D4.1 - Consolidated multidimensional list of needs towards market deployment

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Abbreviations list

ACEM	European Association of Motorcycle Manufacturers
AFIR	Alternative Fuels Infrastructure Regulation
B2B	Business-to-Business
B2C	Business-to-Consumer
BMS	Battery Management System
EMSA	E-Mobility Systems Architecture
EV	Electric Vehicle
EU	European Union
HMI	Human-machine interface
ICEV	Internal Combustion Engine Vehicle
KPI	Key Performance Indicator
kWh	Kilowatt-hour
L-Cat	Light Category Vehicles
LIB	Lithium-ion Battery
NMP	N-Methyl-2-Pyrrolidone (chemical solvent used in LIB production)
OEM	Original Equipment Manufacturer
PFAS	Per- and Polyfluoroalkyl Substances
PTW vehicle	Powered Two Wheelers Vehicle
SBMC	Swappable Batteries Motorcycle Consortium
SoC	State of Charge
SGAM	Smart Grid Architecture Model
UDS	Unified Diagnostic Services
UNECE	United Nations Economic Commission for Europe

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List of figures

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List of tables

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Executive summary

The European Green Deal set ambitious targets for reducing greenhouse gas emissions. In particular, the transport sector has a key role to play in achieving these targets. Swappable battery systems for light vehicles (L-Cat) offer a promising approach to overcoming challenges for battery-electric vehicles such as range anxiety. At the same time, it provides attractive business models for different user groups and user behaviour. The swappable system enables a quick and efficient swapping of empty batteries at corresponding charging stations and can thus accelerate the electrification of L-Cat vehicles.

This report identifies needs associated with the implementation of swappable battery systems. To this end, a list of needs was created that is relevant for the most important stakeholders for market deployment – vehicle manufacturers (OEM), infrastructure providers, end users and battery manufacturers. Each of these players have individual needs that must be considered for the successful development of a coherent and efficient battery swapping system.

For the vehicle OEM, technical compatibility and interoperability of swappable batteries with their vehicles are crucial. Moreover, the technical performance parameters of the battery must be met so that the vehicle can deliver the desired performance. It is therefore important to ensure that swappable batteries can be easily integrated into the vehicle while maintaining good handling and reliable vehicle performance. At the same time the vehicle and the battery must meet safety and performance standards.

Infrastructure providers are crucial for the installation of a reliable and strategical network of battery swapping stations. A sufficient number of charging stations are needed. Those stations must be centrally allocated and easily accessible to ensure availability for users and to foster social acceptance. Infrastructure providers face challenges such as complying with regionally (municipal) differing regulations, approving locations and processes. Also, planning the logistics with the many other (regional) stakeholders is needed to set up the charging station infrastructure. This remains also a request from the European Union in the framework of the Alternative fuels infrastructure Regulation (AFIR), where the European Commission addressed a Standardisation Request (SR) to CEN CENELEC supporting an interoperable infrastructure for electricity supply for road transport, including European standard containing technical specifications with a unified solution for battery swapping for L-Cat vehicles.

The end users' perspective is important for the subsequent market penetration of swappable battery systems. Users are attracted to solutions that reduce range anxiety, eliminate maintenance issues and reduce the total cost of ownership. User-friendly design and a simple battery swapping process is important. The user acceptance of swappable battery systems is fundamental and can only be guaranteed if users recognize the advantages of those systems. New business models enable users to buy or rent batteries separately. This can reduce initial costs and increase the attractiveness of vehicles with swappable batteries. Flexibility can make e-mobility accessible to a wider audience, further increasing social acceptance and market penetration.

Battery manufacturers must produce high-quality, long-lasting and safe batteries and must meet the different requirements of different vehicle models and charging stations. In the end, the battery performance is essential for the vehicle performance and must satisfy the end user. The need for standardisation in battery design is crucial to facilitate interoperability between different battery manufacturers as well as vehicle manufacturers and models. Also, the 2023 EU battery regulation sets the regulatory and sustainability framework especially for the battery manufacturers and distributors.

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The four stakeholder groups have common needs when it comes to swappable battery systems, particularly regarding cost reduction, standardisation and interoperability and compatibility, sustainability and reliability. All stakeholders can benefit from the standardisation of batteries and an increase in production volumes and market deployment. Users want flexible business models such as leasing or subscriptions, while manufacturers rely on mass production to reduce costs. Technologically, interoperability and compatibility are key points, e.g. through standardised communication protocols or regarding the ease of use.

However, further needs have been identified. Vehicle manufacturers need dedicated battery formats, while battery manufacturers insist flexibility in upcoming technological developments. Infrastructure providers are focusing not only on recharging the vehicles but also on the integration of intelligent networks in the light of smart grid business models, and they are responsible for the safety of the charging stations. Environmental factors, such as battery lifespan and recycling, also play a significant role - with a growing weight for circular economy in industry – but is not vital for each individual user as he will not own the battery. Challenges could arise from different priorities among the stakeholder groups, such as the weight of batteries, which users prefer to be very low, and the technical (performance) requirements of vehicle OEMs. Infrastructure providers and battery manufacturers seem to have greater burdens in terms of legal requirements (i.e. AFIR, Battery Regulation) or the harmonization of authority processes concerning differences between municipalities and European regions.

For a successful market deployment of swappable battery systems, all stakeholder perspectives must be considered to ensure interoperability and compatibility, performance, safety, acceptance, and overall system efficiency. A lack of uniform standards might be an obstacle to the widespread implementation of swappable battery systems in Europe. Initiatives such as the STAN4SWAP project but also consortia like e.g. SBMC are crucial for promoting the development of technical standards and facilitating market access.

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1. Introduction

The European Union (EU) Green Deal has set ambitious targets for reducing greenhouse gas emissions, and the transportation sector is a key area for decarbonization. Electric vehicles (EVs) offer a promising solution, but their widespread adoption is hindered by factors such as range anxiety and charging infrastructure limitations.

Swappable battery systems for light category (L-Cat) vehicles present a potential game-changer, allowing for quick and efficient battery swapping at dedicated stations, thus addressing these concerns. While fixed plug-in batteries require vehicles to stop and recharge, swappable batteries are removable and can be easily replaced without interrupting vehicle usage. Recent studies suggest that swappable batteries are superior to plug-in batteries in terms of 24/7 vehicle availability, faster charging, and lower costs [1]. Swappable battery systems have gained traction in the scooter and L-Cat vehicle markets, particularly in South and Southeast Asia. However, standardisation in battery designs and stakeholder interfaces remain a challenge, hindering interoperability and compatibility between vehicle and battery manufacturers. While Europe has limited experience in operating swappable battery systems, efforts are underway to establish technical standards through initiatives like the European Swappable Battery Motorcycle Consortium (SBMC).

The STAN4SWAP project [2] aims to accelerate the market deployment of swappable battery systems for L-Cat vehicles. By developing a standardisation roadmap, STAN4SWAP seeks to ensure interoperability and compatibility[1] between vehicles and batteries from different manufacturers, promoting the adoption of battery-electric L-Cat vehicles. In addition to the technical, market [1] and regulatory aspects [3] as well as education and awareness rising about the role of standardisation, one key objective is to identify the specific needs and challenges associated with swappable battery systems to support their market deployment and foster greater stakeholder engagement. The identified needs for swappable battery systems, followed by needs for pre-normative research, will form the basis for identifying standardisation gaps and addressing them in the standardisation roadmap.

This work package 4 report conducts a comprehensive analysis of the needs and challenges associated with swappable battery systems. The identification of needs considers four key perspectives: the vehicle side, the charging infrastructure side, the battery manufacturer side, and the user side.

By examining the requirements and preferences (*needs*) of each stakeholder side, STAN4SWAP aims to identify both commonalities and contradictions that may influence the development and deployment of swappable battery systems for L-Cat vehicles. One main objective is to identify key areas where standardisation is needed. This information will be invaluable in guiding the project's future work and ensuring that the standardisation roadmap for swappable battery systems effectively addresses the needs of all stakeholders involved.

This report is structured as follows: Chapter 1 introduces the four stakeholder groups that will be analysed. Furthermore, the definition of needs, which is used in the report, is explained. Chapter 2 describes the methodological approach used. Chapter 3 covers the first step of information and data collection and identifies the needs of the four main stakeholders in the stakeholder analysis. Chapter 4

[1] **Interoperability** (of swappable battery systems): Capability to transfer power and / or data among various swappable battery systems, vehicles and battery swap stations, without requiring modifications, special interfaces or conversion hardware

Compatibility (of swappable battery systems): Capability of swappable battery systems to meet the requirements of battery swap stations and vehicles to transfer energy and exchange data without appreciable modifications and any undesirable consequences of unpredictable shortage of performance

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covers the second step of iteration, made for the elaboration of the different needs. For this, results of Chapter 3 are used. This step includes the development and evaluation of a multidimensional list of needs and a comparison of the four sides of the stakeholder analysis. At the end of Chapter 4, the results are used to identify common and conflicting needs. Chapter 5 summarises the results.

1.1 Description of different stakeholder perspectives

A swappable battery system for L-Cat vehicles requires the cooperation and interaction of several interest groups. The four most important stakeholders were analysed, and the respective needs were identified. This ensure, that all needs for a swappable battery system were recorded as comprehensive as possible. Each of these stakeholders' side has an essential role in the swappable battery ecosystem. Those four perspectives have many interfaces, each of which must be considered regarding a successful swappable battery market deployment for L-Cat vehicles. Only the well-functioning interaction ensures a successful implementation of battery swap systems.

In addition to the stakeholders mentioned, there are also other players whose perspectives were only considered in a contextualized manner. This concerns fleet providers for, e.g., scooters with swappable batteries. Their needs are to some extent in line with end users and have been considered in the user perspective. Furthermore, the role of digital companies that manage apps or the corresponding cloud management system for the replaceable batteries was also excluded. All four perspectives, considered here, set out the needs for implementing corresponding systems. The municipalities are also an important player in the implementation of a nationwide network of swapping stations. The needs were considered in the view of the infrastructure providers.

Vehicle side

The focus group of the vehicle perspective are the vehicle manufacturers (Original Equipment Manufacturer - OEM) of the vehicles. Their relevance in the swappable ecosystem is to design the vehicles for an optimized compatibility and interoperability with the battery system. This requires close collaboration with battery manufacturers to ensure, that the batteries can be seamlessly integrated into the vehicles. OEMs are particularly dependent on the needs of their buyer. Therefore, the vehicles must convince the end user both financially and ergonomically and, to a certain extent, by design. The OEM must also ensure that performance as well as safety parameters are meeting the market requirements. OEM will contribute to market introduction and penetration by launching vehicles that utilize the swappable battery system. Important purpose is to define the technical specifications for the vehicles which at the same time places realistic requirements on the battery.

Infrastructure side

Infrastructure providers are companies or organizations that provide the necessary facilities and services for the operation of the swappable battery system. These include the battery swapping stations where end users can swap their empty batteries for charged ones. Their relevance arises from the need to create a widespread and reliable network of swapping stations that meets the requirements of users. On the other hand, the charging infrastructure has an essential interface with the batteries. For example, performance losses or safety risks must be recognized immediately, and the battery must be fully recharged in the desired time. Infrastructure providers also work closely with OEMs and battery manufacturers to ensure that the batteries and vehicles can be smoothly integrated into the system.
The charging station providers must plan and manage the logistics and operation of the battery swap stations. They are as well responsible for the maintenance of the stations. They must work with many regulations, which often also differ locally. Furthermore, they are responsible for the very high investment costs required to set up the infrastructure.

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User side
Users are people or companies that use the L-Cat vehicles with swappable batteries in (daily) operations. Their relevance outcomes from their needs and requirements which have direct influence on the design and acceptance of the swappable battery system. End users are generally looking for convenient, efficient and cost-effective solutions for their mobility needs. They have interfaces with the three other stakeholders. They use the vehicles properly and must handle the swappable battery at the charging infrastructure.
The user is relevant for the market pull. Therefore, the role of users in the swappable battery ecosystem is to create demand for the systems. Their satisfaction and acceptance are crucial for the spread and success of the system. In addition, the usage patterns and preferences of users influence the strategic planning and operation of the battery swap stations. In the case of a free and unregulated market, the system must prevail over alternative systems due to its ease of use and economic incentives.

Battery manufacturer side
Battery manufacturers are responsible for the production of the batteries for the swapping system. They must develop high-quality, long-lasting and safe batteries that meet the requirements of the vehicles and the expectations of the users. The batteries must be compatible and interoperable with different vehicle models and battery swapping stations, align with todays and tomorrows' regulatory requirements. Therefore, they work closely with OEMs and infrastructure providers to ensure that the batteries can be easily replaced and integrated into the infrastructure system.
Battery manufacturers must fulfil the requirements of all three other stakeholders: performance parameters that the OEM or later the customer needs, as well as handling parameters for the user or corresponding interfaces with the infrastructure providers. Also, they need to develop innovative solutions that improve the energy efficiency and longevity of the batteries and must also ensure, that the produced batteries are safe and environmentally friendly.

The following Table 1 highlights the interfaces between the four discussed stakeholders. Close collaboration and clear communication are crucial to ensure efficiency and usability of swappable battery systems.

Stakeholder 1	Stakeholder 2	Interfaces
Vehicle side	Infrastructure side	Close cooperation to coordinate the technical requirements for battery swapping and to ensure the technical integration of the available batteries into vehicles and infrastructure. This requires the coordination of battery compatibility/interoperability and the development of vehicle models as well as infrastructure that enable rapid swapping of the batteries. It is also important to ensure that everything is as compatible as possible with the existing infrastructure.
Vehicle side	User side	Involvement of end users in the development process to ensure that the vehicles are user-friendly and meet user requirements. This can be done through surveys, tests and feedback rounds. End users can provide valuable information to help improve vehicle designs.
Vehicle side	Battery manufacturer side	Working together to develop batteries that are specifically tailored to the needs of the vehicles. This includes defining specifications and standards that guarantee battery performance and safety, especially

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		for the use in different vehicles with individual requirements towards performance key performance indicators (KPIs).
Infrastructure side	User side	Designing the swapping stations and processes to meet the needs of end users. This includes the creation of user-friendly interfaces and the implementation of feedback systems and the communication about user experiences with the swap stations for continuous improvement. In addition to feedback, end users should be involved in the development process to ensure that their needs and wishes are considered from the beginning of development.
Infrastructure side	Battery manufacturer side	Cooperation to develop standardised batteries that can be used in different vehicles an fulfil the requirements towards safety, performance and handling (which is needed for the development of a successful mass market implementation of swappable infrastructure). To ensure effective cooperation, this includes especially the exchange of information on technologies and safety standards. Also training for the staff and the provision of technical information are important.
User side	Battery manufacturer side	Feedback on the performance of batteries in practical use to help battery manufacturers optimize their products. End users' experiences can be crucial for the further development of battery technology. Communicating the benefits and characteristics of batteries to gain end user confidence and promote acceptance. Providing information on battery maintenance and replacement is also important.

Table 1 – Stakeholder interfaces regarding the needs on swappable battery system

1.2 Common understanding of the term "needs"

In the context of this report, the term *"needs"* is used to refer to essential requirements, expectations, or preferences that different stakeholders - such as OEMs, infrastructure providers, users, and battery manufacturers – address, linked to the successful adoption and operation of swappable battery systems, and their deployment on existing as well as on emerging markets. This encompass a range of aspects, including those that are technologically mandatory, those that are desirable, and those that are market driven. Although the distinction between needs and wants is frequently blurred in the context of technology [4], i.e. swappable battery systems, this report aims to highlight the different perspectives of the various interest groups:

- *Requirements* are technical or operational elements that are essential for the proper functioning of the system. For instance, such factors include safety standards, compatibility and interoperability across different vehicle models, and scalability.
- *Requests* refer to favourable properties that improve the usability or performance of the system. Such factors are frequently shaped by market demands or consumer and manufacturer preferences, including aesthetic integration into vehicle design or a rapid swap process for enhanced convenience.
- *Demands* represent critical needs that are driven by external forces, such as regulatory authorities or market pressures. Examples of such factors include cost efficiency or the widespread availability of battery-swapping stations.

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- E*xpectations* are shaped by the assumptions stakeholders have regarding how the system should perform or be experienced. These expectations influence perceptions of quality and satisfaction, such as user convenience during battery swapping or the durability and longevity of the batteries.

Together, these elements form the overarching term *"needs"* that should be addressed for the development, deployment, and long-term success of swappable battery systems. The present report examines the similarities and contradictory needs of the four stakeholder groups defined in 1.1.

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2. Methodology

This report employs a two-stage approach and is outlined in the following. In the first step, data is gathered on the needs of the four stakeholder groups. Different quantitative and qualitative methods were used to get the relevant data from each individual stakeholder side. The data was subsequently evaluated and processed in order to derive the major needs to be addressed, with regard to the fundamental challenges faced by the four stakeholder groups. In the second step, the needs identified in step one are then transferred to the PESTEL framework. The PESTEL analysis that takes place links the different dimensions of the needs with the different perspectives of the stakeholders, in order to identify both similarities as well as contradicting needs. The methodologies used in the two-stage approach are described in more detail below.

Several quantitative and qualitative methods were used to determine the needs (step one) for swappable battery systems in L-Cat vehicles: Desk research, expert interviews, surveys, workshops and in-house expertise from the corresponding project partners R&D departments. Each of these methods was selected to comprehensively cover different perspectives and aspects to identify the most relevant needs.

- *Desk research* was used to investigate and analyse existing literature, studies and market analyses. This method provides an overview of the current state of the art, identifies market trends and highlights existing solutions.
- *Expert interviews* were conducted to gain deeper insights and qualitative data from experts and stakeholders. This method helps to learn about specific requirements and challenges at first hand from practice.
- *Survey and questionnaire* were used to collect qualitative and quantitative data from a broad base of participants representing the four stakeholder groups. This method is useful to systematically record and analyse market opinions and needs.
- *Workshops* provided a platform for the exchange of ideas and the joint development of solutions. This type of format makes it possible to bring different stakeholders together and consider their perspectives.
- *In-house technical expertise* played a key role for the final interpretation of the collected data and identifies needs that may not have been captured by other methods.

Vehicle Side

Surveys and in-house technical expertise were used for the vehicle perspective. The survey, distributed among European Association of Motorcycle Manufacturers (ACEM) members, provided quantitative data on the needs and preferences of OEM regarding vehicle technology. On March 25th, 2024, this comprehensive survey was distributed to a select group of 76 contacts associated with the ACEM E-Mob working group[2].

This survey aimed to gather valuable insights from industry participants, specifically targeting key OEMs in the European light electric vehicle market. Since each OEM usually sends more delegates to the working group the contacts were asked to provide one consolidated answer per OEM to avoid skewing the results due to the influence of different personal opinions between the experts representing one OEM.

The survey received five unique answers from OEMs. Importantly, these 5 OEMs hold a significant position in the market, collectively accounting for more than 50 % of the market share among European

[2] The ACEM E-Mob working group promotes a constructive dialog with European, national and local authorities and relevant stakeholders and exchanges technical knowledge and best practices used in the E-Mobility sector.

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manufacturers of PTW vehicles. This substantial representation from the major players provides a strong foundation for the survey's findings, ensuring that the results are reflective of the broader industry trends and insights. Also, because there are only a few OEMs that deal with swappable battery systems or have experience with them, the number of participants in the survey was low. The in-house expertise helped to translate these needs into concrete technical specifications.

Infrastructure Side

Interviews, workshops and the inherent project consortia expertise were used to identify the infrastructure perspective. Specific needs and challenges were identified through interviews within total five fleet managers who are operating also infrastructure for swappable battery systems. An internal company workshop offered the opportunity to bring together different departmental perspectives and jointly identify the needs for the infrastructure. The in-house expertise helped to categorize the various requirements and complete the missing points. Only a few infrastructure operators have experience with swappable battery systems, which limits the number of available experts and the depth of insights. Though, following the standardisation request (Sreq) of the European Commission to CEN CENELEC (M/581), needs also consider the referred request for European standard development containing technical specifications with a unified solution for battery swapping for L-cat vehicles.

User Side

Interviews and the inherent project consortia technical expertise was used for the user perspective. Interviews within total five fleet managers provided valuable insights into user needs and preferences regarding electric vehicles and swappable battery systems. The in-house technical expertise helped to categorize and evaluate these requirements technically. The customer's feedback from vehicle OEMs supplements the identification of needs at user side. As a swappable battery system is not yet established in Europe, there is no large group of current customers, which limits data collection.

Battery manufacturer Side

From the battery manufacturers' perspective, interviews, desk research and in-house technical expertise were used. Interviews with users of swappable batteries provided insights into needs for the battery and to identify technical challenges. Desk research supplemented these interviews with a comprehensive analysis of the available literature and market studies. The in-house expertise helped to translate this information into distinct requirements. Competing battery cell producers themselves offer only very limited insights, which influences the depth of the data obtained.

Merging perspectives with the PESTEL framework

The PESTEL framework organises information, in this case the identified stakeholder needs, to six categories of factors: political, economic, socio-cultural, technological, environmental/ecological and legal factors. This allows for the implementation of a structured approach to the identification and evaluation of the gathered data (step two), as well as the consideration of the perspectives of the various stakeholders.

- *Political factors*: This category includes the topic of government policies, political subsidies, tax policies and other political issues that have influence on the initial situation of the swappable battery systems.
- *Economic factors*: Economic aspects such as prices, market grow, influence of and economic trends that influence the stakeholder from an economic perspective.
- *Socio-cultural factors*: These factors relate to demographic changes, cultural norms, social attitudes and lifestyles that may influence the acceptance of the swappable system.

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- *Technological factors*: This category includes technological developments, innovation potential, research and development activities that are relevant for the further development of swappable battery systems.
- *Environmental factors*: Ecological and environmental aspects such as environmental regulations, sustainability and environmental protection measures are considered.
- *Legal factors*: These factors include legal framework conditions, labour law, product liability, safety standards and other legal aspects that may affect the swappable battery needs.

The PESTEL framework is used to summarize and compare the needs by enabling a holistic view on specific influences in comparison with individual needs. By applying the PESTEL framework, the different perspectives are systematically recorded, structured and compared with each other. This enables a holistic assessment and assists the identification of similarities and contradictories of different needs.

The results of the partitioning of individual needs into the different perspectives and the different PESTEL categories has been evaluated with eight different European industry experts in autumn 2024.

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3. Stakeholder analysis

Each sub-section in Chapter 3 deals with a specific stakeholder perspective. In the first part of the stakeholder analysis, the information gathered is analysed and, depending on stakeholder-individual aspects and content, the challenges associated with the needs are highlighted. This is followed by a brief outline of the identified major needs that are essential for the successful market deployment of swappable battery systems.

3.1 Vehicle side

Identifying the vehicle's needs is of crucial importance for developing a standard for batteries in swappable battery systems for L-cat vehicles. These needs include all technical, functional and safety-related requirements. An analysis of the needs at vehicle side makes it possible to develop a standard that meets the specific requirements of the OEM and increases the prospects of economic success.
Technical compatibility and interoperability between batteries and vehicles is a key concern. By identifying the specific requirements of the vehicles – such as size, weight, performance and connection options – a later standard can be developed to ensure that the batteries fit a wide range of vehicles. This not only promotes the flexibility and versatility of the system, but also its market acceptance.

3.1.1 Challenges and needs at vehicle side

The requirements on the vehicle side relate in the first place to technical parameters of the battery. To quantify these values, a survey was distributed that had been prepared in advance by KTM F&E and covered the most important parameters. The detailed survey structure and results can be found in Annex 1.
In summary, the survey achieved a critical participation from key OEMs, making the collected data highly valuable for understanding the current landscape and future directions of the European light electric vehicle market. The following listing briefly presents the results of the survey towards the ACEM members on the individual topics queried and thus implicitly presents the corresponding needs with regard especially to different technical specifications for the vehicle and battery performance requirements. The topics were selected based on KTM's in-house expertise.

Voltage
The survey results show a unanimous preference among the respondents for a nominal voltage of 48V for a single battery pack. None of the participants favoured any other voltage options provided in the survey. This suggests that is considered the optimal voltage.

Capacity
The survey results clearly show a preference for battery packs with a capacity of 1.6 to 2 kilowatt-hour (kWh). With 80 % of participants choosing this option, it is evident that this capacity range is favoured for single battery packs among the surveyed group. The 1.1 to 1.5 kWh range also has some support, but it is significantly less popular.

Continuous power discharge
In terms of the continuous discharge power, the 3kW option was the clear preference among participants, with 80 % opting for this option. Only 20 % selected the 2kW option.

Peak power discharge
The survey results show that most participants prefer a battery pack with a peak discharge power of 6 kW.

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Peak power charge

In response to the question of the desired charging/recuperation power of the battery, the participants generally gravitated to lower powers, indicating that high regenerative breaking abilities are less preferred. Only one participant wished for a higher recuperation power.

Charging time

The survey results indicate that 60 % of respondents agreed that a battery should charge for two hours. The remaining 40 % of respondents indicated that a battery should charge for three hours.
Generally, this means that “fast charging” with very high currents is not seen as needed by any participant, allowing for a less complex thermal design of the battery pack.

Multibattery system (series)

The survey results indicate that 60 % of respondents expressed a preference for using two packs in a row in the maximum configuration. The remaining 40 % of respondents indicated a preference for using one pack.
Together with the with for a nominal voltage of 48V (see voltage level) this means that a serial connection of two packs will lead to a system voltage of 72V and therefore to a “high voltage” system with additional safety needs.

Multibattery (parallel)

The survey results indicate that all participants plan on using the batteries in a parallel configuration.
40 % of respondents prefer to use three packs in a row in parallel in the maximum configuration. The remaining 40 % of respondents stated a preference for four packs, while the remaining 20 % opted for two packs.
The survey also asked why parallelization was desired. Results show that 100 % of participants voted Capacity in first place. An increase of the continuous power was chosen in second place, closely followed by an increase of the peak power. Since those features are very similar, it is assumed that both can be realized, if a parallel operation of the packs is possible. To achieve the latter, two options for the parallel packs need to be connected at the same time leading to additional complexity in the pack and multibattery control algorithms.

Multibattery (Operation)

The survey results indicate that 60 % of participants selected the vehicle as the responsible entity which controls the multibattery system, while the remaining 40 % selected that both options shall be supported.

Dimension (Length / Width / Height)

The survey results indicate a preference in the overall dimensions or volume of the battery pack, however there are differences in the distribution of the dimensions. A possible explanation for this is that each OEM tries to stay as close as possible to his current system package in order to avoid fundamental changes and the associated development efforts.
Regarding length, 40 % of participants selected the range 154-200 mm, 40 % opted for 251-300 mm, and 20 % selected 100-150 mm.
Regarding width, 60 % of participants selected 151-200 mm, while the remaining 40 % chose 100-150 mm.
The height measurements yielded the following results: Twenty percent of respondents selected a height range of 301-350 mm, 40 % chose 251-300 mm, 20 % opted for 151-200 mm, and another 20 % selected 100-150 mm.[3]

[3] The Swappable Batteries Motorcycle Consortium (SBMC) is focusing on: Length 190,2 x Width 158,5 x High 309,4 mm, which is around the range of the survey.

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Maximum weight

The survey revealed that 80 % of respondents selected 12 kg as the maximum weight, while the remaining 20 % opted for 9 kg.

It can be noted that the answers regarding weight as perfectly in line with the answers for the desired capacity. The participant who wished for 9 kg was also the one opting for a lower capacity. This shows that the participants have a clear understanding of the technical backgrounds behind their desired pack specifications since achieving a 9 kg pack with the higher capacity rating would be a very challenging feat with the current state of the art of cell technology.

Ergonomic features

When asked to identify the essential characteristics of the battery, the participants were unanimous in their responses. They agreed that the battery must have a robust grip and a functional area. Additionally, 80 % of the participants voted for a built-in State of Charge (SoC) display. The remaining 60 % of participants identified secure footing and an easily readable serial number.

Connection

The survey revealed that 100 % of participants agreed that the "Panel-to-Panel connector" method is the optimal approach for connecting the battery to the vehicle. This answer is expected since it is in line with most other swappable battery systems on the market.

Crucial features

In response to the question of which important battery-related information should be communicated to the driver via the vehicle's HMI, 100 % of the participants voted for remaining range, SoC, remaining charging time, and power reduction. Regarding the pack temperature information, 60 % of the participants chose it. Additionally, 40 % opted for maintenance reminders. State of Health and regenerative braking feedback was mentioned one time each.

Further features could be collected in the free text field. Only one participant missed a crucial feature in the list from the previous question. This shows that the options provided in the multiple-choice list in the previous questions covered most of the needs of most OEMs. It also must be noted that an onboard diagnostic system is standard in the automotive industry.

Vehicle range

The survey revealed that 80 % of the participants consider a range of 90 km to be appropriate, while 20 % find a range of 60 km acceptable when determining the desired range for a target vehicle equipped with a swappable battery system before the need to charge or replace the battery.

Temperatures (low and high)

Most of participants (80 %) have expressed support for limiting the minimal ambient temperatures for the target vehicle to a maximum of -10 °C. The remaining 20 % have expressed support for temperatures up to 0 °C. Regarding warmth, 60 % of participants were satisfied with ambient temperatures up to 40 °C, while the remaining 40 % saw the need of supporting temperatures up to 50 °C.

Ingress protection (IP) rating

In the choice of battery protection, 60 % of the participants opted for IP67 (protected against immersion up to 1 m), while the remaining 40 % were divided between less severe IP65 (protected against water jets) and IP66 (protected against powerful water jets) categories.

Standards

The survey results show how participants voted regarding the standards that a battery must meet. All participants voted on UN ECE R13 and UN 38.3. Additionally, 80 % of participants favoured ISO 26262, while 60 % supported UL 2271 and AIS 156. Among the 40 % who chose one of these standards, their

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votes were distributed across EC No 756/2008, UN ECE R10, IEC 62840, and GB 24155. The remaining 20 % of participants opted for UL 2580, ISO 18243, UN ECE R100, IEC 62619, and R155.
This hints at a possible challenge for standardisation. Since there is a multitude of similar but in details different standards that in some cases also are specific to a region a consensus needs to be found that incorporates all different wishes. Adhering to all mentioned standards may not be feasible due to the potentially high costs for validation and certification.

Communication protocol
The results show that the communication protocol with the battery should be CAN bus. This standard was preferred by 80 % of the participants while the remaining answer showed openness to adapt to any given standard.

Feature communication
For isolated bus transceiver and UDS diagnostics, more than 50 % of the respondents consider these features to be mandatory. On the other hand, for thermal runaway detection, crash detection, Bluetooth connectivity, over the air updates, transport lock, online connectivity and OEM specific functions, the respondents have decided that these features are rather unimportant.

Wakeup method
The wakeup preferences of the participants varied. Since the answers are split between “both” and types of a dedicated wake-up pin it can be concluded that the battery shall support both waking up by a dedicated pin as well as via a message on the bus system.

3.1.2 Major needs to address

Key aspects explored also with the help of the survey includes performance requirements, mechanical interfaces, safety considerations and general desirable features towards the usability of the swappable battery system. The interviewees' responses from the survey were crucial to understanding the needs of OEMs of light electric vehicles.
Based on the survey results, the preferred specifications for the battery pack among the participants include a voltage of 48V, a capacity ranging from 1.6 to 2 kWh, a peak charging power of 3 kW, and a peak output of 6 kW. Ideally, the charging time should be two hours or less. These findings underscore the clear preferences of the OEMs regarding battery pack configurations, feature priorities, and application preferences, notably favouring the use of two packs in series in the maximum configuration for electrical requirements.
The summary of mechanical and ergonomic requirements provides an overview of preferred dimensions, weight, key features, and the preferred connection method for the battery pack, reflecting broad consensus among the OEM participants. OEMs clearly articulated their priorities regarding essential information and standards for batteries, emphasizing critical industry benchmarks.
In the area of requirements for communication, diagnostics, and battery management systems (BMS), the participants' feedback revealed the most important needs and the areas considered less important.
In conclusion, with the help of the survey, a strong reception for swappable battery systems among participants could be identified.

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3.2 Infrastructure side

For a better understanding of needs for various stakeholders on the charging station and infrastructure side, firstly the relevant interest groups (stakeholders) were identified. To this end, an internal workshop was held to discuss the stakeholders involved in setting up a battery swap system and what challenges or obstacles they face in the process. This targeted exchange helped us gain a comprehensive understanding of the requirements and hurdles on the infrastructure and station side.

3.2.1 Associate partners at infrastructure side

To install a network of charging stations, locations are needed where these stations can be set up. Several parties with different needs are involved in this installation.

Location Partners

Location partners are critical stakeholders in the deployment of battery swapping stations, as they provide the physical sites necessary for installation and operation. They include landlords, property managers, parking operators, and other entities that control or manage potential locations. Their cooperation is essential for site approval, lease agreements, and ensuring that the stations align with local regulations and community standards.

- *Landlords and Property Managers*: These stakeholders own or manage properties and must agree to host battery swapping stations on their premises. They are pivotal in negotiating lease terms, ensuring compliance with property policies, and addressing any site-specific concerns. Their approval is crucial for securing locations and moving forward with installations.
- *Parking Operators*: As a specific type of location partner, parking operators manage parking facilities and are responsible for integrating the battery swapping stations into existing parking infrastructures. They are often motivated to enhance the value of their facilities by offering additional services like battery swapping, which can attract more users and increase customer satisfaction.
- *Location Engineers*: Employed or appointed by the location partners, location engineers ensure that the installation complies with all local regulations, building codes, and technical requirements. They typically have a background in electrical or civil engineering and play a crucial role in facilitating the setup process by coordinating with installers and verifying that all standards are met.

Public Entities / Public authorities

Public entities and public authorities are critical stakeholders in the deployment and operation of battery swapping stations. They include local fire departments, city planning departments, utilities, and various government agencies responsible for regulation, safety, and community welfare. Their cooperation and approval are essential for ensuring compliance with local laws, obtaining necessary permits, and maintaining public safety standards.

- *Local Fire Departments*: Responsible for ensuring fire safety compliance, they review safety plans, conduct inspections, and provide guidance on fire prevention and emergency response measures. Their involvement is crucial for mitigating risks associated with battery storage and charging operations. Additionally, their endorsement can enhance trust among local communities and stakeholders.
- *City Planning Departments*: These departments evaluate and approve the installation of battery swapping stations based on zoning laws, land-use policies, and urban development plans. They ensure that the stations align with city infrastructure and community needs, and do not negatively impact the environment or public spaces.

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- *Utility Operators and Energy Regulators*: They manage power supply issues, including grid connections and necessary upgrades. Their approval is required for accessing the electrical grid, and they ensure that the additional load from the stations does not compromise grid stability or violate regulatory standards.
- *Other Government Departments*: Depending on local requirements, other agencies may be involved, such as building preservation departments that ensure the station's presence does not violate heritage or preservation laws, environmental agencies that assess ecological impacts, and transportation authorities that oversee public right-of-way usage.

Insurance provider
Insurance companies play a critical role in the battery charging and swapping ecosystem by providing risk management, coverage, and liability services. However, several key pain points make their involvement in this evolving industry more challenging, limiting their ability to offer optimal insurance products. Addressing these pain points can enhance the adoption of battery swapping infrastructure by creating a safer, more predictable, and better-regulated environment for insurers and operators.

Electricity distributor
Electricity distributors are essential stakeholders in the operation of battery swapping stations, as they provide the necessary electrical energy for the charging infrastructure. Their role is crucial in ensuring a reliable, efficient, and safe power supply to the stations. Collaboration with electricity distributors involves aspects such as grid connection, power upgrades, energy contracts, and compliance with electrical regulations.
However, several challenges can arise when working with electricity distributor. These include lengthy application processes for new connections, high costs for grid upgrades, and complex negotiations over energy tariffs. Addressing these challenges is vital for the successful deployment and operation of the battery swapping infrastructure.

3.2.2 Challenges and needs at infrastructure side

The needs of the individual stakeholders identified in the expert interviews and internal workshop are listed below. These provide an overview of who and, in particular, what needs to be addressed when establishing an infrastructure for swappable battery systems.

Location Partners

- *Site Approval Challenges:* Obtaining approval from location partners can be complex, involving negotiations over lease agreements, site modifications, and alignment with the property owner's policies and business objectives. This results in delays or difficulties in securing site approvals can hinder the deployment timeline of battery swapping stations, limit network expansion, and increase project costs.
- *Regulatory Compliance Concerns:* Location partners are concerned about compliance with local zoning laws, building codes, and safety regulations. They require assurance that the installation will meet all legal requirements and not expose them to legal liabilities. This ensures that regulatory concerns can result in legal issues, fines, or forced removal of the stations, leading to financial losses and reputational damage.
- *Liability and Insurance Issues:* Property owners may worry about potential liabilities associated with hosting battery swapping stations, such as accidents, injuries, or property damage. They need clarity on who bears responsibility in various scenarios. Without adequate liability coverage and clear agreements, location partners may be reluctant to participate, impeding the growth of the battery swapping network.
- *Space and Aesthetic Considerations:* Concerns about the physical space required for the stations and their impact on the property's aesthetics can be barriers. Location partners may have specific

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requirements for how installations should look and where they can be placed. Space constraints and aesthetic objections may limit suitable locations, requiring adjustments in station design or the pursuit of alternative sites.

- *Operational Disruptions:* Location partners may be apprehensive about potential disruptions during installation and operation, such as noise, increased traffic, or interference with other activities on the property. Anticipated disruptions can deter location partners unless mitigated through careful planning, scheduling, and communication about the installation process and operational procedures.
- *Financial Considerations:* Negotiating favourable financial terms is essential. Location partners need to see clear economic benefits, such as rental income or increased foot traffic, to justify hosting the stations. Unattractive financial arrangements can discourage location partners from participating. Flexible and mutually beneficial proposals are necessary to secure and maintain site agreements.
- *Safety and Security Concerns:* Property owners may be worried about the safety of having battery systems on-site, including risks of fire, vandalism. They require assurance that appropriate safety measures and monitoring systems are in place. Without confidence in the safety and security protocols, location partners may refuse to host the stations, necessitating comprehensive safety plans and communication. In addition, cyber security must be guaranteed.
- *Community and Tenant Relations:* Location partners must consider the perceptions and reactions of tenants, customers, or the local community. They may face pushback if the installation is seen as inconvenient or undesirable. Negative feedback from tenants or the community can pressure location partners to decline participation unless proactive engagement and education efforts are undertaken.

Public Entities

- *Regulatory Compliance and Permitting Challenges:* Navigating the complex landscape of regulations and obtaining the necessary permits from various public authorities can be time-consuming and complicated. Different jurisdictions may have varying requirements for safety, environmental impact, zoning, and construction. Delays in obtaining approvals can postpone project timelines, increase costs, and create uncertainty in planning. Non-compliance can result in legal penalties, fines, or forced removal of installations.
- *Safety and Emergency Response Requirements:* Public authorities, especially fire departments, have stringent requirements for fire safety, emergency response plans, and risk mitigation strategies due to the potential hazards associated with battery storage and charging. Meeting these requirements may necessitate additional investments in safety systems, staff training, and infrastructure modifications. Failure to comply can lead to denial of permits or operational restrictions.
- *Environmental and Community Impact Assessments:* Authorities may require detailed studies on the environmental impact, noise levels, traffic flow, and community effects of installing battery swapping stations, particularly in residential or sensitive areas. Conducting these assessments can be costly and time-consuming. Negative findings may lead to denial of approvals or require significant changes to project plans.
- *Grid Connection and Energy Supply Limitations:* Utilities and energy regulators may impose limitations or require significant upgrades to the grid infrastructure to accommodate the additional load from battery swapping stations. Upgrades can be expensive and take considerable time, potentially delaying the project and increasing costs. Limitations on energy supply can restrict the station's operational capacity.
- *Public Right-of-Way and Land Use Restrictions:* Using public land or rights-of-way for installing stations may involve complex legal agreements and adherence to strict regulations to ensure

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public safety and accessibility. Navigating these legal and regulatory requirements can delay installations and add administrative burdens. Restrictions may limit available locations or require costly adaptations.

- *Coordination Between Multiple Agencies:* Projects may need approval from multiple government agencies, each with its own procedures and requirements, leading to coordination challenges. Lack of coordination can result in conflicting requirements, increased administrative workload, and extended timelines. Miscommunication may lead to compliance issues.
- *Public Perception and Political Considerations:* Public entities may be influenced by community opinions and political considerations. Negative public sentiment towards battery swapping stations can lead to increased scrutiny or opposition from officials. Projects may face additional hurdles, such as public hearings or demands for modifications, which can delay implementation and increase costs.
- *Compliance with International and National Standards:* Authorities may require adherence to specific international or national standards for equipment, operations, and safety, which may differ from company practices. Ensuring compliance may require changes to equipment design, operational procedures, or additional certifications, leading to increased costs and development time.

Customers

- *Network Coverage:* A broad network makes it possible to increase the availability of battery swapping stations in different regions, improving accessibility for users. Furthermore, a well-established network can ensure that batteries are charged and serviced quickly and reliably, minimizing downtime.
- *Strategically Placed Locations:* A successful market launch of Swappable Battery Systems requires strategically well-placed locations, as they must be both accessible and close to potential users. Accessibility of the locations increases the acceptance of the system, while proximity to users increases the frequency of use.
- *Charging Safety and Ease:* Important for user acceptance and also for the success of the infrastructure provider is a guaranteed safety and hassle-free swapping experience.
- *Visibility and Error Handling:* Customers need full transparency on station and battery status and an effective error handling.

Insurance

- *Limited Operational and Historical Data:* Insurers rely on extensive data to assess risk and determine coverage. In the L-Cat vehicle battery swapping infrastructure, there is a lack of comprehensive, long-term operational data. This includes insufficient data on battery performance, failure rates, safety incidents, and station downtime, which hinders insurers' ability to accurately assess risks and set premiums. Without reliable historical data, insurers face challenges in pricing premiums, calculating liabilities, and offering insurance products tailored to specific customer needs, such as operators, station owners, and users.
- *Unclear Risk Profile:* The nascent stage of the battery swapping and charging infrastructure industry makes it difficult for insurers to determine clear risk profiles for stations, batteries, and operators. The rapidly evolving technology, varying battery types, and differences in station setups introduce uncertainties. This uncertainty leads to higher premiums or reluctance to insure certain assets. For example, insurers may struggle to assess the safety of different battery chemistries or the reliability of new technologies, like fast-charging solutions or AI-driven battery management systems.
- *Lack of Standardised Safety and Operational Regulations:* Insurance companies face significant challenges due to the absence of industry-wide standards for battery swapping and charging.

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This includes varying regulations across regions, different safety protocols for battery storage, and a lack of unified fire safety standards at charging stations. Inconsistent regulatory frameworks across different jurisdictions make it difficult for insurers to offer policies that cover multiple regions. This complexity increases administrative costs for insurers and adds risk when underwriting policies for cross-border operations.

- *Challenges in Monitoring and Verifying Compliance:* Insurers require robust mechanisms to verify that operators comply with safety standards and maintenance requirements. However, there is currently no centralized system for real-time monitoring of battery stations, safety incidents, or maintenance activities. The inability to track compliance in real time means that insurers cannot respond proactively to potential safety hazards, increasing the likelihood of accidents and claims.
- *High Perceived Liability and Safety Concerns:* Fire risks associated with lithium-ion batteries, particularly in high-density urban areas, pose significant liability concerns for insurers. There have been numerous high-profile incidents of battery-related fires, especially in cities like New York, which has led to greater scrutiny of charging and swapping infrastructures. Insurers are hesitant to provide coverage without robust fire suppression systems and other safety protocols in place. This hesitancy is compounded by public pressure and regulatory bodies calling for stricter oversight of L-Cat vehicle charging infrastructures.
- *Lack of Collaboration Between Insurers and Technology Providers:* The fast pace of innovation in the L-Cat vehicle battery industry has outpaced the insurance sector's ability to adapt. There is a need for closer collaboration between insurers and technology providers to develop insurance products that align with the specific needs of L-Cat vehicle operators, battery manufacturers, and charging infrastructure providers. Without collaboration, insurers remain reactive rather than proactive in addressing the unique risks of the industry. This limits their ability to create innovative insurance solutions that could mitigate risks and foster the adoption of battery swapping technologies.

Electricity Distributors

- *High Costs for Grid Connection and Upgrades:* Establishing a new grid connection or upgrading an existing one can be very costly. Expenses include not only the physical installation but also fees for applications and necessary infrastructure improvements. High initial investments can make the installation of battery swapping stations more difficult, limit scalability, and delay project timelines.
- *Lengthy Application and Approval Processes:* Applying for and obtaining approval for new grid connections or power upgrades can involve complex bureaucratic processes and long waiting times, especially in regions with strict regulations or limited grid capacity. Delays in power supply can postpone the commissioning of stations and negatively affect profitability.
- *Limited Grid Capacity in Certain Areas:* In some regions, the existing grid capacity may not be sufficient to handle the additional load of the charging infrastructure, requiring significant upgrades or alternative solutions. Limited grid capacities can restrict site selection and hinder access to key markets.
- *Complex Energy Pricing Structures:* Negotiating favourable energy tariffs with electricity suppliers can be challenging due to complex pricing structures, peak load charges, and the lack of customized contracts for charging infrastructure operators. Unfavourable energy costs can increase operating expenses and impair the competitiveness of battery swapping services.
- *Compliance with Regulations and Standards:* Compliance with local electrical regulations, safety standards, and environmental requirements requires close collaboration with electricity suppliers and adherence to technical requirements. Non-compliance can lead to legal issues, fines, and safety risks, undermining the trust of partners and customers.

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- *Integration of Renewable Energy Sources:* Utilizing renewable energy to power battery swapping stations is important for sustainability goals but can be challenging due to grid constraints and regulatory hurdles. Difficulties in integrating renewable energy can affect the environmental footprint of the stations and make it harder to achieve sustainability objectives.

3.2.3 Major needs to address

To identified problems, needs, and blockers from various stakeholders at infrastructure side, it is crucial to focus on key areas to ensure the successful implementation and operation of swappable battery systems. By leveraging the combined expertise of industry leaders, research institutions, and standardisation bodies, the infrastructure-related stakeholders can effectively address these needs. Aligning the efforts with industry initiatives focused on swappable battery technologies also enhances the approach to overcome challenges in standardisation and infrastructure development. The most important points are listed below.

Standardisation and Interoperability/Compatibility
Standardisation is vital for the widespread adoption of swappable battery systems. Collaboration with industry consortia and standardisation organizations can help develop common standards.

- *Collaboration with Industry Consortia*: Actively participate in industry associations and working groups to develop standardised technical specifications for swappable batteries. This ensures compatibility and interoperability between different vehicle manufacturers and vehicle types, enabling a more extensive and user-friendly network.
- *Interoperability Across Platforms*: Design battery swapping stations and batteries to be interoperable, allowing seamless integration with various vehicle models from different manufacturers. This enhances user convenience and accelerates market penetration.

Regulatory Compliance and Certification

- *Adherence to International Standards*: Ensure all products possess international certifications and comply with regulations set by standardisation bodies.
- *Harmonization of Regulations*: Advocate for the harmonization of regulations across different regions to simplify compliance and facilitate international deployment.

Technological Innovation and Readiness
By leveraging the research capabilities of consortium partners and the technical expertise of participating organizations, we can push technological boundaries.

- *Adaptable System Design*: Develop modular and flexible designs for battery swapping stations to accommodate future battery technologies and vehicle models. This ensures longevity and relevance as technology evolves.
- *Investments in Research and Development*: Increase investments in R&D to stay ahead of technological advancements, focusing on improving battery performance, safety features, and integration with smart grids.
- *Efficient Production Processes*: Optimize manufacturing processes to produce battery swapping stations at scale, meeting the growing demand in various markets.
- *Global Supply Chain Management*: Establishment of robust supply chains to ensure timely deliveries and reduce costs, leveraging international partnerships.

Risk and Safety Management
Safety is paramount in the deployment of battery swapping infrastructure. Implementing robust safety measures is essential.

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- *Battery Monitoring Systems*: Implement advanced monitoring systems to detect defective or overheated batteries and prevent their charging, thereby enhancing safety during storage and charging.
- *Secure Storage Solutions*: Design stations to securely store batteries, preventing unauthorized access and minimizing the risk of accidents.
- *Standardised Fire Protection Procedures*: Collaborate with local fire departments to establish standardised procedures for handling incidents related to battery swapping stations, ensuring that emergency responders are well-prepared.
- *Training and Awareness Programs*: Provide training for emergency responders and educate stakeholders on safety protocols and emergency procedures.

Infrastructure and Grid Integration

Addressing the challenges posed by electricity suppliers and infrastructure limitations is essential.

- *Efficient Energy Use*: Utilize energy management systems to optimize power consumption, reduce grid strain, and lower operating costs.
- *Integration of Renewable Energy Sources*: Explore and utilize renewable energy sources to power charging stations, achieving sustainability goals and minimizing environmental impact.
- *Negotiation of Energy Supply Contracts*: Work with electricity providers to secure favourable energy contracts that ensure regulatory compliance and cost efficiency.
- *Infrastructure Upgrades*: Partner with energy providers to facilitate necessary grid upgrades, minimizing delays and sharing costs where possible.
- *Suitable location*: Both public and private locations as well as indoor and outdoor can be considered. Each has advantages and disadvantages (e.g. reliance on cooperation or public administration, different requirements for security concepts and different climatic conditions).

Certification and Compliance

Adherence to international standards and obtaining necessary certifications are crucial for building trust among stakeholders.

- *Recognized Certifications*: Ensure that all required certifications, such as CE, ENEC, and fire safety standards, are met and up to date.
- *Active Compliance Monitoring*: Continuously monitor legal changes and adjust products and processes to ensure ongoing compliance.

Performance Monitoring and Optimization

Establishing reliable systems for monitoring station performance and battery status is essential for transparency and operational efficiency.

- *Definition of Key Performance Indicators (KPIs)*: Identify the most important performance indicators to be monitored, such as station availability, battery condition, and usage statistics.
- *Data Analysis and Reporting*: Implement tools for data collection and analysis to make informed decisions and continuously improve operations.

Communication and Awareness Building

Clear and open communication fosters understanding and acceptance of the technology among all parties involved.

- *Transparent Information Provision*: Provide comprehensive information about risks, safety measures, and operational procedures on the website and other communication channels.
- *Stakeholder Engagement*: Engage in active dialogue with customers, partners, and the public to gather feedback and address concerns promptly.

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In total, it can be noticed that the infrastructure side needs to cover a very wide range of aspects. With the needs of the charging station providers, many different (sub-)stakeholders for the provision of infrastructure have to be considered.

3.2.4 European Commission request to CEN CENELEC (M/581)

Under the framework of the European Union's Alternative Fuels Infrastructure Regulation (AFIR), the European Commission issued a Standardisation Request (Sreq) to CEN and CENELEC to establish an interoperable infrastructure for electricity supply in road transport. This includes a European standard that specifies a unified approach to battery swapping for L-Cat vehicles. This Sreq (M/581)[4] calls for the creation of new EU standards to support an interoperable electricity supply infrastructure for road transport.

The standards outlined in this request are intended to foster a unified, interoperable alternative fuels infrastructure across the EU, with digital specifications that prioritize a user-centric approach. The new European standards will contribute to updating Directive 2014/94/EU on the deployment of alternative fuels infrastructure, promoting an open and competitive market for recharging and refuelling services where new technologies and market players can operate fairly.

The physical infrastructure standards requested are to include consistent technical specifications tailored to each transport system and relevant infrastructure. These specifications should align as closely as possible with international standards and existing recharging/refuelling infrastructure, while allowing for adaptations to local, technical, and regulatory conditions.

Standards for communication and interoperability within the recharging infrastructure are also requested. These standards should encompass unified technical specifications, utilizing advanced digital solutions where feasible. Key areas of the electric vehicle recharging ecosystem that should be integrated include:

- Communication between the electric vehicle and the recharging point
- Communication between the recharging point and the (back-end) software management system
- Communication for electric vehicle e-roaming services
- Communication with the grid

CEN and CENELEC shall develop these standards openly to prevent market monopolization by specific players. The standards will ensure technical compatibility across all areas of the electric vehicle recharging system, facilitating smart charging and vehicle-to-grid capabilities in diverse scenarios.

Additionally, the European standard on battery-swapping for electric vehicles will identify and recommend the best technical solutions and specifications for developing a future European standard in this area.[5] Throughout the drafting process, CEN and CENELEC will keep the Commission informed of the progress. Point 9 of Table 2 is specifically addressed to L-Cat vehicles, and thus, is considered in this STAN4SWAP project, cf. [3].

[4] see SR M/581, available at https://ec.europa.eu/growth/tools-databases/enorm/mandate/581_en

[5] see SR M/581 Annex I, Table 6, point 1

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1	European standard containing technical specifications with a unified solution on a supply connector for recharging heavy duty vehicles (DC charging)	31.12.2024
2	European standard containing technical specifications with a unified solution for wireless recharging for passenger cars and light duty vehicles	31.12.2022
3	European standard containing technical specifications with a unified solution for wireless recharging for electric buses	31.12.2022
4	European standard containing technical specifications with a unified solution on inductive static wireless recharging for heavy duty vehicles	31.12.2024
5	European standard containing technical specifications on electric road systems (ERS) with a unified solution for inductive dynamic wireless recharging for passenger cars, light and heavy duty vehicles	31.12.2025
6	European standard containing technical specifications on electric road systems (ERS) with a unified solution for dynamic overhead power supply via a pantograph, for heavy duty vehicles	31.12.2023
7	European standard containing technical specifications on electric road systems (ERS) with a unified solution for dynamic ground level power supply through conductive rails for passenger cars, light duty vehicles and heavy duty vehicles	31.12.2024
8	European standard containing technical specifications with a unified solution for battery swapping for heavy duty vehicles	31.12.2027
9	European standard containing technical specifications with a unified solution for battery swapping for L category vehicles	31.12.2025

Table 2 – List of new European standards supporting an interoperable infrastructure for electricity supply for road transport [5]

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3.3 User side

When considering the needs of end users for swappable battery systems, various perspectives have to be taken into account to get a comprehensive picture.
Firstly, the handling of swappable battery systems must be simple and on par with the use of combustion engine L-Cat vehicles. They expect easy handling while changing the batteries.
Secondly, there is the psychological perspective, which deals with the perception of range anxiety.
Last, the economic perspective plays a crucial role. Users are interested in cost-efficient solutions that not only consider the purchase price but also the operating costs of the vehicles. Also, the maintenance costs as well as effort are very important to them.
Clarifying these different perspectives is essential to fully understand user needs and promote the acceptance of swappable battery systems.

When considering the motorcycle and moped registrations in the most significant EU markets (Figure 1), the difference in numbers of sales between combustion and electric engines is still significant and sales of electric vehicles even decreased in 2023 (and they also decreasing in 2024).

REGISTRATIONS OF MOTORCYCLES AND MOPEDS IN LARGEST EUROPEAN MARKETS					
INTERNAL COMBUSTION ENGINE + ELECTRIC MODELS					
L-category vehicles	Jan - Dec 2019	Jan - Dec 2020	Jan - Dec 2021	Jan - Dec 2022	Jan - Dec 2023
Motorcycles (ICE + Electric)	874.481	880.763	949.480	950.437	1.049.898
Motorcycles (Electric)	11.966	18.007	23.084	43.484	34.764
Mopeds (ICE + Electric)	246.553	280.440	264.807	255.909	193.145
Mopeds (Electric)	52.300	59.289	73.124	85.846	61.011
Motorcycle figures include the following markets: France, Germany, Italy, Spain and the UK					
Mopeds figures include the following markets: Belgium, France, Germany, Italy, the Netherlands and the UK					

Figure 1: European sales figures for two-wheelers from 2019 to 2023, broken down by drive type [6]

Today, many of the electrified vehicles sold are equipped with removable batteries. The lack of an EU common standard does not justify the placement of different branded swapping boxes and people are forced to recharge at home or in the office. The main orientation of users is to recharge the battery without removing it from the vehicle. Indeed, users consider recharging at home or in the office less convenient than in their garage with a normal Shuko plug. In other words, most of the users not owning a garage prefer other mobility solutions (combustion engines motorcycles, cars, etc.).
Sales confirmed this orientation. In Italy, the best sale (in June 2024) among electric motorcycles is a vehicle (BMW CE02) with a non-removable battery. Furthermore, in the same period more than the half of the top five most sold electric motorcycles do not have a removable battery.
However, we observe a totally different situation in Spain where the company SILENCE has been present in the market with its swappable battery systems. SILENCE motorcycles are equipped by swappable batteries compatible with their swapping stations that are present in different Spanish towns.
Consequently, most of SILENCE users do not own batteries, but prefer swapping them. Data provided to STAN4SWAP, confirmed that in Barcelona and Madrid in the Q2 of 2024 about the 95 % of SILENCE users did not buy the battery with their motorcycle (high-capacity battery pack - autonomy about 100 km). This shows that widespread swappable battery systems can make a difference in expanding the market for electric two-wheelers.

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Psychological Effects of Swappable Systems for End User
The fear of range anxiety and running out of battery power is one of the biggest barriers for potential users of electric vehicles. Swapping stations that enable fast and easy swapping of empty batteries with full ones could significantly reduce this concern. Users should feel confident that they can access a fully charged battery at any time, without worrying about the remaining range. They are more anxious to finish their battery charge then remaining without petrol. Indeed, the time needed for charging an electric vehicle (about 4 hours) is much longer than the time needed for refilling a thermal vehicle tank (1 minute). This anxiety is also linked to the higher number of petrol stations in EU towns compared to electric infrastructures. Estimations for Milan show that there are about 250 petrol stations (internal exact data confirmed that 450 petrol stations existed in 2008, and 300 in 2018) allowing combustion vehicle users to refill without any complexity. Often, electric vehicle users must change their usual route to find electric infrastructures. This phenomenon is even more critical in the countryside environment or in the suburbs.

The presence of swapping stations could drastically reverse the habit of users. According to the SBMC consortium, riders would need only 40 seconds to swap their vehicle's empty batteries for fully charged ones, sketch displayed in Figure 2. With a swappable battery system, an "infinite" range by simply swapping the battery at swapping stations is possible and give the user a feeling of freedom.

Figure 2: Sketch of fast charging through battery swapping [7]

The presence of swapping stations reduces range anxiety, and it facilitates the re-use and re-purpose of batteries for a second life, according to a circular economy approach. Furthermore, the diffusion of this model will extend the life of batteries because their BMS is constantly under control when batteries are stoked in their boxes. The consequence is that users will not have to worry about the maintenance of their battery, as the batteries are continuously monitored and maintained externally. This eliminates the concern of the battery losing power. Additionally, swappable batteries are not tied to the age of the vehicle. Users can purchase a new vehicle without worrying about battery life or condition. This means that the performance and range of the vehicle are independent of its age, resulting in a better user experience and lower long-term costs.

3.3.1 Challenges and needs at user side

The needs of end users regarding swappable battery systems must be specifically addressed to promote the acceptance and use of electric vehicles.

Comfort and handling
Part of the reason the weak demand for L-Cat EVs is linked to the fact that users consider combustion engines more practical and convenient. With some thermal 2-wheeler (Euro 5+) vehicles a customer can ride for about 250 km without never refilling the tank. In a middle size town this means refilling once or twice a month. With the same category of vehicle, the electric version has an autonomy of about 70 km,

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meaning charging much more often with significantly longer charging times compared to refill at gasoline models. This explains why sales of electric models correspond to only about 1 % of sales among specific OEM. For the user, it is essential that electric L-Cat vehicle become as suitable as combustion engine vehicles for everyday use. Swappable battery infrastructure ensures that the user does not have to accept the hassle of charging the battery of his vehicle at home (e.g. with the help of extension cables or by removing the battery and carrying it up to the apartment). It is important instead to have easily accessible swapping station for batteries. The subsequent swapping process must be simple and self-explanatory. However, it is also important that the battery is easy to handle. Therefore, the weight of the battery can't be too heavy. Existing scooters have weights of around 12 kg (e.g. PIAGGIO 1 or PIAGGIO VESPA). The battery must be easy to grip and lift. It is also important that it is robust so that it does not break immediately if dropped, for example. The swap of the battery must also be able to take place without risk to the user in the rain, for example. The use and connection of the batteries (in the vehicle or the charging station) must be self-explanatory so that no mistakes can be made.

Economic savings for end user

The presence of swappable stations will lower costs for the final users through (1) higher volumes in the production of the same battery, (2) battery manufacturers selling directly to consumers and not to motorcycle manufactures (one step less in the chain) and (3) different business models that will be created (e.g. rent or pay per use). In the case of PIAGGIO, batteries correspond to the 20-30 % of the price of the vehicle. The presence of swapping stations will allow OEMs to sell electric vehicles without the battery, like today a thermal vehicle is sold without petrol. This aspect can boost the electric market significantly making prices much more competitive. Currently, the 60 km/h version of the PIAGGIO 1 costs 3.600 euros (including the battery) while a combustion equivalent vehicle (Liberty 125 cc) cost 3.000 euros. Without considering the price of its battery, an electrical 2-wheeler could be more attractive to customers.

3.3.2 Major needs to address

For the end user, handling and user-friendliness play a particularly important role. In addition, there are economic factors.

User Friendliness

The simplicity and speed of the battery swapping process must be designed in such a way that users can integrate it into their daily lives with little effort. A straightforward poka yoke swapping process that takes only a few seconds will increase convenience and encourage the use of swappable battery systems.

Ergonomic Factors

The process must be simple for each group of people, according to their physical abilities. The battery must therefore not be too heavy and must be easy to grip and easy to remove from or place in the vehicle or charging station.

Safety Concern

The hardware of swappable battery systems must be trustworthy. Users must feel safe when using the systems and not be exposed to any danger should it rain, or a battery be accidentally dropped from the user.

Psychological effects

Users can be relieved of range anxiety, fear of liability in the event of battery damage and concerns about battery maintenance.

Access to infrastructure

The lack of standardised and easily accessible swapping stations in many EU countries is a significant obstacle. To increase user acceptance, it is necessary that these stations are evenly distributed especially

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in urban areas. A well-developed infrastructure will give users the security of knowing that they will always have access to a full battery.

Economic Efficiency
Standardised batters are cheaper and selling batteries directly to end users can decrease supply chain costs. Depending on the user behaviour and the living space inside a city, other business models are on top much more efficient and are viable with the swappable battery system. Such other business models can be, for instance, battery as a service which then has advantages for companies in the system regarding continuous revenue streams from the battery usage for the industry and in particular lower initial capital expenditure costs for the end user. Due to the flexibility, different business models can also be operated in parallel.

Purchase Cost Reduction
The price of electric vehicles is often a decision factor for buyers. High purchase prices are a criterion for excluding the purchase of an electric scooter. For wider distribution, prices must fall. Through new business models that make it possible to purchase vehicles without the battery, those initial purchase price can be significantly reduced. E-mobility might be available for everyone then.

These challenges and at the same time opportunities for swappable battery systems have been confirmed by different OEMs, associations and consortia based on their experience and knowledge of the European market. The needs above are essential to fully realize the benefits of swappable battery systems for end users and to increase the acceptance of electric vehicles in general.

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3.4 Battery manufacturer side

Standardising battery specifications could provide significant advantages for battery manufacturers by ensuring that batteries are compatible with a variety of vehicles and systems. This could streamline manufacturing processes and decrease expenses related to tailor-made solutions. Among the competitors, cross-brand compatibility and collaboration can increase the market and boost new business opportunities in battery life-cycle management and battery health monitoring.

Implementing standardised battery specifications can pose challenges like technical complexity. Battery systems are complex, and ensuring safety, efficiency, and interoperability/compatibility can be technically challenging. Meeting the technical requirements set by industry guidelines and standards can be difficult [8].

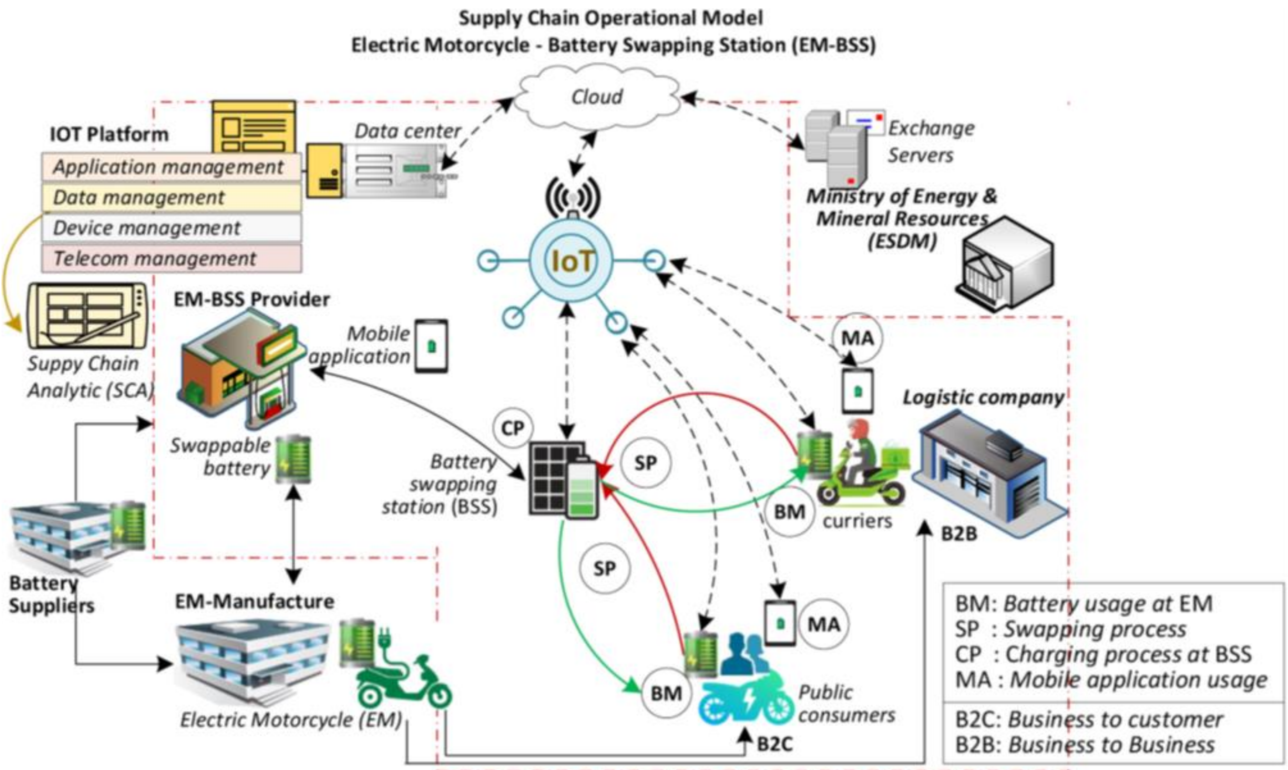

Figure 3: Illustration of the battery swapping process in a charging infrastructure [9]

Japan's Big Four motorcycle manufacturers - Honda, Yamaha, Suzuki, and Kawasaki - have agreed upon swappable battery standards and a final design. All batteries produced under this agreement will be the same size and weight and will share the same durability and safety features. They will be completely swappable with one another [10]. Additionally, the SBMC aims to standardise swappable battery systems for mopeds, motorcycles, tricycles, and light transport four wheelers. These efforts are aimed at making electric mobility more convenient by reducing charging time and eliminating range anxiety for the users.

For motorbike swappable batteries, battery manufacturers must meet certain durability standards to ensure the batteries can withstand the demands of frequent swapping and use. Swappable batteries are designed to be durable under challenging conditions like waterproof, and dustproof. There are also considerations for the durability and health monitoring of swappable batteries in EVs, as suggested by

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the United Nations Economic Commission for Europe (UNECE) [11]. Regulations may include minimum battery performance and durability requirements, standards for re-use of batteries after their end-of-life, and prohibitions against improper disposal. These standards are crucial for promoting the use of swappable batteries in EVs and other devices, enhancing user convenience and broadening market accessibility.

3.4.1 Challenges and needs at battery manufacturer side

Ease of assembly and disassembly

It is imperative for battery producers to develop motorbike swappable batteries in a way that makes assembly and disassembly simple in order to guarantee effective swapping services.

- *Weight*: To facilitate service user handling, batteries should not weigh more than 15 kg.
- *Design Consistency*: To maximize and ensure compatibility with current systems, swappable batteries should retain the similar dimensions, power output, and data exchange protocols of their predecessors.
- *Appealing Appearance*: Batteries should be visually appealing since they are visible component of a brand, and shaped to avoid incorrect plugging
- *Modular Design*: By utilizing modular design principles, the process of assembly and disassembly can be made simpler and more effective. This will make the recycling process much more efficient by enabling the recovery of individual components easier.

Certain vehicle manufacturers, like KTM, Gogoro, KYMCO, etc., have already created electric motorcycles with lightweight, nimble quick-change swappable battery packs that facilitate simple changing and charging.

These design elements are essential for encouraging the wider adoption of electric vehicles, improving user convenience, and supporting the usage of swappable batteries in electric mobility [12].

Cost-effectiveness

The steep price of battery technology continues to be a major obstacle to its broad acceptance, even as manufacturing advancements and scale benefits are made.

- *Lithium-Ion Battery Pricing*: The cost per kWh for lithium-ion batteries is on a downward trend, yet it still poses a significant challenge within the industry. To promote wider use, battery manufacturers are tasked with devising strategies to lower production costs significantly and then transferring these savings to consumers [13].
- *Subsidies and Incentives*: The role of government subsidies and incentives is pivotal in surmounting the financial hurdles associated with battery technology. By providing economic support, these mechanisms can alleviate the burden of high initial costs, making battery-operated solutions more feasible for a broader consumer base.
- *Lifetime Costs*: The total cost of owning battery technology, which encompasses not just the initial investment but also ongoing maintenance and eventual replacement costs, continues to be a daunting challenge. To make these technologies more appealing, battery manufacturers need to innovate ways to enhance battery longevity and minimize the cumulative ownership costs [14].

Interoperability/Compatibility

- *Charging infrastructure interoperability/compatibility:* With the ongoing advancement of battery technologies, the challenge of creating interoperability/compatibility among various chargers and batteries intensifies. It's essential for battery manufacturers to establish universal standards that can support diverse battery types and chemistries, and to ensure these standards are uniformly adopted throughout the industry. Establishing a widespread and reliable charging network is crucial for the adoption of standardised battery charger practices. Having a broad variety of EV charging options and connection mechanism, with their own set of challenges

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regarding affordability, setup, and interoperability/compatibility; it is important for battery manufacturers to design chargers that can effortlessly connect with these different technologies and standards.

- *Charging network challenge:* This involves rolling out adequate infrastructure to support the increasing use of electric vehicles. This necessitates a collaborative approach among battery manufacturers, power providers, and governmental bodies to place enough charging points in key locations [9]. The use and diffusion of energy from renewables have increased exponentially the demand of battery storage system. The batteries are now a key part of the charging infrastructure, also considering the bi-directional approach to grids. For the above reasons the deployment of the infrastructure is critical from a strategy and technical point of view. Achieving interoperability/compatibility between chargers and vehicles is key to a smooth charging process. Battery manufacturers need to comply with established industry standards and protocols to ensure their chargers can be easily incorporated into the existing charging network [9].
- *BMS:* A BMS is a technological system that consists of both software and hardware, including data processing algorithms and communication protocols, as well as sensors and controllers. Voltage and current sensors record the incoming voltage and current. The incoming data is subsequently processed by the controller. Examples of predefined program algorithms include determining SoC, measuring operational temperature, terminating current, and more. Up until now, BMS sensors and controllers have not been particularly governed by any standards. To promote BMS performance, standardisation of sensors and controllers is primarily concentrated on compatibility and integration with other parts of the electric motorcycle. To safely develop harmony between several components, the compatibility is essential [15].
- *Communication:* The use of communications technologies and protocols to enable information sharing between different systems or components is referred to as interoperability at the communications layer. This conversation takes place inside the context of functions and related data models and information items. Stakeholders assert that to facilitate interoperability across the many elements of the charging infrastructure, communication protocols must be standardised [10].

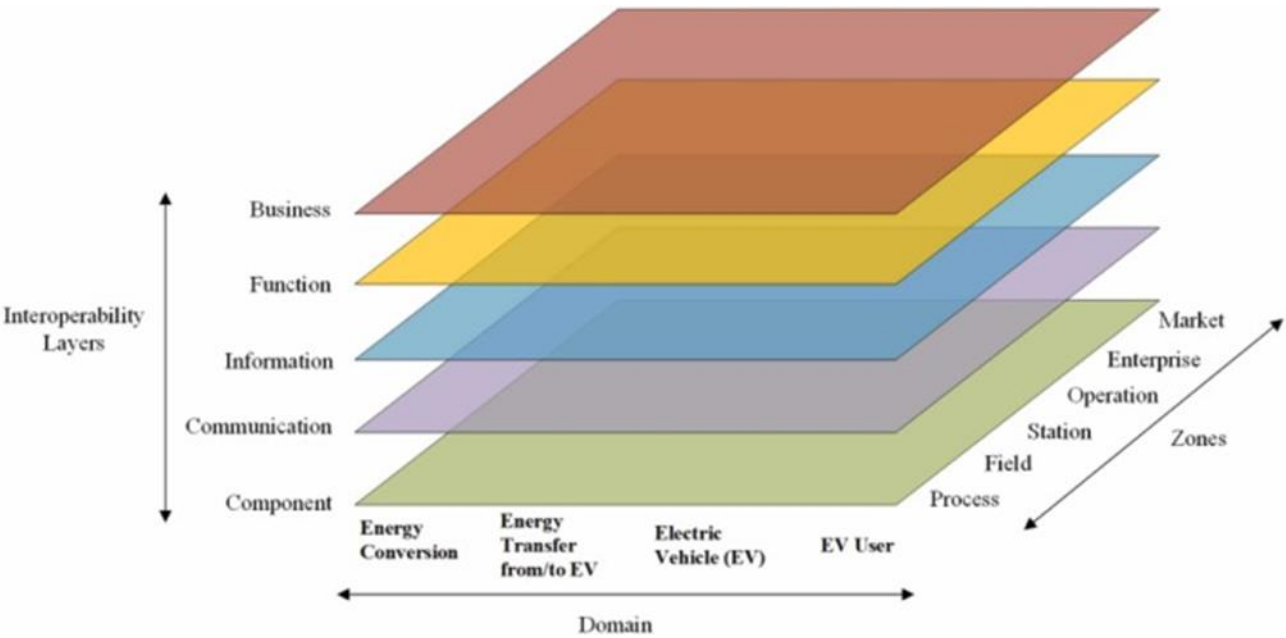

Figure 4: Schematic illustration of the EMSA Model [16]

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The Smart Grid Architecture Model (SGAM), a reference architectural model for smart grid systems, was created by the electrical industry. This architectural model facilitates interoperability and complexity management in cyber-physical smart grid systems [15]. The e-mobility industry uses the E-Mobility Systems Architecture (EMSA) model, which is based on the SGAM model. The interoperability layer, domain, and zone are its three dimensions. Five different interoperability layers are shown in Figure 4: business, function, information, communication, and components. The views of businesses on information exchange inside intelligent networks are incorporated into the business layer. This covers things like market structures, business processes, company models, economic sector rules, and the business cases of the various stakeholders. The function layer, which is independent of actors and the implementation of systems, applications, and components, includes the utilization scenarios of systems, functions, and services and explains how they relate to one another from an architectural standpoint.

Battery Pack Manufacturing

The battery manufacturers require support in developing differentiating technologies in battery materials, cell design, manufacturing and recycling. The existing production lines are not compatible for the next generation manufacturing and the constant switching of cell chemistry directly affects the cost and performance of the processing. The major challenges for the manufacturing process could be (1) A disintegrated supply chain between battery manufacturers and raw materials to application stakeholders. (2) Inconsistent R&I cycles, lead times, pricing and demand levels. (3) Battery and raw materials transportation misalignment leading to delays in timelines. (4) Slow progress often leads to higher scrap rates and hence jeopardizes the short-term goals like circular economy and raw materials recovery. (5) Higher investment requirements with lower profit margin due to unstable value chain. (6) Need for sustainable production regarding energy consumption, toxic chemicals like N-Methyl-2-pyrrolidone (NMP) and per- and polyfluoroalkyl substances (PFAS); circular strategy required from production to recycling.

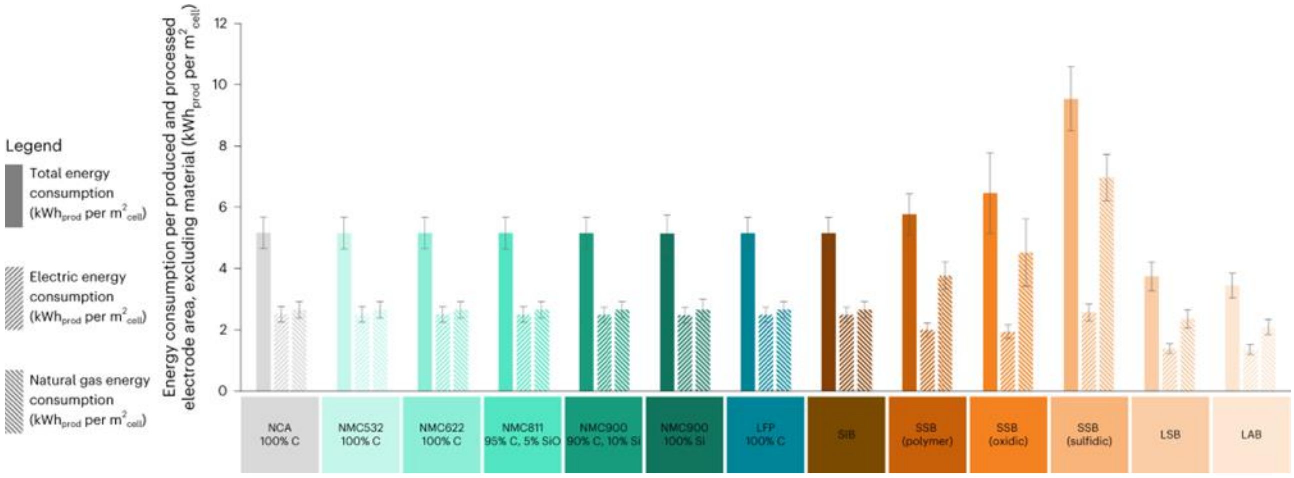

Figure 5: Calculated energy consumption for cell production per produced and processed electrode area of a battery cell factory [17]

Regulatory Aspects

The EU has introduced the EU Batteries Regulation 2023/1542, which replaces the previous EU Batteries Directive. This new regulation encompasses the entire lifecycle of batteries, from their production to eventual reuse and recycling. These regulations are directly impacting the battery and vehicle

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manufacturers. The objective is to establish a sustainable value chain for the battery stakeholders in Europe. Manufacturers of batteries face new requirements based on battery type [18].

- *Carbon Footprint Declaration*: Battery manufacturers must provide information on the carbon footprint associated with their batteries.
- *Recycled Content Requirements*: This encourages the use of recycled materials in battery production.
- *Performance and Durability Standards*: Batteries should meet specific performance criteria.
- *Removability and Replaceability*: Design considerations for easy removal and replacement of batteries.
- *Labelling*: Batteries must carry labels with capacity and duration of use details.

The European Union is identifying and taking actions in the research and strategic developments in the battery manufacturing sector. The regulations aim to stabilize the competitive supply chain by focusing on advanced and sustainable processing techniques.

3.4.2 Major needs to address

Standardising battery specifications is critically important for manufacturers because it offers significant advantages by ensuring battery compatibility with different vehicles and systems. This standardisation can optimize manufacturing processes and significantly reduce the costs associated with customized solutions. However, to be successful, it must address several key manufacturing needs.

Technical complexity and safety
Manufacturing batteries for swapable battery systems is challenging. To ensure safety, efficiency, and interoperability of the systems, battery manufacturers have to be in line with specific guidelines and standards established by the industry. It is important to strike a balance between innovative technologies and costs as well as safety. This requires extensive research and development to create robust solutions that meet market demands.

Durability and longevity
Battery durability is another key concern. Battery manufacturers must ensure that batteries can withstand the demands of frequent swapping. This includes being waterproof and dustproof to function reliably in a range of environments. Guidelines such as those from the UNECE emphasize the need to establish minimum standards for battery performance and durability. These standards are crucial to improving user experience and promoting market adoption.

Interoperability/Compatibility and standardisation
Establishing interoperability/compatibility between different charging infrastructures and battery types is essential. Battery manufacturers need to develop universal standards for the support of different battery types and chemistries. Therefore, close collaboration between manufacturers, utilities and to some extent also governments is needed to create a reliable charging infrastructure that promotes the wide adoption of swappable battery systems.

Cost-effectiveness
High costs for batteries are one of the main hurdles regarding a widespread market adoption. Although lithium-ion battery prices are falling, battery manufacturers need to develop strategies to reduce production costs. Additionally, government subsidies and incentives are critical to overcome financial challenges.

Modularity and design
For a better replacement process, batteries must be designed to be easily assembled and disassembled at the vehicle. Battery manufacturers should ensure that the weight of the batteries does not exceed 15 kg to make it easier for users to handle the batteries. A modular design can increase efficiency in

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manufacturing as well as later recycling by making it easier to recover individual components. In addition, the design should be appealing to strengthen brand identity and avoid misconnections.

Regulatory requirements
The new EU regulations, which cover the entire lifespan of batteries, place additional demands on battery manufacturers. These include carbon footprint declarations, requirements for the percentage of recycled materials, performance and durability standards, and requirements for easy removal and replaceability of batteries. These regulations promote the use of sustainable practices in battery manufacturing and help to level the playing field in the European market.

Addressing these key manufacturing needs is critical to ensuring successful standardisation and implementation of removable battery systems for L-Cat vehicles. By considering technical, economic, and regulatory aspects, battery manufacturers can promote the adoption and efficiency of these technologies while meeting industry challenges.

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4. Multidimensional list of needs

To consolidate the insights gained within the analysis of the needs of the different stakeholder groups on swappable battery systems, an aggregated table was developed using the PESTEL framework (cf. chapter 2). Therefore, a multidimensional *list of needs* based on the six PESTEL categories and the four stakeholder perspectives (cf. chapter 3) was created.

For a better readability, each PESTEL category is depicted in a separate table and subchapter in the following. In the second column of each table, specific keywords are used to encapsulate different key aspects of each PESTEL category. The various needs are aligned with these considerations and within the different topics that the stakeholders have addressed. Although individual needs could be assigned to different categories, each consideration was only included in the tables' key aspect line that best fits for the sake of clarity. An empty text box does not mean that the factor or aspect is not important, but that it may not have been specifically named from the distinct stakeholder side due to the individual methodology used to collect the data (cf. chapter 2). Also, the needs in the tables are not necessarily described in such a way as to formulate a specific need, but rather to address an important point for the stakeholder – these may also be specific problems or other challenges and obstacles. In this case, the specific need is then inferred in the commented section beneath each table. The last section of this chapter works out the similarities and contradictions of the identified needs.

4.1 Political aspects

PESTEL factor	*key aspects*	**Vehicle side**	**Charging station / infrastructure side**	**Users side**	**Battery manufacturer side**
Political	governmental support and clear authorization procedures		Local variations in requirements for safety standards are a particular challenge		
			standardised approval processes for new infrastructure station locations		
			political support for the promotion of infrastructure projects		government subsidies and incentives are pivotal for European battery manufacturing
			approvals necessary by public authorities (e.g. urban planning)		

Table 3 – List of identified policy needs

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The main part of needs addressing political factors relates to the charging station/infrastructure side and are displayed in Table 3. Political measures, such as the expansion of charging stations or the simplification of authorization procedures, can be decisive here. Governments can accelerate the development of the necessary infrastructure through funding programs or legal requirements, which is essential for the successful spread of swappable battery-electric vehicles. From the battery manufacturer side, political measures to promote battery production, such as subsidies for research and development or agreements to secure raw materials, are of crucial importance. This is especially relevant for European battery manufacturing as it necessitates for the market development high initial investment costs for the production ramp-up. Access to resources and industry support through political framework conditions play a major role in ensuring the competitiveness of manufacturers.

The survey results on the vehicle side reveals no specific needs that could be matched to political factors. However, political decisions, such as state subsidies for electric vehicles or strict emissions regulations, could influence the sales of EVs. This governmental support can play a key role in promoting innovation and increasing the acceptance of electric vehicles on the market. For the user side there are no identified needs as well. Nevertheless, political decisions could have an influence on if and how end users accept electric vehicles. Governments could steer consumer behaviour towards electric mobility through incentives such as tax breaks, discounts on the purchase of electric vehicles or the introduction of low emission zones, but also trough clear communication and distinct targets.

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4.2 Economical aspects

PESTEL factor	*key aspects*	**Vehicle side**	**Charging station / infrastructure side**	**Users side**	**Battery manufacturer side**
Economical	*economics of scale*		favourable terms from electricity providers, e.g. due to high purchase volumes	high volumes for mass market adoption needed	economics of scale in production makes batteries cheaper
	competitive business models	competitive vehicle models must be offered in terms of price and performance	must be utilized accordingly (regularly frequented) and need of a large network for availability	new business models i.e. rent, pay per use	performance and price of the batteries must prove themselves against competition
				direct B2C from battery manufacturer to consumers	market and business opportunities in battery life-cycle-management and health monitoring
	attractiveness of swappable battery system	cheaper vehicle price (the battery corresponds to up to 30 % of the price)	attractive and clever chosen locations for stations	competitive purchase price and total cost of ownership for EVs	minimize the cumulative total cost of battery ownership fur users
				cost and revenue efficient infrastructure	high invest requirements, low profit margins for battery production
	cost drivers		high costs for grid connections / installation, energy prices, location fee, insurance		long R&D (lead) time, therefore big team and high investment
	supply chain perspective		simply regulated electricity prices		risks from disrupted supply chains
			good teamwork between all the local partners required		

Table 4 – List of identified economical needs

In the field of economic factors, to reach economics of scale is very import for all stakeholders from the industry – it can be achieved through the mass production (and market deployment) of vehicles, batteries, and infrastructure (stations). The production of standardised products in larger quantities results in a reduction in costs per unit. This applies in particular to standardised batteries in the vehicles, but also to the vehicles themselves or the infrastructure in form of broad installations of charging stations. A more extensive network of charging stations could be managed in a more cost-effective

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manner due to the reduction in unit costs, which in turn would also facilitate more (social) acceptance of electric mobility.

Another point concerns the area of competition-oriented business models. In particular, users could benefit monetary from innovative business models, such as subscription models or leasing options. This might be also relevant for vehicle OEMs to sell their vehicles without the battery to an attractive price, or battery manufacturer, that can lease their batteries to infrastructure operators or directly to customers, which in turn can then use it to provide their own business models. A prerequisite for this is that the infrastructure in operation must be utilized to a sufficient extent, as well as the swappable batteries in the vehicles. This also helps to foster the overall attractiveness of the swappable battery system. From the vehicle perspective, the introduction of swappable batteries could engender cost savings for consumers, as the battery would no longer need to be purchased separately. This would have implications for the charging infrastructure and the necessity for changing stations for customers. For battery manufacturers, such a shift could present both challenges and opportunities. On the one hand, it could facilitate the mass production of a battery model; on the other hand, it could lead to lower profit margins due to competition in the mass market.

Furthermore, an analysis of the cost drivers is essential for an understanding of price developments. Regarding swappable battery L-Cat vehicles, the cost of batteries and other essential components may prove to be a fundamental factor in determining overall expenses for the consumers end use market. Infrastructural considerations are similarly subject to cost-related influences, including the investment costs (and subsequent location fee) for the broad market deployment of stations associated with the local grid integration and insurance costs of the installations. For battery manufacturers, the prices of raw materials play a pivotal role, as they exert a considerable influence on the battery and its production costs.

This aspect also gives rise to the supply chain perspective, and in particular, to the importance of trust and collaboration between business partners. From the perspective of the vehicle manufacturer, it is essential to ensure the availability of key raw materials and components to guarantee the continuity of production. Furthermore, battery manufacturers must optimize their supply chains to ensure cost-effective and efficient production while minimizing risks along the supply chain partners. In the context of charging infrastructure, the cost of electricity assumes particular significance. The process of negotiating energy prices in frame contracts with utilities or energy companies is complex. It necessitates the establishment of direct grid connections, which are costly, coupled with a significant number of battery swapping stations within a given region. The latter might be essential to gain the attention and engagement of energy providers and for further close collaboration between the stakeholders.

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4.3 Social aspects

PESTEL factor	*key aspects*	**Vehicle side**	**Charging station / infrastructure side**	**Users side**	**Battery manufacturer side**
Social	*ergonomics and easy handling*	ergonomic features i.e. rigid handle, functional area for locking, built-in SoC display	convenience for end user with good user interface / app at charging station	no carrying of battery over distances; but good handling (i.e. weight) is mandatory	battery design must be created in such a way that it is easy to handle
	aesthetics		aesthetic design of charging station		visually appealing battery packs
	maintenance efforts			no charging infrastructure at home necessary	
				no worries about maintenance	
	safety concerns		users must have confidence in the infrastructure and its security	no battery at home, which can catch fire, no safety concerns during handling of battery	
	collaborative work	carefully listening to customer needs	collaboration is important with various partners, addressing neighbours' concerns		must meet the requirements of the user, OEM and infrastructure provider should work closely together
	social acceptance		public acceptance of the installations and infrastructure in the cityscape	purchasing of L-Cat EVs will be cheaper for users – mobility for everyone?	
			providing transparent information about risks, safety measures, and operational procedures		safe batteries are mandatory
		vehicle must operate reliable (regardless of environmental circumstances)	system must operate reliably (regardless of environmental circumstances)	peace of mind, less range anxiety due to "infinite" range	battery must operate reliably (regardless of environmental circumstances)
		raising awareness of the advantages of battery swapping systems	raising awareness of the advantages of battery swapping systems		raising awareness of the advantages of battery swapping systems

Table 5 – List of identified social needs

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The identified needs that address social aspects can be roughly categorized into three principal areas: handling, safety aspects, and (social) acceptance. It is essential to prioritize the ease of handling when designing the battery, in conjunction with ergonomic considerations. Additionally, it is therefore imperative to assess the weight of the battery, cf. Table 7 in Chapter 4.4. In addition, the vehicle and the charging station should provide straightforward access to battery information, including e.g. the SoC, and a user-friendly interface. For end users, a significant benefit is the elimination of concerns regarding battery maintenance and the absence of the need to set up dedicated charging stations in their residences.

It is also apparent that close collaboration between the OEMs of the vehicle, infrastructure, and battery manufacturer is of paramount importance when considering the successful market deployment of swappable battery systems. This is the case between different industry stakeholders, but also between the industry and the end user or society, respectively. It addresses the need for strong reliability of the charging infrastructure proceeding, vehicle operation and battery usage, and thereby also fulfilling the customer's desire to be calmed of concerns regarding battery-electric driving range.

The social acceptance is paramount upon the reliability and safety of the battery. Additionally, this is also essential for the installation of a comprehensive network of swapping stations by the charging infrastructure operators and the awareness raising of the systems' advantages.

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4.4 Technological aspects

The technological-based needs are displayed in the following Subchapters 4.4.1 to 4.4.4, with a focus on battery key performance indicators in Table 6, battery dimensioning in Table 7, L-Cat vehicle related needs in Table 8 and Infrastructure related needs in Table 9.

4.4.1 Battery KPI related needs

PESTEL factor	*key aspects*	**Vehicle side**	**Charging station / infrastructure side**	**Users side**	**Battery manufacturer side**
Technological		aspects regarding battery pack KPIs			
	technical parameter	pack voltage: 48V			
		battery capacity: 1.6 - 2 kWh			
		cont. discharge power 3 kW			
		peak discharge power 6 kW			
		peak power charge ca. 2 kW	enough grid supply capacity		
		1 to 2-pack serial connected			
		(max.) 3 to 4 packs parallel configuration for capacity and cont. power increase			
	charging / swapping time	no fast charging needed; charging time of 2 hours or less		battery swapping in less than one minute (ca. 40 seconds), competitive with ICEV refuelling	
	service lifetime		long durability is important for operator effort and economic reasons	if the user does not own the battery, durability is not so important to him	further need to enhance battery longevity / durability standards

Table 6 – List of identified technological needs, related to battery KPIs

It is primarily vehicle manufacturers who request battery-related performance indicators, as these are necessary for the optimal functioning of their vehicles. In addition to the 48V and 2 kWh capacity, the peak discharge power can be up to 3C. While a maximum of one to two packs in series seems reasonable for 48V (72V respectively, e.g. for three- and four-wheeler), the parallel configuration can accommodate up to four packs to achieve the final battery capacity. The necessity of rapid battery charging is not a priority, as the primary objective is to facilitate convenient battery swapping speed for the users. Although the charging station operator and battery manufacturer are interested in a long battery service life, this may be perceived as a relatively minor concern by users, given the possibility of battery swapping after each discharge cycle.

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4.4.2 Battery pack format related needs

PESTEL factor	*key aspects*	**Vehicle side**	**Charging station / infrastructure side**	**Users side**	**Battery manufacturer side**
Technological		aspects regarding battery pack format and dimensioning			
	technical flexibility	most frequently mentioned: Length: 151 to 300 mm Width: 151 to 200 mm Height: 251 to 300 mm *SBMC is focusing on L190,2 x W158,5 x H309,4 mm*	flexibility is needed regarding technological innovations in battery technologies		existing production lines are not compatible for the next generation manufacturing (e.g. changes in cell chemistry), affecting processing costs and performance efficiency
		two-pack serial connection requires additional safety aspects	interoperability between different manufacturers and vehicle models	"Infinite range" is linked to interoperability of different brands	interoperability between different charging stations and vehicle models
	swappable battery weight	maximum weight: 12 kg		maximum weight: 10 kg	maximum weight: 15 kg
	dust and water protection	IP67 ingress protection		must be waterproof / robust so that there is no damage	waterproof, dustproof
	battery to vehicle connection	panel-to-panel connector	connections must be designed in such a way that incorrect contacting is not possible	connections must be designed in such a way that incorrect contacting is not possible	"poka yoke" design to avoid incorrect plugging, and design consistency in dimensions, power output

Table 7 – List of identified technological needs, related to battery pack format

The identified needs show that it is crucial to consider a technical flexibility for battery innovations and at least a range of formats and battery dimensioning. Regarding the vehicle, the OEM survey did not yield clear dimensional parameters with respect to length, width, and height. However, the results are broadly in line with the area that SBMC is currently focusing on, namely L190,2 x W158,5 x H309,4 mm. Similar considerations apply to the charging infrastructure side. It is essential to ensure some grade of technological flexibility in order to effectively respond to emerging battery technologies/formats and integrate them into the existing swapping system. This is also a significant consideration for battery manufacturers, as they typically align their production lines with specific formats.
The concept of a swappable battery represents a significant area of interest in the interoperability of offerings from diverse battery manufacturers, vehicle models, and charging stations.
Another technological aspect is the weight of the battery. In this regard, the outcomes exhibit a discrepancy of approximately 5 kg, with end-users expressing a preference for the most lightweight batteries, which they desire to be no more than 10 kg, and battery manufacturers proposing designs

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reaching up to 15 kg. The results of the vehicle manufacturers' survey fall within this range, with an average weight of 12 kg.

Furthermore, it is crucial to consider the technological aspects of dust and water protection. From the perspective of the vehicle, it is of paramount importance that batteries are safeguarded in a manner that ensures optimal functionality across a range of environmental conditions. For battery manufacturers, the protection of batteries against dust and water is of paramount importance for the purpose of extending battery life and ensuring their safety. This, in turn, addresses the aforementioned desire of all stakeholders for guaranteed reliability of swappable batteries in use.

Ultimately, 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 itself, in order to guarantee optimal performance. Additionally, it is imperative that the infrastructure facilitate seamless interconnection between batteries, thereby preventing erroneous connections during the charging process, as well as those initiated by users when swapping the batteries by themselves. This is particularly pertinent in instances where the battery is to be automatically recharged and its condition is to be subject to continuous monitoring, as outlined in Table 9 of Chapter 4.4.

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4.4.3 L-Cat Vehicle related needs

PESTEL factor	*key aspects*	**Vehicle side**	**Charging station / infrastructure side**	**Users side**	**Battery manufacturer side**
Technological		aspects regarding L-Cat vehicles			
	BMS	the vehicle controls the multibattery system		No worries about maintenance as the BMS is constantly under control for the stoked batteries	standardisation of sensors and controllers regarding compatibility and vehicle integration to promote BMS performance
	data protocols	CAN bus communication protocol			standardised communication protocols to facilitate interoperability across charging infrastructure and vehicle
					design consistency in data exchange protocols
	battery related data	display of battery related information via the vehicle HMI (vast majority) - remaining range - SoC (capacity) - charge time - power reduction			
		mandatory (extra) features (vast majority): - isolated bus transceiver - UDS diagnostics			
		battery wakeup via dedicated pin and via bus system message			
	driving range	driving range without swapping: 90km		driving range without swapping: ca. 100km	
	operating temperature	ambient temperatures: min -10 °C, max 40 °C			
	Efforts in product development	high construction efforts at the beginning, later less due to reduction of complexity of power unit	enabling the integration in smart grids		high R&D efforts

Table 8 – List of identified technological needs, related to L-Cat vehicles

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When the technical requirements are considered from the vehicle perspective, it becomes evident that standardisation is a necessity in the field of BMS integration and communication protocols based on CAN bus technology. From the standpoint of interoperability/compatibility, this is of particular importance, as users have a reasonable expectation of reliability in the battery management system.
Furthermore, it would be beneficial for the driver to have access to specific key figures within the vehicle. In addition to displaying the range in the cockpit, it would be beneficial to also show the remaining battery capacity and the associated charging time. In terms of driving range, the requirements of the vehicle manufacturer and user are largely aligned, with an estimated range of approximately 100 km. It is essential that vehicles be capable of functioning without issues between temperatures of -10 °C and 40 °C, a necessity that particularly addresses battery technology supplier. The required maximum temperature could be even higher in southern Europe, for example. Although vehicle manufacturers and battery manufacturers initially anticipate significant development costs due to the technical efforts in R&D and construction, infrastructure operators also desire the possibility to integrate swappable batteries into smart grids.

4.4.4 Charging infrastructure related needs

PESTEL factor	*key aspects*	**Vehicle side**	**Charging station / infrastructure side**	**Users side**	**Battery manufacturer side**
Technological			aspects regarding charging infrastructure		
	battery to infrastructure interface		establishing reliable systems for monitoring station performance and battery status		batteries are key part of the charging infrastructure
	safe technology		development of universal safety standards		
			comprehensive safety protocols, including advanced battery monitoring systems and secure storage solutions		
			batteries must be monitored constantly		
			developing emergency response plans in collaboration with local fire dep. and providing training programs.		

Table 9 – List of identified technological needs, related to charging infrastructure

The technical needs for the charging stations are mainly mentioned by infrastructure project developers. As previously noted, their objective is also to monitor the battery system within the infrastructure, thereby developing safety standards and enabling continuous monitoring of the battery conditions. An important element is the secure storage of the battery – which is an integral part of the infrastructure - along with providing training for fire brigades in controlled response measures for emergencies. This involves close collaboration with local authorities and emergency services.

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4.5 Ecological aspects

PESTEL factor	*key aspects*	**Vehicle side**	**Charging station / infrastructure side**	**Users side**	**Battery manufacturer side**
Ecological	*installation space / utilization*		space efficient L-Cat vehicle swapping stations in urban areas + no parking space needed	no individual infrastructure needed - charging infrastructure efficiency due to centralization (distinct swapping stations)	battery aging decoupled from vehicle aging
	design for recycling			reuse and repurpose in form of second life batteries	modular design for ease in assembly and disassembly (and efficient recycling)
	renewable energies		Integration of renewable energies into the charging infrastructure		batteries in swapping stations as a storage system can be linked to the use and diffusion of renewable energies, bi-direction approach to grids
	circular economy				circular strategies are important: need for sustainable production (energy consumption; dangerous/toxic chemicals i.e. NMP, PFAS)
					recycled material content requirements (cf. battery regulation)
	minimize waste		defective batteries are properly disposed of		reduce scrap rate in battery production

Table 10 – List of identified ecological needs

Needs that can be attributed to environmental factors are already being addressed around infrastructure, for example through the Alternative Fuels Infrastructure regulation 2023/1804 (AFIR), and around waste, recycling and the circular economy of the battery itself, through the EU battery regulation 2023/1542. The design of charging stations in urban areas should prioritize the efficient use of urban space. The potential expansion of the swappable battery system to encompass the urban area could render conventional parking spaces obsolete, as this eliminates the necessity for the user to provide a dedicated individual charging space for their vehicle.

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In general, to ensure ecological sustainability, the lifespan of the battery must be decoupled from that of the vehicle. For instance, this is addressed by a design for recycling, which enables a second use in the term of reuse or repurposing, as well as the possibilities for replacement of defective modules in the swappable battery. The necessity of integrating the system with a renewable energy supply, and ideally, of providing a bi-directional charging capability, is particularly pertinent for infrastructure operators. This also presents an opportunity for battery manufacturers to optimize the battery's economic lifespan through efficient cycling.
In Europe, there is a growing emphasis on fostering sustainable growth in the European battery production sector and implementing circular material flows. This includes utilizing recycled materials in the manufacturing of new batteries, which is also mandatory demanded from the European battery regulation.

4.6 Legal aspects

PESTEL factor	*key aspects*	**Vehicle side**	**Charging station / infrastructure side**	**Users side**	**Battery manufacturer side**
Legal	*applicable standards*	most important standards: UNECE R136, UN 38.3, ISO 26262, UL 2271, AIS 156	Certifications (CE, ENEC) and compliance with international standards		regulations for durability and health monitoring, e.g. UNECE
			development of universal safety standards through collaboration with industry consortia and standardisation organizations		comply with establ. industry standards and protocols / industry guidelines and standards can be technically challeng. in battery production
			requirements (which also vary locally) for safety standards are particularly challenging		EU Batteries Regulation 2023/1542 i.e. carbon footprint declaration, performance and durability standards, removability and replaceability, labelling
	system limits of standards				universal standards to support diverse battery types and chemistries, that can also be uniformly adopted throughout the battery industry
			need to harmonize the regulations across different regions		globalized supply chains: transport of batteries and raw materials

Table 11 – List of identified legal needs

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Among the legal factors, particular attention is drawn to the compliance with already defined standards, as referenced in [3]. From the vehicle side, this is already particularly relevant due to existing standards with strong reference to the obligation to provide evidence and safety for the electric drive train, the installed battery and the entire vehicle system. Nonetheless, from the perspective of charging infrastructure, universal safety standards are further needed. Today, these still vary locally in some cases and require further close coordination between the industry and standardisation organizations (as well as politics) for the harmonization of the legal basis across different regions. From both the perspective of charging infrastructure and battery manufacturers, meeting (safety) standards can be challenging somehow but is of outmost importance.
However, the EU battery regulation that came into force in 2023 provides a legal framework for Europe, particularly regarding the declaration, performance, labelling, and sustainability of (EV) batteries. Given that battery manufacturers rely on global supply chains and face competition from non-European manufacturers, strong efforts are anticipated due to the current European standardisation within a globalized battery market. On the infrastructure side, the SR (M/581) already calls for the creation of new EU standards to support an interoperable electricity supply infrastructure for road transport, with a distinct focus particularly on a European standard that contains technical specifications with a uniform solution for battery swapping for L-Cat vehicles, cf. chapter 3.2.4.

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4.7 Analysis of similarities

The four stakeholder groups – the vehicle side, the infrastructure side, the user side and the battery manufacturer side – have several common interests and needs regarding swappable battery systems. A key commonality is the importance of political support. Although specific requirements may vary, all stakeholders recognize that policy measures such as subsidies, regulatory frameworks or guidelines to promote electric vehicles and swappable battery infrastructure can have a significant impact. For example, governmental support in standardisation and harmonization of authorization processes and ensuring the availability of resources is pointed out by both the infrastructure side and battery manufacturers. Although they are less directly involved in political factors, the vehicle side could benefit from stricter emissions regulations and the vehicle side as well as the user side could benefit from incentives such as tax breaks that promote market growth and consumer acceptance of electric vehicles.
In terms of economic factors, the importance of reducing costs is generally recognized. All stakeholders can benefit from the economies of scale regarding the swappable battery system. In particular, vehicle OEMs and battery manufacturers seek for low production costs and mass production, which is heavily addressing battery standardisation and the increase of production volumes, while the infrastructure side can reduce unit costs by creating a large network of charging stations. Users would benefit from lower costs for electric vehicles and battery systems, either through lower purchase prices or through new business models such as subscription or leasing options with attractive prices. Swappable battery systems (and therefor mobility) are attractive to everyone because they could reduce the cost of vehicle ownership by eliminating the need for users to purchase batteries outright, therefor increasing consumer demand and further boosting economic viability for manufacturers.
Technological concerns are another point where the needs converge. All stakeholders, whether they manufacture, manage or use batteries, see the importance of interoperability and compatibility, standardisation and the reliability of battery, vehicle and the charging stations. The reliability is said to be crucial as it is linked closely to the social acceptance for swappable battery systems and therefor the market diffusion prospects. Distinct needs on battery performance are of critical importance to vehicle manufacturers, as they depend on performant batteries for optimal vehicle utilization. Meanwhile, the infrastructure side is concerned with integrating various battery technologies into the existing system without compromising performance or safety. Both sides also have a common interest in the technical requirements for seamless battery swapping to ensure user convenience. Battery manufacturers seek flexibility to adapt to new technologies without significant redesign costs, reflecting the standardisation needs on the vehicle and user side, which expect reliability and user-friendly interfaces.
Environmental sustainability is also a shared concern. The infrastructure side and battery manufacturers recognize the need for a circular economy that includes recycling and second use of batteries. Similarly, the user side benefits from these efforts through improved sustainable mobility, while the vehicle side also aims to extend battery life and reduce waste by integrating new technologies. A coordinated approach to waste reduction, battery recycling and the integration of renewable energies for battery charging in the stations helps all parties to adapt to new environmental regulations and market demand for greener mobility solutions. Standardised products can be a solution for waste reduction, production efficiency and waste collection.
The legal aspects of the matter are addressed in discussions between the relevant parties, with particular attention paid to issues of reliability and safety. In essence, the industry needs uniform, applicable regulatory and industry standards and consistent (approval) processes, and that also in and beyond the individual European municipalities.

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4.8 Analysis of contradictions

Despite overlapping needs, the stakeholder groups exhibit some notable differences in priorities and approaches that reflect the unique needs of each side. One important contradiction arises from political aspects. While the infrastructure and battery manufacturers articulate high dependencies on political frameworks for the expansion of charging stations and support for battery production, the vehicle side shows minimal direct points of contact with political factors. For the user side, governmental incentives such as tax breaks could promote acceptance, but compared to the strong dependence on infrastructure developers, in regard to approval processes and local regulations in municipalities, as well as battery manufacturers on government policy, no straight political need was formulated.

The contradictions are even more pronounced when it comes to economic factors. Users value affordability and the availability of flexible, competitive business models such as leasing or subscription options. Meanwhile, vehicle and battery manufacturers are more focused on production costs and ensuring profitability through mass production. Battery manufacturers are faced with the challenge of balancing the lower profit margins of mass-produced batteries with the need to maintain quality and innovation. This tension between cost efficiency for the end user and profitability for the manufacturers can lead to friction. Furthermore, while infrastructure operators can benefit from economies of scale, they require significant upfront investments, particularly in grid integration and the installation of physical infrastructure of charging stations, which is less of a concern for users.

In the social factors' aspects, there are differences in expectations regarding handling and safety. Users value ease of use, particularly the weight of the battery, which should be as light as possible for convenient replacement. Battery manufacturers and vehicle manufacturers, however, are more likely to face technological constraints, such as ensuring performance, which may lead to heavier battery designs. Users prefer batteries weighing around 10 kg, for example, while battery manufacturers suggest designs up to 15 kg. This could create a discrepancy between user convenience and technical feasibility. Meanwhile, the infrastructure side is more focused on ensuring safety and reliability in public spaces, which requires strict standards for charging station installations that are less concerning to end users, who are primarily concerned with convenience and accessibility.

Technologically, while all parties emphasise the importance of interoperability, there are contradictions regarding specific requirements. The vehicle side may require specific battery formats and standards to ensure optimal integration into vehicles, while battery manufacturers need flexibility to adapt to new technologies, potentially creating a conflict in standardisation. Furthermore, infrastructure operators may push for the integration on smart grids and real-time monitoring systems, while vehicle manufacturers and users may prefer simple and user-friendly interfaces. These varying priorities can slow down the coordination of technology usage between all stakeholders.

In terms of environmental factors, the side of the battery manufacturers is primarily interested in the technical feasibility of recycling and extending battery life through second-life applications. In contrast, users and vehicle manufacturers are less directly involved in the intricacies of recycling and focus more on the immediate lifespan and functionality of the batteries in the vehicles they use. Furthermore, the infrastructure side must consider the spatial and urban challenges of installing swapping stations, which could conflict with user preferences for convenience and minimal disruption to existing cityscapes.

Also, around legal factors, battery manufacturers and infrastructure developers face the most stringent regulatory challenges, particularly regarding safety and standardisation. Complying with the new EU battery regulation is a greater burden for battery manufacturer than for the vehicle and user side, which, while further removed from direct compliance with the regulations, still benefit from their results. This discrepancy underscores the different levels of responsibility and impacts felt across the various stakeholder groups. For instance, European standards have been established for vehicle manufacturers and, more recently, for battery manufacturers. However, the standardisation of swappable battery infrastructures is still handled in a highly disparate manner at the local level by municipalities.

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5. Conclusions

The shift towards swappable battery systems for L-Cat vehicle is promising for the reduction of emissions, particularly in urban areas. Electrification of these vehicles offers a promising solution here, but several aspects, including the social topic of range anxiety and inadequate charging infrastructure, are hindering broader adoption. Swappable battery systems have the potential to effectively address these concerns by enabling fast and efficient battery swapping, ultimately increasing the usability and attractiveness of L-Cat vehicles. On top, standardised batteries are more cost-effective and enable flexible business models such as battery as a service (BaaS). This reduces purchase prices of the vehicle when buying them without batteries and lowers operating costs for the end user. Therefore, swappable battery systems could thus be a central component of a mobility transformations in cities.
It became apparent that different stakeholders have different needs for such a system. Cooperation and collaboration between the main stakeholders – vehicle manufacturers, infrastructure providers, end users and battery manufacturers – is therefore essential to define the final requirements for a standardised system.

From the vehicle OEMs' perspective, the most important aspects included performance requirements, mechanical interfaces, safety aspects and features for the user-friendliness of the replaceable battery system. A survey was even able to identify numerical values for key technical parameters.
Both mechanical and ergonomic requirements have been defined and an overview of, for example, performance-related KPIs, preferred dimensions, weight, key functions and preferred connection method for the battery pack is presented in chapter 3.1.

From the perspective of infrastructure operators, regulatory compliance and international certifications are very important to meet the requirements in different regions. Currently there are regional differences. An innovative and modular design is crucial to integrating future battery technologies into existing infrastructure and optimizing the production of charging stations. In addition, safety management is a top priority. Robust monitoring systems and safe storage facilities are essential to minimize operational risks. The integration of renewable energies and the grid-supportive use of the stations contribute to sustainability. Good accessibility and user-friendliness increase the acceptance of the technology.

For end users, good handling and user-friendliness are particularly important for swappable battery systems. It must be possible to replace the batteries quickly and easily. Only in this way they can be easily integrated into everyday life, which is crucial for later market success. Ergonomic aspects are also important. In particular, the weight of the battery plays a role here. In addition, the systems must be safe and inspire confidence so that users can use and accept them without hesitation. Furthermore, they must not be afraid of danger when operating the battery in the rain or after falls. In addition, access to a well-distributed infrastructure helps to reduce range anxiety and further increase acceptance.

For battery manufacturers, the standardisation of battery specifications ensures compatibility with different vehicles, the corresponding infrastructure and, if necessary, different battery technologies. To achieve this, it is necessary to work together with the charging infrastructure operators, but also with the OEM. Furthermore, standardisation of batteries optimizes production processes and reduces costs instead of customized solutions. However, the lower production costs also pose a challenge for battery manufacturers, as the resulting competition between standardised cells creates additional cost pressure. The durability of batteries in a swappable system is important because they are usually cycled more often than in private use. In addition, the batteries must be waterproof and dustproof. Batteries should be

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designed modularly to facilitate swapping and increase user-friendliness. New EU regulations require additional sustainability requirements for the manufacturing process.

The list of needs shows that a successful industrial market deployment of swappable battery systems depends heavily on standardisation (especially technical standards and regarding to authorisation processes) and collaboration between the various stakeholders. Standardisation is a central factor that runs through all interest groups. Uniform standardisation of batteries, charging infrastructure and vehicle integration is crucial for interoperability, which enables these systems to operate smoothly and reliable. Without standardisation, technological differences and unnecessary costs could arise that might be future blockades for the market deployment of swappable battery systems. At the same time, cost reduction regarding the economics of scale is an important driver for market penetration. Vehicle and battery manufacturers can reduce their production costs through standardised systems, which could ultimately lead to more competitive prices for end users. This could further boost demand for electric vehicles, especially if flexible business models such as leasing/rental or battery subscriptions are offered that are attractive to users.
Another important aspect is the increasing focus on environmental and sustainability factors. In particular, battery manufacturers and infrastructure providers are recognising the need for a circular economy in which batteries are recycled and reused. A well-conceived circular economy and the incorporation of renewable energies into charging infrastructure could not only satisfy regulatory requirements but may also enhance public acceptance and mitigate the industry's constant need to develop new batteries – implementing the Re-X approaches (i.e. second-use batteries) might become attractive for the broad market. This underlines that a joint approach to waste reduction, recycling and the integration of renewable energies is necessary for long-term success in terms of market deployment.
Overall, a future market success of swappable battery systems depends on the coordination of the stakeholders in the areas of standardisation, cost reduction and political support. Although there is common ground in the stakeholders' needs, such as the need for battery format standardisation, cost efficiency and environmental friendliness, there are still contradictory priorities, for example, in terms of technological requirements and user-friendliness (i.e. maximum battery weight). Harmonising these priorities is crucial for market deployment.

For a successful standardisation of swappable battery systems for L-Cat vehicles, all perspectives must be 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 system efficiency of the swappable systems. The establishment of European standards can boost the widespread introduction of swappable battery systems. Initiatives such as the STAN4SWAP project and consortia like SBMC are essential in this regard.

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Glossary

STAN4SWAP – A project funded by the EU under the program HORIZON-CL4-2023 whose aim is to propose to develop a robust standardisation roadmap towards boosting innovation to market for swappable Battery Systems for L-cat vehicles deployment as a major contribution to safe, secure, resources and environmental friendly and interoperable decarbonization solution of the Mobility-Transport sector. https://stan4swap.standards.eu/

L Category Vehicle (L-Cat) – Any two-three and four wheeled vehicles (i.e. mopeds, motorcycles, tricycles and quadricycles) classified according to Regulation (EU) No 168/2013 of the European Parliament and of the Council of 15 January 2013 on the approval and market surveillance of two- or three-wheel vehicles and quadricycles Text with EEA relevance. https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A32013R0168

SBMC - Swappable Battery Motorcycle Consortium founded in September 2021 by KTM, Honda, PIAGGIO and Yamaha, and currently including about 40 members including major motorbike OEMs, battery manufacturers, battery station manufacturers, software and hardware manufacturers, systems integrators and others in order to facilitate definition, adoption and use of a single technical standard of swappable batteries for the European Market. https://www.sb-mc.net/

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ANNEXES

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Annex 1: Vehicle OEM survey results

Voltage level – Q1

Question posed:

1

What voltage level should a **single battery pack** have? [V]
Note: Please specify the ***nominal voltage****, not the maximum voltage.* *

	<36V	36V	48V	60V	72V	96V	>96V
Voltage level	◯	◯	◯	◯	◯	◯	◯

Results of the research question:

Voltage level		
Unique answers	**Num**	**Pcnt**
48V	5	100%

Capacity – Q2

Question posed:

2

What capacity should a **single battery pack** have? [kWh]

	≤1kWh	1,1-1,5kWh	1,6-2kWh	2,1-2,5kWh	2,6-3kWh	3,1-3,5kWh	≥3,5kWh
Capacity	◯	◯	◯	◯	◯	◯	◯

Results of the research question:

Capacity		
Unique answers	**Num**	**Pcnt**
1,6-2kWh	4	80%
1,1-1,5kWh	1	20%

Continuous Power Discharge – Q3

Question posed:

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3

What continuous discharge power shall **one battery pack** deliver? [kW] *

	<1kW	2kW	3kW	5kW	6kW	7kW	>7kW
Continuous Power	○	○	○	○	○	○	○

Results of the research question:

Continuous Power (Dch)		
Unique answers	**Num**	**Pcnt**
3kW	4	80%
2kW	1	20%

Peak Power Discharge – Q4

Question posed:

4

What peak discharge power (<10s) shall **one battery pack** deliver? [kW]

	<3kW	4kW	6kW	8kW	10kW	12kW	>12kW
Peak Power	○	○	○	○	○	○	○

Results of the research question:

Peak Power (Dch)		
Unique answers	**Num**	**Pcnt**
8kW	1	20%
6kW	3	60%
4kW	1	20%

Peak Power Charge – Q5

Question posed:

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5

What peak charging/recuperation power (<10s) shall **one battery pack** deliver? [kW]

	<1kW	2kW	3kW	5kW	6kW	7kW	>7kW
Continuous Power	○	○	○	○	○	○	○

Results of the research question:

Peak Power (Ch)		
Unique answers	**Num**	**Pcnt**
2kW	2	40%
<1kW	2	40%
3kW	1	20%

Charging Time – Q6

Question posed:

6

How fast shall one battery pack be charged? [min, hrs]
Note: This shall be the maximum charging speed disregarding thermal limitation and accelerated aging. *

	<30min	1hr	2hr	3hrs	4hrs	6hrs	7hrs and more / don't care
Charging time	○	○	○	○	○	○	○

Results of the research question:

Charging time		
Unique answers	**Num**	**Pcnt**
2hr	3	60%
3hrs	2	40%

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Multibattery System (Series) – Q7

Question posed

7

Shall the battery packs be used in a **multibattery system**? Please specify how many **packs in series** you want to use in the maximum configuration (smaller configurations will work as well).
Note 1: If you just want one pack in series please write "1".
Note 2: Keep in mind, that the overall voltage level scales with the number of serial packs.

Ihre Antwort eingeben

Results of the research question:

Multibat (Series)		
Unique answers	**Num**	**Pcnt**
1	2	40%
2	3	60%

Multibattery System (Parallel) – Q8

Question posed:

8

Shall the battery packs be used in a **multibattery system**? Please specify how many **packs in parallel** you want to use in the maximum configuration (smaller configurations will work as well).
Note: If you just want one pack in parallel please write "1".

Ihre Antwort eingeben

Results of the research question:

Multibat (Parallel)		
Unique answers	**Num**	**Pcnt**
3	2	40%
4	2	40%
2	1	20%

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Multibattery System (why parallel) – Q9

Question posed:

9

If you want to use **parallel packs in a multibattery system**, what is your main intent to do so? Please rank the possibilies below according to the importance to your use-case.

I want to increase the total capacity and therefore vehicle range.

I want to increase the maximum continuous power.

I want to increase the maximum peak power.

Results of the research question:

Multibat (why parallel)		
Capacity	5	100%
Continuous Power	11	45%
Peak Power	14	36%

Multibattery (Operation) – Q10

Question posed:

10

What is your preferred way of **operating a multibattery system**? Where shall be control logic of operating the parallel and serial packs be placed?

Note: In all cases you can assume that the multibattery system itself is able to react on or avoid safety critical situations. *

- **Battery system**: Multibattery acts as one big battery towards the vehicle.
- **Vehicle**: Individual and OEM specific operation of the multibattery system is possible.
- **Both:** Depending on the use-case both of the options above are needed.

Results of the research question:

Multibat (Operation)		
Unique answers	**Num**	**Pcnt**
Vehicle: Individual and OEM specific operation of the multibattery system is poss	3	60%
Both: Depending on the use-case both of the options above are needed.	2	40%

Dimension (Length / Width / Height) – Q11

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Question posed:

11

What shall be the **maximum dimensions** of a **single battery pack**? Please specify length, width, and height according to the coordinate system defined in the picture. [mm]
Note 1: This describes the overall envelope curve around the battery including a possible handle.

	<100mm	100-150mm	151-200mm	251-300mm	301-350mm	351-400mm	>400mm
Length							
Width							
Height							

Results of the research question:

Dim (Length)		
Unique answers	**Num**	**Pcnt**
151-200mm	2	40%
251-300mm	2	40%
100-150mm	1	20%

Dim (Width)		
Unique answers	**Num**	**Pcnt**
151-200mm	3	60%
100-150mm	2	40%

Dim (Height)		
Unique answers	**Num**	**Pcnt**
301-350mm	1	20%
251-300mm	2	40%
151-200mm	1	20%
100-150mm	1	20%

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Maximum Weight – Q12

Question posed:

12

What shall be the **maximum weight** of a **single battery pack**? [kg]

	<6kg	6kg	9kg	12kg	15kg	18kg	>18kg
max. weight	◯	◯	◯	◯	◯	◯	◯

Results of the research question:

max. weight		
Unique answers	**Num**	**Pcnt**
12kg	4	80%
9kg	1	20%

Ergonomic Features – Q13

Question posed:

13

What **ergonomic or mechanical featues** shall be **included in the battery pack**?
Note: You can select more than one option.

- ☐ Handle (rigid)
- ☐ Handle (flexible, e.g. nylon strap)
- ☐ Locking mechanism on battery side (locking mechanism is part of battery)
- ☐ Functional area for locking (battery locked in place by a mechanism on vehicle side)
- ☐ Build in SOC display
- ☐ Easily readable serial number (for end-user)
- ☐ Sonstiges

Results of the research question:

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Ergo features		
Unique answers	**Num**	**Pcnt**
Handle (rigid)	5	100%
Functional area for locking (battery locked in place by a mechanism on vehicle sid	5	100%
Build in SOC display	4	80%
safe stand	1	20%
Easily readable serial number (for end-user)	1	20%
	1	20%

Connection – Q14

Question posed:

14

How shall the **user connect the battery** to the vehicle (traction power and signals)? *

- ◯ Cable (power and signal integrated in one cable)
- ◯ Cable (power and signal separate in two cables)
- ◯ Panel-to-Panel connector (battery automatically connects when placing it in the vehicle or locking it in place)
- ◯ Sonstiges

Results of the research question:

Connection		
Unique answers	**Num**	**Pcnt**
Panel-to-Panel connector (battery automatically connects when placing it in the v	5	100%

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Crucial Features – Q15

Question posed:

15

What are the **crucial battery related information** that shall be communicated to the driver via **the vehicle HMI**?
Note 1: You can select more than one option.
Note 2: You are missing any features in the list below you can specify them in the next question.
*

- ☐ *No battery related infos shall be displayed.*
- ☐ Pack Temperature
- ☐ Remaining Range/Capacity
- ☐ SoC (State of Charge)
- ☐ SoH (State of Health)
- ☐ Maintenance reminders
- ☐ Remaining Charging Time
- ☐ Regenerative Braking Feedback
- ☐ Power reduction (e.g. due to low SOC or high Temperature)
- ☐ BMS/MOSFET Temperature
- ☐ Production date of pack

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Results of the research question:

Crucial features		
Unique answers	**Num**	**Pcnt**
Remaining Range/Capacity	5	100%
SoC (State of Charge)	5	100%
Maintenance reminders	2	40%
Remaining Charging Time	5	100%
Power reduction (e.g. due to low SOC or high Temperature)	5	100%
Pack Temperature	3	60%
Regenerative Braking Feedback	1	20%
SoH (State of Health)	1	20%
	1	20%

Crucial Features (Other) – Q16

Question posed:

16

If you missed any features important to you in the question above please specify them here:

Ihre Antwort eingeben

Results of the research question:

Crucial features (other)		
Unique answers	**Num**	**Pcnt**
Warnings and Error	1	20%
0	3	60%
none	1	20%

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Vehicle Range – Q17

Question posed:

17

What range shall the target vehicle using the swappable battery system offer with one charge and without exchanging the battery? [km] *

	<30km	30km	60km	90km	120km	150km	>150km
Vehicle range	○	○	○	○	○	○	○

Results of the research question:

Vehicle range		
Unique answers	**Num**	**Pcnt**
90km	4	80%
60km	1	20%

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Temperatures (low and high) – Q18

Question posed:

18

What are the **specified ambient temperatures** the target vehicle may experience in the field? [°C]
Note: Derating may occur at the specified borders of the operating range.

	>-10°C	-10°C	0°C	20°C	40°C	50°C	>50°C
Lower bound	○	○	○	○	○	○	○
Upper bound	○	○	○	○	○	○	○

Results of the research question:

Temp (low)		
Unique answers	**Num**	**Pcnt**
-10°C	4	80%
0°C	1	20%

Temp (high)		
Unique answers	**Num**	**Pcnt**
40°C	3	60%
50°C	2	40%

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Ingress Protection (IP) Class – Q19

Question posed:

19

What igress protection (IP rating) the individual battery pack shall offer?
Note: This is for the single battery outside of the vehicle.

Ihre Antwort eingeben

Results of the research question:

IP rating		
Unique answers	**Num**	**Pcnt**
IP65	1	20%
IP67	3	60%
IP66	1	20%

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Standards – Q20

Question posed:

20

What **standards and regulations** shall the battery adhere to? Please write missing standards in the open field in the answer section.
Note: Please remind yourself that additional standards may lead to additional development and part costs, so please only list the standards you really require.

- ☐ AIS 156
- ☐ GB 24155
- ☐ GB 38031
- ☐ EC No 765/2008 ("CE mark")
- ☐ UN ECE R10
- ☐ UN ECE R100
- ☐ UN ECE R136
- ☐ UN 38.3
- ☐ UN GTR 20
- ☐ IEC 62619
- ☐ IEC 62840
- ☐ ISO 18243
- ☐ ISO 26262
- ☐ UL 2271
- ☐ UL 2580
- ☐ Sonstiges

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Results of the research question:

Standards		
Unique answers	**Num**	**Pcnt**
EC No 765/2008 ("CE mark")	2	40%
UN ECE R136	5	100%
UL 2271	3	60%
ISO 26262	4	80%
UN 38.3	5	100%
Evaluate need for UL2580 instead of UL2271	1	20%
AIS 156	3	60%
UN ECE R10	2	40%
IEC 62840	2	40%
ISO 18243	1	20%
GB 24155	2	40%
UN ECE R100	1	20%
IEC 62619	1	20%
21434+ UN R 155, Battery Regulation	1	20%
	1	20%

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Communication Protocol – Q21

Question posed:

21

What is your preffered **communication protocol** to communicate with the battery? *

- ◯ *Don't care / I'm flexible to adopt to everything.*
- ◯ CAN
- ◯ CANopen
- ◯ J1939
- ◯ RS-232
- ◯ RS-485
- ◯ Ethernet
- ◯ Sonstiges

Results of the research question:

Communication protocol		
Unique answers	**Num**	**Pcnt**
CAN	4	80%
Don't care / I'm flexible to adopt to everything.	1	20%

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Features (extra) – Q22

Question posed:

22

Please rate the following featues according to their importance.
Note: Again, we are considering a single battery pack outside of the vehicle.

	not needed	desirable	mandatory	don't know
Isolated bus transciever	○	○	○	○
Thermal runaway detection	○	○	○	○
Crash detection	○	○	○	○
UDS diagnostics	○	○	○	○
Bluetooth connectivity	○	○	○	○
Over-the-air updates	○	○	○	○
Transport lock	○	○	○	○
Online connectivity	○	○	○	○
OEM specific functions	○	○	○	○

Please note that due to the complex nature of the raw result data it is not shown here.

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Wakeup Method – Q23

Question posed:

23

How shall be battery be woken up? *

- *Don't care / I'm flexible to adopt to everything.*
- Via vehicle bus system
- Dedicated wakup-pin
- Both
- Sonstiges

Results of the research question:

Wakeup method		
Unique answers	**Num**	**Pcnt**
Both	2	40%
Dedicated wakup-pin	1	20%
wake-up pin aaditional opportunity	1	20%
Don't care / I'm flexible to adopt to everything.	1	20%

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