Ref. Ares(2025)5319565 - 02/07/2025

Funded by
the European Union

D6.1 - Report on Standardization gaps

Project contract n:	101135417 — STAN4SWAP — HORIZON-CL4-2023-HUMAN-01	
Workpackage, WP title	WP6, Standardization Gaps	
Deliverable nr:	D6.1	
Deliverable title:	Report on Standardization gaps	
Deliverable type:	PU - Public	
Document preparation date:	2025-06-30	
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Revision history

Deliverable title: D6.1 – Standardization gaps
Filename: STAN4SWAP_D6.1_Report on standardization gaps _v1.0

Version	Date	Action	Partner
V1.0	2025-06-30	Final version	KTM F&E

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Abbreviations list

AFIR	Alternative Fuels Infrastructure Regulation (EU) 2023/1804
BMS	Battery Management System
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
DPP	Digital Product Passport
DSO/TSO	Distribution System Operator / Transmission System Operator
EaaS	Energy-as-a-Service
EU	European Union
IEC	International Electrotechnical Commission
IP	Ingress Protection (e.g., IP rating for dust/water resistance)
ISO	International Organization for Standardization
LEV	Light Electric Vehicle
LV	L-category Vehicle (as defined in Regulation (EU) 168/2013 Annex I)
OEM	Original Equipment Manufacturer
PNR	Pre-Normative Research
SBMC	Swappable Battery Motorcycle Consortium
SBS	Swappable Battery System
SOC	State of Charge
SOH	State of Health
TRL	Technology Readiness Level
V2G	Vehicle-to-Grid
VPP	Virtual Power Plant
WP	Work Package

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List of tables

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Executive summary

This Report on Standardization gaps presents the conclusive findings of Work Package 6 (WP6) of the STAN4SWAP project. With inputs from WP2, WP3, WP4 and WP5, WP6 focuses on standardization gaps, where existing international and/or European standards (including projects under development) do not address specific aspects which are deemed essential for the battery-swapping of light vehicles. WP6 identifies future standardization work, in support of interoperability, compatibility and safe and secure deployment of swappable battery systems for Light-vehicle categories. Analog to WP5, the identified topics were clustered into four domains:

- **WP6.1** – Battery level (e.g. safety, BMS optimization, end-of-life protocols),
- **WP6.2** – Vehicle level (e.g. connector design, communication, homologation)
- **WP6.3** – Charging infrastructure level (e.g. site safety, energy metering, grid integration)
- **WP6.4** – Interfaces and full system management (e.g. liability models, data exchange, platform interoperability).

By synthesizing expert discussions, regulatory, and stakeholder inputs, standardization gaps were identified, assessed, and grouped into these four core domains. Each topic was evaluated using a standardized matrix that included criteria such as TRL, regulatory context, standardization potential, and stakeholder relevance. The outcome is a prioritized matrix of standardization gaps that is ready for further processing in WP7, where it will be translated into a standardization roadmap.

1. Methodology

The methodology for Work Package 6 (WP6) was adopted from WP5 and adjusted to identify, structure, and prioritize the standardization gaps related to swappable battery systems (SBS) in the L-category vehicle ecosystem. The process is based on the consolidation of technical, regulatory, and stakeholder-based inputs from WP2, WP3, WP4 and WP5 and culminates in a prioritized matrix of items for future standardization activities aligned with the four WP6 domains.

1.1 Input Basis: Consolidation of WP2–WP5

The process began with a structured synthesis of content from:

- **WP2 – Technical and Market Analysis**, identifying challenges such as system complexity, lack of interoperability, and infrastructure gaps.
- **WP3 – Regulatory and Standardization Landscape**, highlighting existing norms and detecting standardization gaps.
- **WP4 – Stakeholder Needs Assessment**, collecting and categorizing inputs from OEMs, infrastructure operators, end users, and regulators.
- **WP5 – Needs: Development towards PNR**, collecting and categorizing inputs from OEMs, infrastructure operators, end users, and regulators.

These work packages formed the basis for identifying relevant standardization gaps.

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1.2 Expert-Led Topic Identification

In a collaborative expert process involving partners such as Swobbee, VUB, Fraunhofer ISI, and Piaggio, a broad set of unresolved technical and regulatory issues was identified. The findings were organized into four thematic domains reflecting the WP6 task structure:

- **WP6.1 – Battery level**: Topics such as thermal risk, BMS optimization, and end-of-life management.
- **WP6.2 – Vehicle level**: Mechanical and communication interfaces, safety during operation, and homologation challenges.
- **WP6.3 – Charging infrastructure level**: Station deployment, energy metering, and grid integration (e.g. V2G).
- **WP6.4 – Interfaces and full system management**: Topics such as data exchange, liability models, and cross-provider platform interoperability.

1.3 Evaluation and Prioritization Matrix

An evaluation matrix was created to assess each identified topic along key dimensions:

- Area / Technical focus
- Technology Readiness Level (TRL)
- Identified Gaps & Needs
- Relevant Regulatory Context
- Standardization Landscape and Potential
- Expected Output (e.g. guideline, specification)
- Priority Level (qualitative urgency and feasibility)
- Involved Stakeholders or Potential Research Actors

This structured scoring facilitated the transparent comparison and prioritization of identified standardization gaps.

1.4 Consolidation and Allocation

After evaluation, the topics were consolidated and assigned to one or more of the WP6 domains, ensuring thematic consistency and balanced coverage of the SBS system architecture.

1.5 Cross-Validation

The resulting matrix entries were validated by:

- Reviewing feasibility and technical maturity with support from WP2.
- Comparing regulatory relevance with WP3 findings,
- Checking stakeholder alignment using WP4 and WP5 results,

This comprehensive methodology enabled a well-founded and traceable derivation of standardization gaps that will serve as inputs for future standardization planning in WP7.

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2. Systematic Analysis of Standardization Gaps

The systematic analysis carried out in WP6 aimed to transform the consolidated inputs from WP2, WP3, WP4 and WP5 into a structured set of items that require future standardization efforts. This process was guided by the overarching goal of enabling a safe, interoperable, and scalable deployment of swappable battery systems (SBS) across Europe's light electric vehicle (L-category) segment.

To ensure a targeted and manageable analysis, the identified standardization gaps were grouped into four distinct system clusters, reflecting the internal structure of WP6: WP6.1 (battery level), WP6.2 (vehicle level), WP6.3 (charging infrastructure level), and WP6.4 (interfaces and full system management level). Each cluster represents a specific subsystem of the SBS ecosystem and was assessed with respect to its technical maturity, regulatory context, stakeholder relevance, and standardization potential.

The clustering into WP6.1–WP6.4 not only supports clarity and division of responsibilities but also enables focused technical discussion and prioritization within each domain. The resulting matrices capture these findings and present them in a form that is ready for uptake in WP7 and beyond.

This structured and system-wide approach ensures that the identified standardization gaps do not stand in isolation, but form part of a coherent framework for shaping the future standardization roadmap of swappable battery systems in Europe.

2.1 Standardization Gaps at Battery level (WP6.1)

The core of the green transition is the battery which is the critical component that determines the safety, performance, and longevity of electric vehicles (EVs). However, for the safe and efficient swappable EV adoption, the lack of harmonized standards at the battery level must be addressed. Coherent standards must be developed and enforced with the support of stakeholders, regulatory bodies, and standards organizations.

Addressing the inconsistencies in standards across manufacturers and regions is essential to ensure that battery swapping is not only fast and efficient but also **safe, reliable, and interoperable**.

This section outlines the key standardization gaps at the battery level that must be addressed to enhance the reliability, promote innovation and the continued market growth in swappable electric mobility systems.

Safety requirements:
When the manufacturers adopt varied approach for the safety thresholds, it can lead to inconsistent product quality and increased risk of thermal events. Across various battery chemistries and applications, there is a lack of standardized measures for temperature tolerance and fire hazard mitigation. Especially for the Swappable systems, there is a significant need of unified measures to ensure safety since the batteries are charged and stored in common public platforms.

Battery Management Systems (BMS):
The latest BMS technologies are very advanced and robust. Unified standards for cell monitoring, thermal control, or communication protocols can ensure compatibility, integration into larger systems and interoperability.

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End-of-Life Management:
Although there are guidelines and regulations for battery recycling, disposal, and materials recovery, these are minimal and not focused on all battery types. The implementation of enforceable standards can enhance repurposing and promote the circular economy goals.

Longevity and Durability:
Battery lifespan is very diverse based on the chemistry, materials and manufacturing practices. A standardized benchmark for durability and longevity can make it easier to product trade-offs and validate long-term credibility.

Degradation Rates:
Standards like IEC 62660 and ISO 12405 exists for validating battery degradation under different conditions. But the testing methodologies across manufacturers vary and this limits the comprehension of the performance data.

Modular Design:
There is guidance for the modular specifications at cell level like IEC 61960 which includes specification including dimensions and connectors. New guidelines and regulations for modularity at battery level implementation will support interoperability and scalability, especially in swappable battery systems. The modularity will also help adaptability to new innovations and updates.

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Area	Maturity level (TRL)	Gaps & Needs (towards TRL 8-9)	Regulatory context	Standardization landscape (TCs, SCs, WGs, …)	Standards and Regulations to be amended	Standardization expectation	Priority level	Partner / stake holder
Safety requirements		Streamlined testing/certification for Li-ion thermal runaway & propagation mitigation.	- Municipal building/fire codes vary by country.		- EN 50604 & IEC 62619 (Li-ion battery safety)	- Possibly an extension of IEC 62840-3 for indoor applications.		- Battery station manufacturers
		Streamlined testing/certification for Li-ion thermal runaway & propagation mitigation.			- EN 50604 & IEC 62619 (Li-ion battery safety)	- Possibly an extension of IEC 62840-3 for indoor applications.		- Battery station manufacturers
		- Clear underwriting guidelines for multi-operator systems.	- Battery Regulation sets performance & safety that insurers factor in.		- EN 50604, IEC 62619 (battery safety) can inform insurability.	- Possibly recognized best-practices from insurers & sector alliances.		- Battery-swapping operators
	The temperature tolerance and fire hazards measures are needed to be standardized to ensure quality of the system	Standard safety feature protocols	Batteries Regulation (EU) 2023/1542	IEC TC 69		Establishing to ensure the safety and sustainability of batteries used in two-wheelers, promoting a safer transport.	**High** (critical for avoiding hazards)	Standards and regulatory **authorities**

Table 1: WP6.1 Standardization Gaps at Battery level Part I

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Area	Maturity level (TRL)	Gaps & Needs (towards TRL 8-9)	Regulatory context	Standardization landscape	Standards and Regulations to be amended	Standardization expectation	Priority level	Partner / stake holder
Battery management system	The cell monitoring and temperature control withing the battery has no standard approach	Real-time SOH, SOC monitoring	Batteries Regulation (EU) 2023/1542	ISO TC 22 SC38		Ensuring reliability of the swappable system and promoting traceability and transparency	**Medium** (ensures reliability and helps optimization of the operations)	BMS and battery manufacturers
	~6–7 (robust BMS exist, but not fully standardized across networks)	- Unified SoC/SoH data model across different OEMs/stations.		Standardization committees (IEC TC69 WG13, ISO TC22/SC37)	- IEC 62840-1/CDV includes references for BMS data.	- Agreed data structure for consistent SoC, SoH, usage reporting across networks. Accurate calculation of battery capacity, SoC, usage patterns for daily ops.	**Medium** (technical feasibility proven; standardizatio n needed for cross-compatibility)	BMS developers
End-of -life management	Guidelines for recycling, disposal and repurposing of batteries are only at a minimal level	Establishing clear guidelines at quantitative levels		Standardization committees (IEC TC69 WG13, ISO TC22/SC37)	Batteries Regulation (EU) 2023/1542	Support the EU's broader efforts to promote a circular economy and reduce the environmental impact of battery use and disposal.	**Medium** (essential for ensuring circular economy in the system)	Battery manufacturers and recycling partners

Table 2: WP6.1 Standardization Gaps at Battery level Part II

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Area	Maturity level (TRL)	Gaps & Needs (towards TRL 8-9)	Regulatory context	Standardization landscape	Standards and Regulations to be amended	Standardization expectation	Priority level	Partner / stake holder
Longevity/durability	Different manufacturers use varying technologies and materials leading to discrepancies in battery lifespan	Standardizing durability metrics to ensure consistent performance across swappable batteries	IEC 62660 ISO 12405	Standardization committees (IEC TC69 WG13, ISO TC22/SC37)	- EU Battery Regulation (2023/1542)	Standard Testing protocols that simulate real-world conditions such as varying temperature, humidity and usage patterns	**High**	Battery manufacturers
Degradation rates	Standards like IEC 62660 and ISO 12405 provide guidelines for testing and evaluating battery performance, including degradation rates under various conditions.	Inconsistent metrics for measuring and reporting degradation rates, making it difficult to compare batteries from different manufacturers.	IEC 62660 ISO 12405	Standardization committees (IEC TC69 WG13, ISO TC22/SC37)	- EU Battery Regulation (2023/1542)	Establishing unified testing methods to measure and predict degradation to maintain reliability in swapping systems.	**High** (critical for ensuring reliability)	Battery manufacturers

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Modular design	Modular battery systems are guided by standards such as IEC 61960, which focus on cell and module specifications. These standards promote uniformity in battery dimensions, connectors, and interfaces to facilitate compatibility and ease of integration.	Absence of comprehensive standards for modularity in battery packs, leading to challenges in interoperability between vehicles and swapping stations.	No existing regulations for modular design.	Standardization committees (IEC TC69 WG13, ISO TC22/SC37)	- EU Battery Regulation (2023/1542)	Standards focused on scalability, adaptability of modular designs in battery pack level to accommodate future technological advancements	**Medium** (can help widespread adoption of the system and upgrading future products	Battery manufacturers

Table 3: WP6.1 Standardization Gaps at Battery level Part II

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2.2 Standardization Gaps at Vehicle level (WP6.2)

This section provides a detailed overview of the standardization gaps identified at the vehicle level within the project. Initially, the key focus areas of WP6.2 are outlined, highlighting the primary challenges of vehicles with swappable batteries. Following this, a comprehensive table presents the main outputs of WP6.2. This structured format aims to clearly convey the prioritization and potential impact of each topic within the context of future standardization efforts.

Interface connector (mechanical) vehicle <–> battery:
An easy and error-free plugging between battery, charging connector and vehicle is very important. From the perspective of the vehicle, it is essential to establish an effective and secure link between the battery and the vehicle.

Battery mechanical requirements:
The battery mechanical requirements refer to standardized specifications for the physical aspects of batteries used in vehicles, especially in the context of swappable battery systems. These requirements include dimensions such as length, width, and height, alongside weight, IP rating (Ingress Protection), and ergonomics. The aim is to create a unified standard across different Original Equipment Manufacturers (OEMs) to ensure compatibility and interoperability.

Battery electrical requirements:
The battery electrical requirements focus on defining the minimum electrical specifications necessary for swappable battery systems in vehicles. These include requirements related to voltage, capacity, charging power, configuration of cells, to ensure compatibility and interoperability between different manufacturers' systems. The aim is to establish standardized electrical properties for swappable batteries, facilitating their integration across various electric vehicles and enhancing their safety and performance standards.

Interface communication vehicle <–> battery:
The interface communication between a battery and a vehicle focuses on establishing standardized communication protocols to ensure seamless integration and data exchange. Many OEM-specific solutions exist without consistency. The aim is to create a uniform communication protocol for swappable batteries.

EU WVTA:
The WVTA sets comprehensive standards for vehicle safety and environmental compliance, which new technologies like battery swapping must navigate. Without existing standardized regulations specifically for swappable batteries, there is a difficulty in achieving approval, leading to regulatory hurdles.

Vehicle on-board charger:
The charger must meet specific standardization requirements to ensure safe and efficient operation, including mechanical design, electrical connectors, and safety features. Compatibility and interoperability across different vehicle models and charging infrastructures are critical for effective charging solutions and energy management.

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Area	Maturity level (TRL)	Gaps & Needs (towards TRL 8-9)	Regulatory context	Standardization landscape (TCs, SCs, WGs, ...)	Standards and Regulations to be amended	Standardization expectation	Priority level	Partner / stake holder
Interface: connector (mechanical) vehicle <–> battery	standards for automobiles exist and also connections for permanently installed batteries, otherwise many OEM-specific solutions - not consistent	There are some good approaches with existing products, but not the perfect solution for all use cases. This gap should be closed through standardization in order to create a uniform and comprehensive solution that meets the diverse requirements. By introducing standards, interoperability and compatibility can be improved, ultimately leading to more efficient and user-friendly products.	Battery Regulation (EU) 2023/1542 - Article10 Performance and durability requirements AFIR Regulation 2023/1804 -Article 3 Targets for recharging infrastructure dedicated to light-duty electric vehicles	ISO TC22/SC38 CEN TC301	new standard	definition of a solid and reliable connection for a swappable battery solution versus permanently integrated batteries,	**High** topics need further technical understanding and identification	Vehicle & Battery manufacturers
Battery mechanical requirements	the physical dimensions (length/width/height), weight, IP rating and ergonomics are currently different for each OEM and should be standardized				new standard	definition of physical dimensions for a swappable battery solution versus permanently integrated batteries,		Vehicle & Battery manufacturers
Battery electrical requirements	The minimum electrical requirements for voltage, capacity, charging power, configurations (parallel/serial) are currently different for each OEM and should be standardized					definition of electrical requirement for a swappable battery solution versus permanently integrated batteries,		Vehicle & Battery manufacturers

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Table 4: WP6.2 Standardization Gaps at Vehicle level Part I

Area	Maturity level (TRL)	Gaps & Needs (towards TRL 8-9)	Regulatory context	Standardization landscape (TCs, SCs, WGs, ...)	Standards and Regulations to be amended	Standardization expectation	Priority level	Partner / stake holder
Interface: communication vehicle <–> battery	standards for an interface do not exist, many OEM-specific solutions - not consistent	There are some good approaches with existing products, but not the perfect solution for all use cases. This gap should be closed through standardization in order to create a uniform and comprehensive solution that meets the diverse requirements. By introducing standards, interoperability and compatibility can be improved, ultimately leading to more efficient and user-friendly products.	Battery Regulation (EU) 2023/1542 - Article10 Performance and durability requirements AFIR Regulation 2023/1804 -Article 3 Targets for recharging infrastructure dedicated to light-duty electric vehicles	ISO TC22/SC38 CEN TC301		Comparability of data exchange without significant change	**High** topics need further technical understanding and identification	Vehicle & Battery manufacturers
EU WVTA		current regulatory framework does not consider the WVTA (whole vehicle type approval) without including the dedicated propulsion battery	EU L-category Type Approval Regulation (EU) 168/2013	DG GROW	reg. (EU) 168/2013 Amendment of the regulation to facilitate EU WVTA for a vehicle which is designed to be powered by standardized swappable batteries. The max. vehicle performances are managed and limited by the vehicle design and vehicle management systems (e-motor/converter) and not by the battery itself.			
vehicle on-board charger		lack of harmonization of connectors to the grid and to charging stations for low-power charging	AFIR Regulation (EU) 2023/1804	DG MOVE	The lack of harmonized connectors for low-power charging should be addressed within the AFIR regulation. --> this issue is not explicitly related to Swappable Battery Systems and is therefore considered as "out of scope" of Stan4SWAP. However, the issue may be addressed in the project deliverable via a general comment on implementation			Vehicle manufacturers

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					barriers for L-cat. electric vehicles in the EU			

Table 5: WP6.2 Standardization Gaps at Vehicle level Part II

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2.3 Standardization Gaps at charging station infrastructure level (WP6.3)

This section provides a detailed analysis of the standardization gaps identified at charging station/infrastructure level within the project. It begins by explaining the key areas of focus identified in WP6.3, highlighting the primary challenges and opportunities for standardization. Subsequently, a detailed table is presented, summarizing the main outputs of WP6.3.

General installation requirements:
The general installation requirements at the charging station/infrastructure level focus on ensuring safety, legal compliance, and efficient integration into the power grid. Key aspects include uniform safety standards to ensure acceptance by site partners, safe storage and monitoring of batteries during charging, and legal security for installing charging infrastructure to facilitate quick approval by cities and public institutions.

Fire safety for battery systems:
The focus on fire safety for battery systems at the charging station/infrastructure level involves ensuring comprehensive fire safety measures for swap cabinets, charging areas, and storage systems.
This is crucial for maintaining public confidence and safety in using battery swapping systems.

Risk assessment and risk management:
The risk assessment and risk management identify critical risks and proposes mitigation strategies. For example, handling fire at the charging station and the impact on the environment.

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Area	Maturity level (TRL)	Gaps & Needs (towards TRL 8-9)	Regulatory context	Standardization landscape (TCs, SCs, WGs, …)	Standards and Regulations to be amended	Standardization expectation	Priority level	Partner / stake holder
general installation requirements		- Standard footprints/connectors for kiosk installations.	- National/local building codes (zoning, fire dept approvals).	- Possibly relevant to CENELEC TC 64 (electrical installations).				- Building regulators
		- Ventilation & spacing guidelines.		- National code committees (DIN, NF, etc.)				- National code committees (DIN, NF, etc.)
fire safety for battery systems (swap cabinets, charging areas, storage).	~7 (piloted battery swap stations w/ fire-safety features, but no uniform EU approach)	- Harmonized fire protection requirements (indoor/outdoor).	- EU Battery Regulation (EU) 2023/1542 includes safety & sustainability.		- IEC 62840-1 & IEC 62840-3 (safety for battery swap systems)	- Harmonized guidance for battery swap fire detection & containment.	**High** (fire incidents risk damaging public confidence)	- Fire safety authorities, e.g. TÜV / DEKRA
		- Unified safety assessment for large battery deployments.	- Insurance & liability regs.		- IEC 60335 series (chargers/appliances)			- Building code experts
				- CEN/CENELEC committees				- CEN/CENELEC committees
Risk assessment and risk management	N/A (industry readiness / policy aspects)	- Risk models for battery handling/storage.	- No direct EU directive on battery insurance.		- Not a typical IEC/ISO domain. Possibly referencing risk management frameworks (ISO 31000).	- Industry-driven guidelines on coverage & liability disclaimers. Uniform insurance coverage requirements for battery systems (fire, damage, liability) and swap-station operations.	**Medium** (essential for large-scale rollout, but largely driven by insurers & operators)	- Insurance sector (Allianz, Zurich, etc.)

Table 6: WP6.3 Standardization Gaps at charging station/infrastructure level

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2.4 Standardization Gaps at interfaces and full system management level (WP6.4)

This section provides an in-depth analysis of the standardization gaps identified at interfaces and full system management level within the project. It begins by explaining the key areas of focus identified in WP6.4, highlighting the primary challenges and opportunities for standardization. Subsequently, a detailed table is presented, summarizing the main outputs of WP6.4.

Data management:
Data management involves handling the data lifecycle, which includes data collection, storage, processing, and sharing, while ensuring data quality and security. This process involves setting up systems to support data interoperability, ensuring that data can be easily accessed, analysed, and integrated with other systems. It also entails establishing protocols for data backup, recovery, and compliance with relevant data protection regulations, which are crucial for maintaining the integrity and confidentiality of the data.

Battery life-cycle management:
A standardized approach for assessing energy throughput and predicting battery life. It involves creating a common data exchange format to ensure seamless communication and interoperability across different systems and platforms. This is essential for the long-term battery health, for example.

Business model:
A key aspect is clarifying the tax treatment, whether these systems are considered an energy supply or a service, as this has significant implications for fiscal policies and compliance across various jurisdictions. Additionally, establishing an EU-level approach for cross-border scenarios is crucial. This focuses on creating consistent frameworks for liability, insurance, and data exchange across member states, enhancing interoperability and reducing administrative complexity for operators in different regions. These efforts aim to support the efficient deployment and management of swappable battery systems while fostering market expansion within the EU.

Smart Grid integration:
The integration of smart grids at the interfaces and full system management level focuses on several key aspects. Real-time State of Charge (SoC) control and aggregator frameworks are essential for efficiently managing energy distribution and optimizing battery usage across multiple users and systems. Ownership and legal aspects of "mobile" battery feed-in involve clarifying who holds rights and responsibilities as batteries feed energy back into the grid, ensuring that legal frameworks support mobile and distributed energy resources. Economic models and grid acceptance examine the financial viability and regulatory acceptance of utilizing swappable battery systems within the grid, emphasizing the need for business models that align with grid operations and energy markets. These efforts collectively aim to enhance the interoperability and efficiency of battery systems within smart grids.

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Location management:
The aspect of location management focuses on the harmonization of building and permitting codes across different regions. This involves aligning local zoning laws, building codes, and safety regulations to ensure uniformity in the deployment of battery swapping stations. Such harmonization is crucial for minimizing disparities in regulatory requirements, which can pose challenges to the installation and operation of these stations.

Conformance testing:
Conformance testing focuses on ensuring that various components of a swappable battery system function together seamlessly across different regions. This includes testing the interoperability and compatibility of hardware and software interfaces, as well as ensuring data exchange processes meet international standards. A key aspect is achieving cross-border coverage consistency, which involves developing uniform insurance and liability frameworks to manage risks when swappable battery systems are deployed in different regulatory environments. This consistency is essential for reducing administrative complexity and ensuring that systems are insurable and operational across various jurisdictions without interruption.

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Area	Maturity level (TRL)	Gaps & Needs (towards TRL 8-9)	Regulatory context	Standardization landscape (TCs, SCs, WGs, …)	Standards and Regulations to be amended	Standardization expectation	Priority level	Partner / stake holder
Data management	A Backend, with standardized cybersecurity features, is necessary for the data collecting, exchanging and management from different batteries and charging stations belonging to different EaaS operators in order to guarantee the Interoperability;	Nothing exists but there are good examples in other business categories (bank, Communication Operators, etc)	- CRA (EU) 2024/2847 - Data Act (EU) 2023/2854 - GDPR (EU) 2016/679	IEC TC69 – OCA	IEC63584-210 now at (fast track) CDV level; this is the OCPP2.1 which also features battery swapping use cases; Also IEC 63110, IEC 63119 for roaming, ISO 15118 for EV comms	data (& money) collecting, exchange, management within a cybersecure world	**Medium**	IEC TC69 – OCA
	Cybersecurity issues regarding authentication have also to be urgently considered			CEN/CENELEC JTC13	EU Battery Regulation (2023/1542)		**High**	CEN/CENELEC JTC13
Battery life-cycle management		- Standard method for energy throughput & battery life predictions.	- RED delegated act for secure wireless data transfer.					
		- Common data exchange format.		IEC TC21 (Batteries), IEC TC69 WG13 (Swapping), ISO TC22/SC37(Road vehicles), ISO TC22 SC38 (Motorcycles/Mopeds)	EU Battery passport			IEC TC21 (Batteries), IEC TC69 WG13 (Swapping), ISO TC22/SC37(Road vehicles), ISO TC22 SC38 (Motorcycles/Moped s)
Business model	N/A (policy maturity rather than technology)	- Clarify tax treatment (energy supply vs. service?).	- National energy tax laws.		- Taxation law (national legislation)	- Not directly about product standards; more about guidelines to standardize how energy usage data is reported (could help authorities). Ensuring (or clarifying) tax exemptions/levies for battery swapping, electricity usage, battery subscription models.	**Medium** (fiscal incentives can accelerate adoption)	- Ministries of Transport/Energy/Finance
		- EU-level approach for cross-border scenarios.	- AFIR (EU) 2023/1804 to promote e-mobility, but no direct "tax" language.		- Could align with relevant data format standards if consumption must be uniformly reported.			- Industrial associations
			- Competition rules for possible cross-country differences.		- harmonization of national regulations			- EU Commission (DG TAXUD)

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Table 7: WP6.4 Standardization Gaps at interfaces and full system management level Part

Area	Maturity level (TRL)	Gaps & Needs (towards TRL 8-9)	Regulatory context	Standardization landscape (TCs, SCs, WGs, …)	Standards and Regulations to be amended	Standardization expectation	Priority level	Partner / stake holder
Smart Grid integration	~6 (pilots exist for V2G in fleets; still early for swappable battery networks)	- Real-time SoC control, aggregator frameworks.	- AFIR 2023/1804 fosters alternative fuelling & smart solutions but not explicit for removable battery feed-in.	IEC TC69 WG13	- IEC 62840 series, potential future adaptation for bidirectional flow.	- Clear aggregator communication standard for swappable battery nodes.	**Medium–High** (significant potential for energy transition)	- DSOs/TSOs (grid operators)
		- Ownership & legal aspects of "mobile" battery feed-in.	- National grid codes & electricity market rules.	IEC TC69 WG9; IEC TC69 JWG1 (with ISO TC22 SC31)	- IEC 63119, ISO 15118-20 for V2G communications.	- Mechanisms for verifying battery ownership, scheduling feed-in, settling payments.		- Battery station operators
		- Economic models & grid acceptance.		IEC TC69 PT63380; IECTC69 JWG15 (with TC57)	IEC 63380 series for local energy management systems; IEC63382 series for distributed energy systems	Using swappable batteries as grid assets (load balancing, V2G, aggregator-driven "virtual power plants").		- Aggregator platforms
								- IEC TC69, TC57 standard committees
Location management	~7 (examples in some EU cities, no universal approach)	- Harmonized building/permitting codes across regions.	- AFIR (EU) 2023/1804 sets overarching alt-fuel infra goals, not specifics on swap station siting.		- IEC 62840-3 (removable battery systems, if extended to installation).	- EU-wide guidance (CEN/CLC TS or EN) for battery swapping station design, recommended spacing & ventilation. Standard installation criteria for swapping stations (indoor/outdoor, safety zones, mechanical footprints).	**High** (critical for widespread deployment & acceptance)	- Station OEMs
Conformance testing		- Cross-border coverage consistency.						- Certification/lab testing bodies (TÜV, DEKRA)

Table 8: WP6.4 Standardization Gaps at interfaces and full system management level Part II

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Conclusions

The report highlights areas where existing standards are insufficient or non-existent, providing detailed insights into technical requirements, safety protocols, and interoperability challenges essential for market deployment and consumer trust. These findings set the groundwork for developing targeted standardization efforts crucial for the deployment of safe, interoperable, and sustainable swappable battery systems (SBS) across Europe. The methodology used was fully aligned with the technical, regulatory, and stakeholder-specific findings from work packages WP2, WP3, WP4, and WP5.

Analog to WP5, the identified topics were clustered into four domains—battery (WP6.1), vehicle (WP6.2), charging infrastructure (WP6.3), and system interfaces (WP6.4) to address the full scope of the SBS ecosystem.

The basic structure for the resulting evaluation matrix was adopted from WP5, with an emphasis on identifying standardization gaps.:

- A clear mapping of standardization gaps,
- Corresponding TRL assessments,
- Associated standardization potential,
- Recommendations for stakeholder involvement.

Together with the results of the previous WPs, WP6 will now serve as input for WP7, where standardization roadmaps and normative development activities will be derived from the identified gaps. This will pave the way for a more cohesive and unified approach to integrating swappable battery systems and accelerate the transition to sustainable mobility.

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Glossary

L-category Vehicle (LV) – Any two-three and four wheeled vehicles classified according with regulation 168/2013 Annex I.
Pre-Normative Research (PNR): Research activities aimed at developing the foundational knowledge and methodologies needed for future standardization efforts.
Swappable Battery System (SBS): A system that allows batteries to be easily swapped in and out of vehicles, particularly light electric vehicles.
Battery Management System (BMS): A system that manages the performance, safety, and reliability of batteries, including monitoring their state of charge (SoC) and state of health (SoH).
Technology Readiness Level (TRL): A scale used to assess the maturity of a particular technology, ranging from basic research (TRL 1) to full commercial deployment (TRL 9).
Vehicle-to-Grid (V2G): A technology that allows electric vehicles to feed energy back into the power grid.
Virtual Power Plant (VPP): A system that aggregates multiple distributed energy resources, such as batteries, to operate as a single power plant.
Original Equipment Manufacturer (OEM): A company that produces parts and equipment that may be marketed by another manufacturer. 21
Ingress Protection (IP): A rating system that defines the levels of sealing effectiveness of electrical enclosures against intrusion from foreign bodies and moisture.
Light Electric Vehicle (LEV): A category of electric vehicles that includes two, three, and four-wheeled vehicles, typically used for short-distance travel.
Energy-as-a-Service (EaaS): A business model where energy services are provided to customers on a subscription basis.

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