BATTERY2LIFE

D1.1 Demo sites requirements and specifications

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Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs
Education and Research EAER
State Secretariat for Education,
Research and Innovation SERI

Work Package	
Task	1.1
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Dissemination Level	Public
Status	Final
Due Date	31/03/2024
Document Date	29/03/2024
Version	1.0

QUALITY CONTROL

	Name	Organisation	Date
Editor	P. Papadimitriou	PPC	26/03/2024
Reviewer 1	D. Spanoudaki	SLG	28/03/2024
Reviewer 2			
Authorised by Quality Manager	E. Karfopoulos	ICCS	28/03/2024
Authorised by Project Coordinator	A. Amditis	ICCS	29/03/2024

DOCUMENT HISTORY

Version	Date	Beneficiary	Description
V0.1	06/02/2024	A. Anastasiadis (PPC) E. Karfopoulos(ICCS)	Table of Content
V0.2	16/02/2024	R. Stachl	Chang of Chapter 3
	19/02/2024	D. Spanoudaki, A. Anastasiadis, E. karfopoulos	Business use case (pillar 1), market opportunities
	26/02/2024	P. Papadimitriou ,E. Karfopoulos	Consolidation of all the contributions for pillar 1 & 2
V0.3	04/03/2024	P. Papadimitriou ,E. Karfopoulos	Consolidation of all the contributions for pillar 1 & 2 and KPIs
V0.4	18/03/2024	P. Papadimitriou ,E. Karfopoulos	Consolidation of all the contributions for pillar 1 & 2 and KPIs
V0.5	25/03/2024	P. Papadimitriou ,E. Karfopoulos	Consolidation of all the contributions for pillar 1 & 2 and KPIs
V0.6	26/03/2024	P. Papadimitriou	Final draft for peer-review
V1.0	29/03/2024	A. Amditis	Final versions. Ready to be submitted to EC

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LIST OF ABBREVIATIONS AND ACRONYMS

Abbreviation	Meaning
BESS	Battery Energy Storage System
BMS	Battery Management System
BTM	Behind The Meter
B2L	Battery2Life
CPO	Charging Point Operator
CrC	Cyclic redundancy Check
DRT	Distribution of Relaxation Time
EMC	Electromagnetic Compatibility
EMS	Energy Management System
eMSP	e-Mobility Service Provider
EoL	End of Life
EV	Electric Vehicle
FL-EOL	First-Life End-Of-Life
FTM	Front-of-the-meter
HW	Hardware
IoT	Internet of Things
KPI	Key Performance Indicator
KW	Kilo Watts
KWp	Kilo Watts peak
MCU	Micro Controller Unit
MMS	Module Management System
OEM	Original Equipment Manufacturer
PCB	Printed Circuit Board
PV	Photo Voltaic
RES	Renewable Energy Sources
RF	Radio Frequency
SLA	Service-Level Agreement
SoC	State of Charge
SoF	State of Functions

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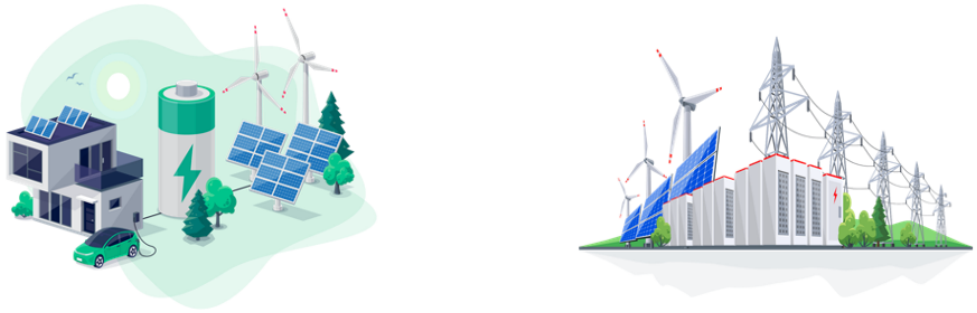
SoH	State of Health
SoS	State of Safety
SoT	State of Temperature
SoW	State of Warranty
SoX	State of Battery
SW	Software
TRA	Thermal Runaway

EXECUTIVE SUMMARY

The scope of this document is to analyse the system requirements of the two demo sites defined under the BATTERY2LIFE project for the application and implementation of a new Battery Management System (BMS) to enable 2nd life applications for retired 1st life batteries under two business contexts: a) industrial load levelling application and b) home storage application.



(a) Domestic storage (b) Industrial load levelling

Figure X.1: Battery2Life 2nd life battery storage applications

The two business applications are presented in Section 2 outlining the challenges and needs for the deployment of 2nd life batteries under different business contexts. The rationality and business opportunity behind the two applications are explained below:

- *Industrial load levelling:*

  The scope of this business use case is to assess the exploitation of the 2nd life of the battery for stationary storage for grid-scale application towards enabling a more efficient integration of electric vehicles into the electricity grids. More specifically, this case is a very appealing path to ensure the efficient integration of fast-charging infrastructure in the weak electricity grids of islands. One existing Greek initiative called “Gr-ECO islands” aims to transform Greek islands into models of green economy, energy autonomy, digital innovation, and ecological mobility and a possible synergy or use case could be applied in collaboration with the initiative. Since electricity grids in islands are characterised by limited power and generation capacity, the sustainability of such investments and the reliability of the charging network operation requires the deployment of grid-impact mitigation actions. The synergetic operation of charging infrastructures (especially for ultra-fast ones) with Renewable Energy

Sources (RES) and stationary battery systems is key factor for the sustainable electrification of transport on islands.

- *Domestic Storage*

According to SolarPower Europe,[1] a growth of the residential battery storage systems up to 32.2 GWh by the end of 2026 is expected for Europe. As a baseline, 2.3 GWh residential battery systems were installed in 2021. Therefore, a growth of 107% can be expected compared to the baseline and within only 5 years. Through this growth, a total capacity of 5.4 GWh could be reached, which equals over 650,000 operating batteries.

Also in 2021, the highest number of battery storage systems within Europe were installed in Germany, Italy, Great Britain, Austria, and Switzerland. Whereas Germany is the largest and most important market. According to the German Federal Network Agency, about 79 % of the newly installed Photo Voltaic (PV) plants were combined with a battery storage system. In the year 2023 more than 530,000 battery systems smaller than 20 kWh were installed in Germany, which is an increase by 153 % compared to the year before.

The high electricity pricing and low feed-in renumeration has led to the fact, that self-consumption gets more important for the amortisation of modern PV systems. For this reason, the number of battery storage systems in use will continue rising, especially in Europe.

In the final part of the document, the partners defined the technical Key Performance Indicators (KPIs) of the project, which will enable the assessment of the project solutions after the demonstration activities.

[1] https://www.solarpowereurope.org/

1 INTRODUCTION

1.1 Project Introduction

BATTERY2LIFE is a project, funded by Horizon Europe programme (co-funded by Swiss Federation) that will facilitate the smooth transition of batteries to 2nd life use and will boost the innovation of the European Battery Industry by providing enablers to implement open adaptable smart Battery Management Systems (BMS), improved system designs and proposing methods for the efficient and reliable reconfiguration of used batteries.

Battery2Life introduces two new battery system design frameworks serving the upcoming market needs: the first supports the business transition for the initial market by restructuring existing battery design patterns while the second one introduces completely new design principles for 1st and 2nd life of future batteries. Furthermore, Battery2Life introduces innovative embedded sensing and more accurate SOX (State of Battery) estimation algorithms, which are also required for 2nd life use (i.e. SOS (State of Safety) and SOW (State of Warranty)). A new Electrochemical Impedance Spectroscopy (EIS) implementation approach is integrated into the BMS, that will enable the detailed safety and reliability monitoring at both cell and module level during 1st and 2nd life stage usage. The project specifies an open BMS concept, data formats, considerations, extends the battery passport concept, and implements interoperable communication via the cloud platform to third parties including the future passport exchange system, to facilitate monitoring and assessment.

Two demonstrations that represent two promising and sustainable business cases, serving the two most common stationary applications have been carefully selected: i) the domestic and ii) industrial (grid-scale) storage, with respect to their operational specificities and requirements.

1.2 Purpose of the deliverable

This deliverable aims to serve two objectives:

- Definition of the description and requirements of the two business use cases: i) industrial load levelling application and ii) home storage application.
- Definition of the technical KPIs that will be used at the end of the project to validate the demonstration activities in WP8 and the technological performance and success for the solutions and use cases.

1.3 Intended audience.

Deliverable D1.1 is a public document aiming to provide the system requirements for the realization of the industrial and domestic 2nd life battery storage systems.

1.4 Structure of the deliverable/correlation with other WPs

The deliverable comprises four sections:

- **Business Use Cases:** it provides and overview over the market opportunities and challenges for the of 2nd life battery storage applications in terms of business development and market uptake.
- **System Requirements:** Defines the methodology for the system requirement analysis as well as the list of the requirements for the 2 business use cases defined in the previous chapter.
- **Definition of the evaluation framework:** Describes the technical KPIs which will be considered for the assessment of the project solutions and their performance compared to their baseline.

2 BUSINESS USE CASES

2.1 Market Analysis & Business opportunities

Increased environmental concerns in the EU dictate its climate strategy which is reflected in the European Climate Law[2] (June 2021), establishing the aim of reaching net zero Greenhouse Gas Emissions (GHG) in the EU by 2050. In addition, the climate law sets an intermediate target of reducing GHG by at least 55% by 2030 compared to 1990 levels. In this respect, it is necessary to focus on the decarbonisation of the energy sector, which is the major pollutant factor. The "Fit for 55" package[3], which is a set of policy proposals by the European Commission to achieve this 55% reduction target, proposes an increase of the target for renewable energy production to 40% by 2030 to support the reduction target of GHG set by the law.

The decentralisation of the energy sector requires the distribution of the generation at all electricity grid levels. This means moving production and distribution closer to the final consumption and adopting environmentally friendly generation solutions (RES). However, the intermittent production of the RES, caused by the probabilistic variations of the wind speed and solar radiation, introduce high stochasticity and challenges in the reliable operation and management of the whole electricity grid. High-RES shares in the production mix will imply larger imbalances from the supply-demand equilibrium. Maintaining the balance between supply and demand is a challenging task and the need for alternatives to deal with renewables in the energy system emerge in the short/mid-term horizon. This implies that sufficient backup capacity must be available to restore the balance in a fast and cost-efficient way. Moreover, it is expected that new RES will be distributed in different levels of the electricity grids and they will be built in different locations compared to where traditional power plants exist now. This will modify the power flows in the electricity grids and will affect the way networks are planned, managed and operated. In this respect, costly changes to the layout of the grid might be requested to accommodate peak power flows.

The energy transition dictates the integration of energy storage capacities across the entire energy value chain to balance and mitigate more efficiently the intermittent RES production.

The energy transition dictates the integration of energy storage capacities across the entire energy value chain to balance and mitigate more efficiently the intermittent RES production under high RES deployment levels more efficiently. According an economic analysis conducted by

[2] https://climate.ec.europa.eu/eu-action/european-climate-law_en#:~:text=The%20European%20Climate%20Law%20writes,2030%2C%20compared%20to%201990%20levels.
[3] https://ec.europa.eu/commission/presscorner/detail/en/IP_23_4754

McKinsey[4] , the Battery Energy Storage Industry is expected to reach USD 120 - 150 billion by 2030 from USD 44-55 billion in 2023, at a compound annual growth rate (CAGR) of 55 % during the 2023-2028 period. Based on this analysis and estimation the 2023market size will be split as: USD 86 billion for utility, USD 10 billion for commercial and industrial and USD 4 billion for residential applications.

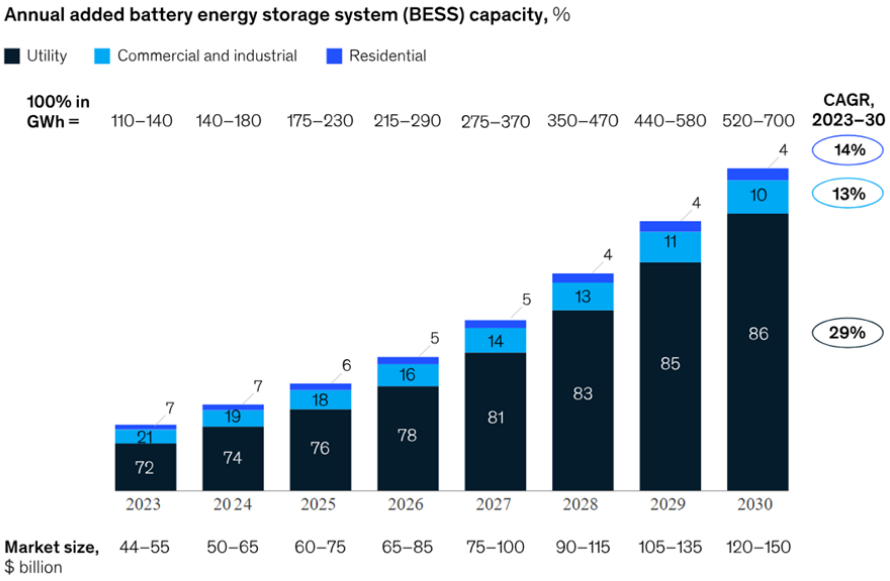


Figure 1 - Annual added battery energy storage system (BESS) capacity. Source McKinsey.[4]

The storage needs differ depending on the required time frame and the grid level that the storage capacity serves. In order to exploit these different needs, new business opportunities can be promoted for diverse energy stakeholders (Figure 1)[5]. At the electricity generation level, power storage can support the generation adequacy and contribute to a more cost-efficient production. To enable black starts after the recovery from (partial) grid blackouts, Combined Heat and Power (CHP) optimisation and absorption of RES spillage are the most common business application for the storage capacities at the highest level of the electricity grid. Such storage needs have time frames ranging from quarter to an hour up to a week at most. At network level, system operators have short duration storage needs. Operating the grid and maintaining balance between

Different time-frames and storage capacities levels are needed promoting different business needs and business opportunities

[4] https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/enabling-renewable-energy-with-battery-energy-storage-systems

[5] Roland Berger Focus "*Business models in energy storage*"

intermittency may lead to frequency deviations and voltage excursions. On a slightly longer time frame, load following is also becoming more important, where sudden changes in energy output from renewables cannot be matched as quickly by scaling up or down conventional generation output. For system operators, the increase in decentralized energy generation attached to the local distribution grid may cause the power flows to go in different directions than initially foreseen with the outlay of the grid. Energy storage may prevent or defer some refurbishment and network reinforcement investments. On wholesale market level, trading and fulfilling the portfolio management function of utilities entails the exploitation of storage capacities to reduce the trading risks. The accuracy of the predictions of the renewable energy output is very important for the trading process. Any deviations from the predictions would require on the-spot sourcing of more electricity or selling of additional volumes. But on the long-term, energy storage systems enable more arbitrage opportunities. Major fluctuations in output lead to larger price differences (i.e. during valley hours). The possibility of storing energy provides the means to take advantage of those differences. Finally, at the lowest grid level, end users have storage needs to improve their energy profile in terms of costs or environmental footprint and to maximise their self-consumption in case of prosumers and to shave demand peaks. Other opportunities for storage include arbitrage on retail markets.

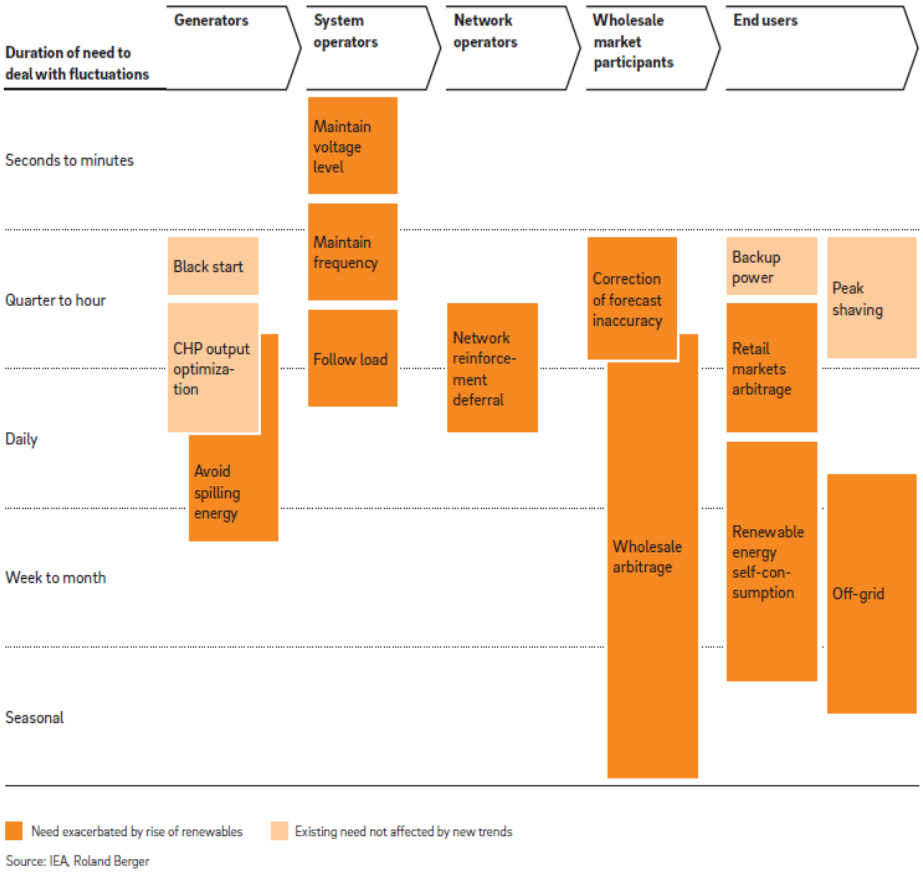


Figure 1 - Storage needs across the value chain(Source: Roland Berger Focus, 2017)[2]

The new Battery Regulation[6] of the European Union is enforced as of July 2023 and ensures that batteries within the EU have a low carbon footprint due to the reduction of resources required, the reduction of raw materials (from non-EU countries), and an increase of reuse and recycling in Europe. The result of this act is the shift to a circular economy, the increase in security of supply for raw materials and energy overall and the enhancement of the EU's strategic autonomy.

A circular economy is implemented by new/enhanced battery designs.

Starting in 2027, consumers will be able to remove and replace the portable batteries in their electronic products at any time of the life cycle. This will extend the life of these products before their final disposal and will further encourage re-use and will contribute to reduction of post-consumer waste stemming from batteries.

In the near future the number of electric vehicle (EV) batteries no longer appropriate for automotive use will dramatically increase. It is estimated that over 5 million metric tons of EV batteries will be inappropriate for mobility purposes by 2030[7]. The majority of manufacturers offer battery warranty covering a time frame of 5-10 years or alternatively driving range of 100,000-150,000 kms[8]. The average EV battery capacity loss is estimated to around 2.3% per year[9]. Therefore, at the end of these warranties, the expected EV battery nominal capacity varies between 70-80%. This is also the First-Life End-Of-Life (FL-EOL) threshold adopted by most within the automotive industry. Although these batteries do not fulfil the automotive and EV drivers' mobility requirements anymore at the end of their lifecycle, their storage capacity can still be exploited for other, less demanding applications in terms of both total capacity and peak performance requirements.

According to the market analysis of second life batteries from the Transparent Market Research[10], the worldwide 2nd-life EV battery market, is expected to grow at a CAGR of 44.7 % from 2022 to 2031, reaching a projected value of USD 9.93 billion in 2031. 2nd-life batteries may be used in various residential, commercial, and industrial applications as energy storage. Of the segments involved in the second-life battery market, the EV charging industry is expected to dominate in the years to come. The industrial segment is also expected to see high revenue in the market.

[6] https://environment.ec.europa.eu/news/new-law-more-sustainable-circular-and-safe-batteries-enters-force-2023-08-17_en
[7] Propulsion Quebec. Lithium-ion Battery Sector: Developing a Promising Sector for Quebec's Economy; KPMG for Propulsion Quebec: Montreal, QC, Canada, 2019.
[8] https://www.irishevs.com/no-you-wont-need-to-replace-your-ev-battery#:~:text=To%20put%20that%20in%20terms,200%2C000%20miles%20(321%2C868km).
[9] https://www.geotab.com/blog/ev-battery-health/
[10] https://www.globenewswire.com/news-release/2023/11/30/2788582/32656/en/Second-life-EV-Battery-Market-to-Surpass-USD-9-93-billion-2031-at-a-CAGR-of-44-7-Exclusive-Report-by-Transparency-Market-Research-Inc.html#:~:text=%2D%20The%20global%20second%2Dlife%20EV,close%20at%20US%24%20528.06%20million.

Table 1: Studies related to the battery EoL[11]

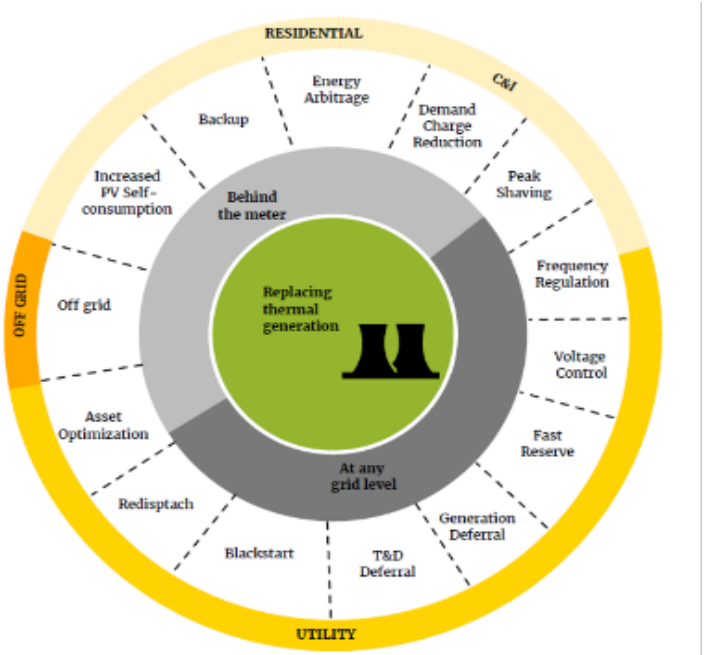
Authors	Year	Study Type	EoL criteria for 1st life
Nuhic et al.	2013	RUL	80% SoH
Dong et al.	2014	RUL	70-75% SoH
Qu et al.	2019	RUL	70% SoH
Lin et al.	2020	RUL	80% SoH
Gou et al.	2020	RUL	80% SoH
Yang et al.	2021	RUL	80% SoH
Catelani et al.	2021	RUL	70% SoH
Arrinda et al	2021	RUL	Application-dependent
Bamati and Chaoui	2022	RUL	70% SoH
Khaleghi et al.	2022	RUL	80% SoH
Assunçao et al.	2016	Second-life assessment	70% SoH
Saez-de-Ibarra et al.	2016	Second-life assessment	80% SoH
Madlener and Kirmas	2017	Second-life assessment	80% SoH
Ioakimidis et al.	2019	Second-life assessment	80% SoH
Wu et al.	2020	Second-life assessment	90-65% SoH
Haram et al.	2021	Second-life assessment	80% SoH
Fallah and Fitzpatrick	2022	Second-life assessment	90-60% SoH
Song et al.	2022	Second-life assessment	80% SoH
Salek et al.	2022	Second-life assessment	80% SoH
Terkes et al.	2023	Second-life assessment	70-80% SoH
Ai et al.	2019	Battery stock projections	Different lifespans
Jiang et al.	2021	Battery stock projections	Different lifespans but 70% SoH
Fallah et al.	2021	Battery stock projections	80% SoH
Sanclemente Crespo et al.	2022	Battery stock projections	Different lifespans but 80% SoH
Canals et al.	2022	Battery stock projections	Based on expected EV lifespan

In fact, the potential for 2nd life battery exploitation is substantial. There are a number of applications, where second life batteries can be used, unlocking new revenue streams to different business stakeholders (Figure 2). Fourteen indicative 2nd life battery services for the electricity grid have been identified for the entire value chain of the energy system (i.e., end-users, utility companies, grid operators and off-grid applications)[12]. It should not be neglected to highlight that the environmental benefits due to actually re-using before recycling used batteries are significant.

The different 2nd life application can be applied at different levels of the electricity grid focusing on specific grid segments (Figure 3). Each segment dictates different storage capacity requirements and serves different business objectives. More specifically, there are three segments in 2nd life BESS which can be considered defining the level of the power capacity needs of the respective storage system. More specifically,

- **Front-of-the-meter (FTM) utility-scale installations** (> 10 MWh)
- **Behind-the-meter (BTM) commercial and industrial installations** (30 kWh – 10 MWh)
- **Behind-the-meter residential installations** (< 30 kWh)

[11] Maite Etxandi-Santolaya, Lluc Canals Casals, Cristina Corchero, "Extending the electric vehicle battery first life: Performance beyond the current end of life threshold", Heliyon, Volume 10, Issue 4, 29 February 2024, e26066.
[12] https://publications.jrc.ec.europa.eu/repository/handle/JRC112543



Source: (Reid and Julve, 2016)

Figure 2 - Indicative 2nd life battery services for the electricity grid.

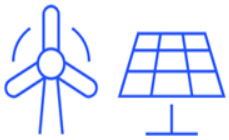
	Front of the meter (FTM)	Behind the meter (BTM)	
			
	Electricity generation and distribution	**Commercial and industrial (C&I)**	**Residential**
Use cases	Price arbitrage Long-term capacity payments Ancillary service markets Derisking renewable generation Investment deferral	Renewable integration (rooftop photovoltaic) Uninterruptable power supply (UPS) Power cost optimization Electric-vehicle (EV) charging infrastructure	Home integration of: Renewable integration (rooftop photovoltaic) EV charging infrastructure

Figure 3 - Three segments in BESS. From utilities to residential BESS. Source

The graph below shows the key stakeholders within the Battery2Life Business Plan, specifically:

i. the battery manufacturer itself (producer),
ii. the customers of 1st life batteries (EV manufacturers and others),
iii. the customers of 2nd life batteries (BESS customers),
iv. Tier 1 (e.g., retired EV batteries), Tier 2 (e.g., battery casings) and Tier 3 (e.g., raw materials) suppliers, and
v. Waste management agents active at the battery's End-of-Life (e.g., hydrometallurgy).

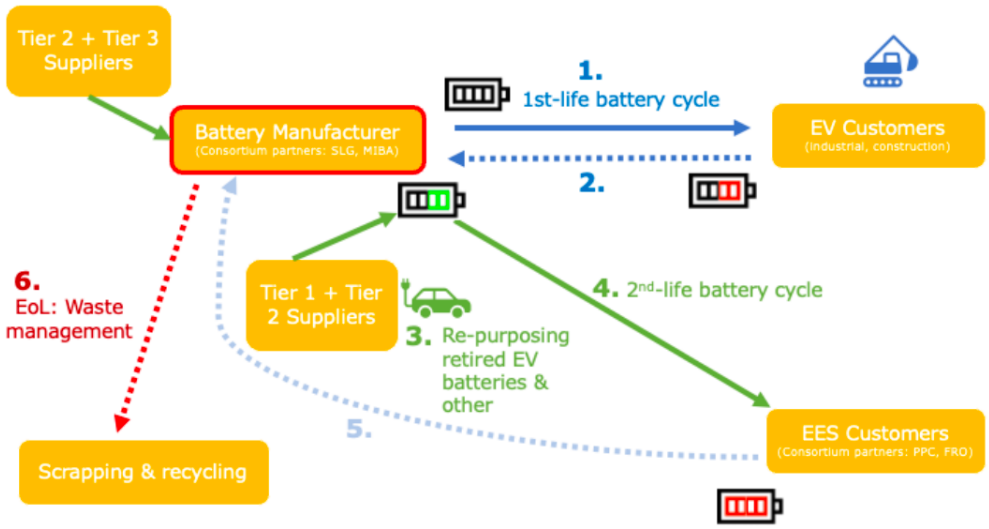


Figure 4 - Three segments in BESS. From utilities to residential BESS

The different battery marketing scenarios are like the ones used auto parts market, and they involve three different market scenarios (Figure 5):

❖ **Closed market scenario**

The Original Equipment Manufacturer (OEM) is expected to collect the reused batteries, re-engineer them in a new application and sell (or rent) them to the end-customer of the 2nd-life application. The closed market model is expected to be adopted because battery and automobile manufacturers may not be interested in sharing data on the use and performance history of the batteries used in their products, they may fear of losing competitive market advantages.

❖ **Intermediate market scenario**

In this scenario, the OEM can close cooperation agreements so that logistics companies will be responsible for collecting batteries and/or with other energy storage companies to re-engineer them for 2nd life applications. In this scenario, a company will be the intermediate between the

end-use customer and the OEM. In this scenario, the OEMs should partially share their knowledge and their data with the intermediate, or simply sell their 2nd life batteries. The dangers for the OEM with this business is: 1) losing control of the used EV battery market, 2) data leakage, "know-how" leakage, 3) risk of damaging its brand in an accident or low performance of the 2nd life battery. The dangers for the intermediate company are:) the possible low quality and performance of the used batteries, 2) the dependence of the company from the OEM.

- **Open market scenario**:

The open market business model considers the possibility of have a market operator providing an online platform to connect customers and sellers and manage inventory according to the supply and demand of 2nd life batteries. This open market approach will be a challenge without adeuqaute blockchain technology to protect sellers and consumers from speculatively market behaviours.

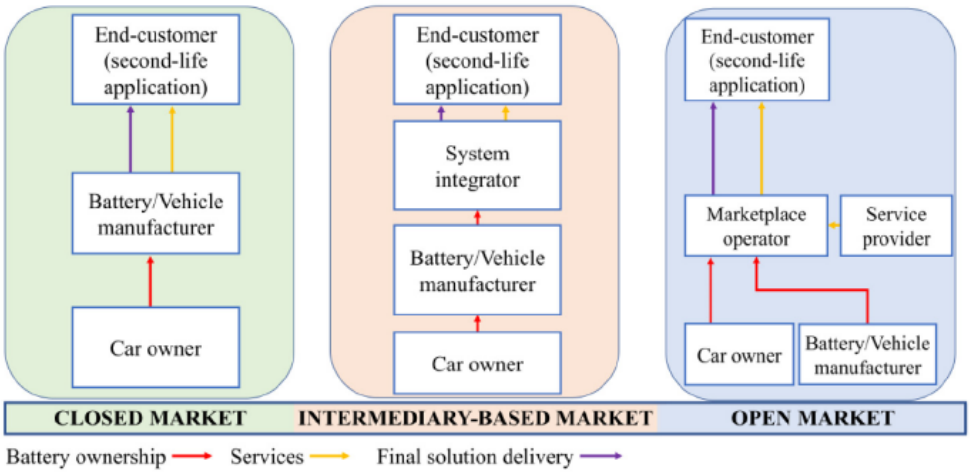


Figure 3 - Three different market scenarios (Sources: Klör et al., 2015[1] & Rufino Júnior et al., 2023[2])

2.2.1 Business context

The scope of this business use case is to assess the exploitation of the 2nd-life stationary storage energy systems for grid-scale application towards enabling a more efficient integration of EVs into the electricity grids. More specifically, this case is a very appealing path to ensure the efficient integration of fast-charging infrastructure in the weak electricity grids of islands. It is possible to envision the integration of such storage systems under the framework of the existing Greek initiative "Gr-ECO islands", which aims to transform Greek islands into models of green economy by tackling key issues such as energy autonomy, digital innovation, and ecological mobility. Since electricity grids on islands are characterised by limited power and generation capacity, the sustainability of such investments and the reliability of the charging network operation require the deployment of grid-impact mitigation actions. The synergetic operation of charging infrastructures (especially for ultra-fast ones) with RES and stationary battery systems is key factor for the sustainable electrification of transport on islands not only in the EU but worldwide.

Envisioning the adoption of this business use case is the future of green e-mobility charging hubs, where several charging infrastructures supporting different charging levels (from 22 kW up to > 150 KVA) will serve the needs of different vehicle types simultaneously, which integrates both renewable and 2nd life storage solutions to minimise their environmental footprint and grid impact. The synergetic operation of charging infrastructures and RES aims to contribute to the decarbonisation of the transport sector by enabling green charging even when charging demand and RES production do not coincide by exploiting the storage capacity of 2nd life batteries. Furthermore, since the charging power of such charging hubs will impose additional burden to the electricity grid, especially in the case of high-power chargers, the 2nd life storage can be exploited to shave demand peak shaving and relieve the grid pressure.

The 2nd life battery storage system of Battery2Life will be integrated in the ~~PPC's~~ PPC Innovation Hub in Kantza, Greece. The Innovation Hub is an R&D campus which already includes buildings (with available equipment), RES (i.e. PVs), Electric Vehicle (EV) charging stations, battery storage systems etc.

The Innovation Hub services provided include tests in its laboratories, accreditations, research, inspections in the areas of the PPC Group, instrument calibration, specialized studies, applications and analyses, specialized consultation studies as well as materials and general equipment inspections for quality control of existing and under purchase items of all types of installations. Currently, the Innovation Hub includes 6 different buildings, where 17 modern testing laboratories are located also covering areas related to robotics & digital systems (i.e., Unmanned Aerial Vehicles), Internet of Things & Industrial Applications (i.e., IoT devices, platforms, innovative industrial solutions) and e-mobility (i.e., EVs, charging stations) sections. Apart from the laboratories though, each building comprises of 3 floors and 70 different offices on average. They host more than 300 PPC employees, including technicians, engineers, and scientific personnel. Moreover, the Innovation Hub includes power production units, such as PVs and a power generator, to provide enough electricity load for sustaining the entire campus operation as well as a nearby distribution substation to conduct grid flexibility scenarios along with the Innovation Hub building demands.

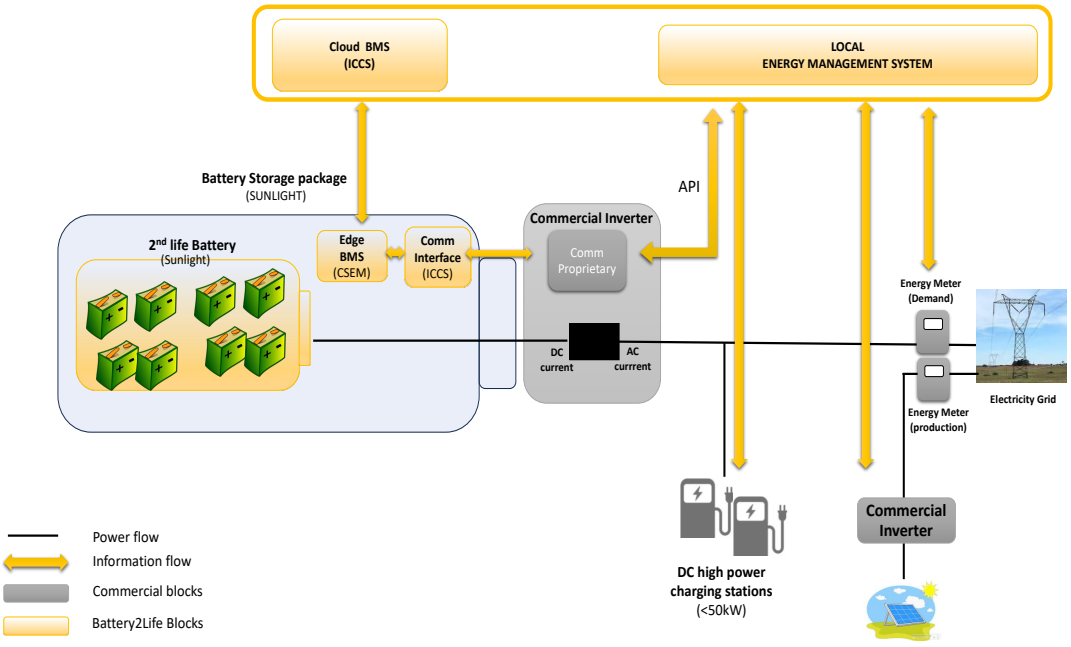


Figure 5 – High level architecture for the industrial load levelling application in Greece.

The Innovation Hub includes an EV charging microgrid. This is equipped with 2 DC chargers (of 50 DC and 60 DC respectively for 4 vehicles with a total capacity of >100 KW) and a PV park of 40KWp

installed power. Currently, this allows the 4 vehicles to charge up to twice per day (totalling 8 complete car charges in a day) and by the time of the project execution several scenarios will be necessary to fulfil. The demonstrations (Figure 5) will aim to test the microgrid and assess the potential of the exploitation of the 2nd battery life storage solution to minimize the grid impact of charging demand peaks and exploit the local RES. The impact on the operation of the electromobility microgrid ecosystem (charging infrastructures, battery storage, RES) in grid-connected and islanded operation will be assessed.

The business stakeholders of the BATTERY2LIFE project involved in this business use case and their role is presented in the following table.

Table 2: Stakeholders involved in the first business use case (Pillar 1)

Battery2Life Beneficiary	Business Role	Responsibility
PPC	Charging Point Operator/e-Mobility Service Provider	Facility owner and operator
SLG	Battery OEM	Provide 2nd life battery storage capacity
CSEM	Research & development centre	Provide the BMS for the 2nd life battery storage
ICCS	Research institute	Provide the cloud BMS and the Energy Management System (EMS)

2.2.2 Battery storage capacity sizing

One of the key aspect for the realisation of the 2nd life battery storage application is the adequate and accurate sizing of the storage system. The requirements for storage capacity are dictated by the demonstration needs and specifications of the pilot site.

In the Greek pilot site, the 2nd life storage system will be used to limit the grid impact of the high-power charging stations. The 2nd life battery capacity will be exploited to smoothen out the charging demand peaks of high-power charging stations for passenger vehicles (50 kW nominal power) and to promote the local consumption of the PV production (40 kWp).

In order to define the battery capacity requirements, a sensitivity analysis is performed for battery storage capacity. The results are shown in the following figure. To achieve a fully green energy charging of the EVs, with respect to a typical daily PV production profile, a battery of approximately 50 kWh energy capacity is needed with around 30 kW maximum power transfer.

In this respect, the green area in Figure 6 shows the PV production surplus which can be stored in the 2nd life battery which can be exploited afterwards to serve (partially) the EV charging demand (blue area).

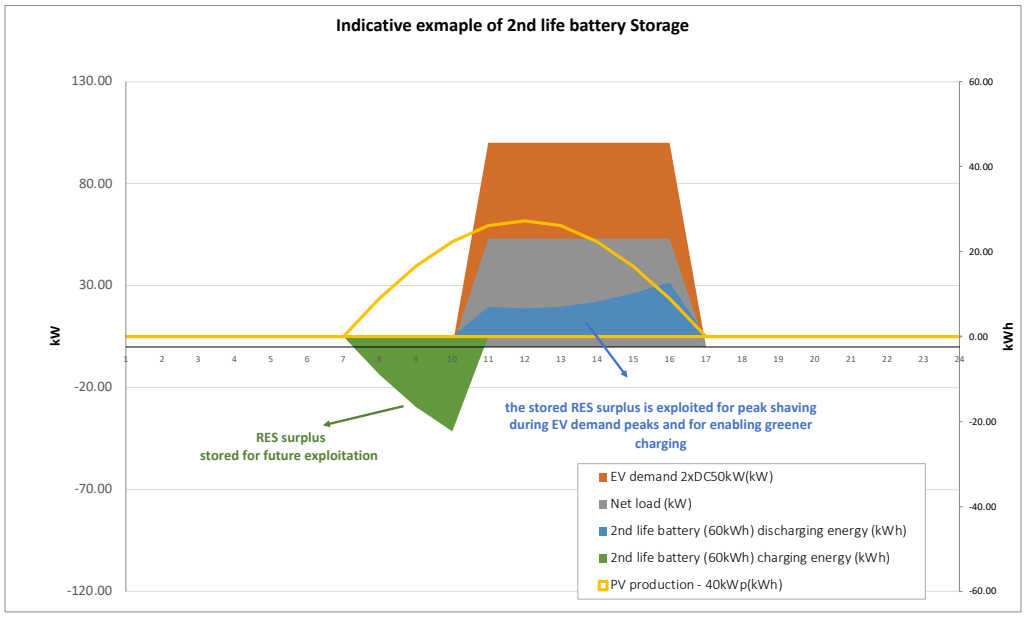


Figure 6 – Indicative operation of the 2nd life battery storage system in the Greek pilot (Pilar 1)

2.2.3 Re-engineering of used BS

Sunlight will take the following path to re-engineer the used batteries:

Sunlight will follow the following process and require the following inputs to re-engineer the used BS and ensure it's safe and successful integration into the Innovation Hub infrastructure:

1. Sunlight will search its database for used batteries at the end of their 1st life.
2. Reclaiming and disassembly:
    a. Returning the used batteries back to the factory of Sunlight.
    b. Sunlight will start the disassembly of the batteries, to obtain the modules for the new BS.
        i. The modules will be opened, and some cells will be sent to CIDETEC for testing.
3. Design of the new BS:
    a. Sunlight will design the new pack for the 2nd life BS, keeping in mind an easy scalability of the manufacturing processes.
    b. Sunlight will also design the electrical system of the re-used battery. In both cases, 1) and 2) input is needed from PPC about the required specifications

and needs of the pilot site, in which the re-used BS will be installed and tested.

4. Assembly:
    a. Two (or three) identical prototypes will be prepared.
    b. Sunlight will build the electrical system of the BS.
    c. The advanced BMS from CSEM will be installed.

Before shipping to PPC, testing will be performed, to secure the safety of the BS during shipping.

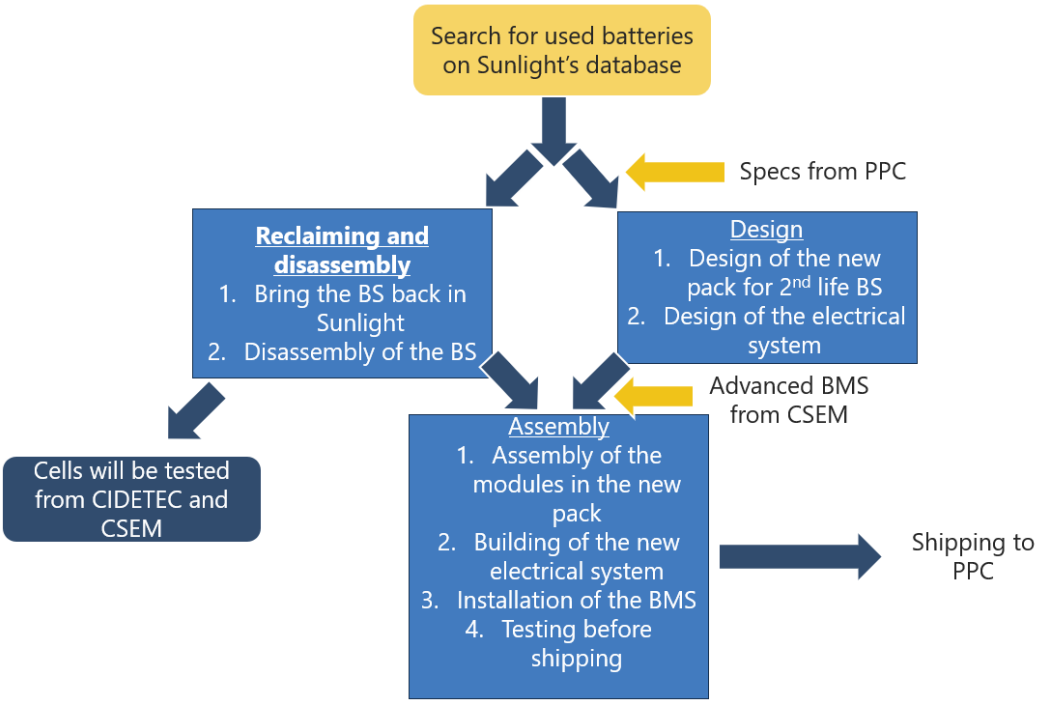


Figure 7 - The process and partner inputs to build the BS with 2nd life battery modules.

2.2.4 Additional pilot deployment requirements

The BESS that will be provided by SUNLIGHT (battery capacity) and CSEM (battery BMS) should be integrated in the local electricity grid of PPC. The operational profile of the 2nd life battery will be defined in collaboration with the production profile of the PV and the demand profile of the high-power charging stations. In this respect the following activities and developments need to be performed in order to integrate the 2nd life battery capacity into the premises of PPC.

- Interconnecting the 2nd battery life to the electricity grid

The interconnection of the 2nd life battery to the local electricity grid requires power electronic interfaces for the conversion of the DC power to AC power and the synchronisation with the electricity grid. A commercial battery inverter should be purchased with respect to the power requirements and the specifications of the battery (voltage, currents, etc.)

- Local Energy Management System

After the integration of the 2nd life battery into the local ecosystem of PPC, there is need for an energy management system that aggregates the production and demand profiles from the related assets and defines the optimal battery operational profile towards absorbing any excess of PV energy production and reduce the demand peaks of the EV charging as far as possible.

2.3 Domestic storage application

2.3.1 Business context

According to SolarPower Europe, a growth of the residential battery storage systems up to 32.2 GWh by the end of 2026 is expected for Europe. As a baseline, 2.3 GWh residential battery systems were installed in 2021. Therefore, a growth of 107% can be expected compared to the baseline and within only 5 years. Through this growth, a total capacity of 5.4 GWh could be reached, which equals over 650,000 operating batteries.

In 2021 the highest number of battery storage systems within Europe were installed in Germany, Italy, Great Britain, Austria and Switzerland. Whereas Germany is the most important market. According to the German Federal Network Agency, about 79 % of the newly installed pv-plants were combined with a battery storage system. In the year 2023 more than 530.000 battery systems smaller than 20 kWh were installed in Germany, which is an increase by 153 % compared to the year before.

The high electricity price and low feed-in renumeration lead to the fact, that self-consumption gets more important for the amortisation of the pv-system. For this reason, the number of battery storage systems will continue rising, especially in Europe.

For the second business use case concerning domestic home storage applications, B2L consortium partner Fronius will integrate and test the B2L prototype in their home system testbed, supporting AC power of up to 10kW. MIBA will provide the 2nd life batteries for this prototype. The aim will be to assess the efficiency and operability of the whole system using 2nd life batteries compared to 1st life batteries. The efficiency guideline for PV storage systems forms the basis of the performed tests. The tests are done using the load profile from the performance simulation model

for PV battery systems. A reference case is used to assess the energy efficiency of residential PV battery systems. It consists of a time series of one second over a one-year period of the PV output power and the electrical load demand.

2.3.2 Battery storage capacity sizing

The ideal battery sizing is highly dependent on the customer's needs and electricity demands. Therefore, modular battery systems are the accepted approach in the market. The modular system can be easily customised and in case of changing needs over the time, the battery size can be easily extended.

According to the performance simulation model for PV battery systems [3], two reference cases were assessed. Both can be combined within the same battery, although there are some notable limitations. For a 5 kW PV system, a battery system of more than 10 kWh is not advisable. Therefore, bigger battery systems should be combined with the second use case (10 kW PV system).

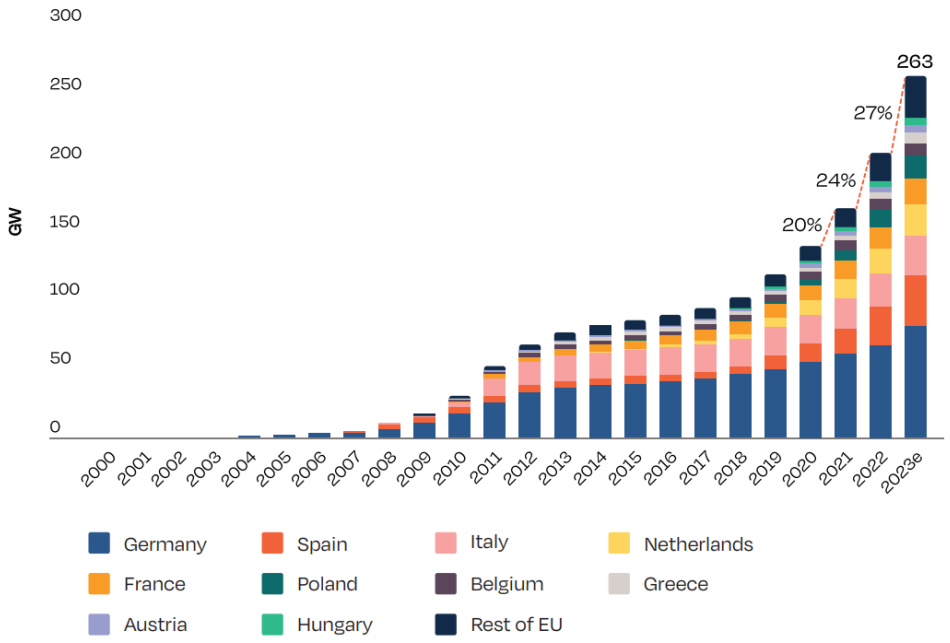


Figure 8 - EU cumulative solar PV installed capacity (Source: Solar Power Europe, 2023[13])

[13] https://www.solarpowereurope.org/insights/outlooks/eu-market-outlook-for-solar-power-2023-2027

The installed PV capacity in 2023 is divided in following applications: Residential 33%, commercial & industrial 33% und utility-scale 34%. There is a notable lack of quantitative and statistical data or studies which track the average nominal size of home storage batteries.

One possible method to verify the efficiency of a whole home application setup is a standard developed by the HTW-Berlin. This standard will be used in pillar 2 to get comparable data. As in the figure below the different losses of actual configurations in the field are shown.

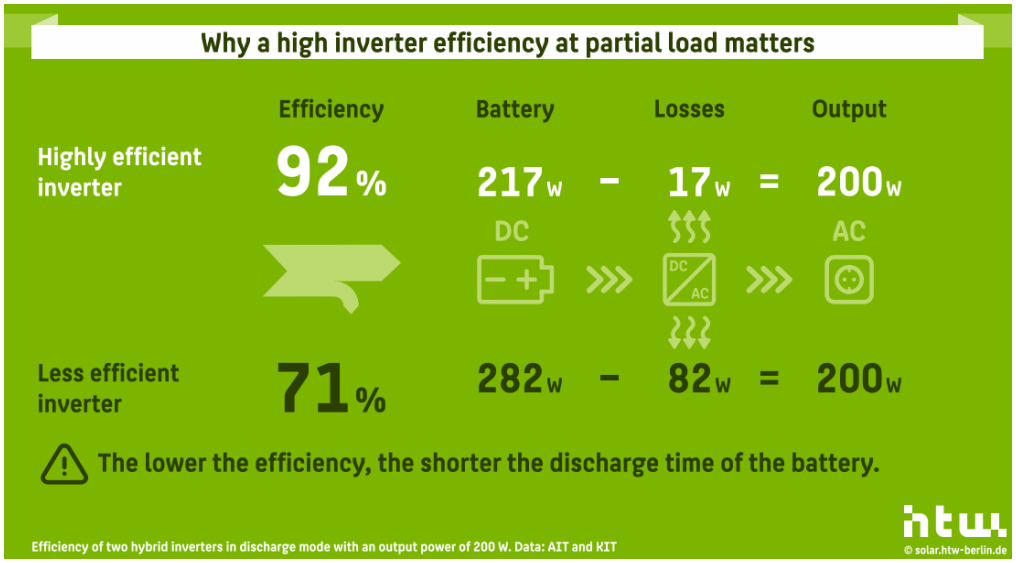


Figure 9 - The Energy Storage Inspection report from the HTW-Berlin

As there is no second use market yet the data referred to in the reports and publications only refers to new batteries. With the growing installation of solar PV systems, also the capacity of a home storage may increase. A simple calculation for the capacity of a home storage battery is up to 1.5 times the power of the used hybrid PV inverter. With the high capacity of traction batteries, 2nd life applications may see an increased storage need since the input voltage of PV inverters is within the same range as automotive applications. A lower overall State of Health (SoH) and therefore a higher internal resistance will affect the overall efficiency, which won't be comparable to the latest battery models, exiting production today.

For pillar 2, traction batteries from the field are equipped with a nominal capacity of 10kWh. Concerning the voltage range of the inverters, three modules should be sufficient, and the actual capacity will depend on the selection criteria, the technical KPIs and the overall SoH of the batteries after their retirement from the 1st life application.

2.3.3 New design of BS for 1st & 2nd life (Pillar 2)

So summarise, the main challenges for the new designs and applications for both business use cases will be:

- Modular design of the battery packs;
- Reusability of E/E and BMS components and their compatibility with each other;
- Process and required equipment for disassembly;
- No use of gap filler within the casing of the batteries;

To tackle these challenges the design of the 2nd life BS will influence the 1st life design. As the existing design is already modular (Fig.11) there are still possibilities to adapt materials, cells used in parallel and connection methods.

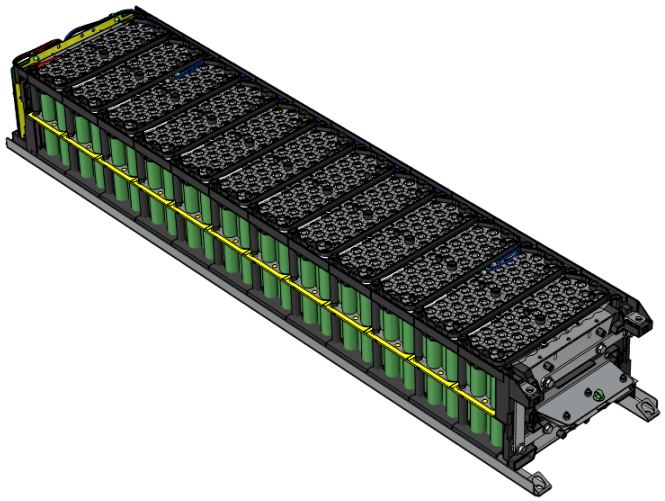


Figure 10 - Miba modular concept

Also, the actual design uses an adaptable cooling system, which will not be needed in home storage applications. The main challenges will therefore lie in the interconnection of different MMS and E/E components, since a new design requires some retrofitting compatibility. The enabler will be the smart module-selection procedure and a lower effort needed to reassemble the BS.

2.3.4 Additional pilot deployment requirements

The battery storage system provided by Miba and the BMS stemming from AIT will be connected to an inverter from FRO. Following the assembly, the entire system will be tested as a joint unit. The following challenges have been identified:

1. Wireless communication

   As the proposed solution will use wireless communication within the BMS and the resulting implications for the stability of information flows, the system should be tested concerning its Electromagnetic Compatibility (EMC), which may result in different test setups.

2. Smart Sensors

   Integrating sensors requires dedicated space within the battery casing. Therefore, the footprint should be kept minimal, and a smart position will be needed. Also, interference with power pulses on the DC-link may present a challenge.

3. Interconnection

   Connecting the battery system to the inverter from FRO for communication tests will be necessary to fulfil the requirements set out by the Modbus protocol.

4. Time of reassembly

   The whole time needed for dismantling 1st life BS, deciding which modules to select and reassembling them do a 2nd life BS will affect different subsequent KPIs. Measuring the duration for the whole process will affect the overall feasibility and cost estimation of the production times and costs.

3 SYSTEM REQUIREMENT ANALYSIS

3.1 Methodology

A common template will be used for the description of the requirement analysis, which contains the following elements and data points per system component:

- *Requirement identification – unique identifier of each requirement;*
- *Requirement title – the short title of the requirement;*
- *Priority – selection of priority of the requirements from critical (high) one to optional*
- *(low) one;*
- *Description of requirement – description of the requirement details;*
- *Verification method – principal description of how the requirement will be verified;*
- *Considered requirements – list of references to requirements which are fully or partially implemented by this requirement.*

Table 3 - Common BATTERY2LIFE requirements template.

<Requirement ID> <Requirement title>	**Priority: High/ Normal/Low**
<Requirement description>	
Verification:	
<How the requirement will be verified?>	
Considered requirements:	
< pilot site requirements, etc. >	
Business use case relevance:	
< *reference to the respective business use case***>**	

3.2 Cloud-based BMS

The diagram in Figure 11 illustrates the conceptual architecture of the cloud BMS and the respective interactions with the edge BMS ad the user:

- The blue boxes define the processes which are related to the processing, storage, accessing of data which are sourced from the edge BMS. The blue boxes are in-built modules that offer vendor -gnostic services for data collection.
- The grey boxes define the processes which are needed for handling data which are provided by external resources, ex. battery specifications which might will be provided by the battery OEM based on unified template via the user interface or data related to the forecasted battery operational profiles under specific business applications.
- The red boxes define the battery-related services which will be developed within the Battery2Life project and can be implemented either at cloud or edge BMS level.
- The yellow boxes define the communication interfaces that needs to be established to allow data information between the edge- and cloud- BMS as well as between cloud-based BMS processes and the BMS cloud.

More specifically,

- **Authentication module** : responsible for providing access to cloud resources to identified users.
- **User management module** : responsible for registering accounts to the platform and managing user accounts
- **Storage module :** database module that stores all the necessary information and data
- **Time scheduler module** : provides the functionality of scheduling time period in which different processes will be executed

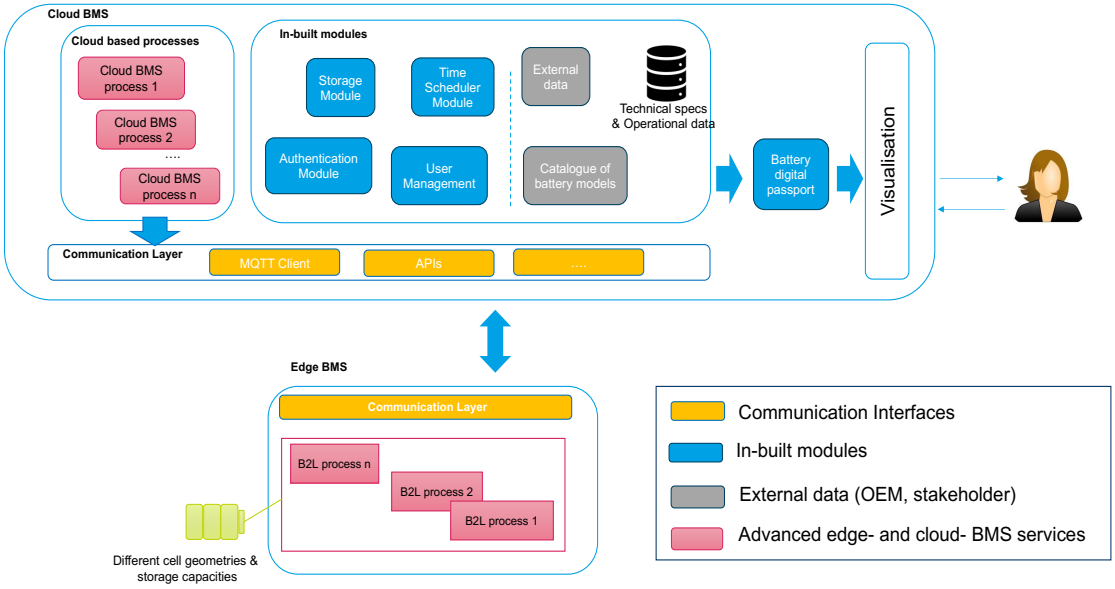


Figure 11 – Conceptual architecture for the cloud/edge BMS

Requirement # 1	Establishment of a secure, reliable and stable communication link between cloud BMS and edge BMS	Priority: High
A secure and reliable communication link should be established for the information exchange between the edge and the cloud BMS. This communication should be bidirectional meaning that operational data needs to be communicated to the routines of the BMS while updated BMS parameters should be communicated to the edge BMS for more efficient operation		
Verification:		
Data is stored in the cloud BMS from the edge BMS and information is forwarded to the edge BMS and all security protection mechanisms are considered (OAuth 2.0, https,etc.)		
Considered requirements:		
-		
Business use case relevance:		
Pillar1 and pillar 2		

Requirement # 2	Both operational data and technical specs of the battery modules and cells needs to be stored in the BMS cloud	Priority: High
The technical specifications of the battery are dictated by the digital battery passport. Unless there is an automatic way to retrieve battery specifications, a unified template will be used such as provided by a battery OEM to provide data in a homogeneous way via the user interface. The enhanced cloud-based BMS routines requires historical and real operational profiles which are not included in the battery passport. Thus, both operational and technical data needs to be collected in the BMS.		
Verification:		
Technical data from battery OEMs and operational data from the edge BMS are stored in the database in the cloud BMS		
Considered requirements:		
Requirement #1 establishment of communication between edge and cloud BMS		
Business use case relevance:		
Pillar1 and pillar 2		

Requirement # 3	User management should be established to ensure data access rights and privacy	Priority: High
The cloud BMS should be equipped with a user management module which allows the definition of agreements for data sharing and visualization.		
Verification:		

Technical specifications of the batteries and operational data are visible only to responsible and authorised battery owners or operators.
Considered requirements:
< pilot site requirements, etc. >
Business use case relevance:
Pillar 1 and pillar 2

Requirement # 4	**The user should be able to provide external data to the cloud BMS to calculate SoW**	**Priority: High**
The estimation of the SOW requires inputs from the operation of the battery during the 1st life application as well as estimated operational profiles from the 2nd life battery application. The operational profile might include data about SoC, temperature, voltage, current, operational cycles, depth of discharge, etc. The granularity of the operational data varies depending on the data exploitation purpose. For instance, assessing operational deviations might need measurements in time-scale of seconds.		
Verification:		
Edge BMS is updated with the new parameter values.		
Considered requirements:		
Requirement #1 establishment of stable communication between edge and cloud BMS		
Business use case relevance:		
Pillar 1 and pillar 2		

Requirement # 5	**The respective communication interfaces (gateway) at the edge BMS should be developed with respect to the cloud communication specifications**	**Priority: High**
The communication interface at edge BMS will facilitate the information flow between the process at edge BMS and the ones in the cloud BMS. The communication specifications with the cloud BMS are defined in Requirement #1. However, the information exchange specifications with the process in the edge BMS needs to be defined.		
Verification:		
There is information exchange between the cloud and the edge BMS		
Considered requirements:		
Requirement 1		
Business use case relevance:		
Pillar 1 & 2		

3.3 Industrial load levelling application

3.3.5 Open Adaptable BMS

Requirement # 6	A new or an updated PCB needs to be designed for the edge BMS serving the enhanced BMS needs.	Priority: High
A new or an updated PCB needs to be designed for the edge BMS based on the new functionalities consolidated in the BMS, such as embedded EIS, SoH estimators, etc...		
Verification:		
Verification of the EIS PCB development and integration: • ***Embedded EIS available at cell level*** ***Verification of the integration of edge BMS processes on the slave edge BMS*** • *SOT estimation available at module level or edge BMS* • *SOC estimation available at module level or edge BMS*		
Considered requirements:		
< pilot site requirements, etc. >		
Business use case relevance:		
Pillar 1		

Requirement # 7	The operational constraints implied by the new PCB design should be considered for the battery capacity design.	Priority: High
Maximum voltage constraints should be considered when the design architecture of the battery pack is considered to meet the capacity requirements of the storage application.		
Verification:		
The technical specifications of the battery pack are in line with the new PCB and the integration of the latter to the battery pack is successful.		
Considered requirements:		
< pilot site requirements, etc. >		
Business use case relevance:		
Pillar 1		

Requirement # 8	The egde BMS should be connected to the module conductors to ensure operational safety	Priority: High
Conductors are exploited in order to ensure the safe operation of the battery in case of abnormal operational conditions. The edge BMS which will be developed in the project should be connected with the conductors conforming to their technical specifications ex. Signals, cables, voltage level, etc.		
Verification:		
Safety checks will be performed according to the functional safety definition for BMS hardware & software		
Considered requirements:		
< pilot site requirements, etc. >		
Business use case relevance:		
Pillar 1		

Requirement # 9	An interface needs to be developed to connect the B2L egde BMS to a commercial battery inverter	Priority: High
In order to realise the bidirectional power flow between the 2nd life battery and the electricity grid, the edge BSM needs to be connected to a commercial battery inverter via an intermediate interface. This interface will physically connect the two edges (BMS and inverter) and will be responsible for the semantic data conversion from both edges		
Verification:		
Lab testing of the communication interfaces before deployment		
Considered requirements:		
< pilot site requirements, etc. >		
Business use case relevance:		
Pillar 1		

Requirement # 10	The edge BMS should have adequate processing capacity to host enhanced SoX estimators	Priority: Normal
New SoX algorithms will be developed and embedded in the edge BMS which will allow to have a more accurate estimation of the State of Temperature (SoT), State of Charge (SoC), State of Safety (SoS).		
Verification:		

The SoC and SoT algorithms running on the BMS will be benchmarked against external references. Comparable results will indicate that the SoC and SoT are successfully hosted in the BMS.
Considered requirements:
< pilot site requirements, etc. >
Business use case relevance:
Pillar 1

Requirement # 11	**The edge BMS should have adequate storing capacity to store operational datasets before being uploaded to the cloud BSM**	**Priority: Normal**
The cell or module operational data is critical for the enhanced routines in order to perform compound processes and estimate the operational status and health of the battery. In some case, the granularity of the datasets might be in seconds. Thus, the interfacing with the cloud BMS will be periodically or event-based triggered to communicate information about the operation of the battery or in case that an event occurred.		
Verification:		
The BMS can store 1 day of battery data (measured each 1 second or more) and relevant data (safety related) for 1 week.		
Considered requirements:		
< pilot site requirements, etc. >		
Business use case relevance:		
Pillar 1		

3.3.6 Advanced embedded SOX estimation

In 2nd life BESS applications, the safety tracking presents an important task, since the BESS has already aged and due to the degradation of its HW and SW, it cannot be expected to work with the same efficiency and reliability as a 1st life battery. The 2nd life EoL becomes more unpredictable, and even if the application is usually less restrictive, dangerous events are more likely to happen. Keeping this risk in mind, advanced SoX estimators need to be developed in the project to address this issue and allow for adequate monitoring and safety conditions.

In case of the industrial load levelling application, first, EPFL will develop **State of Charge (SoC) and State of Temperature (SoT)** estimators based on EIS. Cells will be equipped with individual EIS acquisition chains to allow accurate estimation. The EIS is carried out on a regular basis, that depends on the battery usage (in general once per week is sufficient). The EIS is then decomposed

using the Distribution of Relaxation Time (DRT) technique, the output is then used to update the Equivalent Circuit Model (ECM) parameters used for the SoC estimation. The SoC estimator runs continuously on the BMS (1Hz, but can run faster). For EIS based SoT a similar algorithmic pathway is used.

There is also a specific estimator that indicates the **State of Safety (SoS)**. This indicator tries to quantitatively estimate the current safety level of a battery. The safety of a battery can be described as the inverse function of the different abuse mechanisms than can take place within a battery. The numerical value of the SoS can be defined by the detection and ranking of different dangerous events or critical ageing effects, such as Li-plating and TRA. Hence, for developing a SoS indicator, first other fault detection algorithms must be developed first. In case of the industrial load levelling application, the SoS estimator will based on EIS measurement for both TRA and li-plating early detection in real-time.

Additionally, **State of Warranty (SoW)** indicator is developed, which is a meta-state that qualitatively describes the warranty fulfilment level of an electric vehicle. All the relevant warranty information is synthesized in a single merit while maintaining the level of detail through the qualitative substates. The developed SoW is calculated with a rule-based logic of an expert system that evaluates the quantitative value of three substates: i) the remaining warranty, ii) the remaining health and iii) the remaining useful warranty. The SoW provides a synthesized and user-friendly description of the warranty fulfilment state while providing quantitative detailed information of the most relevant features of each of the different maintenance methodologies.

Requirement # 12	**The SoT and SOC estimators developed by EPFL should be integrated in CSEM's edge BMS**	**Priority: High**
The SoT and SoC estimators should run locally at the edge BMS and their parameters should periodically be adjusted based on the calculations that are recorded by at the cloud BMS		
Verification:		
- *The SoT and SoC values computed locally are in line with the baseline measurement* - *The SoC and SoT values computed locally are recomputed in less than 1 second.*		
Considered requirements:		
< pilot site requirements, etc. >		
Business use case relevance:		
Pillar 1		

Requirement # 13	The calibration of the parameters of the SoT and SOC estimators is performed at the cloud and communicated to the edge BMS	Priority: Normal
Algorithms are executed real-time at edge BMS level, but the definition/readjustment of the parameters are performed at the cloud BMS. The EIS outcome (ex. Real and imag. Part of frequency (Nyquist curve) need to be communicated to the cloud. Based on these measurements the new parameters will be computed by a routine executed in the BMS cloud and they should be communicated back to the edge BMS.		
Verification:		
The SoC and SoT estimator are accurately evolving over time w.r.t. the reference sensor (i.e. there is no divergence). The model parameter update though the cloud leads to improved prediction performance when compared to prediction results obtained by using previous model parameters.		
Considered requirements:		
-		
Business use case relevance:		
Pillar 1		

Requirement # 14	The data from the SoT/SoC model parameter update (in particular EIS) needs to be communicated to the cloud BMS on a regular basis.	Priority: High
EIS output needs to be communicated to the cloud to send the output (ex. Real and imag. Part of frequency (Nyquist curve)).		
Verification:		
The EIS data is available on the cloud at most 1 hour after the measurement was carried out (in the case the communication is operational). Or at most 1 day after the communication has resumed.		
Considered requirements:		
-		
Business use case relevance:		
Pillar 1		

Requirement # 15	EIS-based SoS estimator developed by CIDETEC should be compatible with CSEM's edge BMS	Priority: High/ Normal/Low
The SoS estimator will be integrated on the edge BMS developed by CSEM. This means that EIS-based SoS estimator should be compatible in terms of measurement frequency, frequency range, sample time, and the microcontroller shall have Matlab coder support		
Verification:		

This requirement can be verified by the validation of the SoS estimator algorithms once it is integrated on CSEM's edge BMS.
Considered requirements:
BMS requirement
Business use case relevance:
Pillar 1

Requirement # 16	**The EIS-based SoS estimator will receive EIS measurement from the edge BMS.**	**Priority: High/ Normal/Low**
The SoS estimator will receive the values of the real and imaginary part of the impedance from each cell of the battery at the defined time interval (to be defined later in the project).		
Verification:		
EIS measurements are properly received by SoS estimator in the defined time interval.		
Considered requirements:		
BMS requirement		
Business use case relevance:		
Pillar 1		

Requirement # 17	**The EIS-based SoS estimator will be updated periodically and stored in the edge BMS.**	**Priority: High/ Normal/Low**
The SoS estimator will be a non real-time estimator, and will be updated in the sample time of each individual cell impedance. The resulting indicator will be received by the edge BMS.		
Verification:		
SoS estimation is properly received by CSEM's edge BMS.		
Considered requirements:		
BMS requirement		
Business use case relevance:		
Pillar 1		

Requirement # 18	**The SoW estimator will receive the SoH, the date and the cumulative value of the discharged energy.**	**Priority: High/ Normal/Low**
The input data for a proper SoW estimator are the SoH, the date and the cumulative value of the discharged energy. Since the SoW is integrated in the cloud, this data needs to be sent to the cloud by the edge BMS. The time interval to obtain/update the inputs must be weekly/monthly.		
Verification:		

Check that the variables will be remotely obtained. Check that the obtained values will be accessible to the cloud server that contains the SoW estimator. Check that the inputs are provided in the specified time interval and sample time.
Considered requirements:
Communication/cloud system requirement
Business use case relevance:
Pillar 1 and pillar 2

Requirement # 19	**The SoW estimator will be integrated in the cloud**	**Priority: High/ Normal/Low**
SoW estimation algorithm will be hosted in the cloud. The inputs of this algorithm must be obtained remotely from the system. The developed algorithm must be executed in a cloud server.		
Verification:		
Check that the inputs are provided to the cloud server. Check that the server can host the SoW estimator. Check that the execution of the estimator is done properly in the cloud server.		
Considered requirements:		
Communication/cloud system requirement		
Business use case relevance:		
Pillar 1 and pillar 2		

Requirement # 20	**The SoW estimator will be updated periodically.**	**Priority: High/ Normal/Low**
SoW estimator will not be real-time estimation, but it will be updated periodically (could be weekly or monthly, to be defined later in the project).		
Verification:		
Check that the SoW estimator is executed periodically on the cloud server within the defined time interval. Check that the results are saved and updated in the corresponding database.		
Considered requirements:		
Demonstrator requirement		
Business use case relevance:		
Pillar 1 and pillar 2		

3.3.7 Embedded EIS

The proposed architecture is illustrated in Figure 12, where a pack composed of several modules is connected to the cloud. For the sake of clarity, only the interaction around the 1st module will be explained (the same logic applies to all modules within the pack). The following steps are followed:

1) EIS is measured at cell level by the embedded EIS board. The board directly computes the Nyquist diagram
2) The processed EIS is sent to the BMS slave (at module level)
3) The EIS is forwarded to the BMS master (at pack level)
4) The EIS is sent to the cloud
5) In the cloud the updated ECM parameres are computed
6) The new ECM parameters are sent to the BMS master
7) All results are transmitted to the BMS slave and finally to the EIS board
8) SoT and SoC is computed using the new parameters

It is worth pointing out that step 8) (SOT and SOC computation), takes place continuously, whereas, the EIS measurement and parameter update (i.e. steps 1-7) are carried out only when required (i.e. after a significative usage of the battery, when model parameters might have changed). This can be on a daily or weekly basis for instance.

The proposed illustration in Fig. 13 may evolve based on the specific requirements that will be developed in WP2 (BMS architecture), but in a high level this approach will be followed by CSEM and SLG.

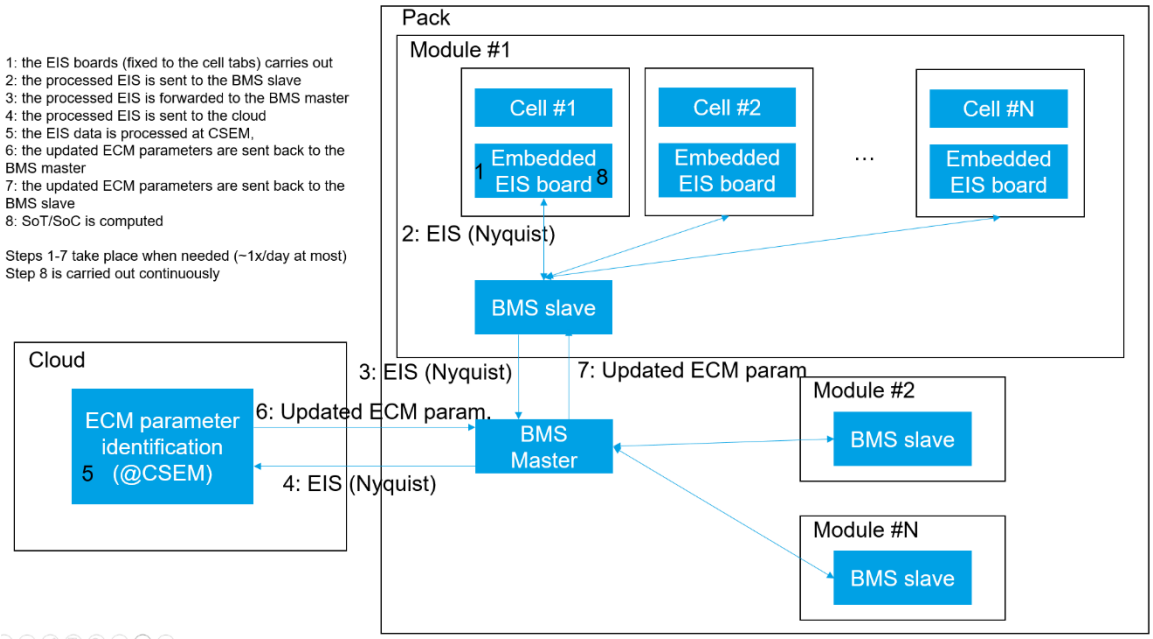


Figure 12 Reference architecture for the edge BMS

Requirement # 21	**The EIS should be electromechanically connected with the cells**	**Priority: High**
The EIS boards are physical connected to the cells. The preferred solution is to use screws. However other options are also acceptable and will be considered. There will be one EIS board per cell in the module. The EIS boards are mechanically and electrically connected to the cell.		
Verification:		
The EIS boards are fixed in a robust way: *1) Mechanically the system is stable even in the case of minor vibrations* *2) The signals (in particular EIS) are of good quality*		
Considered requirements:		
< pilot site requirements, etc. >		
Business use case relevance:		
Pillar 1		

Requirement # 22	The embedded EIS should be capable of measuring an EIS correctly and transforming the raw EIS data to Nyquist diagram accurately.	Priority: High
The EIS board transmits the Nyquist diagram (real and imaginary) part to the Edge BMS (not the raw EIS data).		
Verification:		
The results provided by the EIS board are compared to the Nyquist plot obtained via a reference equipment.		
Considered requirements:		
< pilot site requirements, etc. >		
Business use case relevance:		
Pillar 1		

3.4 Domestic storage application

3.4.1 Open adaptable BMS

Requirement # 23	Design a Master BMS PCB which handles the communication, computation and balancing.	Priority: Normal
A new master BMS PCB needs to be developed which wirelessly communicates with each MMS.		
Verification:		
The finale master BMS PCB will be tested step by step. Each component group is checked separately and tested for proper function. The communication with the cloud gateway and the home system inverter will be tested in close cooperation with the individual partners.		
Considered requirements:		
< pilot site requirements, etc. >		
Business use case relevance:		
Pillar 2		

Requirement # 24	BMS voltage measurement accuracy and number of channels	Priority: Normal
The Module Management System (MMS) should provide a 5mV voltage measurement accuracy. Each MMS should be able to monitor at least 12 cells		
Verification:		
Testing of the implemented features.		
Considered requirements:		
< pilot site requirements, etc. >		
Business use case relevance:		
Pillar 2		

Requirement # 25	MMS temperature inputs	Priority: Normal
The developed MMS should provide up to 8 temperature inputs.		
Verification:		
Compare measured temperature from MMS/BMS with externally measured temperature (e.g. climatic chamber temperature).		
Considered requirements:		
< pilot site requirements, etc. >		
Business use case relevance:		
Pillar 2		

Requirement # 26	BMS power supply	Priority: High
A 12V power supply will be attached to feed the BMS and optionally, a second power supply may be used for the MMS. These supplies need to be sufficient to avoid failures or underperformance.		
Verification:		
Power supply will be measured.		
Considered requirements:		
Business use case relevance:		
Pillar 2		

Requirement # 27	BMS Communication	Priority: Normal
The BS must have a RS485 and CAN interface.		
Verification:		
System integration test		
Considered requirements:		
-		
Business use case relevance:		
Pillar 2		

Requirement # 28	The edge BMS should be able to integrate the new functionalities.	Priority: High
The edge BMS should be able to host the new functionalities such as SoS-based SoF and active balancing. For that, necessary processing and memory capacity will be available.		
Verification:		
New functionalities such as SoS-based SoF and active balancing are integrated in the edge BMS.		
Considered requirements:		
BMS requirement		
Business use case relevance:		
Pillar 2		

Requirement # 29	The edge BMS should have storing capacity for operational data before being uploaded to the cloud BMS.	Priority: Normal
Some functionalities are run in the cloud, such as SoW, so necessary data to be sent periodically needs to be first stored in the edge BMS.		
Verification:		
The edge BMS can store the necessary data.		
Considered requirements:		
BMS requirement		
Business use case relevance:		
Pillar 2		

3.4.2 Advanced embedded SOX estimation

Regarding advanced SoX estimators for the domestic storage application, different approach is needed compared to the industrial approach, since the available HW and measurement equipment will be different. In this case, no EIS measurement will be carried out, but each individual cell voltage, current, SOC and system temperature tracking will be developed. Consequently, SoS will be addressed by the definition of a SoF that considers SOC, temperature, current, and safety limit for avoiding Li-plating. The SoF defines the maximum charging/discharging current depending on battery conditions during operation.

As for SoW estimator, the requirements are similar to the one presented in the industrial application.

Requirement #18	**The SoW estimator will receive the SoH, the date and the cumulative value of the discharged energy.**	**Priority: High**
The input data for a proper SoW estimator are the the SoH, the date and the cumulative value of the discharged energy. *Since the SoW is integrated in the cloud, this data need to be sent to the cloud by the edge BMS.* *The time interval to obtain/update the inputs must be weekly/monthly.*		
Verification:		
Check that the variables will be remotely obtained. Check that the obtained values will be accessible to the cloud server that contains the SoW estimator. Check that the inputs are provided in the specified time interval and sample time.		
Considered requirements:		
Communication/cloud system requirement		
Business use case relevance:		
Pillar 1 and pillar 2		

Requirement #19	**The SoW estimator will be integrated in the cloud**	**Priority: High**
SoW estimation algorithm will be hosted in the cloud. The inputs of this algorithm must be obtained remotely from the system. The developed algorithm must be executed in a cloud server.		
Verification:		
Check that the inputs are provided to the cloud server. Check that the server can host the SoW estimator. Check that the execution of the estimator is done properly in the cloud server.		
Considered requirements:		
Communication/cloud system requirement		
Business use case relevance:		
Pillar 1 and pillar 2		

Requirement #20	The SoW estimator will be updated periodically.	Priority: Normal
SoW estimator will not be real-time estimation, but it will be updated periodically (could be weekly or monthly, to be defined later in the project).		
Verification:		
Check that the SoW estimator is executed periodically on the cloud server in the defined time interval. Check that the result is saved and updated in the corresponding database.		
Considered requirements:		
Demonstrator requirement		
Business use case relevance:		
Pillar 1 and pillar 2		

Requirement # 30	SoS-based SoF developed by CIDETEC should be compatible with AIT's edge BMS.	Priority: High
The SoF will be integrated and run on AIT's edge BMS. This means that it should be compatible in terms of sample time, and data type.		
Verification:		
This requirement can be verified by the validation of the algorithms once it is integrated on the edge BMS.		
Considered requirements:		
BMS requirement		
Business use case relevance:		
Pillar 2		

Requirement # 31	SoS-based SoF will consider the necessary measurements from the cells and the system.	Priority: High
The estimator will limit the operating current depending on each individual cell SOC, voltage and current, measurements as well as system level temperature, at the defined time interval (to be defined later in the project). These measurements need to be done by the edge BMS.		
Verification:		
Necessary measurements are carried out in the edge BMS.		
Considered requirements:		
BMS requirement		

Business use case relevance:
Pillar 2

Requirement # 32	**SoS-based SoF will be continuously limiting the charging/discharging current.**	**Priority: Normal**
SoS-based SoF will be integrated as known current limits depending on operation conditions. Therefore, the operating current will be constantly limited.		
Verification:		
The estimator address properly the safety of the cell by constant current limiting.		
Considered requirements:		
BMS requirement		
Business use case relevance:		
Pillar 2		

3.4.3 Active Balancing

Requirement # 33	**Design a PCB which supports active balancing.**	**Priority: Normal**
A new module management system (MMS) PCB needs to be developed which supports active balancing.		
Verification:		
The finale PCB will be tested step by step. Each component group is checked separately and tested for proper function.		
Considered requirements:		
< pilot site requirements, etc. >		
Business use case relevance:		
Pillar 2		

Requirement # 34	**Active balancing current**	**Priority: Normal**
High balancing (>200mA) current which allows fast cell balancing to fulfil the requirements for second-life cells.		

Verification:
Balancing current will be measured and switching behaviour checked.
Considered requirements:
< pilot site requirements, etc. >
Business use case relevance:
Pillar 2

3.4.4 Smart sensors

Requirement # 35	**Choosing a type of pressure sensor that is suitable for the measurements**	**Priority: Normal**
Various commercially available pressure sensor types exist. The measuring principles can be strain, piezoelectric, capacitive, and inductive. Each of these types have different advantages and disadvantages like robustness, reliability, accuracy, sensitivity, dynamic range, response time and temperature dependency. A sensor type that fits best for measuring the pressure inside a battery pack based on the above-mentioned points will be chosen.		
Verification:		
Evaluation of different sensor types based on their datasheets. Measuring with chosen sensor the pressure while cycling the battery / battery module.		
Considered requirements:		
< pilot site requirements, etc. >		
Business use case relevance:		
Pillar 2		

Requirement # 36	**Choosing a type of strain sensor that is suitable for the measurements**	**Priority: Normal**
Various commercially available types of strain sensors exist. For measuring the strain in a battery pack / module most likely a strain gauge is the most suitable due to its dimensions and the relatively easy application on a cylindrical shaped battery. Various geometric forms exist that can measure strain in specific ways (linear, rosette, torsional, shear etc.).		
Verification:		

Evaluation of different sensor types based on their datasheets. Measuring with chosen sensor the strain while cycling the battery / battery module.
Considered requirements:
< pilot site requirements, etc. >
Business use case relevance:
Pillar 2

Requirement # 37	**Integration of Strain and Pressure Sensors in battery module**	**Priority: Normal**
Minimum one pressure and one strain sensor will be integrated in a battery module.		
Verification:		
Minimum one pressure and strain sensor have been successfully integrated in a battery module.		
Considered requirements:		
< pilot site requirements, etc. >		
Business use case relevance:		
Pillar 2		

Requirement # 38	**Sensor location inside the battery module**	**Priority: Normal**
Finding best suitable location for integration of pressure and strain sensor in the battery module.		
Verification:		
Measuring the pressure and strain with the sensors integrated in the battery module.		
Considered requirements:		
< pilot site requirements, etc. >		
Business use case relevance:		
Pillar 2		

3.4.5 Wireless Connectivity

Requirement # 39	Development of a wireless MMS PCB and communication protocol	Priority: Normal
The communication should be wireless between each MMS and between the BMS and the cloud. The main requirement for a wireless BMS is to provide the host MCU or sometimes also referred as master BMS controller with cell data (mainly cell voltage and temperature) when requested. For the wireless module communication (on macro cell level) the first approach is to use the 2.4 GHz band for the module management system (MMS) communication. A dedicated wireless microcontroller with RF-core should handle the radio protocol. The communication between the MMS and master BMS should be reliable and secure. This can be achieved by using a cyclic redundancy check (CRC) to detect communication errors.		
Verification:		
Evaluation of different protocols in closed and noisy environment.		
Considered requirements:		
The following system requirements should be fulfilled: *Maximum of 8 wireless MMS (nodes)* *Low standby current* *Low latency* *Wireless throughput (up to 0.2 Mbps)*		
Business use case relevance:		
Pillar 2		

3.4.6 Battery System Design requirements

Requirement # 40	BS-voltage	Priority: Normal
The BS-design should enable a recombination of modules, so that the voltage-range of the 2nd life BS is within 150V-530V.		
Verification:		
Measure the battery-voltage continuously and perform an overcharge and overdischarge until the BMS disconnects the BS.		
Considered requirements:		

< pilot site requirements, etc. >
Business use case relevance:
Pillar 2

Requirement # 41	**Precharge**	**Priority: Normal**
The BS must be able to precharge a load with a capacity of 3300µF and an inductance of 255µH		
Verification:		
The battery is able to finish the precharge-process when connected to an Fronius inverter in pillar 2		
Considered requirements:		
< pilot site requirements, etc. >		
Business use case relevance:		
Pillar 2		

Requirement # 42	**Environment-temperature**	**Priority: Normal**
The BS must be functional within following temperature range: -20°C-60°C.		
Verification:		
Test border temperatures in a climatechamber.		
Considered requirements:		
< pilot site requirements, etc. >		
Business use case relevance:		
Pillar 2		

4 DEFINITION OF EVALUATION FRAMEWORK

The scope of the section is to present the technical Key Performance Indicators (KPIs) which will enable the assessment of the performance of the project solutions as well as their impact. They are therefore an important staple in the baseline definition and evaluation task of the project.

In the next table the list of the KPIs for the validation of the demonstrators is presented.

Table 4 - KPIs for demonstrator validation.

KPI #	Description
KPI- 1	25% less time needed to manufacture the 2nd life batteries ESS when using the project enablers compared to current methods (without the enablers). This will be calculated using data collected in WP7.
KPI- 2	The 1st and 2nd life of the battery is extended by 10% when using the project enablers compared to without the enablers. This will be calculated using data collected during the project testing activities.
KPI- 3	Early detection of thermal runaway. Currently there is no detection of such incidents. This will be confirmed during the project testing activities
KPI- 4	EV battery assessment time is reduced by 25%. This will be calculated using data collected in WP7.
KPI- 5	20% improvement in reliability of EV battery state assessment when using the innovative SoX algorithms and the diagnostic tool compared to conventional assessment methods. This will be calculated using data collected in WP7.
KPI- 6	Reduction of 30% of repurposing/refurbishment cost for adapting EV batteries to stationary applications in 2nd life. This will be calculated using data collected in WP7.
KPI- 7	>25% reduction in carbon footprint for the complete battery life cycle when using the project enablers. This will be calculated in the project LCA report.
KPI- 8	Uptime or availability of the cloud BMS (>99%)
KPI- 9	Communication failures between the cloud and the edge BMS (<2%)
KPI- 10	Improve the EVRES synergy by achieving >80% synchronisation of the EV demand and RES production by exploiting storage capacities
KPI- 11	Reduce the power flow from the upstream grid by 20%

4.1 Definition of project technical KPIs

For the definition of the technical KPIs the following template has been adopted.

Table 5 - Common BATTERY2LIFE template for technical KPIs.

KPI #no	Title
Description:	*Narrative*
How to measure the KPI:	*formula*
Unit metric:	
Data type:	
Data needed to calculate KPI:	
KPI measurement:	*timeframe*

4.1 Cloud BMS

KPI #8	Uptime or availability of the cloud BMS (>99%)
Description:	*This metric measures the percentage of time a service or system is available to serve customer requests.*
How to measure the KPI:	*Server running time divided by the demonstration period*
Unit metric:	*%*
Data type:	*time*
Data needed to calculate KPI:	*Cloud performance metrics*
KPI measurement:	*timeframe*

KPI #9	Communication error rate between the cloud and the edge BMS (<2%)
Description:	*The error rate measures how often a communication link fails or a request result in an error.*

How to measure the KPI:	*Number of requests resulted in error divided by the total number of requests*
Unit metric:	*%*
Data type:	*time*
Data needed to calculate KPI:	*Cloud performance metrics*
KPI measurement:	*timeframe*

4.2 Business use case #1 - Industrial load levelling application

KPI #1	**25% less time needed to manufacture the 2nd life batteries ESS when using the project enablers compared to current methods (without the enablers).**
Description:	*By using already existing components from the 1st life battery the time can be reduced, in comparison with the use of the 2nd life modules from the 1st life battery.*
How to measure the KPI:	*time of assembly of an equivalent ESS system-time of 1st life disassembly- time of 2nd life assembly= time gained*
Unit metric:	*minutes*
Data type:	*time*
Data needed to calculate KPI:	*time of 1st life disassembly, time of 2nd life assembly, time of assembly of an equivalent ESS system*
KPI measurement:	*timeframe*

KPI #2	**The 1st and 2nd life of the battery is extended by 10% when using the project enablers compared to without the enablers. This will be calculated using data collected during the project testing activities.**
Description:	*The introduction of innovative embedded sensing and SoX estimation algorithms will enable the detailed safety and reliability of the battery and this will extend battery's life.*
How to measure the KPI:	*Compare 1st life prediction of deterioration, against 2nd life with enablers.*
Unit metric:	*Ah*
Data type:	*Capacity*
Data needed to calculate KPI:	*Battery measurement*
KPI measurement:	*Energy stored*

KPI #3	Early detection of thermal runaway
Description:	*Verification by indicating how much earlier (X min) is TRA detected. SoT will be computed based on EIS trained models. The obtained value is a proxy of the cell core temperature.*
How to measure the KPI:	*TRA event time – TRA detection time*
Unit metric:	*minutes*
Data type:	*Boolean (TRA is going to happen or not)*
Data needed to calculate KPI:	*This KPI can be addressed with testing data of T4.2. Reference cell (core) temperature estimation (will be done on a few cells only, in lab conditions).* *Measurements of EIS magnitude and phase, temperature, voltage, and time which is going to provide the estimation.*
KPI measurement:	*Testing time, some hours.*

KPI #4	EV battery assessment time is reduced by 25%.
Description:	*Reduction of EV battery state assessment time by data-driven diagnostic tool, compared to Sunlight's necessary time for EV battery evaluation by testing (estimated).*
How to measure the KPI:	*(Time SLG - Time data driven)/ Time SLG [%]*
Unit metric:	-
Data type:	*Numeric [%]*
Data needed to calculate KPI:	*1. Estimated assessment time by testing: considering modules delivery, testing, and later data analysis.* *2. Assessment time by data-driven diagnos-tic tool: Data receiving, processing, and diagnosis by data analysis. No delivery time is considered since data analysis is carried out.* *3. First life data for the data-driven diagnosis time estimation.*
KPI measurement:	

KPI #5	20% improvement in reliability of EV battery state assessment when using the innovative SoX algorithms and the diagnostic tool compared to conventional assessment methods.
Description:	*The reliability of a system can be evaluated considering the estimators, and additional functionalities available on a BMS, such as SoC, SoS, SoW, balancing, smart sensors, etc. New estimators and functionalities included, together with the improvements of the existing ones will improve whole system reliability. So, a reliability improvement matrix will be developed where each estimator, and functionality covered in the project are evaluated from reliability*

*point of view. In case of **Pillar I, SoC, SoH, SoT, SoS and SoW** will be evaluated.*

How to measure the KPI:	*1. Each estimator and functionality will be evaluated from the reliability point of view. In case of new estimators or functionalities, improvement of 100% will be considered.* *2. Individual reliability improvements will be combined as follow: sum of each improvement ratio divided by number of estimators and functionalities considered.*
Unit metric:	-
Data type:	*Numeric [%]*
Data needed to calculate KPI:	*1. Number of developed SoX and functionalities in WP4, regarding CSEM's BMS.* *2. Reliability improvement of each estimator and functionality.*
KPI measurement:	

KPI #6	**Reduction of 30% of repurposing/refurbishment cost for adapting EV batteries to stationary applications in 2nd life.**
Description:	*By designing a process partners will reduce the cost of repurposing/refurbishment learning for the production of the 2nd life battery for supporting later on the manufacturers during the transition to the 2nd life batteries market. Furthermore, after installing the embedded smart monitoring and assessment functionalities the cost will be reduced even more.*
How to measure the KPI:	*The cost to construct the first battery and the cost to construct the second battery by comparison with the cost of constructing a 1st and 2nd life battery from the ground up.*
Unit metric:	*Eur (€)*
Data type:	*Cost*
Data needed to calculate KPI:	*Cost of construction 1st and 2nd life battery*
KPI measurement:	*At the time of constructing the 2nd life battery.*

KPI #10	Improve the EVRES synergy by achieving >80% synchronisation of the EV demand and RES production by exploiting storage capacities
Description:	*The PV production at local level does not always coincide with the EV charging demand resulting in reverse power flows from the renewable sources. Storage capacity (based on 2nd life batteries) can be expoited for the more efficient integration of the renewables at local level and reduce the electrical distance between production and consumption.*
How to measure the KPI:	*Percentage of charging demand served by RES and storage capacity*
Unit metric:	*%*
Data type:	*Energy*
Data needed to calculate KPI:	*Charging demand profile, PV production profile*
KPI measurement:	*Demonstration period*

KPI #11	Reduce the power flow from the upstream electricity grid by 20%
Description:	*EV charging demand is expected to have siginificant impact on the electricity grid operation and planning, especially when considering high-power charging infrastructures. Exploiting local renewables in combination with storage capacities to serve demand at local level will enable more efficient integration of high-power charging stations and unlock new business models for the 2nd life battery storage systems in e-mobility.*
How to measure the KPI:	*Percentage of EV charging demand served by local RES and/or storage capacities.*
Unit metric:	*%*
Data type:	*Demand*
Data needed to calculate KPI:	*Charging demand profile, PV production profile, Storage profile*
KPI measurement:	*Demonstration period*

4.3 Business use case #2 - Domestic storage application

KPI #1	**25% less time needed to manufacture the 2nd life batteries ESS when using the project enablers compared to current methods (without the enablers).**
Description:	*By using already existing components from the 1st life battery the time can be reduced, in comparison with the use of the 2nd life modules from the 1st life battery.*
How to measure the KPI:	*Compare the time of disassembling from the current battery to redesigned ones on a sample base.*
Unit metric:	*minutes*
Data type:	*time*
Data needed to calculate KPI:	*Time of disassembly*
KPI measurement:	*timeframe*

KPI #2	**The 1st and 2nd life of the battery is extended by 10% when using the project enablers compared to without the enablers. This will be calculated using data collected during the project testing activities.**
Description:	*The introduction of innovative embedded sensing and SoX estimation algorithms will enable the detailed safety and reliability of the battery and this will extend battery's life.*
How to measure the KPI:	*This will be calculated using data collected during the project testing activities. Use data of cycling with and without active balancing*
Unit metric:	*Ah*
Data type:	*Energy throughput*
Data needed to calculate KPI:	*Cycling tests*
KPI measurement:	*Modelling SoH*

Co-funded by the European Union

KPI #3	Early detection of thermal runaway.
Description:	*Early detection of thermal runaway. Currently there is no detection of such incidents.*
How to measure the KPI:	*This will be confirmed during the propagation testing activities. By using smart sensors*
Unit metric:	*seconds*
Data type:	*time*
Data needed to calculate KPI:	*sensor data from testing*
KPI measurement:	*time to thermal runaway*

KPI #4	EV battery assessment time is reduced by 25%.
Description:	*Reduction of EV battery state assessment time by data-driven diagnostic tool, compared to MIBA's necessary time for EV battery evaluation by testing (real testing time if it will be done, otherwise estimated time).*
How to measure the KPI:	*(Time MIBA - Time data driven)/ Time MIBA [%]*
Unit metric:	-
Data type:	*Numeric [%]*
Data needed to calculate KPI:	*1. Estimated/Real assessment time by testing: considering modules delivery, testing, and later data analysis.* *2. Assessment time by data-driven diagnostic tool: Data receiving, processing, and diagnosis by data analysis. No delivery time is considered since data analysis is carried out.* *3. First life data for the data-driven diagnosis time estimation.*
KPI measurement:	-

KPI #5	20% improvement in reliability of EV battery state assessment when using the innovative SoX algorithms and the diagnostic tool compared to conventional assessment methods.

Description:	*The reliability of a system can be evaluated considering the estimators, and additional functionalities available on a BMS, such as SoC, SoS, SoW, balancing, smart sensors, etc. New estimators and functionalities included, together with the improvements of the existing ones will improve whole system reliability. So a reliability improvement matrix will be developed where each estimator, and functionalities covered in the project are evaluated from reliability point of view. In case of* ***Pillar II, SoC, SoH, SoF, SoW, smart sensing and active balancing*** *will be evaluated.*
How to measure the KPI:	*1. Each estimator and functionality will be evaluated from the reliability point of view. In case of new estimators or functionalities, improvement of 100% will be considered.* *2. Individual reliability improvements will be combined as follow: sum of each improvement ratio divided by number of estimators and functionalities considered.*
Unit metric:	-
Data type:	*Numeric [%]*
Data needed to calculate KPI:	*1. Number of developed SoX and functionalities in WP4, regarding AIT's BMS.* *2. Reliability improvement of each estimator and functionality.*
KPI measurement:	*N/A*

KPI #6	**Reduction of 30% of repurposing/refurbishment cost for adapting EV batteries to stationary applications in 2nd life.**
Description:	*By designing a process partners will reduce the cost of repurposing/refurbishment learning for the production of the 2nd life battery for supporting later on the new designs that are easier and more cost-efficient. Furthermore, after installing the embedded smart monitoring and assessment functionalities the cost will be reduced even more.*
How to measure the KPI:	*The cost to construct the first battery and the cost to construct the second battery by comparison with the cost of constructing a 1st and 2nd life battery from the ground up.*
Unit metric:	*Eur (€)*
Data type:	*Cost*
Data needed to calculate KPI:	*Cost of construction 1st and 2nd life battery*
KPI measurement:	*At the time of constructing the 2nd life battery.*

5 CONCLUSIONS

This document aims to analyse the system requirements of the two demo sites: a) industrial load levelling and b) home storage application. The two business applications were presented in Business Use Cases (Section 2) outlining the challenges and needs for the deployment of 2nd life batteries under different business contexts. These business challenges and needs we provide guidelines for the definition of the specifications of the different components of the cloud and edge BMS.

Additionally, the project technical KPIs were defined which will enable the assessment of the project solutions after the demonstration activities.

6 REFERENCES

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