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D7.1 – Standardization Roadmap about Swappable Battery System for L-cat vehicles

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Abbreviations list

AFIR	Alternative Fuels Infrastructure Regulation (EU) 2023/1804
BMS	Battery Management System
CAN	Controller Area Network protocol
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
CRA	European Cyber Resilience Act, Regulation (EU) 2024/2847
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 Batteries 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
WVTA	Whole Vehicle Type Approval

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Executive summary

The transport sector is responsible for around 25% of the EU total emissions. The European Green Deal is calling for all stakeholders of the European transport sector to support the deployment of cleaner and more energy efficient vehicles, to be able to live up to the goals set out in the Paris agreement. To this end, electric vehicles (EVs) play an important role in the decarbonization of the sector. However, the downtime required to charge the batteries of these vehicles is a hindrance to a more widespread adoption of the technology. This is true both when it comes to EVs used for long distance transportation as well as for the light categories (L-cat) EVs with limited energy storage capacity often used in urban environment for shorter distances. This hindrance can be addressed with battery swapping systems which allow the users of EVs to swap empty batteries with fully charged ones. This solution offers a lot of benefits for cities and citizens including improved air quality and potential support to solving congestion challenges. However, for the innovation to fulfil its potential interoperability is essential.

The Horizon Europe CSA (Coordination and Support Action) project Stan4SWAP recognizes the need for integrating standards into the innovation process from an early stage to ensure swift transition. The project works in a holistic manner along the full value chain of L-cat mobility to identify the issues, challenges, and gaps which may be eased by standardization. The aim is to ensure interoperability of swappable batteries among different vehicles and swapping stations. To boost the industrial deployment of this innovative technology, the project will develop a standardization roadmap for a Swappable Battery System for L-cat vehicles. This roadmap aims at being a full part of the EU standardization work program for the following years and send a significant signal to all stakeholders of the value chain to join efforts and contribute to the work.

The present document: D7.1 proposes a standardization roadmap and recommendations, in support of a swappable battery system for L-cat vehicles market and boosting its deployment, as a contribution to the EU's decarbonation mobility strategy, especially in an urban context.
Interoperability, compatibility, as well as safe and secure communication are overarching principles driving the drafting of this standardization roadmap.

The roadmap includes Pre Normative Research (PNR) and standardization challenges and needs related to swappable battery systems for L-cat vehicles.
Special attention is also considered regarding safe and secure swapping phase, with appropriate communication steps towards ensuring the swap of empty battery packs to charged ones, as well as evaluating if the battery packs are still valid for primary applications (mobility), or needs to move to secondary life, then to end of life.

Recommendations focus on:
- Regulation improvement, coherence, and complementarities
- Support to PNR
- Standardization development
- Education and training
- Strengthening active international cooperation

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1. Introduction

Standards play a crucial role in fostering economic efficiency, particularly in the context of industrial production, technological innovation, and market expansion. When all conditions are met, standards create a robust framework that enhances productivity, minimizes costs, and accelerates market access.

Table 1 below summarizes main tasks standards contribute to support with the major related economic effects (Source: based on Tassey (1982, 2000) and Swann (2000)[1]):

Task	Characteristics
Compatibility and Interoperability	• Description of required product characteristics for interaction in a technical system • Favoring of component innovations
Quality and Security	• Definition of set points, e.g. function level, performance and efficiency variance • Reduction of the users' transaction costs
Reduction of variants	• Limiting the characteristic attributes of a product / system, e.g. in terms of size and quality • Favoring of economies of scale • Reduction of investment risks
Provision of information and measured values	• Provision of information to describe, quantify and evaluate (product) characteristics • Reduction of transaction costs between suppliers and buyers

Table 1: Classification of specifications and standards based on economic effects

Stan4SWAP is a Horizon Europe CSA (Coordination and Support Action) project to boost standardization for swappable batteries of light electric vehicles (EVs of L-category) in support of a quick, effective and performant mobility scheme. While several standards exist for L-category vehicles, there is an urgent need to contribute in a significant and organized manner to setting up a roadmap for standardization in support of unified interoperable systems.

Stan4SWAP proposes to develop a robust standardization roadmap towards boosting innovation to market for Swappable Battery Systems for L-cat vehicles deployment as a major contribution to safe, secure, resources and environmentally friendly and interoperable decarbonization solution of the Mobility-Transport sector.

[1] Swann, G. P. (2000). The Economics of standardization. Final Report for Standards and Technical Regulations Directorate Department of Trade and Industry. Manchester Business School. University of Manchester Manchester 2000.
Tassey, G. (1982). The Role of Government in Supporting Measurement Standards for High-Technology Industries, Research Policy, 11, 311-320.
Tassey, G. (2000). Standardization in Technology-Based Markets. Research Policy, 29 (4-5), 587-602.

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The project aims to contribute to the European regulatory, standardization, competitiveness, and excellence by disseminating its results to a wide audience and enhancing cooperation and engagement with international standardization organizations throughout the entire project duration. This specific aspect of the project is covered in this deliverable.

1.1 Standardization Landscape

There are three main levels of standardization, respectively national, regional (European in our case) and International.
Figure 1 below sums-up these levels and the main reference EU and International bodies, respectively:

- CEN, CENELEC and ETSI at EU level (Regional)
- ISO, IEC, ITU at International level
- National levels are composed with national standardization body (NSB) or several sector related bodies (NSBs)

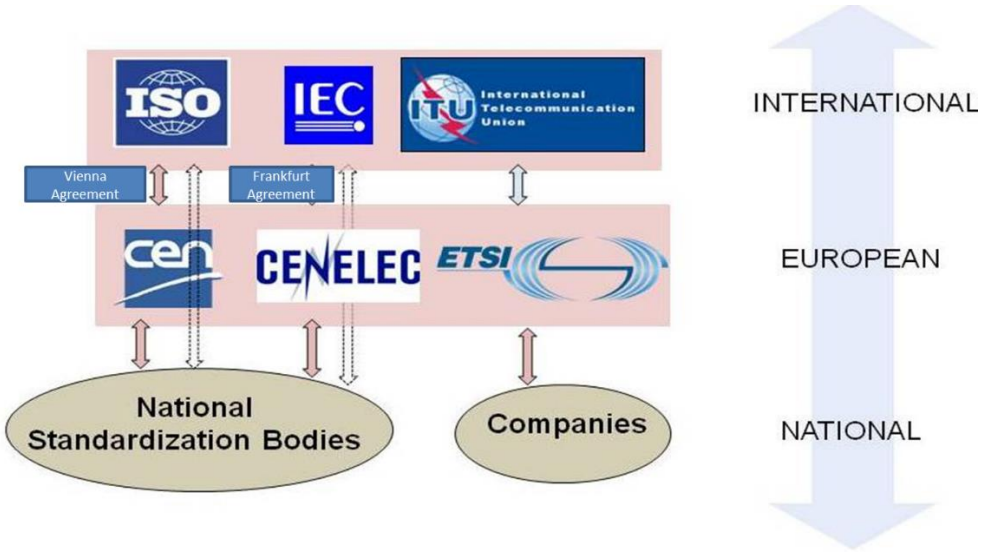

Figure 1: Standardization Landscape

The three European Standardization Organizations: CEN, CENELEC, and ETSI, as part of the standardization landscape, are recognized as the European Standards Organizations (ESOs) by the European Union (EU).

Standardization in the field of swappable batteries mainly takes place at CEN and CENELEC, while ETSI, the European Telecommunications Standards Institute, focuses on ICT. Therefore, recommendations of this deliverable (standardization roadmap) where to address the identified standardization needs mainly focus, at EU level, on CEN and CENELEC, both headquartered in Brussels, Belgium, and ISO and IEC at International level, both headquartered in Geneva, Switzerland.

CEN is an association that brings together the National Standardization Bodies of 34 European countries. Likewise, CENELEC is an association that brings together the National Electrotechnical Committees of 34 European countries.

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The two organizations represent a network of 90,000 experts, 366 European partners, and 482 Technical Bodies.
The total number of living documents from these organizations is 24,721 at the end of September 2025.

1.2 Purpose of the deliverable

This deliverable is the Standardization roadmap for swappable battery systems for LVs, with recommendations, including to the European Commission and European Standardization Organizations for future standardization needs and priorities to be addressed in line with related regulations and in support of EU´s decarbonization strategy in the mobility sector.

Its main purpose is about boosting the deployment of swappable battery LVs, supporting interoperable, safe and secure solutions through standardization, as well as standardization in support of compatibility of sub-systems and components, as a contribution to EU´s objectives, to urban carbon neutral development, to overcoming existing barriers in the Single Market (industrial ecosystems), and to enhancing the leader role of EU standardization at global level, as well as branding its Excellence.

1.3 Outline of the deliverable

This deliverable has merged inputs from all WPs towards drafting this complete standardization roadmap (D7.1), with recommendations. Two on-line workshops (on July 15th 2025 and on Oct 06th 2025) opened to all concerned stakeholders have been organized toward completing and validating the content of the roadmap.

This deliverable results from the comprehensive state of the Art analysis (see chapter 2), to set the scene, followed (see chapter 3) by the list of needs in support of raising technical and technology maturity (feeding WP5 about needs for Pre-Normative research – PNR -), as well as in support of deployment (market) of swappable battery systems as a solution to L-category decarbonized mobility (feeding WP6 about Standardization Gaps).

The mapping of needs is organized with subdivisions at four levels:

1. Battery level
2. Vehicle level
3. Charging Infrastructure level
4. Interfaces and full system management (Communication towards safe and secure usages, including about validation process for allowing the swap process at charging station)

2. State of the Art

A comprehensive State of the Art assessment has been run, analyzed and reported, to generate a clear picture of the swappable battery system for LVs.
This includes the following:

- Technical & Market state of the Art, conducted and reported by WP2 in its deliverable D2.1
- Regulation and Standardization, conducted and reported by WP3 in its deliverable D3.1, which provides a comprehensive mapping for regulatory and standardized landscapes surrounding

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swappable battery systems, clearly identifying areas of action to address under "needs and gaps" (respectively, WPs 6, 7)

- Consolidated list of needs towards market deployment, conducted and reported by WP4 in its deliverable D4.1, identifying needs associated with implementation of swappable battery systems

For a successful standardization of swappable battery systems for LVs, all perspectives of the eco-system are considered. This maximizes the likeliness for the necessary interoperability and compatibility, enables the desired performance for different vehicle models, ensures safety, promotes acceptance (especially on the user side), and increases the overall efficiency of the swappable battery systems. The establishment of European standards will boost the widespread introduction of swappable battery systems. It also underlines the importance of Initiatives such as STAN4SWAP project and consortia like SBMC (Swappable Batteries Motorcycle Consortium) are essential in this regard.

3. Needs for swappable battery system deployment

3.1 Interoperability and compatibility

Task 7.1 of WP7 identified actions to be considered, in response of the need for "unified solution" – i.e. as requested in the AFIR – as a way to ensure interoperability between LVs' brands and models, allowing users and citizens to swap their batteries whatever their vehicle – no discrimination -.

Task 7.2 of WP7 identified actions to be considered, in support of compatibility of different components within the same battery or battery system, that can be standardized, with the aim to open the market to any supplier producing such standardized (certification) components.

Both outcomes justify the establishment and underline the relevance of the present standardization roadmap.

3.2 Communication, safety and security

Task 7.3 of WP7 addressed the challenges and needs regarding compliance with the new battery regulation, as well as communication at and between battery, vehicle, and charging station level. It also tackled needs related to informing users and operators, as well as about types of data, their collection, storage and communication, considering GDPR and cybersecurity aspects, for a safe and secure use.

Outcomes support the establishment of this standardization roadmap.

4. Needs for Pre-Normative Research

Needs for Pre-Normative Research are results from WP5, which focused on identifying and prioritizing key topics for Pre-Normative Research (PNR) related to swappable battery systems (SBS) for LVs. The outcome is a structured foundation for future standardization activities that support safe, interoperable, and scalable deployment of Swappable Battery System technologies across Europe. By aligning technical, regulatory, and stakeholder-driven perspectives, WP5 provides a robust basis for targeted and impactful standardization activities, contributing to the decarbonization and digitalization of urban mobility systems.

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The methodology was based on the outcomes from WP2, WP3 and WP4, through expert discussions and structured evaluation. A wide range of PNR topics has been identified, assessed, and grouped into four core domains:

- Battery level (Task 5.1)
- Vehicle level (Task 5.2)
- Charging infrastructure level (Task 5.3)
- Interfaces and full system management (Task 7.4)

Each topic was evaluated using a standardized matrix that included criteria such as TRL, regulatory context, standardization potential, and stakeholder relevance. The outcome (deliverable D5.1) is a prioritized list of PNR topics that has been further processed in WP6, then considered in the work of WP7, and completed, amended and validated during two workshops organized by WP7.
The outcomes are a full part of the present standardization roadmap (see chapter 6 below)

5. Standardization Gaps

Standardization gaps are results from WP6, following inputs from respectively 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 LVs. Analog to WP5, the identified topics were clustered into four domains:

- Battery level (Task 6.1)
- Vehicle level (Task 6.2)
- Charging infrastructure level (Task 6.3)
- Interfaces and full system management (Task 6.4)

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 (deliverable D6.1) is a prioritized matrix of standardization gaps that has lead the processing in WP7, where translated into its standardization roadmap.

6. Organization of the Standardization Roadmap

The work conducted in this WP7 has been organized through analyzing the outcomes from WP5 (Needs for Pre-Normative Research), respectively WP6 (Standardization Gaps), from 3 main perspectives:

- Interoperability, dealing with system and interface level (Task 7.1)
- Compatibility of components (Task 7.2)
- Communication incl. safety and security (Task 7.3)

The reason for this split of work is towards ensuring meeting main aims as described in chapter 3 above.

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These outcomes feed a standardized matrix, based on the ones from WP5 and WP6, adding contributions from Tasks 7.1, 7.2 and 7.3, to the three perspectives here above.

6.1 System Approach

As guiding the entire work of Stan4SWAP, the identification of needs has been organized following a system approach, from components to applications with interface considerations, from vehicles to charging infrastructures, then robust, safe and secure communication.

6.1.1 Description of the eco-system

Figure 2 below describes the eco-system as considered in Stan4SWAP. This system comprises key elements, essential to the smooth operation and wide adoption of battery swapping systems for these vehicles:

- Swappable batteries (battery packs)
- Vehicles
- Swapping stations
- Battery Management Systems (BMS)
- Services and communication
- Broader infrastructure and society

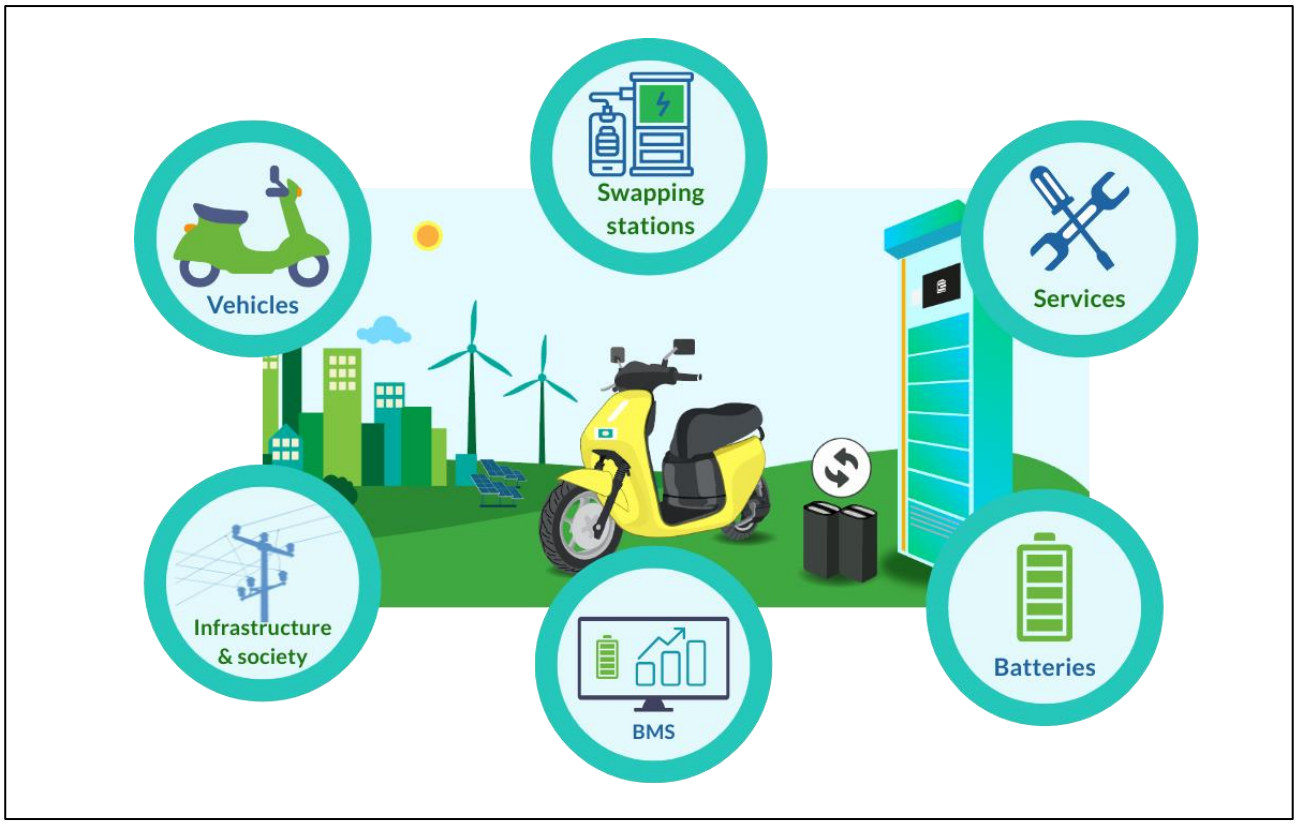

Figure 2: The ecosystem of swappable batteries

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Swappable batteries are components of **electric vehicles**, while Stan4SWAP has a specific focus on LVs. Swapping stations are providing standardized, safe, and readily available swappable batteries. In terms of physical elements, the standardization roadmap will, thus, concentrate on:

- Battery pack
- Vehicle
- Swapping charging station
- Grid

With two levels of direct interface:

- Battery pack – vehicle
- Battery pack – charging station

With three levels of communication:

- Battery pack – vehicle
- Battery pack – charging station for validation of swap and evaluation of the battery pack inserted (identification, SoH, SoC, thresholds to next life cycle stage – secondary life, end of life and communication to users and operators)
- Charging station – grid (data to grid for smart applications such as local grid balancing)

6.1.2 Subdivision of the roadmap

Based on the description of the eco-system above, the roadmap is subdivided in 2 parts, respectively for PNR and standardization gaps; Each part being dived in 4 tables:

1. Standardization Roadmap at battery level
2. Standardization Roadmap at vehicle level
3. Standardization Roadmap at swapping charging station level
4. Standardization Roadmap about communication

Each table will contain information that help the prioritization of the topics, both in terms of importance (Priority) and timing. Timing being expressed in terms of launching activities following the split as below:

- **T1: to be launched within 2 years**
- **T2: to be launched within 4 years**
- **T3: to be launched within 5 years**

The tables also contain information related to existing initiatives and committees where the topic can be allocated in due time.
Finally, the tables contain information about relevant categories of experts/stakeholders to engage in the standardization work.

For PNR, the following information are provided

Area	Maturity level (TRL)	Gaps & Needs (towards TRL 8-9)	Regulatory context	Standardization landscape (TCs, standards, ...)	Standardization expectation	PNR (topics proposition)	Priority level T1 → 2years T2 → 4years T3 → 5years	Partner / stake holder

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For Standardization gaps, the following information are provided

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 T1 → 2years T2 → 4years T3 → 5years	Partner / stake holder

7. Standardization Roadmap

7.1 Introduction

The identification of domains/topics of importance, follows the work conducted in the previous WPs of Stan4SWAP, and especially WP5 about mapping needs for Pre-normative Research (PNR), where maturity still needs improvement prior to launching standardization development, as well as WP6 about standardization gaps.

These needs cover 4 different levels:

- Battery level (chapter 7.2): Topics such as thermal risk, BMS optimization, and secondary life, and end-of-life management (i.e. thresholds towards decision making).
- Vehicle level (chapter 7.3): Mechanical and communication interfaces, safety during operation, and homologation challenges.
- Charging station/infrastructure level (chapter 7.4): Station deployment, energy metering, and grid integration (e.g. V2G).
- Interfaces and full system management (chapter 7.5): Topics such as data exchange, liability models, and cross-provider platform interoperability.

In coherence with EU´s decarbonization strategy and objectives, especially in the mobility sector as primary application, and contributing to the EC standardization request M/581, in support of the EU Alternative Fuels Infrastructure Regulation (AFIR) (EU) 2023/1804, the work is considering the following aspects, where standardization will have a key role to play (safety and security aspects being, of course, a topic considered in each aspect):

- *Standardization towards interoperability*
- *Standardization towards compatibility*
- *Standardization towards communication*

Thus, an additional subchapter (chapter 7.6) concentrates on communication, respectively:

- communication protocols
- visual communication
- written communication

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- digital communication

This subchapter aims at identifying where standards could ensure a proper, safe and relevant operation through robust communication, considering the EU regulatory landscape, esp. for batteries and e-vehicles.
Another important subchapter (chapter 7.7), market oriented, is dedicated to validation of swap action at swappable charging stations, in a way to ensure proper communication with and to users and operators.

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7.2 Standardization Roadmap at battery level

7.2.1 Pre-Normative Research (PNR)

Area	Maturity level (TRL)	Gaps & Needs (towards TRL 8-9)	Regulatory context	Standardization landscape (TCs, standards, ...)	Standardization expectation	PNR (topics proposition)	Priority level T1 → 2years T2 → 4years T3 → 5years	Partner / stake holder
Safety requirements	The temperature tolerance and fire hazards measures needs to be standardized to ensure quality of the system	Standard safety feature protocols	Batteries Regulation (EU) 2023/1542	IEC TC 69 IEC TC21 / SC21A CLC TC21X	Establishing to ensure the safety and sustainability of batteries used in two-wheelers, promoting a safer transport.	Define standards and protocols for safety features	**High** (critical for avoiding hazards) **T1 → 2years**	Standards and regulatory authorities
Battery management system	The cell monitoring and temperature control withing the battery has no standard approach	Real-time SOH, SOC monitoring		ISO TC 22 SC38	Ensuring reliability of the swappable system and promoting traceability and transparency	Develop fundamental state- monitoring requirements	**Medium** (ensures reliability and helps optimization of the operations) **T1 → 2years**	BMS and battery manufacturers

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Secondary life and End-of -life management	Guidelines for moving to next life (secondary), then end of life with recycling, disposal and re-purposing of batteries are only at a minimal level	Establishing clear guidelines at quantitative levels		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.	Establish protocols for end-of-life management	**Medium** (essential for ensuring circular economy in the system) **T1 → 2years**	Battery manufacturers and recycling partners
Interface: connector (mechanical) vehicle <–> battery	standards for automobiles exist. standards about connections of permanently installed batteries also,	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 & durability requirements AFIR Regulation 2023/1804 -Article 3 Targets for recharging infrastructure dedicated to light- duty electric vehicles	ISO TC22/SC38 CEN TC301 IEC SC23H (TS63066)	definition of a solid and reliable connection for a swappable battery solution versus permanently integrated batteries,	define connector for power supply and data communication including mechanical fixture	**High** (towards interoperability and compatibility) topics need further technical understand ing and identification **T1 → 2years**	Battery and connectors manufacturers and OEMs
Battery mechanical requirements	the physical dimensions (length/width/ height), weight, IP rating and ergonomics are currently different for each OEM and should be standardized				definition of physical dimensions for a swappable battery solution versus permanently integrated batteries,	define physical properties of SWAP battery		Battery manufacturers and OEMs

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Table 2:PNR at Battery level

7.2.2 Standardization Gaps

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 T1 → 2years T2 → 4years T3 → 5years	Partner / stake holder
Safety requirements		Streamlined testing/certification for Li-ion thermal runaway & propagation mitigation.	- Municipal building/fire codes vary by country.	CLC TC21X IEC SC21A IEC TC69	- EN 50604 & IEC 62619 (Li-ion battery safety)	- Possibly an extension of IEC 62840-3 for indoor applications.	**High** (critical for avoiding hazards) **T1 →2years**	- Battery station manufacturers
		Streamlined testing/certification for Li-ion thermal runaway & propagation mitigation.		CLC TC21X IEC SC21A IEC TC69	- 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.	C LC TC21X IEC SC21A IEC TC69	- EN 50604, IEC 62619 (battery safety) can inform insurability.	- Possibly recognized best-practices from insurers & sector alliances.		- Battery-swapping operators

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	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.		Standards and regulatory **authorities**
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) **T1 →2years**	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 62840-1:2025 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; standardization needed for cross-compatibility) **T1 →2years**	BMS developers

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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) **T2 →4years**	Battery manufacturers and recycling partners
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** **T1 →2years**	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) **T1 →2years**	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 and SC38)	- 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 **T1 →2years**	Battery manufacturers

Table 3: Standardization Gaps at Battery level

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7.3 Standardization Roadmap at vehicle level

7.3.1 Pre-Normative Research (PNR)

Area	Maturity level (TRL)	Gaps & Needs (towards TRL 8-9)	Regulatory context	Standardization landscape (TCs, standards, ...)	Standardization expectation	PNR (topics proposition)	Priority level T1 → 2years T2 → 4years T3 → 5years	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	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	definition of a solid and reliable connection for a swappable battery solution versus permanently integrated batteries,	define connector for power supply and data communication including mechanical fixture	**High** topics need further technical understanding and identification T1 → 2years	Battery and connectors manufacturers and OEMs
Battery mechanical requirements	the physical dimensions (length/width/height), weight, IP rating and ergonomics are currently different for each OEM and should be standardized				definition of physical dimensions for a swappable battery solution versus permanently integrated batteries,	define physical properties of SWAP battery		Battery manufacturers and OEMs

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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	improved, ultimately leading to more efficient and user-friendly products.			definition of electrical requirement for a swappable battery solution versus permanently integrated batteries,	define electrical properties of SWAP battery		Battery manufacturers and OEMs
Interface: communication vehicle <–> battery	standards for an interface do not exist, many OEM-specific solutions - not consistent				Comparability of data exchange without significant change	define communication protocol for SWAP battery		Battery manufacturers, BMS, and OEMs

Table 4: PNR at vehicle level

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7.3.2 Standardization Gaps

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 T1 → 2years T2 → 4years T3 → 5years	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	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 T1 → 2years	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

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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	and user-friendly products.				definition of electrical requirement for a swappable battery solution versus permanently integrated batteries,		Vehicle & Battery manufacturers
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 **T1 → 2years**	Vehicle & Battery manufacturers

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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.		**Medium** **T2 → 4years**	
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	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 barriers for L-cat.		**Medium** **T2 → 4years**	Vehicle manufacturers

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					electric vehicles in the EU			

Table 5: Standardization Gaps at Vehicle level

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7.4 Standardization Roadmap at swapping charging station level

7.4.1 Pre-Normative Research (PNR)

Area	Maturity level (TRL)	Gaps & Needs (towards TRL 8-9)	Regulatory context	Standardization landscape (TCs, standards, ...)	Standardization expectation	PNR (topics proposition)	Priority level T1 → 2years T2 → 4years T3 → 5years	Partner / stake holder
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 requests (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.	- R&D on advanced fire detection & suppression systems.	**High** (fire incidents risk damaging public confidence) **T1 → 2years**	- Fire safety authorities, e.g. TÜV / DEKRA
		- 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.	- Testing protocols for thermal runaway barriers in multi-battery racks.		- Battery station manufacturers
		- Unified safety assessment for large battery deployments.	- Insurance & liability regs.	- IEC 60335 series (chargers/appliances)				- Building code experts
								- CEN/CENELEC committees

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Accurate calculation of battery capacity, SoC, usage patterns for daily ops.	~6–7 (robust BMS exist, but not fully standardized across networks)	- Unified SoC/SoH data model across different OEMs/stations.	- EU Battery Regulation 2023/1542 (battery passport/data).	- IEC 62840-1 & IEC 62840-3/CDV includes references for BMS data.	- Agreed data structure for consistent SoC, SoH, usage reporting across networks.	- Real-time SoC algorithms factoring usage, temperature, discharge cycles.	**Medium** (technical feasibility proven; standardization needed for cross-compatibility) **T1 → 2years**	- BMS developers
		- Standard method for energy throughput & battery life predictions.	- RED delegated act for secure wireless data transfer.	- IEC 63110 / 63119, ISO 15118 (EV comms)		- "Battery Health Score" approach for cost & environmental analytics.		- OEMs
		- Common data exchange format.						- Standardization committees (IEC TC69 WG13, ISO TC22/SC37)
Ensuring (or clarifying) tax exemptions/levies for battery swapping, electricity usage, battery	N/A (policy maturity rather than technology)	- Clarify tax treatment (energy supply vs. service?).	- National energy tax laws.	- Not a standardization domain per se.	- Not directly about product standards; more about guidelines to standardize how energy usage data is reported (could help authorities).	- Policy research on best fiscal models (battery-as- service vs. electricity sale).	**Medium** (fiscal incentives can accelerate adoption) **T2 → 4years**	- Ministries of Transport/Energy/Finance

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subscription models.		- 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.		- Streamlined cross-border approach.	**Medium** (in support of market deployment) **T3 → 5years**	- Industrial associations
			- Competition rules for possible cross- country differences.					- EU Commission (DG TAXUD)
Using swappable batteries as grid assets (load balancing, V2G, aggregator-driven "virtual power plants").	~6 (pilots exist for V2G in fleets; still early for swappable battery networks)	- Real-time SoC control, aggregator frameworks.	- AFIR 2023/1804 fosters alternative fueling & smart solutions but not explicit for removable battery feed-in.	- IEC 62840 series, potential future adaptation for bidirectional flow.	- Clear aggregator communication standard for swappable battery nodes.	- Control algorithms for "mobile V2G."	**Medium–High** (significant potential for energy transition) **T1 → 2years**	- DSOs/TSOs (grid operators)
		- Ownership & legal aspects of "mobile" battery feed-in.	- National grid codes & electricity market rules.	- IEC 63119, ISO 15118-20 for V2G communications.	- Mechanisms for verifying battery ownership, scheduling feed-in, settling payments.	- Market design for aggregator-based use of distributed battery modules.		- Battery station operators

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		- Economic models & grid acceptance.						- Aggregator platforms - IEC TC69, TC57 standard committees
Standard installation criteria for swapping stations (indoor/outdoor, safety zones, mechanical footprints).	~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.	- Load-bearing studies for multi-battery racks.	**High** (critical for widespread deployment & acceptance) **T1 → 2years**	- Station OEMs
		- Standard footprints/connectors for kiosk installations.	- National/local building codes (zoning, fire dept approvals).	- Possibly relevant to CENELEC TC 64X (electrical installations).		- Building code alignment, best practices for safe installation.		- Building regulators
		- Ventilation & spacing guidelines.						- National committees (DIN, NF, etc.)
Uniform		- 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.	- Actuarial models for multi- operator battery pools.	**Medium**	- Insurance sector (Allianz, Zurich, etc.)

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insurance coverage requirements for battery systems (fire, damage, liability) and swap-station operations.	N/A (industry readiness / policy aspects)	- 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.	- Uniform approach for cross-border claims.	(essential for large-scale rollout, but largely driven by insurers & operators) **T2 → 4years**	- Battery-swapping operators
		- Cross-border coverage consistency.						- Certification/lab testing bodies (TÜV, DEKRA)

Table 6: PNR at charging station/infrastructure level

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7.4.2 Standardization Gaps

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 T1 → 2years T2 → 4years T3 → 5years	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 Committee (DIN, NF, etc.)				- National code Committee (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) **T1 → 2years**	- 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) **T2 → 4years**	- Insurance sector (Allianz, Zurich, etc.)

Table 7: Standardization Gaps at charging station/infrastructure level

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7.5 Standardization Roadmap at Interfaces and full system management level

7.5.1 Pre-Normative Research (PNR)

Area	**Maturity level (TRL)**	**Gaps & Needs (towards TRL 8-9)**	**Regulatory context**	**Standardization landscape (TCs, standards, …)**	**Standardization expectation**	**PNR (topics proposition)**	**Priority level** T1 → 2years T2 → 4years T3 → 5years	**Partner / stake holder**
System Level (Swappable Ecosystem)	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.)	Battery Regulation (EU) 2023/1542 (and battery passport) for consideration of data to be collected, stored and shared AFIR Regulation 2023/1804 Cybersecurity (to be completed)	CEN TC 301 CEN CENELEC JTC 13 CEN CENELEC JTC 24	data (& money) collecting, exchange, management within a cybersecure world	define cybersecure backend with standard communication system and Authorization system	**High:** topics need further technical understanding and DPP framework defined, with list of data to be considered T1 → 2years	

Table 8: PNR at interfaces and full system management level

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7.5.2 Standardization Gaps

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 T1 → 2years T2 → 4years T3 → 5years	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 to high** T1 → 2years	IEC TC69 – OCA
	Cybersecurity issues regarding authentication have also to be urgently considered			CEN/CENELEC JTC13	EU Battery Regulation (2023/1542)		**High** T1 → 2years	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	EU Battery passport		**Medium to high** T2 → 4years	IEC TC21 (Batteries), IEC TC69 WG13 (Swapping), ISO TC22/SC37(Road vehicles), ISO TC22 SC38
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).	**Medium** (fiscal incentives can accelerate adoption) T2 → 4years	- 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

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			- Competition rules for possible cross-country differences.		- harmonization of national regulations	Ensuring (or clarifying) tax exemptions/levies for battery swapping, electricity usage, battery subscription models.		- EU Commission (DG TAXUD)
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 fueling & 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) **T2 → 4years**	- 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) **T2 → 4years**	- Station OEMs
Conformance testing		- Cross-border coverage consistency.					**Medium** **T3 → 5years**	- Certification/lab testing bodies (TÜV, DEKRA)

Table 9: Standardization Gaps at interfaces and full system management level

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7.6 Standardization Roadmap about communication

7.6.1 Communication protocols

Communication **Following domains/topics identified are crucial for proper communication, identification and supporting reliable swap operations, as well as complying with EU regulation (i.e. battery-D, battery passport); consequently level of priority is HIGH with a timeline for launching work T1 à 2 years**		
Domains/Topics in communication protocols	**Issues identified**	**Comments and suggestions**
Standardized Communication Protocols	Need for standardized communication protocols on battery, vehicle and charging infrastructure level.	• Based on existing Communication protocol standard, suggestion = CAN • Also addressed and confirmed as relevant by stakeholders in July 15th 2025 workshop
Basic measured sensor information à current, voltage, temperature (max., min., average)	Need for standardized framework/procedures	• Base on battery level for further parameters which will be communicated • Necessary for comparison • Also addressed and confirmed as relevant by stakeholders in July 15th 2025 workshop
State of Charge (SOC)	Standardized protocols	• Actual State of Charge (SOC) level of the battery • Also addressed and confirmed as of relevant by stakeholders in July 15th 2025 and Oct 06th 2025 workshops
State of Health (SOH)		• Up-to-date data for the parameters for determining the state of health (SOH)) of batteries as set out in Annex VII of BattReg • Also addressed and confirmed as relevant by stakeholders in July 15th 2025 and Oct 06th 2025 workshops
BMS state		• This signal indicates the BMS state (according with its state machine); states like: idle, discharge, charge,
Errors		• Internal Battery & BMS diagnosis; error identification with standardized error Ids
Max. charge voltage		• Requested maximum charge-voltage (pack)
Min. pack voltage		• Minimum allowed pack voltage

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Discharge/charge limit		• necessary for power derating reduction due to high temp, or low voltage, recuperation, vehicle, chargers, battery stations, …
Battery identification info		• Standardized Serial Number that serves as a unique battery identifier. (incl. knowledge about manufacturer, battery model/type)
Actual capacity		• Actual battery capacity; Capacity based on SOH =remaining capacity
Evolution of self-discharging rates		• According to BattReg
Expected lifetime		• Up-to-date data for the parameters for determining the expected lifetime of batteries as set out in Annex VII of BattReg
Date of manufacture		• According to BattReg
Energy throughput		• According to BattReg
Capacity throughput		• According to BattReg
Tracking of harmful events		• The tracking of harmful events, such as the number of deep discharge events, time spent in extreme temperatures, time spent charging in extreme temperatures
No. charge-discharge cycles		• Number of full equivalent charge-discharge cycles
Software reset info	Who is allowed to perform a software reset and how is that compatible with the CRA?	• The battery management system shall include a software reset function, in case economic operators carrying out preparation for re-use, preparation for repurposing, repurposing or remanufacturing need to upload different battery management system software. If the software reset function is used, the original battery manufacturer shall not be held liable for any breach of the safety or functionality of the battery that could be attributed to battery management system software uploaded after that battery was placed on the market
Counter frame incl. cyclic redundancy check	Challenging to fulfil CRA with respect of the Battery Regulation. Clarification on EU-level is needed.	• Convenient solution for CAN to meet CRA

Table 10: Standardization Needs for communication protocols

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7.6.2 Visual communication

Communication **Following domains/topics identified, are crucial for proper communication, identification and supporting reliable swap operations, as well as complying with EU regulation (i.e. battery-D, battery passport); consequently level of priority is HIGH with a timeline for launching work T1 à 2 years**		
Domains/Topics for visual communication	**Issues identified**	**Comments and suggestions**
Manufacturer info	Standardization needed to be robust over lifetime of the battery	• Label
Battery identification info		• Label
Battery category		• Label
Place & date of manufacture		• Label
Weight		• Label
Capacity		• Label
Chemistry		• Label
Hazardous substances		• Label
Usable extinguishing agent		• Label
Critical raw materials		• Label
Carbon footprint		• Label
Safety warnings		• Label • Standardized pictograms highly recommended
Separate collection symbol		• Marking
Chemical symbol		• Marking
QR-Code		• Marking • Base for digital battery passport
CE-marking		• Marking

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Table 11: Standardization Needs for visual communication

7.6.3 Written communication

Communication **Following domains/topics identified, are crucial for proper communication, identification and supporting reliable swap operations, as well as complying with EU regulation (i.e. battery-D, battery passport); consequently level of priority is HIGH with a timeline for launching work T1 à 2 years**		
Domains/Topics in written communication	**Issues identified**	**Comments and suggestions**
Instructions	Battery, Vehicle and Charging infrastructure level	• Also addressed and confirmed by stakeholders in July 15th 2025 workshop
Safety information	Battery, Vehicle and Charging infrastructure level	• Usage of standardized pictograms • Also addressed and confirmed by stakeholders in July 15th 2025 workshop
Technical Documentation	Battery, Vehicle and Charging infrastructure level	• Also addressed and confirmed by stakeholders in July 15th 2025 workshop
Declaration of Conformity	Needs to be included in the information package	• According to EU Battery Regulation
Recycled Content	Needs to be included in the information package	• According to EU Battery Regulation
Electrochemical Performance and durability parameters	Standardization is needed towards performance and durability index	• According to EU Battery Regulation

Table 12: Standardization Needs for written communication

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7.6.4 Digital communication

Communication **Following domains/topics identified, are crucial for proper communication, identification and supporting reliable swap operations, as well as complying with EU regulation (i.e. battery-D, battery passport); consequently level of priority is HIGH with a timeline for launching work T1 à 2 years**		
Domains/Topics in digital communication	**Issues identified**	**Comments and suggestions**
Battery Passport • Battery Identification • Manufacturing data • Technical specifications • Usage data • End-of-life • Sustainability	On various points, a standardized framework, definition, procedure, calculation etc. is needed	• Details according to Article 77 + Annex XIII of EU Battery Regulation • Open points should be considered in harmonized standards for the EU Battery Regulation • Also addressed and confirmed by stakeholders in July 15th 2025 workshop
Information on prevention and management of waste batteries	Needs to be included in the information package	• According to Article 74 of Batt Reg • Also addressed and confirmed by stakeholders in July 15th 2025 workshop

Table 13: Standardization Needs for Digital communication

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7.6.5 Additional communication items

During Stan4SWAP workshops gathering main categories of stakeholders, including consumers' representatives, a few additional topics have been identified in support of easing information to users. The two topics below would definitely contribute to this aim, but do not necessarily need standardization development; However, the topics really worth to be mentioned, for future consideration.

Other		
Domains/Topics	**Issues/propositions raised**	**Comments and suggestions**
Sounds and spoken warning signals	Addressed by stakeholders during Stan4SWAP July 15th 2025 workshop	• This would definitely be a benefit in terms of safety and for the customer, but it is not necessary for the function of the battery or the whole swappable battery eco system. à no need for standardization
Visual status indicators for SOC and SOH	Addressed by stakeholders during Stan4SWAP July 15th 2025 workshop	• This would definitely be a benefit for the customer, but it is not necessary for the function of the battery or the whole swappable battery eco system. à no need for standardization

Table 14: Addition suggestions

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7.7 Standardization Roadmap about validation of swap action at Swapping Charging Station

From topics and issues collected during the Stan4SWAP workshops, organized in a way to get feedback, ideas, and expressions of needs by stakeholders, protocols validation access to swap process at Swapping Charging Station, as well as check about validity of the battery pack for its actual level of application (primary application) or need to move to next "level" (secondary application, end of life), a list of topics has been mapped, where standardization could support harmonization of all processes, and ensure safety, security, money related transaction and liability throughout the process, as well as useful and operational information.
Swappable Batteries Motorcycle Consortium (SBMC), as one of the main stakeholders consulted during the workshops, has mapped such needs based on existing deployment, protocols and processes, market experience, but with the aim to move to unified solutions/options, and, thus, guarantee interoperability and compatibility, while keeping communication with the users and owners of the battery packs, as well as operators.

The main driver for such swap actions related and dedicated standardization roadmap are respectively, safety, integrity, interoperability, that could be summarized as follows[2]:

Safety

- Electric shock
- Short circuit
- Thermal runaway or fire

Integrity

- Grid compatibility
- Power factor and grid stability
- Distribution integrity (Energy meter)

Interoperability

- Energy/money exchange among different Operators
- Cyber secured data exchange among different Operators
- User swap/charging independency by specific network

  In order to avoid:

  - Market Fragmentation — each network operates in isolation
  - Low utilization of stations — limited to one brand's users

[2] From BluEV, member of SBMC, promoting standardization development

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- Higher cost per kWh — due to duplicated infrastructure and low throughput
- Limited user convenience — users can't swap outside their brand's network
- Excessive station deployment — every operator must cover the entire city independently

Table 15, hereafter, sums-up domains/topics where Pre-Normative Research work supported by EU funding would help boosting safe, secure, and efficient swapping charging stations development, as key element for market deployment and feeding further standardization development.

Validation of swap actions at the swapping charging station T1 à 2 years		
Domains/Topics	**Issues/needs/information to communicate**	**Comments and suggestions**
Swapping Station Unit Scope (Physical)	Compartment Dimensions	Safe docking system with automatic locking and connection mechanisms
	Overall Dimensions	Defines the overall size and footprint of the station
	Number of slots	Indicates the total battery capacity the station can handle simultaneously
	Location space and fixation	Distance between walls, depending on maintenance door and available space
Swapping Station Unit Scope (Environmental)	IP Rating	i.e. IP54 rain proof or higher
	Lightning Protection Level	IEC 62305
	Ventilation (Outdoor-direct sun)	Station and per slot ventilation
	Heating System	Battery compartment heating system
Swapping Station Unit Scope (Safety)	Flood Detection	Detects water ingress to prevent electrical hazards
	Smoke Detector	Alerts early signs of fire through smoke detection
	Fire Extinguisher	Automatically suppresses fire in battery slots using aerosol or water
	Emergency Power Suppression	Cuts power in critical emergencies
	External Emergency Shutdown	Manual shutdown for rapid response
	Per Channel Temperature Sensor	Backup for BMS sensors to detect overheating

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	Anti-theft Measures	Prevents theft with motion detection alarm (CCTV, locks, …)
Swapping Station Unit Scope (Electrical)	Surge Arrestors & Circuit Breakers	Protect station from voltage spikes and electrical faults
	Energy Meter	Certified meter with proper precision class (IEC 62052-11) with RS485 or CAN communication
	Charging Efficiency	Smart charger with more than 93% of efficiency with adequate power factor and low harmonics to not affect the grid
	AC Source	Tension/frequency/nb of phases with adequate earthing
	Infrastructure	Power budget and maximum grid load (i.e. compliance with regulation)
Swapping Station Unit Scope (Communication & Other features)	Charging Protocol	Chemistry independency: LFP/NCM or any other chemical. Voltage levels: 48V/60V/72V. CC/CV charging with high-rate continuous feedback loop between BMS and charger. Cybersecurity authentication
	Display Screen	For swapping process feedback and ads
	Audio Feedbacks	For swapping process feedback
	Noise Level	Depends on country, state or city
	Customer/Contract Identification & Swap Process	QR, NFC and Bluetooth (Multiple operator Interoperability)
	Backup Power for Operation and Sensors (No charging)	Depending on the batteries to power the control circuits and communication gateway
Battery Passport	Information from QR code or from BMS	Extraction of Information for identification and validation phase towards swapping, decision about life cycle level, etc....
Interoperability	Dimension + Connector + Communication Battery-Station interoperability	Check, inform, correct, etc....
	Subscriber-Operator communication interoperability	How and Which information to share and to whom, which in a black box, GDPR compliant, etc..

Table 15 : Needs for PNR and standardization work at swap action level

In addition to Table 15 topics ensuring safe, secure and efficient swap process at swapping charging station, Stan4SWAP recommends further EU funded projects to support and promote digital twin development, both at city level to identify where to ideally install charging stations, as well as at charging station level to optimize its capacities, including availability of storage capacities, and its usages, services to and with the grid.

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8. Recommendations and further steps

8.1 Regulation

Bringing the research and innovation community together with industrial stakeholders early on into the standardisation process is key to identify the issues and priorities, share views on future developments and stakeholder/users' needs, and to provide recommendations to the European Commission and European Standardization Organizations for future standardization needs, as well as alignment of pieces of legislation. It is thus recommended to further refer to standards in the regulatory landscape, and ideally to harmonized standards, as a way to set a clear pathway of compliance.
This means a recommendation to the European Commission to consider emitting Standardization requests to European Standardization organizations (ESOs) covering the entire swappable battery eco-system, sub-systems, components, and services. This will boost innovation to market(s), and EU leadership and competitiveness enhancement.

Modular design of batteries isn't considered so far in any regulation. Fulfilling this "gap" would help in meeting modularity in battery packs, leading to solving challenges in interoperability between vehicles and swapping stations for instance. This includes design for recycling.

Current regulatory framework does not consider the EU WVTA without including the dedicated propulsion battery. In swappable system market, the vehicle and the owner of the vehicle, are not necessarily owning the batteries. Stan4SWAP recommends amendment of the regulation to facilitate EU WVTA for a vehicle which is designed to be powered by standardized swappable batteries[3].

8.2 Support of innovation and PNR

The work carried out leads to a consolidated and structured proposal of Pre-Normative Research (PNR) topics that are critical for the deployment of safe, interoperable, and sustainable swappable battery systems (SBS) across Europe. The applied methodology ensures full alignment with the technical, regulatory, and stakeholder-specific findings from Stan4SWAP.
By clustering the identified topics into four domains—battery, vehicle, charging infrastructure, and system interfaces—, as well as for validating the swap action, the consortium was able to address the full scope of the SBS ecosystem. Each domain includes short-term (T1 up to 2 years) "quick win" topics, medium term (T2 up to 4 years) and long-term (T3 up to 5 years) challenges requiring more fundamental research.
Tables 2, 4, 6, 8, 15 in chapter 7 above list main topics where PNR will be essential to boost maturity raise and then initiate standardization development. It is, thus, recommended to include these topics in future EU funding related calls, as a way to support EU leadership in this innovative mobility solutions.

The resulting tables of proposals provides:

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

[3] this issue will be similar for all other categories of vehicles with swappable batteries systems (i.e. cars and trucks, as from the Alternative Fuel Infrastructure Regulation (AFIR).

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It support elements towards drafting future EU funding calls.
There are already several partners with the key expertise towards applying to such EU funding calls in the field of battery exchange between manufacturers and operators of swapping charging stations, and different two-wheeled vehicle manufacturers. The driving companies in this area are already organized in relevant associations such as the SBMC (Swappable Batteries Motorcycle Consortium).

8.3 Standardization development

From the consolidated and structured list of topics for standardization, as from tables 3, 5, 7, 9, 10-13, 15 in chapter 7 above, main recommendations from Stan4SWAP are:

1. A priority to support the above mentioned PNR topics as essential inputs towards feeding future standardization development

2. Development of a CWA (CEN/CENELEC Workshop Agreement) for the swapping charging station, to specify required technical specification in support of interoperability, compatibility, safe and secure operations, and relevant validation of the batteries and communication to validate the swap action.

Recommendations about which data to standardize
About sets of data, as relevant for ensuring interoperability and compatibility, it has to be considered that each data bit has an economic impact and an ecologic footprint, when it is created, stored, processed and transmitted. Thus, Stan4SWAP recommends to initially limit the required data elements to those which are essentially needed for the sole functioning of the swappable batteries eco-system, including compatibility and interoperability.
This set of data is very stable, as it is only amended in rare cases when the core/basic functionality of the eco-system changes, or when the requirements related to interoperability and compatibility are modified.

Minimum Set of Data:
It is mandatory to respect this set of data for the implementation of a standardized eco-system and interoperable and compatible sub-systems and components.
Such data may be called the **"Minimum Set of Data"**, that could be common between regions (global level).

Additional set of data:

Additional set of data should be defined, containing data, which is required by applicable regulations, and other relevant standards, granting compliance with the applicable legal requirements and the applicable state-of-the-art (i.e. with regards to safety, security, and product liability).

This set of data is also relatively stable, as it is only amended when regulatory requirements are changing, or in case of relevant progress of the applicable state-of-the-art.

Depending on the legal requirements and the state-of-the art in the Region of implementation, this set of data may be mandatory as well. So, in the context of European standardization, this

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data might complete the "Minimum Set of Data". However, in view of international standardization it is recommended to consider this data as a separate set of data (Regional context).
Such data may be called the **"Additional Mandatory Data".**

"Additional Optional Data (support data)":

A third set of data may be defined for data which enables and/or supports the practical implementation of the eco-system or its sub-systems and components, including data which is essential for the implementation of viable business applications and related processes as well as the overall management of the eco-system (i.e. user registration, billing, payment and other data which enables the monitoring of sub-systems and components).

Especially in the early years of implementation of the eco-system, the content of this set of data will change frequently. Since such data is neither essential for the sole operation of the eco-system, nor for granting interoperability and compatibility (see "Minimum Set of Data") and also not for compliance with the (regional) regulatory framework (see "Additional Mandatory Data"), one may say that such set of data does not need to be standardized at all, to allow for the necessary flexibility of data content.
But, this is not necessarily the case, because besides the functioning of sub-systems and components within the standardized eco-system, it is necessary to understand the terms "compatibility" and "interoperability" also in a wider context, including business models and system management.

It is therefore advisable to define a broad set of "support data" which covers as much as possible the already known and potentially needed data related to business applications and system management. This set of data should not be mandatory, and the standard should not prevent the introduction of additional data which is not (yet) included in the standardized set of data.

Such data may be called the "**Additional Optional Data**".

Given that the standardized set of data will likely need to be amended over time and considering that the "Additional Mandatory Data" is defined in a regional context, it is advisable to decouple the standard for the set of data from other generic standards related to the eco-system, sub-systems or components.

8.4 Education and Training

Education and Training is a highly important topic, where Stan4SWAP recommends a careful attention and urges towards actions. Indeed, while standardization is a booster of innovation to markets, there are still major misunderstandings among stakeholders, concerning the role and strong benefit of standards. In addition to raising awareness and organizing information sessions with enlarged communication campaigns, there is also a critical need for experts to actively engage in the standardization activities within the Technical Committees and their Working Groups.

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These aspects have been comprehensively addressed by Stan4SWAP WP 8 and its task T8.4 "Education and Training", which provides education and training materials for standardization in the mobility and transport ecosystem of swappable batteries within the scope of Stan4SWAP.
In particular, it presents four outputs available at Education & Training | Stan4swap:

- Handbook, on "Standardization and Standards for Mobility and Transport in the Ecosystem of Swappable Batteries" with six specific case studies
- Learning video, "Standardization and standards for mobility and transport in the ecosystem of swappable batteries – basic topics"
- Learning video, "Standardization and standards for mobility and transport in the ecosystem of swappable batteries – advanced topics"
- Stan4SWAP factsheets

The material will be made widely available throughout Stan4SWAP channels and platforms, as well as through relevant additional initiatives of partners and stakeholders.

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9. Conclusion

Stan4SWAP Standardization Roadmap about Swappable Battery System for LVs has been developed by considering such an eco-system as a relevant, viable, and sustainable solution for decarbonizing urban mobility, and thus contributing to EU´s commitment towards carbon neutrality by 2050.

Context of the work has been about:

- **Political – Political Support:**
  Impact and market boost of government policies, subsidies, and regulatory frameworks on the development of electric vehicles and related battery swapping infrastructure

- **Economic – Cost Reduction:**
  Emphasis on **economies of scale** to lower production costs for and more efficient use of batteries and infrastructure while introducing flexible business models and more affordable vehicles

- **Technological – Interoperability:**
  Importance of standardization, interoperability, and reliability among batteries, vehicles, and charging stations to **ensure user convenience and enhance market acceptance**.

Challenges faced at market level:

- **Economic – Priorities:**
  Users seek affordability and **flexible business models**, while vehicle and battery manufacturers focus on production **costs and profitability**

- **Technological / Social – Expectations:**
  Users prioritize lightweight and **user-friendly** batteries, while battery and vehicle manufacturers face **performance** constraints

Stan4SWAP concentrated on:

- **Standardization Issues:**
  Lack of uniform standards for battery design and interoperability between different manufacturers

- **Investment Costs:**
  The significant **upfront investments** required for establishing a network of battery swapping stations

- **Regulatory:**
  Varying regional regulations (in municipalities) and safety standards for battery swapping stations

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- **User Acceptance:**
  Users may still experience range anxiety due to inadequate infrastructure and the perceived inconvenience of battery swapping compared to traditional refueling

- **Durability and Reliability Concerns:**
  Batteries in swappable systems must withstand frequent cycling and harsh environmental conditions, necessitating **robust designs** that can be costly and complex to achieve

Stan4SWAP scope:

- **Benefits of swappable battery systems**:
  - **Reduction of emissions** in urban areas through electrification
  - Swappable battery systems can **alleviate range anxiety** and enhance usability
- **Importance of Standardization**:
  - Essential for **interoperability** across vehicles, batteries, and infrastructure
  - Reduces costs through **economies of scale** and enhances market attractiveness
- **Market Success Factors**:
  - Coordination among stakeholders to harmonize differing priorities and developing the best possible technical system, which can be then successful in the market
  - Establishment of European standards to facilitate widespread adoption of swappable battery systems

This full roadmap highlights areas where existing standards are insufficient or non-existent, provides 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 eco-system across Europe.
With an emphasis on:

- A clear mapping of standardization gaps
- Associated standardization potential
- Recommendations for stakeholder involvement

Stan4SWAP also identifies several categories of recommendations :

- Recommendation about **improving and aligning** pieces and elements of **regulation and policies**
- Recommendation for further **support to PNR** topics towards boosting maturity and meeting standardization “ready TRL” (i.e. Horizon Europe IA), including **support to pilots and demos** at full scale and real use cases/context (i.e. city tests)
- Recommendation for **launching standardization development**, EN, TS, TR, CWA (i.e. CWA about swappable charging station for L-cat battery system and communication protocols towards validating swap action, SoH of the pack for proper life cycle related allocation, contribution to local grid – storage capacity -, etc…)

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- Recommendation about considering **additional roles of charging stations** (i.e. new business models – BaaS, battery ownership, pricing contribution of charging station (storage) in support of decentralized grid management, …)
- **Education and Training**, raising awareness about role and relevance of standards, motivating experts to join standardization drafting teams, ….

Glossary

L-category Vehicle (LV) – Any two-three and four wheeled vehicle classified according to regulation (EU) 168/2013 Annex I.

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