BATTERY2LIFE

D2.3 BMS cloud platform

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LIST OF ABBREVIATIONS AND ACRONYMS

Abbreviation	Meaning
API	Application Programming Interface
BMS	Battery Management System
ECM	Equivalent Circuit Model
EIS	Electromechanical Impedance Spectroscopy
EoL	End of Life
DRT	Distribution of Relaxation time
FEC	Full Equivalent Cycles
ID	Identifier
OEM	Original Equipment Manufacturer
RUL	Remaining Useful Life
SoC	State-of-Charge
SoH	State-of-Health
SoS	State-of-Safety
SoW	State-of-Warranty
SoX	State-of-Battery

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EXECUTIVE SUMMARY

This document is a deliverable from the EU-funded project “BATTERY Management system and System design for stationary energy storage with 2nd LIFE batteries”. It represents D2.3, “BMS cloud platform”. It is an outcome of Task 2.3 and presents the design of an open cloud platform Battery Management System (BMS), which builds upon the insights from Task 1.2, to support the efficient management of 2nd life batteries in various applications. The cloud platform enables seamless communication between the embedded BMS, third-party services, data storage and management, and provides remote control and monitoring.

This deliverable provides documentation of the cloud platform’s components and functionalities, including architectural diagrams, data models, and implementation details. Initial testing focuses on the communication between third-party services and the embedded BMS, with testing datasheet, as the demonstration sites require more time to be prepared for more comprehensive testing. Moreover, a roadmap for full deployment outlines the steps for further development, integration, and validation.

In conclusion, this document provides the baseline of the cloud platform design which is a crucial component of the project providing monitoring and management of all project component, advancing the battery digital passport and thereby paving the way for 2nd life battery.

1 INTRODUCTION

In this section, is described the project introduction, purpose of the deliverable, intended audience, the correlation with other WPs and the structure of the deliverable.

1.1 Project Introduction

BATTERY2LIFE is a project, funded by Horizon Europe program that will facilitate the smooth transition of batteries to 2nd life use and boost the innovation of the European Battery Industry by providing enablers to implement open adaptable smart Battery Management Systems (BMS) and 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 the battery. Furthermore, Battery2Life introduces innovative embedded sensing and more accurate State of Battery (SoX) estimation algorithms, new SoX indicators appropriate for 2nd life use -i.e. State of Safety (SoS) and State of Warranty (SoW)- and a new Electromechanical Impedance Spectroscopy (EIS) implementation approach by integrating it in the BMS, that will enable the detailed safety and reliability monitoring at both cell and module level during 1st and 2nd life usage. The project will specify an open BMS concept, data formats, considering and extending the battery passport concept, and 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: The domestic and industrial (grid-scale) storage, with respect to their operational specificities and requirements.

The project's duration extends from January 2024 to December 2026.

1.2 Purpose of the deliverable

The deliverable aims to provide a more comprehensive description of the BMS open cloud platform of the project. It will describe the design of an open and interoperable BMS, integrating predictive analytics, complying with the battery digital passport concept, and enhancing battery lifecycle management. This approach supports an easier transition of 1st life batteries to 2nd life and improves the management of the batteries.

1.3 Intended audience

Deliverable 2.3 “BMS cloud platform” is a public document aiming to give insight into the design of the BMS cloud platform of the project. The intended audience for this deliverable includes stakeholders involved in the design, implementation, and deployment of the BMS Open Cloud Platform, as well as those interested in advancing battery management systems for 2nd life applications.

1.4 Structure of the deliverable/ correlation with other WPs

This deliverable is a continuation of the Task 1.2, and it describes in more detailed and technical manner the design of the BMS open cloud platform. The structure of the deliverable is as follows:

- **Section 2** – *Requirements and Design Principles*: Outlines the foundational principles and requirements guiding the platform's development.
- **Section 3** – *Cloud Platform Architecture*: Details the architectural design and key components of the cloud platform.
- **Section 4** – *Data Models*: Describes the data models underpinning the platform’s functionality and interoperability.
- **Section 5** – *Roadmap for Full Deployment*: Lays out the plan for achieving full-scale implementation.
- **Section 6** – *Conclusions*: Summarises the deliverable and key takeaways.

2 REQUIREMENTS AND DESIGN PRINCIPLES

This section outlines the foundational requirements and design principles of the BMS cloud platform.

2.1 Inputs from Task 1.2

The outputs of Task 1.2 provide the insight of the development of the BMS cloud platform in Task 2.3. The key insights are the following:

- **Openness and Interoperability:** To ensure seamless integration with diverse systems and vendors, standard data formats, open APIs, and compliance with the battery digital passport.
- **Cloud-Edge Interaction:** Real-time communication between cloud BMS and embedded BMS (edge BMS) should be characterised with low latency and scalability.
- **Security and Data Integrity:** The platform must incorporate all the security mechanisms to secure data transfer and access.
- **Algorithms State Machine Diagrams**: The state machine diagrams are described in *D1.2 "Open-source and interoperable BMS Principles"* and outline the workflow and transitions of the algorithms within the BMS, such as State of Charge (SoC) and State of Safety (SoS) estimators. Further details can be found in D1.2.

2.2 Design Goals

The following design principles have been established to guide the development of the BMS cloud platform:

- Openness and Vendor Neutrality
  - The platform must use open standards, ensuring compatibility with diverse systems and devices.
  - APIs and communication protocols avoid vendor lock-in must be used to support integration with existing infrastructures.
- Security
  - Ensure end-to-end encryption for all communications between the edge BMS, cloud platform, and third-party systems.
  - Implement robust user authentication and access controls to ensure data integrity and privacy.
  - Include mechanisms to detect and mitigate cyberattacks or unauthorised access.
- Scalability
  - Design for scalability in order to accommodate the growing number of devices, data streams, and business cases as the adoption of 2nd life batteries increases.

- Fault Tolerance
    - Include cloud platform load balancing, and redundancy to maintain high availability and system resilience under varying loads.
- Interoperability and Integration
    - Utilise lightweight communication protocols (e.g., HTTPS, MQTT) to support constrained embedded BMS needs while ensuring bidirectional communication.
    - Ensure compliance with the battery digital passport concept, integrating relevant data structures for monitoring and traceability.
- User-Friendly APIs and Interfaces
    - Develop RESTful Web Services for third-party integration, prioritising simplicity and ease of use.

2.3 Alignment with Project Goals

The BMS cloud platform is a cornerstone of the BATTERY2LIFE project, aligning with the following objectives:

- Supporting the transition to 2nd life applications:
    - Facilitate remote monitoring, updates, and predictive analytics to ensure optimal performance of 2nd life batteries.
- Enabling Sustainability and Innovation:
    - Promote a circular economy by extending battery lifecycles, and enabling openness and interoperability across systems and stakeholders.
- Addressing Business Needs:
    - Provide a robust and adaptable platform for industrial and residential storage applications.

3 CLOUD PLATFORM ARCHITECTURE

This section describes the architecture of the BMS cloud platform. It is designed to ensure openness, scalability, and fault tolerance. The main component of the cloud BMS is depicted in Figure 1. Further details about the functionalities of each algorithm (e.g., SoC, SoH, SoW) can be found in *D1.2 "Open-source and interoperable BMS Principles"* and *D1.3 "BMS specifications and advanced algorithms for 2nd life"*, both are public documents.

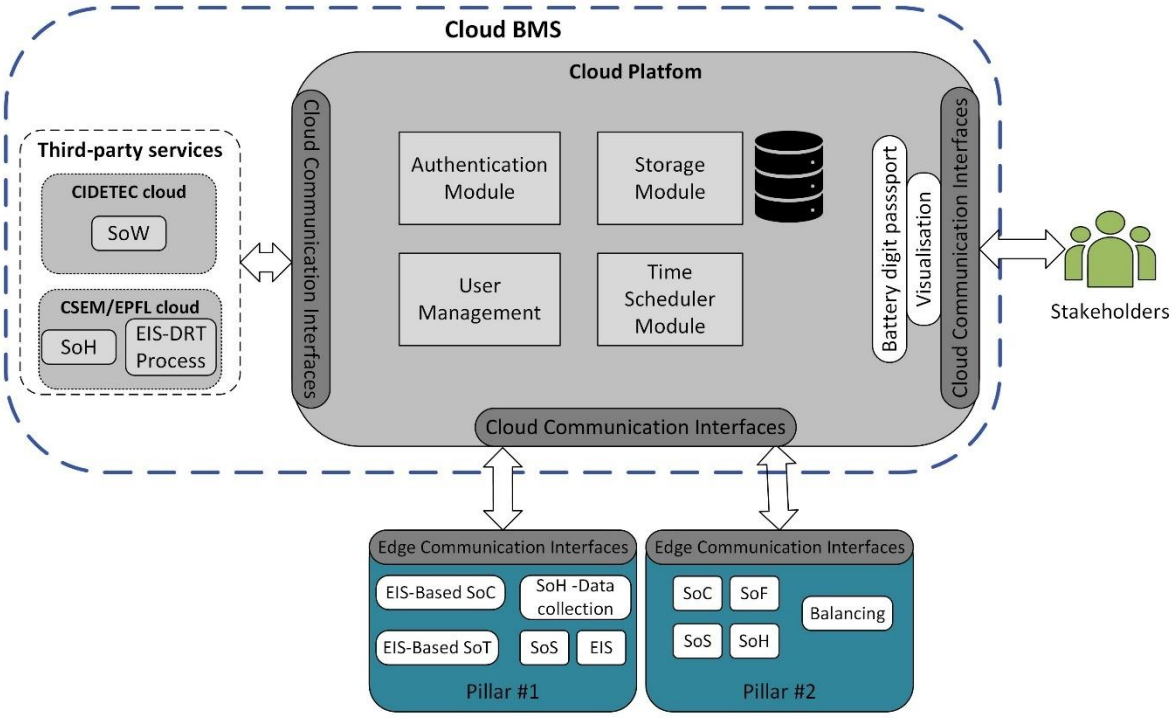

Figure 1. High-level component architecture of the BMS cloud platform

A high-level representation of the architecture is:

- **Cloud Platform Core**: A centralised infrastructure is responsible for data storage, processing and analytics.
- **Embedded BMS Interface**: Wireless communication module for data exchange between edge BMS and the cloud BMS.
- **Third-Party and Stakeholders Integration Layer**: APIs for interaction with external stakeholders, such as energy providers, manufacturers, and service platforms.
- **User Interface**: A user-friendly dashboard for monitoring and management.

Key data flows:

1. **From edge BMS to cloud BMS and backwards**: Real-time data transmission and updates on the parameters of the battery using HTTPS protocol. MQTT protocols may also be used

as follow-up action if during the validation period is suggested to enhance the data transfer.

2. **From Cloud to Third-Party Systems and Stakeholders and backwards**: Information sharing via RESTful APIs.

3.1 Components and Roles

The BMS Cloud Platform is composed of several interconnected modules:

3.1.1 Data Ingestion Layer:

- Collects real-time data wireless from edge BMS of the batteries for tracking battery states (e.g., SoC, SoH, SoW).
- Remote firmware updates for the edge BMS (e.g. update Equivalent Circuit Model (ECM) to the edge BMS).
- The time scheduler module is to update the frequency of communication between the BMS and the cloud. In specific situations or if more data are required for the cloud-based algorithms, it is given the option, through a user interface, to the users to request data from the edge BMS at a different frequency.

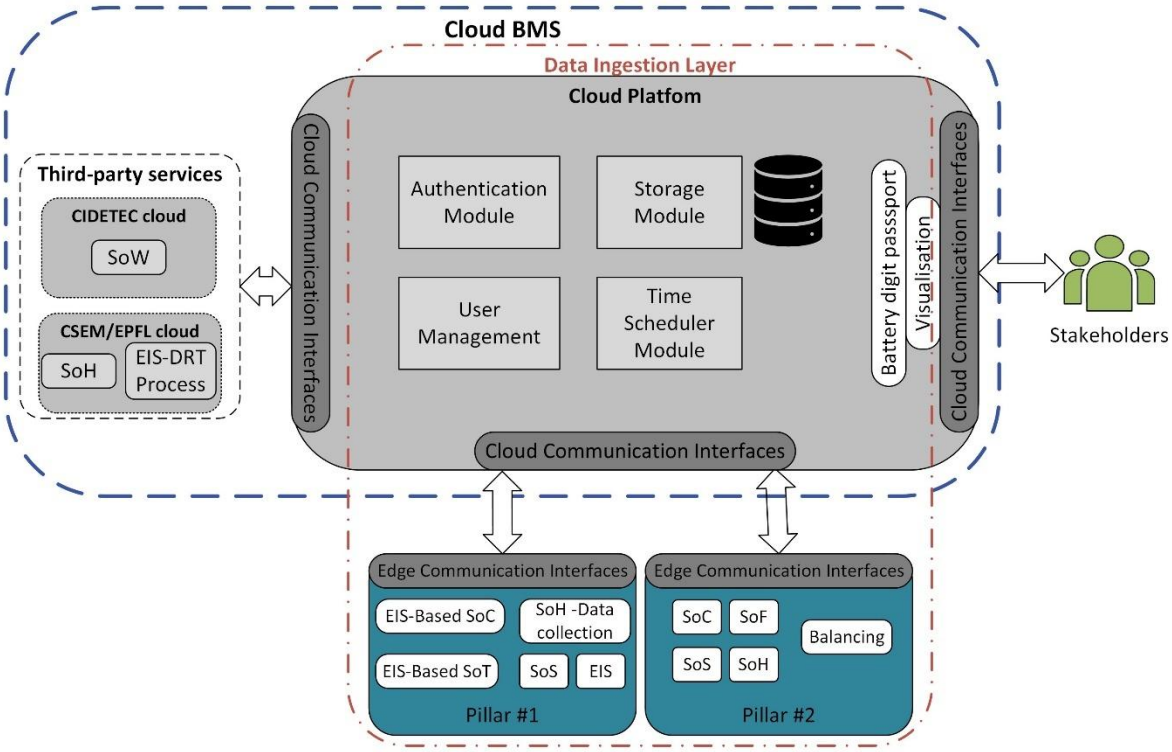

Figure 2. Data Ingestion Layer

3.1.2 API Gateway:

- Provides standardised APIs for third-party systems and applications.
- Ensures data access control and seamless integration with diverse platforms.

Figure 3. API endpoints sample

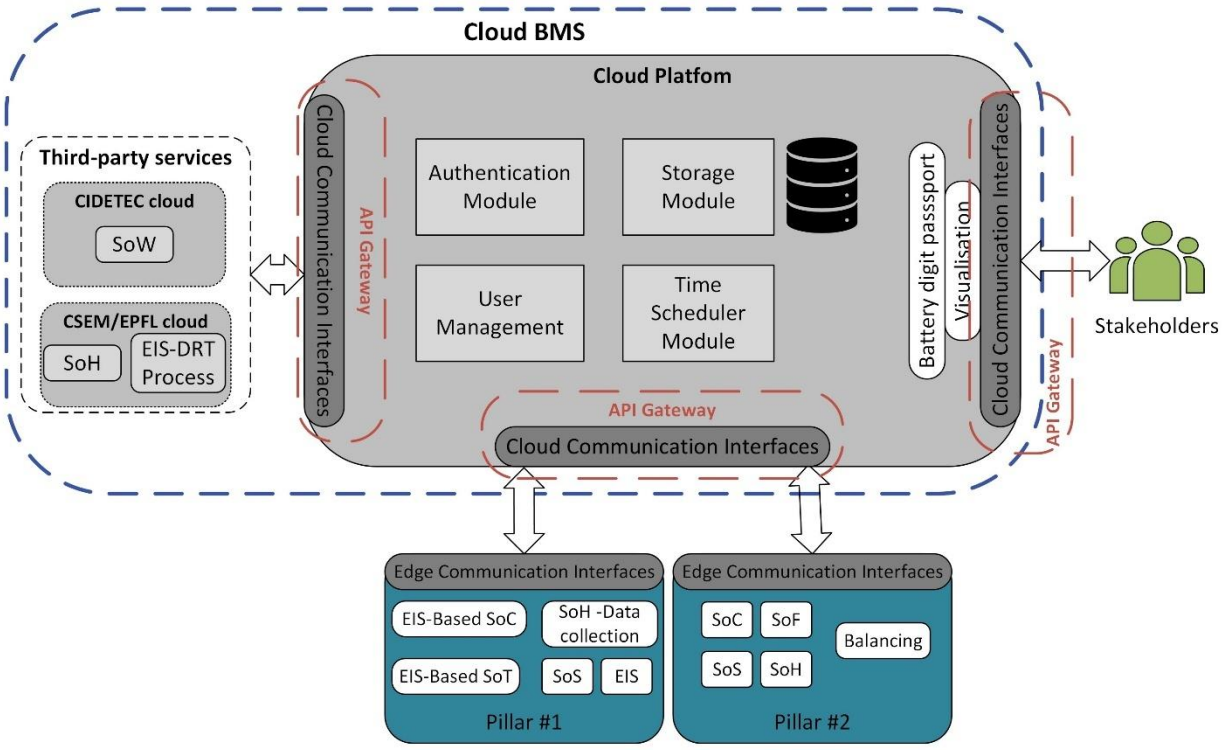

Figure 4. API Gateway

3.1.3 Security Module:

- Implements end-to-end encryption, firewalls, and intrusion detection mechanisms.
- Manages user authentication and role-based access control to prevent unauthorized access to the backend and to API endpoints. Django framework is used as it provides user management functionality and the ability to give different levels of access to various resources. Django provides different authentication methods. The one that is chosen is the JWT Token Authentication method that ensures that the resources will be accessible once a token is sent along with the appropriate credentials.
- To ensure data integrity and maintain system availability during outages, database mirroring and backup mechanisms will be implemented. The backup procedure includes full backups of the entire virtual machine.

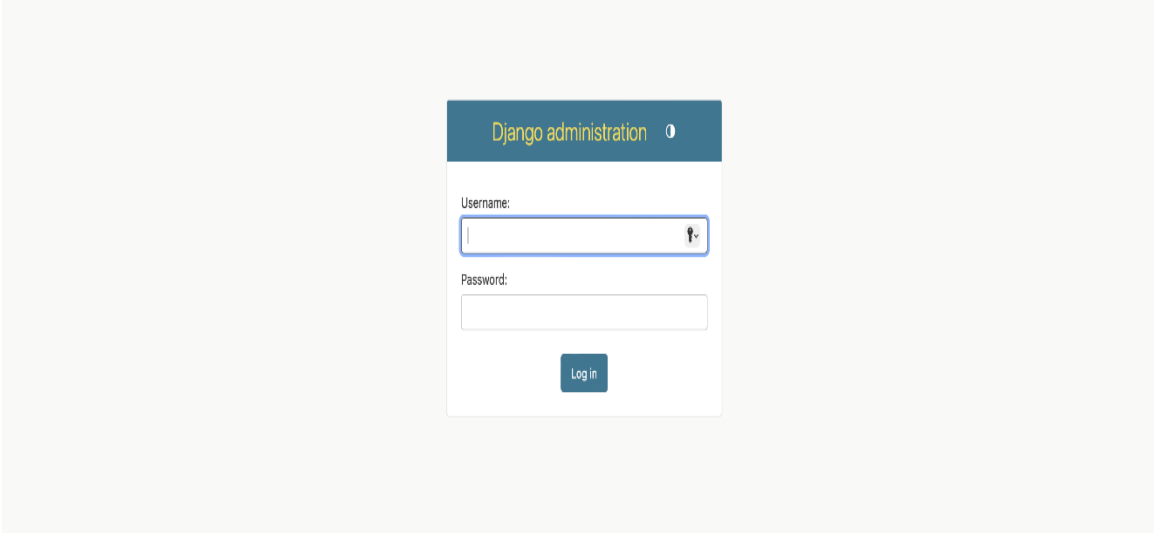

Figure 5. Back-End authentication access

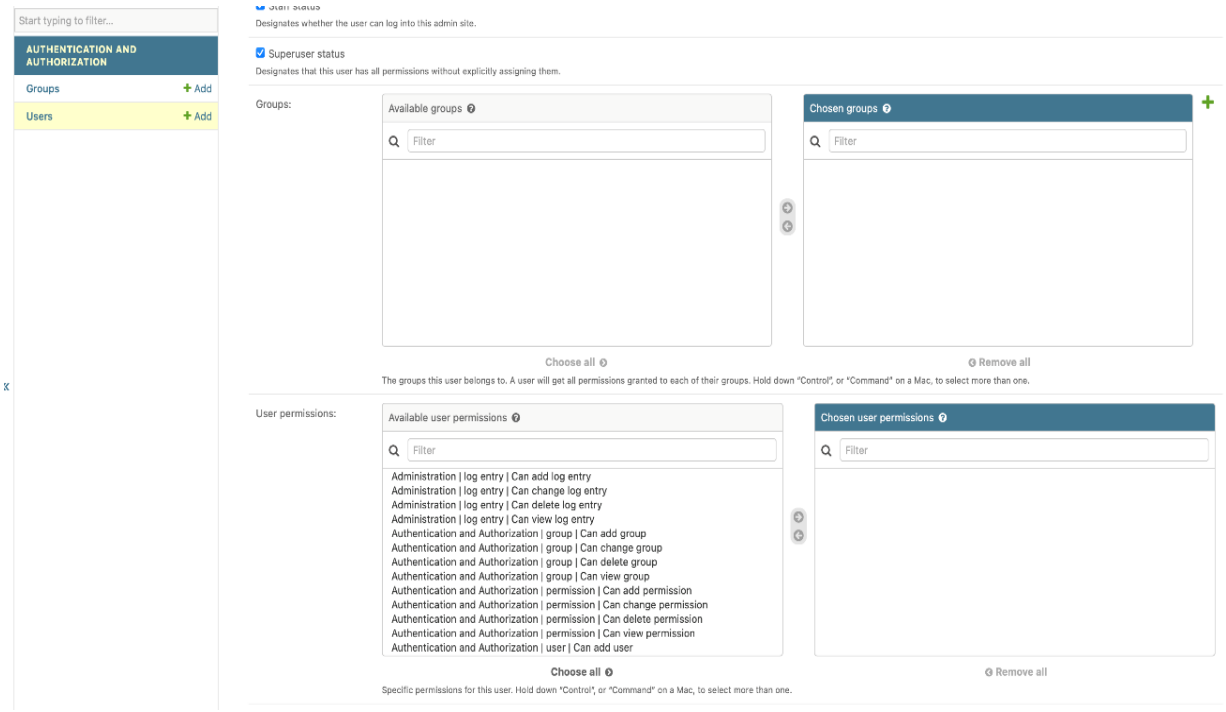

Figure 6. Backend Authentication and Authorization: Role-Based Access to Cloud Data

3.1.4 Data Processing and Analytics Engine:

- Implements diagnostic algorithms provided by EPFL and CIDETEC to assess battery performance and safety, such as forecasting the SoW and the Remaining Useful Life (RUL). Currently, they are under development and have been designed in order to ensures interoperability and seamless integration with the cloud platform. These algorithms are ideally implemented in the cloud, as they require significant computational power for the capabilities of edge BMS. They provide diagnostic insights about the battery status and updates for the edge BMS that are not directly critical to the battery's operation. In addition, more services for new diagnostic capability can be developed to meet future needs and connected to the cloud platform. Furthermore, these services can potentially be integrated into the cloud platform.

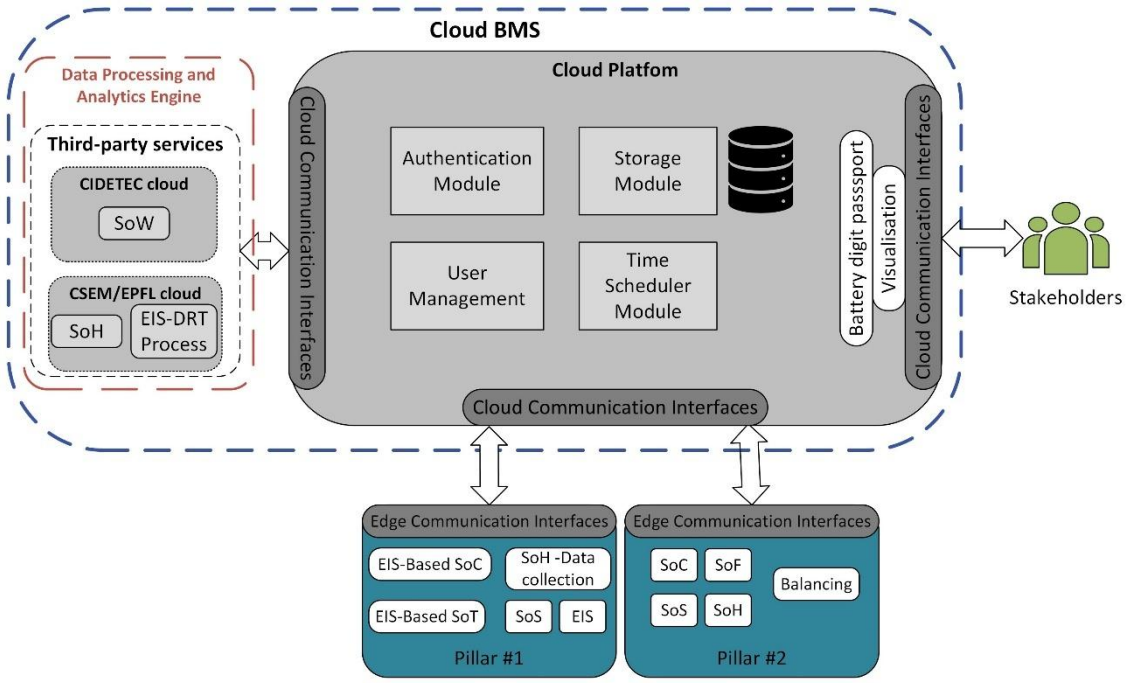

Figure 7. Data Processing and Analytics Engine

3.1.5 Database and Storage (Storage Module):

- Ensures secure and reliable storage of raw and processed data that are output from the cloud diagnostic algorithms.
- Storage all the data received from edge BMS, third-party services and the data provided by battery manufacturers.
- Historical records can be accessible for diagnostic and analytics processes. These data are presented in Section 4.
- Postgres 17 will be used as database for the project. The database Postgres 17 was chosen for its scalability, high performance, and robust support for complex data types. This aligns with the cloud platform's need to handle diverse and high-volume data load. Additionally, it's security features, such as encryption and role-based access controls, ensures data integrity while complying with the project's requirements of openness and interoperability.

3.1.6 Monitoring and Management Dashboard:

- Offers real-time visualizasion of SoX parameters, battery health, and operational analytics that are stored in the cloud platform via user friendly visualisation interfaces.
- Supports user-driven configuration and updates.

3.2 Suitability for SLG and MIBA Business Cases

The proposed cloud platform architecture has been designed to accommodate the operational needs of both SLG and MIBA business cases. For SLG's business case (industrial load levelling

applications), the platform supports seamless integration with the components of Pillar 1, provides scalability, real-time data management and advance analytics, which can assist in the optimization of the battery performance. For MIBA's business case (domestic storage applications), the platform supports adaptability to residential setups, efficient resource management, and a user-friendly visualization interface.

4 DATA MODELS

To enable seamless communication between the cloud BMS platform with the edge BMS of the battery and third-party services and stakeholders an intolerable data model should be structured. This section outlines the structure of data models, the communication standards and the alignment with the battery digital passport concept.

4.1 Data model Specification

The data models define the structure and organisation of the data exchanged between system components. The key components of the data model are:

4.1.1 Static Data

This data represents information that remains unchanged.

Some of this data has already been defined in *D1.3 "BMS specifications and advanced algorithms for 2nd life"* and a more detailed description of them can be found there. These data are 25 parameters and their time stamp values. They are the output of a diagnostic-sizing tool that is designed from CIDETEC and there will be saved to the cloud's database for each battery case separately. These will be taken into consideration for the calculation of the SoW algorithm:

	Parameter	type		Parameter	type
1.	**SoC max**	double	**14.**	**number of modules**	double
2.	**SoC min**	double	**15.**	**number of cells**	double
3.	**FECs per day**	double	**16.**	**ID of OEM**	double
4.	**Days per year**	double	**17.**	**ID of project**	double
5.	**SoH at EoL**	double	**18.**	**ID of system**	double
6.	**Enom**	double	**19.**	**T max**	double
7.	**Icha max**	double	**20.**	**T avr**	double
8.	**Icha std**	double	**21.**	**T min**	double
9.	**Idch max**	double	**22.**	**xh0_time**	Vector of doubles [5x1]
10.	**Idch mean**	double	**23.**	**xh0_FEC**	Vector of doubles [5x1]
11.	**lifespan in years**	double	**24.**	**SoH evolution**	Vector of doubles [40x1]
12.	**lifespan in FECs**	double	**25.**	**FECs evolution**	Vector of doubles [40x1]
13.	**number of packs**	double	**-**	**time evolution**	Vector of doubles [40x1]

Table 1: Diagnostic-sizing tool output parameters

In addition, battery manufacturers will be granted access to the cloud in order to provide a static list of their batteries' information via the cloud platform's user interface. They will supply as much data as possible from the following list:

- **Unique Identifier:** A globally unique ID for the battery (e.g., QR code, serial number).
- **Manufacturer Name:** Company that manufactured the battery.
- **Model and Type:** Specifications such as model number, battery chemistry (e.g., Li-ion), and capacity.
- **Production Date:** Date and location of manufacture.
- **Carbon Footprint:** Greenhouse gas emissions data for the manufacturing process.
- **Material Composition:** Specific proportions of materials used in the battery.
- **Energy Capacity:** Rated capacity.
- **Cycle Life:** Expected number of charge/discharge cycles.
- **Voltage and Current Ratings:** Maximum and nominal values.
- **Durability Metrics:** Data on expected and tested lifespan under various conditions.
- **Operating Conditions:** Typical temperature ranges, charging speeds, and storage conditions.
- **Material Recovery Information:** Percentages and quantities of recoverable materials.
- **Waste Documentation:** Information on non-recyclable components.
- **Recycling Facility:** Details of where the battery was recycled or dismantled.
- **Recycled Content:** Proportion of recycled materials used in manufacturing.
- **Regulatory Approvals:** Certifications for compliance with international and regional regulations.

This list could be modified depending on the regulations and the future needs of the battery industry.

4.1.2 Dynamic Data

These data are dynamically changing depending on the battery status (battery level) or by the new algorithm calculations that take place at the third-party service (cloud level).

At first, data is being sent from the edge BMS to the cloud. The frequency that is sent to the cloud platform depends on the edge BMS communication module, how they handle the data and manage the data traffic. Hence, in the testing phase, the optimal frequency will be defined. All this data is stored in the cloud's database. These data are presented in Table 2.

	Pillar #1		Pillar #2	
	Name	Type	Name	Type
Cell Measurement	cell_ids	int	cell_ids	int
	voltage	float	soc	double
	temperature	float	soh	double
	current	float	sos	“single” or “int”
	sot	float	Equivalent cycles	Vector of doubles
	phase	float		
	soc	float		
	sos	float		
EIS Measurements	status	str		
	event_id	str		
	cell_id	int		
	frequency	float		
	amplitude	float		
	phase	float		
	current_offset	float		
	v_start	float		
	v_end	float		
	temperature	float		

Table 2: Data transferred from edge to cloud BMS

The cell id serves as indicator of the cell inside the battery pack as it is shown in Figure 8. This allows for an analytic history of the battery cell to be created and analysed. Additional data can be also added to the data structure sent to the cloud if more information needs to be associated with the cell.

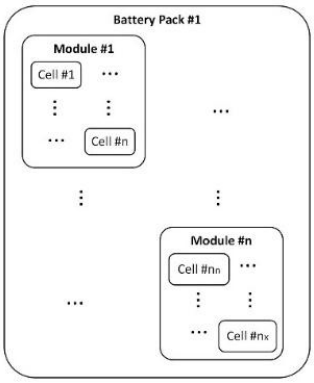

Figure 8. Battery pack architechure

Some of these data are used as input for the algorithms (SoW, SoH, EIS-DRT process) that run in the third-party services. Therefore, the necessary data is requested from the cloud to these third-party services via the communication protocols described in the next section. The outputs of the algorithms are sent back to the cloud for storage. In Pillar 1 there is an exchange of data from the cloud BMS to the edge BMS. EIS command and the ECM parameters, which are output of the EIS-DRT process, are forwarded to the edge BMS to ensure the EIS-algorithms running at the battery level, can operate more accurately with the updated parameters.

4.2 Openness and Interoperable Communication Framework

This section defines the standard communication protocols and models for data exchange between the BMS and the cloud, ensuring openness and interoperability across diverse systems and stakeholders.

The communication between the edge BMS and the cloud platform will use the HTTPS protocol to establish a request – response messaging system in a typical client – server architecture. Furthermore, an eclipse mosquitto broker server that uses the MQTT protocol is configured and ready to be utilised in case the network latency or the update functionalities need additional optimisation**.**

To facilitate seamless communication and data exchange, the following components are used:

- **RESTful APIs**
  - Allow third-party systems to access battery data through standardised endpoints. Access to these endpoints will be given only to authorised users even for the non-critical actions (GET requests for listing).
- **Api ENDPOINT -JSON RESPONSE**
  - The system will use JSON format to provide responses to the BMS or the other third-party services.

These processes are also implemented to enable bidirectional communication between the cloud and the edge BMS. Furthermore, they ensure compatibility with diverse stakeholders as RESTful APIs and JSON are open and widely adopted standards which are supported across various platforms and technologies. By avoiding closed protocols, new technologies and business cases requirements can be integrated in the future.

4.2.1 Pillar 1: Communication overview

The communication between the edge BMS in Pillar 1 and the cloud will use the protocols and architecture defined above to be established and functional.

4.2.1.1 Pillar 2: Communication Overview

In Pilar 2 additional devices will be used in order to create a gateway that will provide the necessary data to the cloud. These devices include a raspberry pi with a CAN HAT attached to it

that will be used to send / receive data from the BMS. The data will follow an agreed protocol so that they can be encoded / decoded.

4.3 Battery Digital Passport Integration

The functionality of the cloud ensures compliance with the battery digital passport as it supports:

- **Identification:** Each battery is assigned with a unique identifier, which is saved in the database. Information about the battery characteristics, battery manufacturer and other details as it is described above, is also saved with the battery identification. Additional data connected to the battery can be added to the list to comply with the battery passport regulations.
- **Lifecycle Tracking:** Each battery identification is connected with all the estimation calculated by the advance monitoring algorithm and the status of the battery during its operation. In this way, comprehensive data about the battery can be used for the evaluation of the battery performance statistics, recycling processes (promote circular economy) and more.
- **Data accessibility and transparency:** Data within the database can be accessed by those that have the authority to do so. Depending on the regulations and the agreements between the stakeholders, access can be granted to battery raw data and metadata produced by the advance monitor algorithms.

5 ROADMAP FOR FULL DEPLOYMENT

The first version of the cloud has been already deployed. At the time of writing this deliverable, communication with Pillar 1 and the third-party services is scheduled to be tested. Testing will continue with Pillar 2, which is expected to begin from M14. There might be slight changes in the parameters or/and in the architecture of the cloud if, during the testing, new solutions are identified that enhance simplicity, improve speed, or address unforeseen issues encountered during the design phase.

Further tests will take place during WP5 where the integration and validation of BMS software and hardware will occur. Stakeholders, including demonstration sites operators and project partners will actively participate in this phase to provide feedback and ensure alignment with the operational requirements.

5.1 Suitability for SLG and MIBA Business Cases

Testing and validation in demonstration sites will further ensure that the platform meets the unique requirements of these business use cases, with iterative enhancements based on stakeholder feedback. Specific scenarios, including high-demand industrial operations and localized residential storage, will be examined to validate the platform's effectiveness.

6 CONCLUSION

The cloud platform plays a vital role in the management and monitoring of the batteries and at the same time complies with the battery digital passport concept. The system delivers a comprehensive solution by combining embedded BMS at the battery level and the cloud platform. The embedded BMS is responsible for managing the battery at the battery level, where crucial operations take place, such as safety functions which requires low latency. In this way it is ensured rapid and reliable responses. Meanwhile, operations requiring significant computational power or those not directly impacting the battery functionality are executed in the cloud such as SoW, SoH and EIS-DRT process. Relative services can be easily integrated in the cloud BMS as widely recognized and publicity protocols, formats and interfaces are being used ensuring openness and interoperability.

Additionally, information reflecting the battery's state is securely stored in the cloud. Only authorised users can have access to these data. The owner of the cloud can grant access to a potential external user to all or specific data from the database depending on the user's degree of confidentiality. Moreover, the traceability of the battery is supported as the battery's important information during the battery's life cycle are being stored in the cloud database. Hence, this data can be utilized for statistical analyses, operational insights, and other purposes.

In conclusion, the cloud platform enables efficient management and monitoring, supports openness and interoperability, complies with the battery digital password by facilitating traceability and stakeholder engagement and ensures futureproofing to any changes by adapting to the evolving requirements of the battery applications, chemistry, and regulations. This can be achieved by updating the relative cloud components and BMS functionalities, making it a pivot component in the project.