equation in the power (see deliverable 3.2 for more details) applies at each time step:
$$P_{grid}(t) = P_{demand}(t) + P_{storage}(t) \quad [1]$$
Where $P_{demand}(t)$ is the power demand of the building, $P_{grid}(t)$ is the power imported from/exported to the grid, and $P_{storage}(t)$ is the power associated to energy storage (Convention : $P_{storage}(t) > 0$when the battery is charging and $P_{storage}(t) < 0$ when the battery is discharging).
The reference power profile corresponds to the power demand of the building stated in equation [1]. The reference energy can then be estimated as follows:
$$E_{ref}(t) = [P_{demand}(t)].\Delta t$$
$$E_{ref}(t) = \left[P_{grid}(t) - P_{storage}(t)\right].\Delta t \quad [2]$$</td></tr>
</table>

	The same goes for the energy excess in the reference case ($E_{excessref}$) $E_{excess,ref}(t) = max\left(0, \Delta t * \sum_{i}^{n} P_{demand,i} - P_{subcription,i}\right)$ $E_{excess,ref}(t) = max\left(0, \Delta t * \sum_{i}^{n} P_{grid,i} - P_{storage,i} - P_{subcription,i}\right)$		
RWTH Aachen			
Source of Baseline condition	**Literature values**	**Company historical values**	**Values measured at start of project**
			√
Details of Baseline	*See Details of Baseline in* ***Power KPI*** *section.*		
City of Kempten			
Source of Baseline condition	**Literature values**	**Company historical values**	**Values measured at start of project**
	√	√	√
Details of Baseline	**<u>Auto Consumption</u>** The reference scenario without the ELSA battery system has no option to store PV energy. The reference is described in the KPI E_{AutoC}. **<u>Participation at the primary reserve market</u>** The reference scenario without an ELSA battery system shows no contribution margin from the primary reserve. There is no other opportunity in the district participating at the primary reserve market therefore the $C_{Ref\ PR}$ = 0. **<u>Reactive power compensation</u>** The reference scenario is the load profile of a company or industrial site without any reactive power compensation. Furthermore the monthly invoice of the DSO for the reactive power is used. Without the ELSA system there is no compensation of the reactive power and therefore no reduction of the costs for reactive power. The reference scenario $C_{Ref\ Q}$ = 0. **Balance group optimization** See Baseline in Energy KPI section **Participation to the energy trade market** Cost the BoEU would have to cover its electrical energy by buying from energy supplier via public grid and producing energy in the BoEU.		

	$$C_{\text{Ref\_participation}} = \sum_{i=1}^{n} (E_{grid,i}) * C_{grid} + \sum_{i=1}^{n} (E_{\text{self-consumption,i}}) * C_{\text{self-consumption}}$$ n: the period of times e.g. 262800 (1/4 for 1 year) C_{grid}: constant price for the energy purchased via public grid [€/kWh] $C_{\text{self-consumption}}$: the constant incremental costs for producing the energy in the BoEU with the PV system [€/kWh]

SASMI Building			
Source of Baseline condition	**Literature values**	**Company historical values**	**Values measured at start of project**
			√
Details of Baseline	*See Details of Baseline in **Power KPI** section.*		

3.7.4 CO2 emissions

BASIC KPI INFORMATION						
KPI Name	CO2 emissions			**KPI ID**	WP2_KPI_4	
Strategic objective	Reduction of CO_2 emissions by optimizing energy consumption and energy generation over a specific period of time.					
DEMO where KPI applies	**City of Terni**	**Ampere Building**	**Nissan Office**	**RWTH Aachen**	**City of Kempten**	**SASMI Building**
		√		√		√
KPI description	This indicator evaluates the amount of CO_2 emission in kg. Typically, CO_2 is reduced due to improved RES utilization resulting from implementation of the ELSA optimization.					
KPI formula	$\Delta CO_2 = CO_{2_{Ref}} - CO_{2_{ELSA}}$[unit: kg] $\Delta CO_{2_{\%}} = \frac{CO_{2_{Ref}} - CO_{2_{ELSA}}}{CO_{2_{Ref}}} \cdot 100\%$[unit: %]					
Unit of measurement	% of reference CO_2 emission					
Reporting period	At the end of each use case demonstration					
Relevant standards	None					
Connection / link with other relevant defined KPIs						

KPI CALCULATION METHODOLOGY		
Ampere Building		
KPI step methodology ID	**Step**	**Responsible**
KPI CO2 description	For the CO2 emission, a conversion factor of 68 g of CO2 / kWh is considered for the generation of electricity in France. The conversion factor is a median value estimated from the CO2 emissions over the year 2017 extracted from the website (RTE France, 2017).	UTRCI
CO2 emission assessment	$CO2e(t) = Conv._{factor} * E_{cons}(t)$	UTRCI

KPI CO2 calculation	$\Delta CO2 = Conv._{factor} * \left(E_{consref}(t) - E_{cons}(t)\right)$ $\Delta CO2_{\%} = \frac{Conv._{factor} * \left(E_{consref}(t) - E_{cons}(t)\right)}{Conv._{factor} * E_{consref}(t)}$	UTRCI
RWTH Aachen		
KPI step methodology ID	**Step**	**Responsible**
KPI description CO_2 emissions	The CO_2 emissions due to the power consumption are calculated over the optimization time horizon and are measured in g. The difference in CO_2 emissions after and before the deployment of the ELSA scheduling is determined in relation to CO_2 emissions without any ELSA energy management and measured in %. The adapted power demand per time step is measured and weighted with the amount of CO_2 emitted per kW on the power grid system level in that specific time step. This value of CO_2 emitted per kW is calculated based on the current electricity generation mix [1] and the CO_2 emissions associated to each of the generation sources [2]. Sources: [1] *ENTSO-E Transparency Platform.* [Online] Available: https://transparency.entsoe.eu/. [2] H.-J. Wagner *et al.,* “CO2-Emissionen der Stromerzeugung: Ein ganzheitlicher Vergleich verschiedener Techniken,” in *BWK 59 (2007) Nr. 10*	RWTH Aachen
CO_2 emissions after deployment of the ELSA scheduling and in reference scenario	$CO_{2\,ELSA_{el}} = \sum_{t=1}^{t_{end}} \left(P_{ELSA_{el,t}} \cdot \Delta t \cdot CO_2Emission_{el,t}\right)$ $CO_{2\,Ref_{el}} = \sum_{t=1}^{t_{end}} \left(P_{Ref_{el,t}} \cdot \Delta t \cdot CO_2Emission_{el,t}\right)$	RWTH Aachen
Difference in CO_2 emissions	$\Delta CO_{2\,\mathrm{ELSA}_{el}} = CO_{2\,\mathrm{ELSA}_{el}} - CO_{2\,\mathrm{Ref}_{el}}$	RWTH Aachen

	$$\Delta CO_{2\ \mathrm{ELSA}_{el,\%}} = \frac{\Delta CO_{2\ \mathrm{ELSA}_{el}}}{\Delta CO_{2\ \mathrm{Ref}_{el}}} \cdot 100\%$$	
SASMI Building		
KPI step methodology ID	**Step**	**Responsible**
KPI CO2 description	The CO2 emission related to the energy use in SASMI building is estimated using a conversion factor. The department for business, energy and industrial strategy from the government of the United Kingdom issued in August 2017 a report on GHG conversion factors. The equivalent amount of CO2 emitted corresponding to the electricity consumed in UK is of 0.38146 kg CO2/kWh, including the grid losses for transmission and distribution. More information can be found (Department for Business Energy & Industrial Strategy, 2017).	UTRCI
CO2 emission assessment	See KPI in **Ampere Building** site.	UTRCI
KPI CO2 calculation	See KPI in **Ampere Building** site.	UTRCI

KPI DATA COLLECTION							
Ampere Building							
Data	**Data ID**	**Methodology for data collection**	**Source/tools/instruments for data collection**	**Location of data collection**	**Frequency of data collection**	**Minimum monitoring period**	**Responsible**
Energy consumed by the building	E_cons	Measurement	Sensor	Building site	5 min		UTRCI
Energy generated by the PV	E_gen_PV	Measurement	Sensor	Building site	5 min		UTRCI
Energy charged	E_ch_B4B	Measurement	Sensor	Building site	5 min		UTRCI

in the B4B							
Energy dis-charged from the B4B	E_dis_B4B	Measure-ment	Sensor	Building site	5 min		UTRCI
Conver-sion fac-tor CO2/E	CO2e	Survey	RTE electricity transportation				UTRCI
RWTH Aachen							
Data	**Data ID**	**Methodol-ogy for data collection**	**Source/tools/in-struments for data collection**	**Location of data collec-tion**	**Fre-quency of data col-lection**	**Mini-mum monitor-ing pe-riod**	**Respon-sible**
System Load	P_system	Measure-ment	Measurement equipment	Substa-tion	15 min		RWTH Aachen
RES power in the sys-tem	P_RES	Simulation	Data sheet of system		15 min		RWTH Aachen
Battery storage power	P_storage	Measure-ment	Measurement equipment	Storage system	15 min		RWTH Aachen
Flexible devices power	P_flexDevice	Measure-ment	Measurement equipment	Device	15 min		RWTH Aachen
Current CO2 emission in power grid	CO2_grid		ENTSO-E Trans-parency Plat-form		15 min		RWTH Aachen
SASMI Building							
Data	**Data ID**	**Methodol-ogy for data collection**	**Source/tools/in-struments for data collection**	**Location of data collec-tion**	**Fre-quency of data col-lection**	**Mini-mum monitor-ing pe-riod**	**Respon-sible**
Energy con-sumed by the build-ing	E_cons	Measure-ment	Sensor	Building site	5 min		UTRCI

Energy generated by the PV	E_gen_PV	Measurement	Sensor	Building site	5 min		UTRCI
Energy charged in the B4B	E_ch_B4B	Measurement	Sensor	Building site	5 min		UTRCI
Energy discharged from the B4B	E_dis_B4B	Measurement	Sensor	Building site	5 min		UTRCI
Conversion factor CO2/E	CO2e	Survey	Government of UK				UTRCI

KPI BASELINE			
Ampere Building			
Source of Baseline condition	**Literature values**	**Company historical values**	**Values measured at start of project**
			√
Details of Baseline	*See Details of Baseline in **Power KPI** section.*		
RWTH Aachen			
Source of Baseline condition	**Literature values**	**Company historical values**	**Values measured at start of project**
			√
Details of Baseline	*See Details of Baseline in **Power KPI** section.*		
SASMI Building			
Source of Baseline condition	**Literature values**	**Company historical values**	**Values measured at start of project**
			√
Details of Baseline	*See Details of Baseline in **Power KPI** section.*		