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D5.1 – Recommendation for PNR work

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Abbreviations list

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

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Executive summary

This deliverable presents the results of Work Package 5 (WP5) of the STAN4SWAP project, which focused on identifying and prioritizing key topics for Pre-Normative Research (PNR) related to swappable battery systems (SBS) for L-category vehicles. The goal was to create a structured foundation for future standardization activities that support safe, interoperable, and scalable deployment of SBS technologies across Europe.
The methodology was based on consolidated inputs from:

- **WP2** (Technical and Market Analysis),
- **WP3** (Regulatory and Standardization Overview), and
- **WP4** (Stakeholder Needs Assessment).

Through expert discussions and structured evaluation, a wide range of PNR topics was identified, assessed, and grouped into four core domains:

- **WP5.1 – Battery level** (e.g. safety, BMS optimization, end-of-life protocols),
- **WP5.2 – Vehicle level** (e.g. connector design, communication, homologation),
- **WP5.3 – Charging infrastructure level** (e.g. site safety, energy metering, grid integration),
- **WP5.4 – Interfaces and full system management** (e.g. liability models, data exchange, platform interoperability).

Each topic was evaluated using a standardized matrix that included criteria such as TRL, regulatory context, standardization potential, and stakeholder relevance. The outcome is a prioritized list of PNR topics that are ready for further processing in WP6, where they will be translated into a standardization roadmap.

By aligning technical, regulatory, and stakeholder-driven perspectives, WP5 provides a robust basis for targeted and impactful standardization activities, contributing to the decarbonization and digitalization of urban mobility systems.

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1. Methodology

The methodology for Work Package 5 (WP5) was developed to identify, structure, and prioritize topics for Pre-Normative Research (PNR) related to swappable battery systems (SBS) in the L-category vehicle ecosystem. The process is based on the consolidation of technical, regulatory, and stakeholder-based inputs from WP2, WP3, and WP4 and culminates in a prioritized matrix of research topics aligned with the four WP5 domains.

1.1 Input Basis: Consolidation of WP2–WP4

The process began with a structured synthesis of content from:

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

These work packages formed the basis for defining relevant and pressing PNR topics.

1.2 Expert-Led Topic Identification

In a collaborative expert process involving partners such as Swobbee, VUB, Fraunhofer ISI, and Piaggio, a broad set of unresolved technical and regulatory issues was identified. The findings were organized into four thematic domains reflecting the WP5 task structure:

- **WP5.1 – Battery level**: Topics such as thermal risk, BMS optimization, and end-of-life management.
- **WP5.2 – Vehicle level**: Mechanical and communication interfaces, safety during operation, and homologation challenges.
- **WP5.3 – Charging infrastructure level**: Station deployment, energy metering, and grid integration (e.g. V2G).
- **WP5.4 – Interfaces and full system management**: Topics such as data exchange, liability models, and cross-provider platform interoperability.

1.3 Evaluation and Prioritization Matrix

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

- Area / Technical focus
- Technology Readiness Level (TRL)
- Identified Gaps & Needs
- Relevant Regulatory Context
- Standardization Landscape and Potential
- Expected Output (e.g. guideline, specification)
- Priority Level (qualitative urgency and feasibility)
- WP5 subtask allocation
- Involved Stakeholders or Potential Research Actors

This structured scoring facilitated the transparent comparison and prioritization of diverse PNR topics.

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1.4 Consolidation and Allocation

After evaluation, the topics were consolidated and assigned to one or more of the WP5 domains, ensuring thematic consistency and balanced coverage of the SBS system architecture.

1.5 Cross-Validation

The resulting matrix entries were validated by:

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

This comprehensive methodology enabled a well-founded and traceable derivation of the core PNR priorities that will serve as inputs for future standardization planning in WP6.

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2. Systematic Analysis of PNR

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

To ensure a targeted and manageable analysis, the identified PNR topics were grouped into four distinct system clusters, reflecting the internal structure of WP5: WP5.1 (battery level), WP5.2 (vehicle level), WP5.3 (charging infrastructure level), and WP5.4 (interfaces and full system management level). Each cluster represents a specific subsystem of the SBS ecosystem and was assessed with respect to its technical maturity, regulatory context, stakeholder relevance, and standardization potential.

Within **WP5.1 (battery level)**, key research needs were identified in the areas of thermal safety (e.g. fire behavior of LFP and NMC cells), battery management system (BMS) optimization, and end-of-life protocols such as second-life usage and recycling. These topics are particularly urgent in light of the EU Battery Regulation 2023/1542, which places increasing demands on safety, lifecycle documentation, and recyclability.

WP5.2 (vehicle level) focused on the physical and digital integration of swappable batteries into light electric vehicles. This includes the design and standardization of mechanical connectors, communication interfaces, and on-vehicle safety features. Special attention was given to vehicle configurations that rely on multiple battery units (e.g. cargo trikes) and the implications for vehicle homologation and user ergonomics.

In **WP5.3 (charging infrastructure level)**, the analysis addressed requirements for station design, fire safety, installation in public spaces, and integration into the power grid. Topics such as energy throughput monitoring, station-level energy balancing, and the potential for Vehicle-to-Grid (V2G) or Virtual Power Plant (VPP) functionality were evaluated. These areas are considered central for municipalities and infrastructure operators planning to deploy battery swapping systems at scale.

WP5.4 (interfaces and full system management) encompasses cross-cutting topics that span all subsystems. These include shared data models and communication protocols, liability and insurance frameworks, and the interoperability of business models in multi-provider environments. The integration of SBS into existing backend systems via standard APIs was identified as a key enabler for market expansion and regulatory compliance.

The clustering into WP5.1–WP5.4 not only supports clarity and division of responsibilities but also enables focused technical discussion and prioritization within each domain. The resulting matrix (see section 3) captures these findings and presents them in a form that is ready for uptake in WP6 and beyond. Each topic entry is accompanied by a maturity assessment (TRL), a description of research gaps, and a proposed path toward normative development.
This structured and system-wide approach ensures that the selected PNR topics do not stand in isolation, but form part of a coherent framework for shaping the future standardization roadmap of swappable battery systems in Europe.

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2.1 WP 5.1 PNR at Battery level

Area	Maturity level (TRL)	Gaps & Needs (towards TRL 8-9)	Regulatory context	Standardization landscape (TCs, standards, …)	Standardization expectation	PNR (topics proposition)	Priority level (i to vii as above defined)	Sub Task WG5	Partner / stake holder
Safety requirements	The temperature tolerance and fire hazards measures needs to be standardized to ensure quality of the system	Standard safety feature protocols	Batteries Regulation (EU) 2023/1542	IEC TC 69	Establishing to ensure the safety and sustainability of batteries used in two-wheelers, promoting a safer transport.	Define standards and protocols for safety features	High (critical for avoiding hazards)	WP 5.1 PNR @ battery	Standards and regulatory authorities
Battery management system	The cell monitoring and temperature control withing the battery has no standard approach	Real-time SOH, SOC monitoring		ISO TC 22 SC38	Ensuring reliability of the swappable system and promoting traceability and transparency	Develop fundamental state-monitoring requirements	Medium (ensures reliability and helps optimizatio n of the operations)	WP 5.1 PNR @ battery	BMS and battery manufacturers
End-of -life management	Guidelines for recycling, disposal and repurposing of batteries are only at a minimal level	Establishing clear guidelines at quantitative levels		Batteries Regulation (EU) 2023/1542	Support the EU's broader efforts to promote a circular economy and reduce the environmental impact of battery use and disposal.	Establish protocols for end-of-life management	Medium (essential for ensuring circular economy in the system)	WP 5.1 PNR @ battery	Battery manufacturers and recycling partners

Area	Maturity level (TRL)	Gaps & Needs (towards TRL 8-9)	Regulatory context	Standardization landscape (TCs, standards, …)	Standardization expectation	PNR (topics proposition)	Priority level (i to vii as above defined)	Sub Task WG5	Partner / stake holder
Interface: connector (mechanical) vehicle <–> battery	standards for automobiles exist. standards about connections of permanently installed batteries also,	There are some good approaches with existing products, but not the perfect solution for all use cases. This gap should be closed through standardization in order to create a uniform and comprehensive solution that meets the diverse requirements. By introducing standards, interoperability and compatibility can be improved, ultimately leading to more efficient and user-friendly products.	Battery Regulation (EU) 2023/1542 - Article10 Performance and durability requirements AFIR Regulation 2023/1804 -Article 3 Targets for recharging infrastructure dedicated to light-duty electric vehicles	ISO TC22/SC38 CEN TC301 IEC TS 63066	definition of a solid and reliable connection for a swappable battery solution versus permanently integrated batteries,	define connector for power supply and data communication including mechanical fixture	ii. topics need further technical understanding and identification	WG5	KTM F&E
Battery mechanical requirements	the physical dimensions (length/width/height), weight, IP rating and ergonomics are currently different for each OEM and should be standardized				definition of physical dimensions for a swappable battery solution versus permanently integrated batteries,	define physical properties of SWAP battery		WP 5.2 PNR @ vehicleWP 5.1 PNR @ battery level	KTM F&E

Table 1 WP5.1 PNR at Battery level

2.2 WP 5.2 PNR at vehicle level

Area	Maturity level (TRL)	Gaps & Needs (towards TRL 8-9)	Regulatory context	Standardization landscape (TCs, standards, …)	Standardization expectation	PNR (topics proposition)	Priority level (i to vii as above defined)	Sub Task WG5	Partner / stake holder
Interface: connector (mechanical) vehicle <–> battery	standards for automobiles exist and also connections for permanently installed batteries, otherwise many OEM-specific solutions - not consistent	There are some good approaches with existing products, but not the perfect solution for all use cases. This gap should be closed through standardization in order to create a uniform and comprehensive solution that meets the diverse requirements. By introducing standards, interoperability and compatibility can be	Battery Regulation (EU) 2023/1542 - Article10 Performance and durability requirements AFIR Regulation 2023/1804 -Article 3 Targets for recharging infrastructure dedicated to light-duty electric vehicles	ISO TC22/SC38 CEN TC301	definition of a solid and reliable connection for a swappable battery solution versus permanently integrated batteries,	define connector for power supply and data communication including mechanical fixture	ii. topics need further technical understanding and identification	WP 5.2 PNR @ vehicle WP 5.1 PNR @ battery level	KTM F&E
Battery mechanical requirements	the physical dimensions (length/width/height), weight, IP rating and ergonomics are currently different for each OEM and should bzuü+i e standardized				definition of physical dimensions for a swappable battery solution versus permanently integrated batteries,	define physical properties of SWAP battery		WP 5.2 PNR @ vehicle WP 5.1 PNR @ battery level	KTM F&E

Area	Maturity level (TRL)	Gaps & Needs (towards TRL 8-9)	Regulatory context	Standardization landscape (TCs, standards, …)	Standardization expectation	PNR (topics proposition)	Priority level (i to vii as above defined)	Sub Task WG5	Partner / stake holder
Battery electrical requirements	The minimum electrical requirements for voltage, capacity, charging power, configurations (parallel/serial) are currently different for each OEM and should be standardized	improved, ultimately leading to more efficient and user-friendly products.			definition of electrical requirement for a swappable battery solution versus permanently integrated batteries,	define electrical properties of SWAP battery		WP 5.2 PNR @ vehicle	KTM F&E
Interface: communication vehicle <–> battery	standards for an interface do not exist, many OEM-specific solutions - not consistent				Comparability of data exchange without significant change	define communication protocol for SWAP battery		WP 5.2 PNR @ vehicle	KTM F&E

Table 2 WP5.2 PNR at vehicle level

2.3 WP 5.3 PNR at charging station/infrastructure level

Area	Maturity level (TRL)	Gaps & Needs (towards TRL 8-9)	Regulatory context	Standardization landscape (TCs, standards, …)	Standardization expectation	PNR (topics proposition)	Priority level (i to vii as above defined)	Sub Task WG5	Partner / stake holder
fire safety for battery systems (swap cabinets, charging areas, storage).	~7 (piloted battery swap stations w/ fire-safety features, but no uniform EU approach)	- Harmonized fire protection req'ts (indoor/outdoor).	- EU Battery Regulation (EU) 2023/1542 includes safety & sustainability.	- IEC 62840-1 & IEC 62840-3 (safety for battery swap systems)	- Harmonized guidance for battery swap fire detection & containment.	- R&D on advanced fire detection & suppression systems.	High (fire incidents risk damaging public confidence)	WP 5.3 PNR at charging station/infrastructure level	- Fire safety authorities, e.g. TÜV / DEKRA
		- Streamlined testing/certification for Li-ion thermal runaway & propagation mitigation.	- Municipal building/fire codes vary by country.	- EN 50604 & IEC 62619 (Li-ion battery safety)	- Possibly an extension of IEC 62840-3 for indoor applications.	- Testing protocols for thermal runaway barriers in multi-battery racks.			- Battery station manufacturers
		- Unified safety assessment for large battery deployments.	- Insurance & liability regs.	- IEC 60335 series (chargers/appliances)					- Building code experts
									- CEN/CENELEC committees

Area	Maturity level (TRL)	Gaps & Needs (towards TRL 8-9)	Regulatory context	Standardization landscape (TCs, standards, …)	Standardization expectation	PNR (topics proposition)	Priority level (i to vii as above defined)	Sub Task WG5	Partner / stake holder
Accurate calculation of battery capacity, SoC, usage patterns for daily ops.	~6–7 (robust BMS exist, but not fully standardized across networks)	- Unified SoC/SoH data model across different OEMs/stations.	- EU Battery Regulation 2023/1542 (battery passport/data).	- IEC 62840-1 & IEC 62840-3/CDV includes references for BMS data.	- Agreed data structure for consistent SoC, SoH, usage reporting across networks.	- Real-time SoC algorithms factoring usage, temperature, discharge cycles.	Medium (technical feasibility proven; standardization needed for cross-compatibility)	WP 5.3 PNR at charging station/infrastructure level	- BMS developers
		- Standard method for energy throughput & battery life predictions.	- RED delegated act for secure wireless data transfer.	- IEC 63110 / 63119, ISO 15118 (EV comms)		- "Battery Health Score" approach for cost & environmental analytics.			- OEMs
		- Common data exchange format.							- Standardization committees (IEC TC69 WG13, ISO TC22/SC37)
Ensuring (or clarifying) tax exemptions/levies for battery swapping, electricity usage, battery	N/A (policy maturity rather than technology)	- Clarify tax treatment (energy supply vs. service?).	- National energy tax laws.	- Not a standardization domain per se.	- Not directly about product standards; more about guidelines to standardize how energy usage data is reported (could help authorities).	- Policy research on best fiscal models (battery-as-service vs. electricity sale).	Medium (fiscal incentives can accelerate adoption)	WP 5.3 PNR at charging station/infrastructure level	- Ministries of Transport/Energy/Finance

Area	Maturity level (TRL)	Gaps & Needs (towards TRL 8-9)	Regulatory context	Standardization landscape (TCs, standards, …)	Standardization expectation	PNR (topics proposition)	Priority level (i to vii as above defined)	Sub Task WG5	Partner / stake holder
subscription models.		- EU-level approach for cross-border scenarios.	- AFIR (EU) 2023/1804 to promote e-mobility, but no direct "tax" language.	- Could align with relevant data format standards if consumption must be uniformly reported.		- Streamlined cross-border approach.			- Industrial associations
			- Competition rules for possible cross-country differences.						- EU Commission (DG TAXUD)
Using swappable batteries as grid assets (load balancing, V2G, aggregator-driven "virtual power plants").	~6 (pilots exist for V2G in fleets; still early for swappable battery networks)	- Real-time SoC control, aggregator frameworks.	- AFIR 2023/1804 fosters alternative fueling & smart solutions but not explicit for removable battery feed-in.	- IEC 62840 series, potential future adaptation for bidirectional flow.	- Clear aggregator communication standard for swappable battery nodes.	- Control algorithms for "mobile V2G."	Medium–High (significant potential for energy transition)	WP 5.3 PNR at charging station/infrastructure level	- DSOs/TSOs (grid operators)

Area	Maturity level (TRL)	Gaps & Needs (towards TRL 8-9)	Regulatory context	Standardization landscape (TCs, standards, …)	Standardization expectation	PNR (topics proposition)	Priority level (i to vii as above defined)	Sub Task WG5	Partner / stake holder
		- Ownership & legal aspects of "mobile" battery feed-in.	- National grid codes & electricity market rules.	- IEC 63119, ISO 15118-20 for V2G communications.	- Mechanisms for verifying battery ownership, scheduling feed-in, settling payments.	- Market design for aggregator-based use of distributed battery modules.			- Battery station operators
		- Economic models & grid acceptance.							- Aggregator platforms
									- IEC TC69, TC57 standard committees
Standard installation criteria for swapping stations (indoor/outdoor, safety zones, mechanical footprints).	~7 (examples in some EU cities, no universal approach)	- Harmonized building/permitting codes across regions.	- AFIR (EU) 2023/1804 sets overarching alt-fuel infra goals, not specifics on swap station siting.	- IEC 62840-3 (removable battery systems, if extended to installation).	- EU-wide guidance (CEN/CLC TS or EN) for battery swapping station design, recommended spacing & ventilation.	- Load-bearing studies for multi-battery racks.	High (critical for widespread deployment & acceptance)	WP 5.3 PNR at charging station/infrastructure level	- Station OEMs
		- Standard footprints/connectors for kiosk installations.	- National/local building codes (zoning, fire dept approvals).	- Possibly relevant to CENELEC TC 64 (electrical installations).		- Building code alignment, best practices for safe installation.			- Building regulators
		- Ventilation & spacing guidelines.							- National code committees (DIN, NF, etc.)

Area	Maturity level (TRL)	Gaps & Needs (towards TRL 8-9)	Regulatory context	Standardization landscape (TCs, standards, …)	Standardization expectation	PNR (topics proposition)	Priority level (i to vii as above defined)	Sub Task WG5	Partner / stake holder
Uniform insurance coverage requirements for battery systems (fire, damage, liability) and swap-station operations.	N/A (industry readiness / policy aspects)	- Risk models for battery handling/storage.	- No direct EU directive on battery insurance.	- Not a typical IEC/ISO domain. Possibly referencing risk management frameworks (ISO 31000).	- Industry-driven guidelines on coverage & liability disclaimers.	- Actuarial models for multi-operator battery pools.	Medium (essential for large-scale rollout, but largely driven by insurers & operators)	WP 5.3 PNR at charging station/infrastructure level	- Insurance sector (Allianz, Zurich, etc.)
		- Clear underwriting guidelines for multi-operator systems.	- Battery Regulation sets performance & safety that insurers factor in.	- EN 50604, IEC 62619 (battery safety) can inform insurability.	- Possibly recognized best-practices from insurers & sector alliances.	- Uniform approach for cross-border claims.			- Battery-swapping operators
		- Cross-border coverage consistency.							- Certification/lab testing bodies (TÜV, DEKRA)

Table 3 WP 5.3 PNR at charging station/infrastructure level

2.4 WP 5.4 PNR at interfaces and full system management level

Area	Maturity level (TRL)	Gaps & Needs (towards TRL 8-9)	Regulatory context	Standardization landscape (TCs, standards, …)	Standardization expectation	PNR (topics proposition)	Priority level (i to vii as above defined)	Sub Task WG5	Partner / stake holder
System Level (Swappable Ecosystem)	A Backend, with standardized cybersecurity features, is necessary for the data collecting, exchanging and management from different batteries and charging stations belonging to different EaaS operators in order to guarantee the Interoperability	Nothing exist but there are good examples in other business categories (bank, Communication Operators, etc)	Battery Regulation (EU) 2023/1542 (and battery passport) for consideration of data to be collected, stored and shared AFIR Regulation 2023/1804 Cybersecurity (to be completed)	CEN TC 301 CEN CENELEC JTC 13 CEN CENELEC JTC 24	data (& money) collecting, exchange, management within a cybersecure world	define cybersecure backend with standard communication system and Authorization system	iii topics need further technical understanding and DPP framework defined, with list of data to be considered	WP 5.4 PNR @ full system management level	PIAGGIO

Table 4 WP 5.4 PNR at interfaces and full system management level

Conclusions

The work carried out in WP5 led to a consolidated and structured proposal of Pre-Normative Research (PNR) topics that are critical for the deployment of safe, interoperable, and sustainable swappable battery systems (SBS) across Europe. The applied methodology ensured full alignment with the technical, regulatory, and stakeholder-specific findings of WP2, WP3, and WP4.

By clustering the identified topics into four domains—battery (WP5.1), vehicle (WP5.2), charging infrastructure (WP5.3), and system interfaces (WP5.4)—the consortium was able to address the full scope of the SBS ecosystem. Each domain includes both short-term "quick win" topics and long-term challenges requiring more fundamental research.

The resulting evaluation matrix provides:

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

This structured PNR agenda ensures that the proposed topics are not only technically relevant but also timely and actionable for future standardization efforts under WP6 and beyond.

As a result, WP5 lays the foundation for a harmonized European approach to the development of standards in the area of SBS for L-category vehicles. The PNR priorities presented in this report support regulatory alignment, reduce market fragmentation, and accelerate the deployment of interoperable solutions across the mobility and energy sectors.

These results will now serve as input for WP6, where standardization roadmaps and normative development activities will be derived from the identified research priorities.

Glossary

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

Pre-Normative Research (PNR): Research activities aimed at developing the foundational knowledge and methodologies needed for future standardization efforts.

Swappable Battery System (SBS): A system that allows batteries to be easily swapped in and out of vehicles, particularly light electric vehicles.

Battery Management System (BMS): A system that manages the performance, safety, and reliability of batteries, including monitoring their state of charge (SoC) and state of health (SoH).

Technology Readiness Level (TRL): A scale used to assess the maturity of a particular technology, ranging from basic research (TRL 1) to full commercial deployment (TRL 9).

Vehicle-to-Grid (V2G): A technology that allows electric vehicles to feed energy back into the power grid.

Virtual Power Plant (VPP): A system that aggregates multiple distributed energy resources, such as batteries, to operate as a single power plant.

Original Equipment Manufacturer (OEM): A company that produces parts and equipment that may be marketed by another manufacturer.

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Ingress Protection (IP): A rating system that defines the levels of sealing effectiveness of electrical enclosures against intrusion from foreign bodies and moisture.

Light Electric Vehicle (LEV): A category of electric vehicles that includes two, three, and four-wheeled vehicles, typically used for short-distance travel.

Energy-as-a-Service (EaaS): A business model where energy services are provided to customers on a subscription basis.

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