*Proceedings of the International Conference on Industrial Engineering and Operations Management*

Publisher: IEOM Society International, USA DOI: 10.46254/IN05.20250185
Published: November 6, 2025

# Fuzzy Delphi Analysis of Battery-as-a-Service Procurement Strategies: Sustainable Mobility Insights from India and Global EV Markets

**Upasana Halder**
Vinod Gupta School of Management
Indian Institute of Technology, Kharagpur, WB 721302, India
upasanahaldar@kgpian.iitkgp.ac.in

**Rudra P. Pradhan**
Vinod Gupta School of Management
Indian Institute of Technology, Kharagpur, WB 721302, India
rudrap@vgsom.iitkgp.ac.in
ORCID Id: https://orcid.org/0000-0001-7518-5001

**Himanshu Chandra**
Vinod Gupta School of Management
Indian Institute of Technology, Kharagpur, WB 721302, India
himanshu2020chandra@kgpian.iitkgp.ac.in

## Abstract

Battery-as-a-Service (BaaS) is increasingly recognized as a transformative procurement model in the electric vehicle (EV) sector, enabling cost reduction, lifecycle optimization, and alignment with circular economy principles. Unlike traditional ownership, BaaS separates the battery from the vehicle, offering it as a service through leasing or swapping. To identify robust procurement strategies for BaaS, this study employed the Fuzzy Delphi Method (FDM), which integrates expert consensus with fuzzy set theory to capture uncertainty in judgments. A panel of domain experts evaluated 27 potential procurement variables. The results emphasize the importance of fiscal incentives, interoperability, collaborative governance, and local supply resilience in shaping viable BaaS ecosystems. Globally, the findings provide a benchmark for designing procurement frameworks that balance affordability, sustainability, and risk-sharing. This study contributes to methodological advancement by applying FDM to BaaS procurement, producing a consensus-driven foundation for future modelling and empirical validation. For India, where batteries constitute up to 40% of EV cost and national schemes such as FAME-II, the PLI program for advanced cells, and the draft battery swapping policy (2022) are reshaping the sector, these strategies are particularly relevant in reducing cost barriers and ensuring supply resilience. The study offers consensus-based foundation for both Indian and international contexts.

## Keywords
Battery-as-a-Service (BaaS), Electric Vehicles (EV), Procurement Strategy, Fuzzy Delphi Method, Expert Consensus

## 1. Introduction

Battery-as-a-Service (BaaS) is emerging as an innovative procurement and business model in the electric mobility and energy storage sectors. Instead of selling batteries as a one-time product with each vehicle, manufacturers and service providers offer battery usage as a service, decoupling the battery from the vehicle purchase. This model has been pioneered in the electric vehicle (EV) industry by firms like NIO in China, where BaaS enables cost efficiency, operational flexibility, and optimized battery lifecycle management. By addressing core consumer concerns such as range anxiety and the high upfront cost of batteries, BaaS is seen as a disruptive strategy to spur EV adoption (Bhattacharya & Bhattacharya, 2023). Under a typical BaaS arrangement, customers buy an EV without a battery and lease or subscribe to a battery plan, swapping or recharging batteries through an operator. This approach transfers the burden of battery ownership and maintenance from the end-user to the provider, overcoming major EV limitations like expensive battery ownership and slow charging times (Jiang et al., 2024). It thereby allows greater scalability and servitization in the supply chain, aligning with broader trends in the automotive industry toward "X-as-a-Service" business models (Singh et al., 2022).

BaaS has rapidly expanded across multiple domains of e-mobility and energy storage**.** In the passenger vehicle segment, for example, NIO's BaaS program lets car buyers rent the battery separately, significantly reducing the vehicle's purchase price and allowing flexibility in battery upgrades. Commercial fleets and public transportation stand to benefit as well battery swapping infrastructure is being deployed for high-utilization vehicles like taxis, buses, and delivery trucks, where minimizing downtime is critical (X. Chen et al., 2022). In the two- and three-wheeler market, battery swapping has become a practical solution in dense urban areas: companies such as Gogoro in Taiwan have pioneered modular battery swap networks for electric scooters, and countries like India are promoting similar models for e-bikes and rickshaws. Notably, India's national policy recognizes battery swapping for 2W/3W as key to accelerating electrification under resource constraints (Tripathi et al., 2023). Beyond vehicles, the BaaS concept is also being applied to stationary energy storage systems. For instance, in community renewable energy projects, a third-party can own a large battery that local users access as a shared service, eliminating the need for each user to invest in their own battery (Hernández, 2023). This extension of BaaS to stationary domains (e.g. community energy storage or home batteries) further illustrates its potential to transform traditional supply chains by servitizing battery assets in various contexts (Davis & Hiralal, 2016). Across these domains, BaaS represents a shift from product ownership to asset-sharing and leasing, with implications for procurement strategies at every level of the battery value chain.

The rise of BaaS is driving a profound transformation in battery supply chains and procurement practices**.** Under the BaaS model, the ownership and procurement of batteries are typically centralized and professionalized, rather than distributed among individual vehicle owners. EV manufacturers, battery producers, and new specialist firms often form partnerships or joint ventures to manage battery assets and infrastructure. For example, some automakers have created battery leasing subsidiaries in collaboration with cell suppliers, effectively pooling battery procurement and managing a shared inventory of swappable batteries (Li & Yuan, 2025). This separation of vehicle and battery ownership requires new procurement strategies: firms must acquire large volumes of standardized batteries for the service fleet, maintain those batteries, and replace them on schedule based on usage and State-of-Health criteria. BaaS thus shifts the focus to life-cycle procurement batteries are procured not just for one-time sale, but for continuous rotation through first-life and second-life uses. Studies highlight that BaaS can facilitate better battery lifecycle control, enabling cascade utilization (e.g. repurposing EV batteries into stationary applications) and centralized recycling, which improves overall sustainability. Additionally, the BaaS model redistributes financial and operational risks among stakeholders: consumers avoid the risk of battery degradation and obsolescence, while providers take on those risks in exchange for recurring revenue streams. For instance, leasing-based models inherently shift battery residual value risk from the end-user to the company operating the service (Gonzalez-Salazar et al., 2023). To manage these risks and high capital requirements, BaaS firms are innovating in procurement and financing – using strategies like bulk battery purchase agreements, asset leasing arrangements, and public-private financing of swap infrastructure (Hu et al., 2024). Overall, procurement in the BaaS context becomes a strategic, ongoing process of securing battery supply, ensuring quality (through standardization and testing), and coordinating across the supply chain. It demands tight coordination among stakeholders: vehicle OEMs, battery manufacturers, service operators, and even electric utilities must work in concert to align battery specifications, share data, and co-invest in infrastructure (Zhu et al., 2024).

Supportive policy frameworks around the world are catalyzing the BaaS model by reshaping incentives and standards in the EV supply chain. China has led in BaaS adoption, underpinned by strong government policies. The dual-credit policy for automakers (which rewards EV production and penalizes excessive combustion vehicle production), alongside dedicated subsidies for battery swapping stations, has created a favourable ecosystem for BaaS in China (L.

Yang & Xianye, 2024). These policies encourage manufacturers to separate vehicle and battery value, as seen with Chinese OEMs like NIO and BAIC offering battery-leasing options. In India, the government's FAME-II scheme (Faster Adoption and Manufacturing of Electric Vehicles) explicitly promotes battery swapping for certain vehicle segments, providing financial incentives that reduce the upfront cost of EVs without batteries and support the deployment of swapping infrastructure. India's recent policy initiatives including a draft national battery swapping policy, aim to standardize battery interfaces and offer subsidies for swap stations, making the country a strategic testbed for BaaS business models (Patel et al., 2024). Meanwhile, in the European Union, policy attention to battery sustainability and circular economy is indirectly fostering interest in servitization models like BaaS. The EU's new regulations (such as the Battery Directive and Digital Product Passport requirements for batteries) emphasize lifecycle traceability, standardization, and recycling, which align with the BaaS approach of centralized battery management and reuse (Kim et al., 2023). European automakers have experimented with battery leasing (for example, Renault's battery leasing for ZE vehicles and early swapping pilots like Better Place), though a comprehensive BaaS ecosystem is still nascent in Europe. Nonetheless, the aggressive environmental targets and data-sharing mandates in the EU provide an enabling environment for BaaS innovation (Chen et al., 2024). Globally, the convergence of policy support from China's infrastructural subsidies to India's market incentives and the EU's regulatory push for interoperability is transforming how batteries are procured and deployed, nudging the industry toward service-based procurement and away from the traditional ownership paradigm.

Central to BaaS's viability are new business models like battery leasing, subscription plans, and novel financing mechanisms, as well as investments in infrastructure and standards. In practice, BaaS offerings often use a leasing or subscription model where users pay a monthly fee or per-swap charge for battery use. For instance, NIO's subscription plans charge a monthly fee instead of battery ownership, coupled with the ability to swap for a fully charged battery in minutes. These leasing models lower the entry cost of EVs for consumers (e.g. saving on the order of $10,000 per vehicle by excluding the battery), while creating a new revenue stream over the battery's service life. Implementing such models requires significant infrastructure investment: networks of battery swap stations, each costing on the order of hundreds of thousands of dollars/euros, need to be strategically deployed. Companies and governments have begun sharing this investment burden, for example, automakers partner with battery suppliers and local governments to co-fund swap stations and to ensure enough standardized spare batteries are available (Zhu et al., 2024). Risk-sharing is inherent in these partnerships. The battery service operator assumes the technological and market risks of managing a large battery fleet (from performance degradation to fluctuations in energy prices), while vehicle OEMs benefit from increased sales and governments gain progress toward emissions targets. Another important aspect is technological standardization. BaaS can only scale if batteries are interoperable across different vehicle models or at least within a broad platform. In markets like China, a degree of standardization has been achieved (e.g. unified battery pack designs for taxis or trucks), but elsewhere, lack of common standards remains a challenge (Murugan & Marisamynathan, 2024). Industry consortia and policymakers are thus working on standards for battery dimensions, communication protocols, and safety, which would enable an open BaaS ecosystem where multiple manufacturers share swap stations. In parallel, digital platforms and IoT technologies are being adopted to manage battery inventories and optimize procurement schedules. Real-time data on battery health and usage can inform procurement decisions (when to retire or redeploy batteries) and align production with demand, exemplifying how BaaS is driving innovation in supply chain coordination and battery asset management.

### 1.1 Objectives

The objective of this study is to identify and prioritize the strategies influencing the adoption of procurement strategies in the context of the Indian Electric Vehicle Battery (EVB) infrastructure. Specifically, the study aims to:

- Identify the factors influencing the adoption of procurement strategies through a comprehensive review of existing literature.
- Map and shortlist these strategies using frequency analysis to determine their relevance and prevalence in prior studies.
- Determine the most critical strategies from a firm-level perspective within the Indian EVB ecosystem by employing expert surveys and the Delphi method.

## 2. Literature Review

The transition toward sustainable electric mobility has intensified the need for innovative battery procurement models that align with circular economy principles. In the context of BaaS, procurement strategies play a pivotal role in determining the efficiency, affordability, and environmental performance of battery usage across the electric vehicle lifecycle. This analysis categorizes procurement strategies into four dominant models Leasing, Owner-Operator, Outsourcing, and Public-Private Partnership (PPP) each reflecting distinct approaches to asset ownership, control, and lifecycle management. Drawing on a comprehensive set of academic sources, this study interprets these models through the lens of circular economy imperatives such as *Refuse*, *Reduce*, *Reuse*, *Repair*, *Refurbish*, *Recycle*, and *Recover*, offering a structured understanding of how procurement decisions influence battery circularity and service efficiency.

**Leasing-Based Procurement Models**

Leasing has emerged as the most prominent procurement model within the Battery-as-a-Service (BaaS) domain, enabling users to access batteries without assuming ownership, thus advancing the principles of servitization and circular economy. Multiple forms of leasing such as pay-per-use, subscription-based, and battery rental models collectively support the *Refuse*, *Reduce*, and *Reuse* imperatives by eliminating redundant ownership and promoting shared battery infrastructure. For example, (Bege & Tóth., 2024) detail how subscription models eliminate the need for individual ownership, aligning user incentives with sustainability through reduced material consumption and better lifecycle control. Similarly, (Gonzalez-Salazar et al., 2023) present annual leasing mechanisms where batteries are centrally maintained, repaired, and replaced directly enabling *Refurbish*, *Repair*, and *Recycle* pathways.

Another significant model is the *Vehicle-Electricity Separation*, introduced through wet and dry leasing variations. As discussed by (Yang & Xianye., 2024), wet leasing incorporates full-service access, including maintenance and energy provisioning, whereas dry leasing outsources these responsibilities to the user. This bifurcation not only improves service personalization but also shifts the burden of lifecycle optimization to service providers, thus encouraging modular design and *Recover* processes. Moreover, advanced digitalized models such as the AI-IoT-enabled battery pooling platforms proposed by (Ding et al., 2025) illustrate how centralized procurement managed via intelligent algorithms can reduce over-specification and enhance utilization rates.

Fleet-targeted leasing also plays a vital role, particularly in emerging markets like India, where (Tripathi et al., 2023) emphasize its affordability and suitability for standardized operations in two- and three-wheeler segments. These approaches not only lower entry barriers for low-income users but also create centralized battery loops that reduce resource wastage and support multi-user reuse strategies. (Kim et al., 2023) further extend this idea through SaaS-based procurement frameworks, enabling modular bundling and demand-responsive provisioning which further reinforces the *Refuse* and *Reduce* tenets by avoiding overproduction and misaligned inventory management.

**Owner-Operator Procurement Models**

The owner-operator model typically involves the user or fleet operator owning the battery asset, thereby assuming full responsibility for its lifecycle. This traditional linear model, while still prevalent, is increasingly scrutinized for its limited alignment with circular economy goals. Tahara et al., (2020) describe the All-Fix Battery Ownership model, which imposes high upfront costs and lacks flexibility for variable usage demands. However, hybrid ownership schemes, which combine fixed batteries with swappable modules, are gaining attention for enhancing resource efficiency without fully relinquishing control. Zhou et al., (2025) argue that centralized ownership models where firms or OEMs retain battery control offer improved reuse and refurbish potential compared to decentralized user-based ownership.

In another approach, (He et al., 2025) proposed Carbon-Adjusted Battery Procurement, where sourcing decisions incorporate emissions intensity to encourage low-carbon and *Refuse*-oriented procurement. These models introduce environmental parameters into supply chain decision-making, aligning well with policy-driven sustainability goals. Bhattacharya & Bhattacharya., (2022) showcase the benefits of OEM-led battery ownership (e.g., NIO), which enables better reuse, predictive diagnostics, and strategic end-of-life planning through centralized control.

Furthermore, platform-mediated or aggregator-based ownership, as discussed by (McCrossan & Shankaravelu., 2021; Pisano et al., 2023), facilitates risk reduction and enhances reuse potential by pooling battery assets and allocating them based on demand, especially in second-life applications. Sindha et al., (2023) also contribute to this discourse by highlighting hybrid battery sourcing mixing first-life and reused batteries to reduce virgin material consumption and extend asset usability across lifecycles.

**Outsourcing Procurement Models**

Outsourcing shifts the procurement and management responsibilities to external stakeholders such as third-party BaaS providers, energy service companies (ESCOs), or community-led consortiums. This model allows for scalability and specialization, which in turn facilitates circular strategies across battery lifecycles. (Bege & Tóth., 2024) explain both centralized OEM-led procurement models and decentralized supplier arrangements with embedded Extended Producer Responsibility (EPR), enabling localized reuse loops and lower logistics footprints. He et al., (2025) explore collaborative investment models where OEMs co-own battery inventories with operators, distributing risk and promoting *Refurbish* and *Reuse* through better lifecycle coordination.

Community-oriented models such as CESS (Community Energy Storage Systems) discussed by (Al-Alawi et al., 2022) and crowd-based energy integration platforms proposed by (Cheng et al., 2024) enable decentralized energy distribution and underutilized asset reallocation thus aligning well with *Refuse* and *Reuse* principles. Moreover, digital platforms managing pooled batteries and shared infrastructure, as discussed by (Cao et al., 2021; Toorajipour et al., 2022), exemplify how digital transformation can support circular procurement through real-time tracking, demand prediction, and lifecycle visibility.

NIO–CATL's strategic alliance (Zeng et al., 2025) and the swapping-operator procurement model described by (Pocola., 2024) reflect how long-term outsourcing contracts can streamline supply chains and ensure high reuse potential through modular design and extended service life. (Marchesano et al., 2023) further explore grid-integrated and centralized pooling strategies that enable operators to not only manage energy provisioning but also extend the value of battery assets across mobile and stationary applications.

**PPP-Contracting and Public-Private Models**

Public-Private-Partnership (PPP) models focus on shared responsibility between governments and private stakeholders to enable the deployment and scaling of BaaS systems. These models are instrumental in reducing the financial and infrastructural barriers associated with battery procurement and service delivery. (Bege & Tóth., 2024) outline performance-based contracts that tie procurement payments to battery performance indicators like State of Health (SoH), thereby incentivizing *Repair* and *Reuse* during the service life.

(Patel et al., 2024; Setiawan et al., 2023) highlight subsidy-based initiatives and shared infrastructure funding where governments co-invest in BSS (Battery Swapping Station) deployment. These schemes promote *Refurbish* and *Reduce* by enabling shared battery usage across multiple users. Similarly, models like the "Liuzhou Model" described by (Zhao & Jiang., 2021) underscore city-wide integration of NEVs, urban planning, and infrastructure sharing as instruments for circular procurement.

Moreover, long-term policy interventions such as India's FAME and PLI (Bose et al., 2024; Tripathi et al., 2023) illustrate how financial incentives and regulatory backing can facilitate local procurement ecosystems, reduce supply chain dependency, and support indigenous battery production—all contributing to *Reduce*, *Recover*, and *Reuse* strategies. (Davis & Hiralal., 2016) provide further insight into utility-led battery provisioning, where public entities install and operate battery infrastructure for end-users, effectively minimizing redundant private ownership and enhancing centralized control.

Lastly, (Chen et al., 2022; Murugan & Marisamynathan., 2024) elaborate on how PPP-driven deployment of multi-type stations and centralized collection systems optimize infrastructure use, reduce overbuilding, and enable large-scale *Recover* and *Reuse* integration.

It offers a comprehensive representation of procurement strategies across leasing, ownership, outsourcing, and PPP frameworks. Each model contributes uniquely to enabling the circular economy through diverse applications of the R-imperatives. Leasing supports servitization and modularity; owner-operator models enable direct lifecycle control; outsourcing leverages digital and financial efficiency; and PPP frameworks institutionalize sustainability via policy alignment. Together, they form a multidimensional roadmap toward sustainable battery ecosystem development within the BaaS paradigm.

## 3. Methods

To address the different strategy variables in EVB procurement infrastructure, this study adopts a three-phase exploratory framework. Phase I involves a systematic literature review to identify strategies which are critical to the adoption of electric vehicle battery procurement infrastructure cross components such as battery specifics, infrastructure, time, stakeholder and economic dimensions, drawing on peer-reviewed studies from databases such as Scopus and Web of Science. Based on the literature review, Phase II mapped out the most frequently used strategy variables to the adoption of battery procurement infrastructure. According a close ended questionnaire was prepared for a pilot fuzzy Delphi study. Phase III employs a fuzzy Delphi method, engaging 40 experts ranging from 4 policy maker, 15 industry and 21 academic experts to refine and validate the factors. Thus, concluding with the most relevant factors that enable the adoption of best procurement particularly in the Indian context.

The Fuzzy Delphi Method (FDM) is a hybrid decision-making technique that integrates the traditional Delphi method with fuzzy logic to address ambiguity and subjectivity in expert judgments. Developed to overcome limitations in handling uncertain or imprecise human evaluations, FDM efficiently consolidates expert opinions while reducing the need for multiple survey rounds (Zhao and Li 2016). A structured questionnaire was developed using a modified Saaty scale, ranging from 1 (extremely irrelevant) to 5 (extremely relevant) (Table 1). Each scale point was mapped to a corresponding linguistic variable and then to a fuzzy triangular number (FTN), reflecting the inherent vagueness in human judgment.

Table 1: Measurement scale for the FDM survey

| **Linguistic variable** | **Rating** | **Corresponding TFN** | **p** | **q** | **r** |
|---|---|---|---|---|---|
| Extremely irrelevant | 1 | (0.1, 0.1, 0.3) | 0.1 | 0.1 | 0.3 |
| Irrelevant | 2 | (0.1, 0.3, 0.5) | 0.1 | 0.3 | 0.5 |
| Normal | 3 | (0.3, 0.5, 0.7) | 0.3 | 0.5 | 0.7 |
| Relevant | 4 | (0.5, 0.7, 0.9) | 0.5 | 0.7 | 0.9 |
| Extremely relevant | 5 | (0.7, 0.9, 0.9) | 0.7 | 0.9 | 0.9 |

Source: Own elaboration

Interviewers evaluate factors using an adapted Saaty linguistic scale (1–5), where each score corresponds to a fuzzy triangular number (FTN). Results are expressed through FTNs assigned to each linguistic variable. These FTNs are constructed by partitioning the interval into five values aligned with the triangular format (p, q, r). The fuzzy triangular numbers (FTNs) are generated by distributing the scale across the five comparison indices. Each index is assigned an FTN structured in the (p, q, r) triangular format, where:

p = Lower bound (minimum value)

q = Peak (most likely value)

r = Upper bound (maximum value)

This partitions the 0–1 continuum into overlapping fuzzy sets that mathematically represent the linguistic importance levels. For example, "extremely relevant" is represented as (0.7, 0.9, 0.9), while "Extremely irrelevant" is (0.1, 0.1, 0.3) (Table 1). The aggregated fuzzy values were converted into crisp scores using defuzzification techniques, such as centroid or weighted average methods. The resulting factor weights were analyzed to establish a prioritized list of variables. Reliability and validity were assessed.

## 4. Data Collection

Relevant factors enabling procurement strategy adoption were shortlisted for the fuzzy DELPHI analysis in three phases. In phase I, based on the reviewed literature published in databases such as Scopus and Web of Science, an exhaustive list of 300 variables were shortlisted. In phase II, based on the review of the literature and mapping, factors to the adoption of procurement strategies were shortlisted, and after removing duplicate factors, a finalized list of 22 factors was shortlisted. Table 2 represents the short-listed barriers along with references and descriptions of the factors. In Phase III, the target group of experts, including academicians and researchers across engineering and interdisciplinary departments, industry experts and policy makers, were chosen for their expertise in EV battery procurement infrastructure. A list of 55 experts was prepared. Respondents were engaged via email, phone, and in-person visits. 33 experts agreed to the survey. However, 27 completed responses were finalized, of which 7 experts (4 industry, 2 academicians and 1 policy maker) submitted responses online while the remaining 20 experts (19 academicians, 1 policy maker) were interviewed in person. Based on the response, a fuzzy DELPHI analysis was implemented. Based on a cut-off score of 0.56 from the fuzzy triangular numbers mentioned in Table 1, final factors were concluded.

Table 2: Procurement Strategy adoption variables in Indian EVB Infrastructure

| Serial Number | Factors | Detail Description | Key References |
|---|---|---|---|
| **1** | Government-Subsidized Procurement | Governments provide financial incentives (e.g. subsidies, tax breaks) to build battery-swap infrastructure and standardize batteries, lowering upfront costs for providers and users. This public support encourages widespread adoption of shared battery systems. | (Setiawan et al., 2023) |
| **2** | Platform-Driven Asset Sharing | A digital platform aggregates multiple operators' battery procurement, coordinating shared access to pooled battery assets. This platform management minimizes idle batteries and improves utilization across fleets. | (Cao et al., 2021) |
| **3** | OEM–Operator Collaboration | Electric vehicle manufacturers and battery-service operators jointly procure and manage battery fleets. By sharing ownership and responsibilities, they align incentives for modular design and lifecycle management. | (Setiawan et al., 2023; Gorityala & Radhika, 2024) |
| **4** | Producer-Driven BaaS | Battery producers (suppliers) operate battery-swap services instead of vehicle OEMs. In this model, battery manufacturers invest in and run the swapping infrastructure, standardizing the upstream value chain and potentially expanding station networks. | (Jiang et al., 2024) |
| **5** | Third-Party Battery Ownership (CESS) | A third-party (e.g. utility or aggregator) owns community energy storage systems (CESS) and leases capacity to households or vehicles. By owning shared batteries (e.g. community or fleet units) and renting their use, this model eliminates individual asset duplication and reduces users' capital outlays. | (Al-Alawi et al., 2022) |
| **6** | Platform-Based Procurement | Centralized procurement through a digital platform or aggregator. Fleets or service providers jointly source batteries in volume, achieving economies of scale and standardization. This model reduces fragmented production by pooling demand for batteries. | (Zhang & Rao, 2016) |
| **7** | Community Battery Ownership | Local communities or cooperatives collectively own battery assets (for example, a group of EV operators co-owns charging stations). Shared ownership spreads costs and enables high utilization: batteries owned by a community (e.g. e-rickshaw pool) are used by many members, lowering per-unit cost and excess capacity. | (Hasan, 2020) |
| **8** | Carbon-Adjusted Battery Procurement | Battery sourcing decisions include lifecycle carbon intensity criteria. Procurers favour low-carbon manufacturing and suppliers. By internalizing carbon footprint in procurement (e.g. weightings in bids), this approach steers purchases toward greener batteries and supports decarbonization. | (He et al., 2025) |
| **9** | Net Cost Contracting | A contractual model where the BaaS operator provides service and collects user fees, bearing demand (ridership) risk. The operator receives payments (often | (AEEE, 2024) |

| | | | |
|---|---|---|---|
| | | per vehicle-km or fixed fees) from a public authority but funds operation through end-user revenue . Net cost contracts align operator incentives with actual usage. | |
| **10** | Gross Cost Contracting | Here the public authority handles fare collection and sets service parameters, paying the operator based on inputs (e.g. fleet size or kilometers). The operator bears minimal revenue risk. This arrangement decouples operator income from ridership, often used to promote service stability. | (AEEE, 2024) |
| **11** | Cost-Plus Contracting | The provider is reimbursed for incurred costs plus a pre-agreed fee or profit margin. This model (common in negotiated or development contracts) removes incentive to minimize costs, as all allowable expenses are covered. Cost-plus contracts thus transfer most risk to the purchaser. | (Bege & Tóth, 2024) |
| **12** | Management Contracting | The public sector retains ownership of batteries and infrastructure, contracting out only the operation/maintenance. A private firm is paid to manage the BaaS operations (without owning assets). This lets the government keep control of assets while leveraging private management expertise. | (AEEE, 2024) |
| **13** | Negotiated Contracting | Contracts are awarded through direct negotiation with pre-qualified providers rather than competitive bidding. This can expedite procurement but may yield higher costs. Negotiated contracting is typically used for complex BaaS projects or pilot. | (Bege & Tóth, 2024) |
| **14** | Co-operative Contracting | Multiple organisations (e.g. OEMs, fleets, municipalities) jointly procure BaaS services. By combining demand and standardizing requirements, co-operative procurement (e.g. pooled RFPs) achieves bulk discounts and lowers transaction costs. | (Electrification Coalition, 2018) |
| **15** | Competitive Contracting | Open competitive tenders or auctions for battery services and infrastructure. Bidders submit proposals (often for long-term supply/leasing contracts) under specified requirements. Competitive procurement aims to minimize costs through market forces, similar to standard PPP bid processes. | (Bege & Tóth, 2024) |
| **16** | Pay-Per-Use Battery Leasing | Users pay only for the battery energy or swapping events they actually use, rather than a flat fee. For example, customers might pay per kilowatt-hour or per swap. This aligns costs with consumption, avoids paying for idle capacity, and discourages over-provisioning of batteries. | (Shi & Hu, 2016.; Al-Alawi et al., 2022) |
| **17** | Subscription-Based Battery Leasing | Customers pay a recurring fee (often monthly or annual) to lease battery capacity. In effect, batteries are rented on a subscription plan (much like mobile phone plans). This decouples battery cost from vehicle purchase and ensures steady revenue for providers. | (Bege & Tóth, 2024; India EV Landscape, 2022) |
| **18** | All-Fix Battery Model | The battery is sold permanently with the EV (traditional ownership). Under this model, users purchase the full battery at vehicle sale. All-fix sales require high upfront investment, give owners sole responsibility for charging/replacement, and typically result in lower circular usage. | (Yang & Xianye, 2024) |

| | | | |
|---|---|---|---|
| **19** | CapEx-Light Leasing | Users (especially fleets) lease vehicles and/or batteries instead of buying them outright. This minimizes capital expenditure by replacing purchases with operational leases. As a result, providers can scale services (e.g. larger fleets) without heavy initial procurement of battery assets. | (India EV Landscape, 2022) |
| **20** | Individual Battery Ownership | End-users (e.g. households or single-vehicle owners) install and own their own battery storage. In this model, individuals invest in batteries for their own use. This approach maximizes local self-consumption but leads to fragmented asset control and less opportunity for efficient reuse across users. | (Al-Alawi et al., 2022) |
| **21** | Dry Leasing | The provider supplies the battery only; all other services (charging, maintenance, swapping infrastructure) are the user's responsibility. The user is liable for energy costs and upkeep. Dry leasing simplifies the offering (battery-only) but may deter users who want a turnkey service. | (Yang & Xianye, 2024) |
| **22** | Wet Leasing | The provider leases the battery together with full service: charging, maintenance, and swapping are included. The user pays a bundle rate while the provider handles operations. Wet leasing transfers most operational risk to the provider and offers users convenience (battery "as a service"). | (Yang & Xianye, 2024) |
| **23** | Soggy Leasing | A hybrid lease where costs and responsibilities are shared. For example, the provider leases the battery but shares or subsidizes charging/swapping costs (often via government support). This "mixed" model blends dry and wet leasing attributes, reducing user costs while still involving the provider. | (Yang & Xianye, 2024) |
| **24** | Differential Leasing Models | Multiple leasing options are offered to serve different customer segments. For example, high-performance vs. standard battery leases, or OEM-owned vs. third-party leases. By differentiating terms (e.g. pricing or service levels), providers can match diverse user needs and improve overall battery utilization. | (Wu & Li, 2024) |
| **25** | Manufacturer-Led Vertical Integration | EV makers vertically integrate the battery supply chain, controlling production, leasing, and recycling of batteries. In this model the OEM owns the entire battery lifecycle, which enhances quality control and can facilitate closed-loop reuse within a single corporate system. | (Wu & Li, 2024) |
| **26** | Vehicle Sharing Models | Shared-mobility or car-sharing services provide EV access without ownership. A fleet of shared vehicles (with central charging/swapping) reduces the number of batteries needed per user. High vehicle turnover in such models lowers the total battery procurement requirement and increases per-battery utilization. | (Huang et al., 2021) |
| **27** | Decentralized Supplier Models | Battery procurement is outsourced to regional or local suppliers (often under extended producer responsibility schemes). Instead of centralized OEM sourcing, regional EPR-compliant firms supply batteries, shortening transport distances and enabling local recycling loops. This decentralization supports smaller-scale, flexible supply. | (Bege & Tóth, 2024) |

## 5. Results and Discussion

The results are subdivided into two subsections: numerical results and graphical results. A detailed analysis of the Fuzzy DELPHI output is given in these two sub-sections. In addition, the results are further subdivided into strengthening high-impact factors, weaknesses of the rejected factors and policy level improvement under the subheading of proposed improvement. The result is shown in Table 3.

Table 3: Fuzzy DELPHI Result

| Codes | Strategy Variables | Mean Score | Accept/Reject |
|---|---|---|---|
| S1 | Government-Subsidized Procurement | 0.647848 | Accept |
| S2 | Platform-Driven Asset Sharing | 0.621603 | Accept |
| S3 | OEM–Operator Collaboration | 0.619516 | Accept |
| S4 | Producer-Driven BaaS | 0.643258 | Accept |
| S5 | Third-Party Battery Ownership (CESS) | 0.502837 | Reject |
| S6 | Platform-Based Procurement | 0.498988 | Reject |
| S7 | Community Battery Ownership | 0.496506 | Reject |
| S8 | Carbon-Adjusted Battery Procurement | 0.494317 | Reject |
| S9 | Net Cost Contracting | 0.505298 | Reject |
| S10 | Gross Cost Contracting | 0.499698 | Reject |
| S11 | Cost-Plus Contracting | 0.517029 | Reject |
| S12 | Management Contracting | 0.509374 | Reject |
| S13 | Negotiated Contracting | 0.487678 | Reject |
| S14 | Co-operative Contracting | 0.502914 | Reject |
| S15 | Competitive Contracting | 0.504487 | Reject |
| S16 | Pay-Per-Use Battery Leasing | 0.646678 | Accept |
| S17 | Subscription-Based Battery Leasing | 0.516904 | Reject |
| S18 | All-Fix Battery Model | 0.611658 | Accept |
| S19 | CapEx-Light Leasing | 0.519485 | Reject |
| S20 | Individual Battery Ownership | 0.518775 | Reject |
| S21 | Dry Leasing | 0.450306 | Reject |
| S22 | Wet Leasing | 0.493557 | Reject |
| S23 | Soggy Leasing | 0.484173 | Reject |
| S24 | Differential Leasing Models | 0.49581 | Reject |
| S25 | Manufacturer-Led Vertical Integration | 0.476461 | Reject |
| S26 | Vehicle Sharing Models | 0.568669 | Reject |
| S27 | Decentralized Supplier Models | 0.635567 | Accept |

### 5.1. Numerical Results

The Fuzzy Delphi Method (FDM) was employed to validate and prioritize the strategy variables relevant to the adoption of battery procurement services in the Indian electric mobility ecosystem. Experts were asked to rate each enabler on a five-point fuzzy linguistic scale. The final decision on the inclusion of enablers was based on the calculated defuzzified mean score, with a cutoff value set at 0.56, in line with expert consensus.

As shown in Table 1, a total of 7 strategy variables out of 27 met the threshold and were therefore retained for further analysis.

### 5.2 Graphical Results

To enhance the interpretability of the Fuzzy Delphi results, a bar chart visualization was created (see Figure 1). The bar chart presents the Delphi mean scores for 27 BaaS procurement strategy variables (S1–S27). Bars are colour-coded by inclusion status, with green denoting accepted variables (score ≥ 0.60) and red representing rejected ones. A dashed blue line marks the 0.60 acceptance threshold, creating a clear visual division between consensus-approved and rejected strategies.

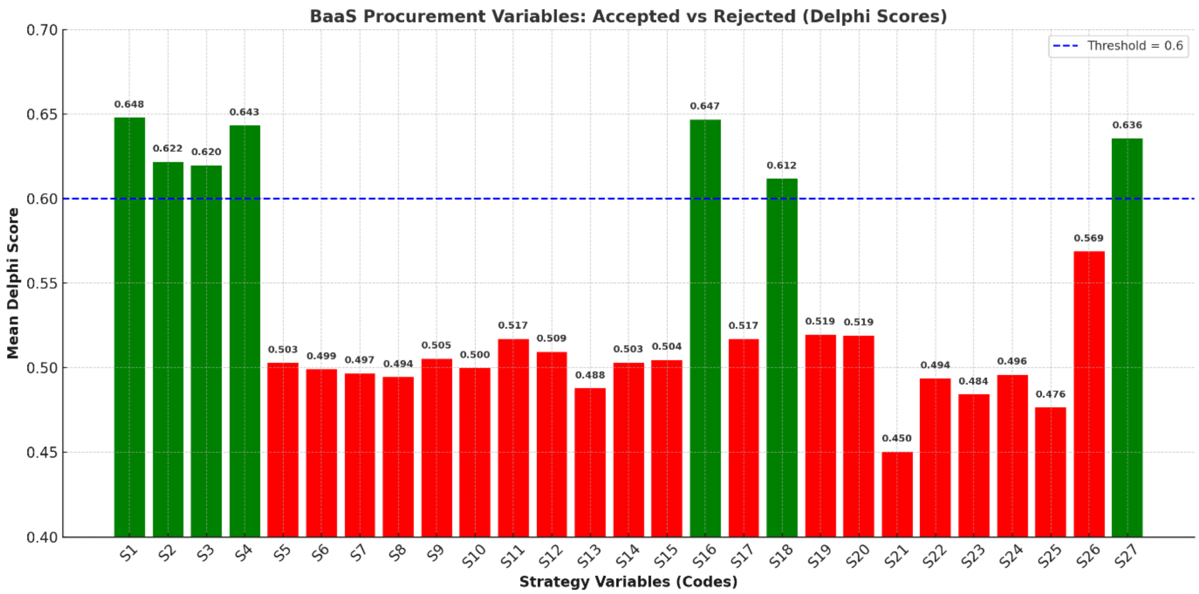


Figure 1: Fuzzy DELPHI Output

The distribution shows that accepted variables are tightly clustered just above the threshold, ranging from 0.611 (S18: All-Fix Battery Model) to 0.648 (S1: Government-Subsidised Procurement). Rejected variables mostly lie between 0.45 and 0.57, indicating that while they were not far from the cut-off, they lacked sufficient consensus. Notably, the majority of accepted scores hover close to the threshold rather than being substantially higher, suggesting that the panel reached a narrow but clear consensus. Conversely, the lowest-scoring variable, S21 (Dry Leasing), at 0.450, illustrates the clear lack of support for some models.

Overall, the chart confirms the Delphi panel's decision-making, showing a sharp boundary at the 0.60 cut-off with a handful of accepted strategies just surpassing the line, and the rest falling short. This clustering underscores the contested nature of BaaS procurement models and the importance of precise thresholds in consensus-driven selection.

The chart also supports rapid stakeholder communication by summarizing complex expert consensus in a simple visual, making it especially useful for policymakers and industry practitioners seeking to understand which drivers warrant strategic focus.

## 5.3 Proposed implementation policies for the accepted variables:

### 5.3.1 Strengthen High-Impact Factors

Government-Subsidized Procurement(S1)

Government-subsidised procurement has emerged as a central enabler of BaaS adoption because it reduces initial capital barriers and aligns market incentives with sustainability. Theoretically, such interventions are explained through policy-induced transaction cost reductions, where subsidies mitigate risks of high upfront investments (Yang & Xianye, 2024). In India, the FAME-II scheme and the proposed battery swapping policy integrate subsidies for battery-leasing and swapping infrastructure, directly lowering user and operator costs (Setiawan et al., 2023). Globally, China's dual-credit and NEV subsidy programs have catalyzed large-scale swapping stations for buses and taxis (Zeng et al., 2025), while the EU Battery Regulation embeds procurement support into mandates for recycling and standardization (Toorajipour et al., 2022). Thus, governments not only finance but also standardize BaaS through fiscal and regulatory levers, ensuring cost parity with conventional ownership models.

Platform-Driven Asset Sharing(S2)

Platform-driven models leverage digital servitization and resource pooling theories, enabling shared use of scarce battery assets. In practice, platforms optimize utilization by matching demand and supply dynamically, thereby minimizing idle capacity (Cao et al., 2021). In India, BatterySmart and Vidyut have pioneered app-based battery-swapping networks for two- and three-wheelers, promoting interoperability across fragmented OEM ecosystems. Globally, Gogoro's IoT-enabled swap network in Taiwan and Swobbee's shared micromobility batteries in Europe exemplify how platforms unlock economies of scope (Ding et al., 2025). These strategies transform procurement into a collaborative process: instead of OEM-specific assets, platforms aggregate procurement across multiple operators, reducing duplication and strengthening circular flows.

OEM–Operator Collaboration(S3)
Collaboration between OEMs and operators reflects relational contracting and vertical coordination theory, where risks and investments are shared to stabilize service ecosystems. Indian examples include Hero MotoCorp's partnership with Gogoro and Sun Mobility's collaborations with multiple OEMs, both enabling standardized batteries across fleets (Setiawan et al., 2023). Globally, NIO–Sinopec's collaboration integrates swap stations with fuel retail networks, aligning OEM technology with operator infrastructure (Gorityala & Radhika, 2024). Implementation strategies include joint ventures, co-financing of swap hubs, and shared maintenance responsibilities. This alignment reduces opportunism risks in fragmented ecosystems and ensures lifecycle traceability of procured batteries.

Producer-Driven BaaS(S4)
Producer-driven BaaS aligns with the producer responsibility and servitization theory, where battery manufacturers extend their role beyond production into lifecycle service provision. In India, companies like Sun Mobility design and operate smart battery pools, while Mahindra collaborates with Vidyut for pay-per-km leasing that shifts ownership risks to producers (Hui et al., 2022). Globally, CATL's entry into battery swapping (China) illustrates how producers leverage scale and control to standardize modules (Wu & Li, 2024). This model ensures that procurement emphasizes design-for-reuse and second-life readiness, as producers internalize lifecycle costs and revenues.

Pay-Per-Use Battery Leasing(S16)
Pay-per-use reflects usage-based pricing theory, linking cost to consumption while aligning with circular economy principles of reducing idle assets. In India, Vidyut's usage-based rentals for Mahindra EVs and Sun Mobility's per-swap fee for e-rickshaws exemplify flexible procurement tailored to affordability (Shi & Hu, n.d.). Internationally, Gogoro's subscription tiers and Lime's micromobility fleets bill per ride or swap, embedding energy-as-a-service in mobility (Al-Alawi et al., 2022). Implementation relies on IoT telematics for real-time metering and billing, making procurement demand-responsive and resource-efficient.

All-Fix Battery Model(S18)
Though traditional, the all-fix model remains significant in procurement discourse. From a theoretical perspective, it aligns with linear ownership models, but contemporary strategies retrofit it with circular obligations. In India, EVs sold with fixed batteries are governed by the Battery Waste Management Rules (2022), mandating Extended Producer Responsibility for recycling (Gonzalez-Salazar et al., 2023). Globally, the EU Battery Regulation imposes recycled content quotas even for fixed-battery EVs (Tahara et al., 2023). Thus, the strategy is not to abandon fixed procurement but to overlay it with end-of-life traceability and second-life repurposing.

Decentralized Supplier Models(S27)
Decentralized procurement promotes resilient supply networks and local circular loops, reducing logistics emissions and dependency on centralized monopolies. In India, the ACC-PLI scheme mandates localized value addition and supports regional suppliers for cell manufacturing (Bege & Tóth, 2024). Globally, the EU Battery Alliance fosters multiple regional gigafactories, while the US IRA incentivizes domestic supply diversification (Toorajipour et al., 2022). Implementation involves multi-supplier procurement, local recycling mandates, and digital traceability to ensure quality across fragmented networks. This strategy makes BaaS less vulnerable to global supply chain disruptions and accelerates localized circular economies.

### 5.3.2 Proposed analysis of the weakness of the rejected BaaS Procurement Variables

S5: Third-Party Battery Ownership (CESS) was rejected for introducing undue complexity and regulatory overhead with no clear benefit to the core BaaS model. Similarly, S6: Platform-Based Procurement was dismissed as too complex and largely duplicative of existing sharing strategies. S7: Community Battery Ownership was deemed impractical due to coordination difficulties and governance challenges, and S8: Carbon-Adjusted Battery Procurement was judged overly technical and tangential, offering little direct impact on the business model's viability. In a similar vein, the panel found traditional contracting approaches to be misaligned with BaaS needs. S9: Net Cost Contracting and S10: Gross Cost Contracting were viewed as too narrow and ineffective at allocating battery-related costs and risks, while S11: Cost-Plus Contracting was rejected as inflexible and insufficiently cost-efficient. Likewise, S12: Management Contracting, S13: Negotiated Contracting, and S14: Co-operative Contracting were seen as lacking structural stability or relying too heavily on stakeholder coordination. S15: Competitive Contracting was also deemed undesirable because pure competitive bidding could undermine the long-term partnerships required in a BaaS model. For leasing and ownership strategies, additional alternative schemes were likewise dismissed. S17: Subscription-Based Battery Leasing was judged unnecessary given the acceptance of the more flexible pay-per-use model, and S19: CapEx-Light Leasing was considered too vague and overshadowed by better-defined leasing frameworks. Similarly, S20: Individual Battery Ownership was rejected as directly contrary to the BaaS principle of decoupling battery ownership from vehicle usage. Both S21: Dry Leasing and S22: Wet Leasing were found unsatisfactory, the former for being too limited in scope and the latter for overlapping with better-established offerings and S23: Soggy Leasing (a hybrid approach) offered no distinct advantage and was therefore discarded. More complex variants, such as S24: Differential Leasing Models, were dismissed as overly intricate and impractical to standardize. Finally, S25: Manufacturer-Led Vertical Integration was rejected due to concerns over reduced flexibility and increased monopolistic control, and S26: Vehicle Sharing Models was viewed as outside the procurement focus and irrelevant to battery-leasing strategy.

### 5.3.3 Policy and Governance Improvements

Policy and governance improvements for the accepted BaaS procurement strategies can be framed more concisely in an integrated manner. For government-subsidised procurement (S1), clearer inclusion of BaaS in incentive schemes and fleet procurement rules is essential to lower upfront costs and create demand certainty. Strengthening platform-driven asset sharing (S2) requires regulators to establish interoperability and data-sharing standards so that multiple operators can pool and manage batteries transparently. In the case of OEM–operator collaboration (S3), governments can play a coordinating role by brokering joint ventures and public–private partnerships, ensuring that shared risks and responsibilities are institutionalized. Similarly, producer-driven BaaS (S4) benefits from policy frameworks that encourage or mandate manufacturers to bundle leasing and swapping services, coupled with guidelines on lifecycle accountability. To sustain pay-per-use leasing (S16), governance should provide transparent billing rules and consumer protections while supporting early pilots through targeted subsidies. For all-fix battery models (S18), stricter end-of-life and extended producer responsibility regulations can ensure sustainability, alongside gradual movement toward modular standards. Finally, decentralized supplier models (S27) require governments to promote supplier diversity through open technical standards and local-content incentives, thereby building resilience and competitive balance in the BaaS supply chain.

## 6. Conclusion and Future Research

This study used a multi-round fuzzy Delphi analysis to identify and validate critical procurement strategies for Battery-as-a-Service (BaaS) systems. We distilled expert input on an initial set of candidate approaches, retaining those with mean ratings above 0.60. The Delphi panel ultimately converged on ten key strategies, reflecting strong consensus on measures such as government-supported leasing, collaborative OEM–operator arrangements, shared battery platforms, carbon-aware procurement, and innovative financing models. In sum, the analysis fulfilled its purpose of vetting strategy options through structured expert consensus: the validated strategies represent a focused set of procurement and policy levers that stakeholders agree are most important for enabling BaaS.

For practitioners and policymakers, these findings offer actionable guidance. The endorsed strategies underscore how battery leasing and sharing schemes can reduce EV capital costs, improving affordability as noted in industry analyze. In India's context with ambitious EV targets and increasing government support for battery swapping our results point to specific policies (e.g. targeted subsidies, circular-economy regulations, public–private partnerships) that can accelerate BaaS deployment. Globally, automotive manufacturers, fleet operators, and governments can draw on this expert-validated framework to design procurement contracts and infrastructure plans that align economic incentives with sustainability. For example, embedding maintenance and end-of-life recycling obligations in procurement agreements (a circular approach) can extend battery life and reduce environmental impact. By highlighting consensus strategies, the study contributes to BaaS procurement literature by moving beyond conceptual discussions to an empirically grounded set of priorities.

Future research should build on this work by testing and extending the results. Empirical modelling and simulation studies can incorporate the validated strategies as variables in supply-chain optimization or investment models, assessing their quantitative impact on costs and emissions. Field research or pilot programs (e.g. trial BaaS offerings by EV fleets) could evaluate the real-world performance of these approaches. Cross-national comparisons would be valuable: examining whether the consensus strategies hold in different regulatory and market environments (for instance, contrasting mature markets with emerging economies). Finally, continuing to refine and update the expert consensus, perhaps integrating data-driven methods or broader stakeholder input, will ensure that procurement strategies remain aligned with evolving technology and policy landscapes. Overall, this study lays the groundwork for a systematic, evidence-based approach to designing BaaS procurement frameworks that support the EV transition worldwide.

## References

Al-Alawi, M. K., Cugley, J., & Hassanin, H. Techno-economic feasibility of retired electric-vehicle batteries repurpose/reuse in second-life applications: A systematic review. In *Energy and Climate Change* (Vol. 3). Elsevier Ltd., 2022.

Albertsen, L., Richter, J. L., Peck, P., Dalhammar, C., & Plepys, A. Circular business models for electric vehicle lithium-ion batteries: An analysis of current practices of vehicle manufacturers and policies in the EU. *Resources, Conservation and Recycling*, 172, 2021.

Bege, A., & Tóth, Á. Economic Analysis of Electric Vehicle Manufacturers: A Comparative Study. *Chemical* Engineering *Transactions*, 114, 937–942, 2024.

Bhattacharya, S., & Bhattacharya, L. Battery-as-a-Service NIO's Strategy CASE IN POINT, 2023.

Bose, D., Gupta, A., Tiwari, S., Yadav, D., & Sharma, V. Secondary Batteries for Sustainable Energy: A Comprehensive Review of the Indian Landscape. *Proceedings - 2024 International Conference on Social and Sustainable Innovations in Technology and Engineering, SASI-ITE 2024*, 413–417, 2024.

Cao, Y., Zhang, X., Zhou, B., Duan, X., Tian, D., & Dai, X. MEC Intelligence Driven Electro-Mobility Management for Battery Switch Service. *IEEE Transactions on Intelligent Transportation Systems*, 22(7), 4016–4029, 2021.

Chen, L., Ma, H., Wang, Y., & Li, F. Vehicle Routing Problem for the Simultaneous Pickup and Delivery of Lithium Batteries of Small Power Vehicles under Charging and Swapping Mode. *Sustainability (Switzerland)*, 14(16), 2022.

Chen, W., Shiralizade, H., & Glaa, B. Circulating for Service Sustainability Examining relationship between sustainability and servitization in both B2B and B2C context of electric vehicles Circulating for Service Sustainability-Examining relationship between sustainability and servitization in both B2B and B2C context of electric vehicles. www.liu.seiiiACKNOWLEDGMENTS, 2024.

Chen, X., Xing, K., Ni, F., Wu, Y., & Xia, Y. An Electric Vehicle Battery-Swapping System: Concept, Architectures, and Implementations. *IEEE Intelligent Transportation Systems Magazine*, 14(5), 175–194, 2022.

Cheng, X., Shen, H., Huang, Y., Cheng, Y. L., & Lin, J. Using Mobile Charging Drones to Mitigate Battery Disruptions of Electric Vehicles on Highways. *2024 Forum for Innovative Sustainable Transportation Systems, FISTS 2024*, 2024.

Cui, D., Wang, Z., Liu, P., Wang, S., Dorrell, D. G., Li, X., & Zhan, W. Operation optimization approaches of electric vehicle battery swapping and charging station: A literature review. In *Energy* (Vol. 263). Elsevier Ltd., 2023.

Davis, M. J. M., & Hiralal, P. Batteries as a Service: A New Look at Electricity Peak Demand Management for Houses in the UK. *Procedia Engineering*, 145, 1448–1455, 2016.

De Kwant, C., Rahi, A. F., & Laurenti, R. The role of product design in circular business models: An analysis of challenges and opportunities for electric vehicles and white goods. In *Sustainable Production and Consumption* (Vol. 27, pp. 1728–1742). Elsevier B.V., 2021.

Ding, D., Li, Z., Zhang, J., Liu, X., Zhang, J., Li, Y., Cai, P., Liu, J. X., & Long, G. eBaaS: AIoT-Enabled eBike Battery-Swap as a Service for Last-Mile Delivery. *WWW 2025 - Proceedings of the ACM Web Conference*, 5045–5053, 2025.

Etxandi-Santolaya, M., Canals Casals, L., Montes, T., & Corchero, C. Are electric vehicle batteries being underused? A review of current practices and sources of circularity. In *Journal of Environmental Management* (Vol. 338). Academic Press, 2023.

Feng, Y., & Lu, X. Construction planning and operation of battery swapping stations for electric vehicles: A literature review. In *Energies* (Vol. 14, Issue 24). MDPI, 2021.

Gonzalez-Salazar, M., Kormazos, G., & Jienwatcharamongkhol, V. Assessing the economic and environmental impacts of battery leasing and selling models for electric vehicle fleets: A study on customer and company implications. *Journal of Cleaner Production*, 422, 2023.
Gorityala, A., & Radhika, S. Revamping the Iconic TVS Vehicle: The Ultimate Electric Ride-Hailing Solution with Battery Swapping Technology. *2024 IEEE 11th Uttar Pradesh Section International Conference on Electrical, Electronics and Computer Engineering (UPCON)*, 1–6, 2024.
He, Y., Tan, X., Hong, Z., Wang, F., & Huang, L. Pricing decision in the power battery supply chain under BaaS business model considering carbon quota trading and government subsidies. *Energy for Sustainable Development*, 85, 2025.
Heath, G. A., Ravikumar, D., Hansen, B., & Kupets, E. A critical review of the circular economy for lithium-ion batteries and photovoltaic modules–status, challenges, and opportunities. In *Journal of the Air and Waste Management Association* (Vol. 72, Issue 6, pp. 478–539). Taylor and Francis Ltd., 2022.
Hernández, M. S. Beliefs and attitudes of canarians towards the chilean linguistic variety. *Lenguas Modernas*, 62, 183–209, 2023.
Hu, X., Yang, Z., Sun, J., & Zhang, Y. When should capital-constrained swap service providers partner with battery lessors? *Transportation Research Part E: Logistics and Transportation Review*, 190, 2024.
Huang, Y., Qian, L., Soopramanien, D., & Tyfield, D. Buy, lease, or share? Consumer preferences for innovative business models in the market for electric vehicles. *Technological Forecasting and Social Change*, 166, 2021.
Hui, Y., Jiang, Z., & Ran, C. Research of Passenger Vehicles in Battery Rental Model Based on Mathematical Model. *2022 IEEE* International *Conference on Electrical Engineering, Big Data and Algorithms (EEBDA)*, 815–818, 2022.
India EV Landscape eMaaS-Revolutionizing the mobility space, 2022.
Islam, M. T., & Iyer-Raniga, U. Lithium-Ion Battery Recycling in the Circular Economy: A Review. In *Recycling* (Vol. 7, Issue 3). MDPI, 2022.
Jiang, Z.-Z., Li, K., Tang, C. S., & Yang, S. A. Offering EV Battery Swapping as a Service: EV Manufacturers or Battery Producers? 2024.
Kader, T. Case Study: "NIO: Battling Tesla with Battery as a Service.", 2023.
Kim, J., Moon, J., Do, Y., Kim, H., & Jeong, J. Research on a SaaS (Software as a Service)-based Digital Product Passport System Model for the EV Battery Industry Value Chain. *WSEAS Transactions on Business and Economics*, 20, 2466–2475, 2023.
Li, C., & Yuan, K. Optimal Service Operation Strategy in Battery Swapping Supply Chain. *Mathematics*, 13(7), 2025a.
Li, C., & Yuan, K. F. The Impact of Subsidies on Pricing Decisions in the Battery Swapping Supply Chain Under the "Vehicle and Battery Separation" Model. *Managerial and Decision Economics*, 2025b.
Marchesano, M. G., Guizzi, G., Vespoli, S., & Ferruzzi, G. Battery Swapping Station Service in a Smart Microgrid: A Multi-Method Simulation Performance Analysis. *Energies*, 16(18), 2023.
McCrossan, C., & Shankaravelu, K. A review of the second life electric vehicle battery landscape from a business and technology perspective. *IEEE Green Technologies Conference*, 2021-April, 416–423, 2021.
Mominul Hasan, A. S. M. Electric rickshaw charging stations as distributed energy storages for integrating intermittent renewable energy sources: A case of Bangladesh. *Energies*, 13(22), 2020.
Murugan, M., & Marisamynathan, S. Investigating the potential of a battery swapping method at refuel stations for electric vehicle: A case study of INDIA. *Transportation Research Part F: Traffic Psychology and Behaviour*, 107, 254–274, 2024.
Nurdiawati, A., & Agrawal, T. K. Creating a circular EV battery value chain: End-of-life strategies and future perspective. *Resources, Conservation and Recycling*, 185, 2022.
Patel, M., Arora, P., Singh, R., Mahapatra, D., Chaturvedi, V., & Kumar Saini, S. Impact of battery swapping in the passenger sector: EV adoption, emissions, and energy mix. *Energy*, 298, 2024.
Pisano, A., Saba, M., & Baldovino, J. A. A Critical Review of NIO's Business Model. *World Electric Vehicle Journal*, 14(9), 2023.

Pocola, T. O. Optimal Battery Sizing and Control in a Stacked Revenue Model Incorporating a Renewable Energy Community. www.ewi.tudelft.nl, 2022.
Rodemann, T., Kataoka, H., Jatschka, T., Raidl, G., Limmer, S., & Meguro, H. Optimizing the positions of battery swapping stations-Pilot studies and layout optimization algorithm. *https://www.honda-mpp.com/in/*, 2023.
Setiawan, A. D., Zahari, T. N., Anderson, K., Moeis, A. O., & Hidayatno, A. Examining the effectiveness of policies for developing battery swapping service industry. *Energy Reports*, 9, 4682–4700, 2023.

Shao, S., Guo, S., & Qiu, X. A mobile battery swapping service for electric vehicles based on a battery swapping van. *Energies*, 10(10), 2017.

Shi, L., & Hu, B. Battery as a Service: Flexible Electric Vehicle Battery Leasing, 2023.

Sindha, J., Thakur, J., & Khalid, M. The economic value of hybrid battery swapping stations with second life of batteries. *Cleaner Energy Systems*, 5, 2023.

Singh, M., Jiao, J., Klobasa, M., & Frietsch, R. Servitization of Energy Sector: Emerging Service Business Models and Startup's Participation. *Energies*, 15(7), 2022.

Slattery, M., Dunn, J., & Kendall, A. Transportation of electric vehicle lithium-ion batteries at end-of-life: A literature review. *Resources, Conservation and Recycling*, 174, 2021.

Sopha, B. M., Purnamasari, D. M., & Ma'mun, S. Barriers and Enablers of Circular Economy Implementation for Electric-Vehicle Batteries: From Systematic Literature Review to Conceptual Framework. *Sustainability (Switzerland)*, 14(10), 2022.

Tahara, K., Ishikawa, K., & Ishigaki, M. Battery as a Service for Electric Vehicles: Design and Optimization of Partially Swappable and Shareable Battery System, 2023.

Toorajipour, R., Chirumalla, K., Parida, V., Johansson, G., Dahlquist, E., & Wallin, F. Preconditions of Circular Business Model Innovation for the Electric Vehicle Battery Second Life: An Ecosystem Perspective. *Advances in Transdisciplinary Engineering*, 21, 279–291, 2022.

Tripathi, S., Barala, C. P., Mathuria, P., & Bhakar, R. Battery Swapping Policy Review: An Indian and International Scenario. 2023 *IEEE PES Conference on Innovative Smart Grid Technologies - Middle East (ISGT Middle East 2023) - Proceedings*, 2023.

Wang, Y., Tian, J., Sun, Z., Wang, L., Xu, R., Li, M., & Chen, Z. A comprehensive review of battery modeling and state estimation approaches for advanced battery management systems. In *Renewable and Sustainable Energy Reviews* (Vol. 131). Elsevier Ltd., 2020

Wu, D., & Li, J. Research on the Optimal Leasing Strategy of Electric Vehicle Manufacturers. *World Electric Vehicle Journal*, 15(1), 2024.

Yang, J., Guo, F., & Zhang, M. Optimal planning of swapping/charging station network with customer satisfaction. *Transportation Research Part E: Logistics and Transportation Review*, 103, 174–197, 2017.

Yang, L., & Xianye, L. Evolutionary game analysis of new energy vehicle battery swapping station construction in china under low-carbon policies. 26, 2024.

Yang, S., Li, R., & Li, J. "Separation of vehicle and battery" of private electric vehicles and customer delivered value: Based on the attempt of 2 Chinese EV companies. *Sustainability (Switzerland)*, 12(5), 2020.

Zeng, Y., Yao, X., Yang, S., & Hsu, W. Strategic Marketing Analysis of NIO: A Case Study on Electric Vehicle Industry in China. *SHS Web of Conferences*, 215, 01006, 2025.

Zhang, X., & Rao, R. A Benefit Analysis of Electric Vehicle Battery Swapping and Leasing Modes in China. *Emerging Markets Finance and Trade*, 52(6), 1414–1426, 2016.

Zhao, D., & Jiang, Z. The Summary of NEV Business Model Based on Four-Elements Model. *IOP Conference Series: Earth and* Environmental *Science*, 1802(3), 2021.

Zhou, X., Pang, B., & Tang, R. As a service or a product? A comparison of electric vehicle battery supply models. *Omega (United Kingdom)*, 130, 2025.

Zhu, P., Qian, X., Liu, X., & Pardalos, P. M. SALES OR RENTALS? PRICE AND SERVICE DECISIONS FOR ELECTRIC VEHICLE MANUFACTURERS. *Journal of Industrial and Management Optimization*, 20(3), 1090–1113, 2024.

Zubi, G., Dufo-López, R., Carvalho, M., & Pasaoglu, G. The lithium-ion battery: State of the art and future perspectives. In *Renewable and Sustainable Energy Reviews* (Vol. 89, pp. 292–308). Elsevier Ltd., 2018.

## Biographies

**Upasana Haldar** is a PhD scholar at the Indian Institute of Technology Kharagpur, India. Her research focuses on operations management. Her research interests encompass operations management, project finance, and business analytics. Her scholarly contributions include numerous publications in national and international refereed journals, addressing topics such as innovation and infrastructure. She has actively participated in organizing various national and international conferences, serving as a convenor and contributing to the academic discourse in her fields of expertise.

**Rudra Prakash Pradhan** is a Professor at the Vinod Gupta School of Management, Indian Institute of Technology Kharagpur. He holds a Ph.D. from the Indian Institute of Technology Kharagpur and has been a faculty member at this school since 2007. Prof. Pradhan's research interests encompass infrastructure and project finance, business analytics, financial economics, and transport economics. His scholarly contributions include numerous publications in national and international refereed journals, addressing topics such as innovation, economic growth, and the nexus between finance and infrastructure. He has actively participated in organizing various national and international conferences, serving as a convenor and contributing to the academic discourse in his fields of expertise.

**Himanshu Chandra** is a PhD scholar at the Indian Institute of Technology Kharagpur, India. He is a sustainability enthusiast working specifically on circular economy practices in India and other developing countries. His scholarly contributions include numerous publications in national and international refereed journals, addressing topics such as innovation and infrastructure. He has actively participated in organizing various national and international conferences, serving as a convenor and contributing to the academic discourse in her fields of expertise.