Proceedings of the International Conference on Industrial Engineering and Operations Management

Publisher: IEOM Society International, USA DOI: 10.46254/AP06.20250057
Published: August 5, 2025

Barriers of Battery Leasing in Indian Electric Vehicle Infrastructure: Insights from a Delphi Study

Rudra Prakash Pradhan
Vinod Gupta School of Management
Indian Institute of Technology, Kharagpur, WB- 721302, India
rudrap@vgsom.iitkgp.ac.in

Ann Mary Varghese
Vinod Gupta School of Management
Indian Institute of Technology, Kharagpur, WB- 721302, India
annmaryvar008@gmail.com

Avinash Chauhan
Vinod Gupta School of Management
Indian Institute of Technology, Kharagpur, WB- 721302, India
avinashchauhan15@kgpian.iitkgp.ac.in

Roopa Raju
Vinod Gupta School of Management
Indian Institute of Technology, Kharagpur, WB- 721302, India
rajuroopa@gmail.com

Deep Choudhury
Vinod Gupta School of Management
Indian Institute of Technology, Kharagpur, WB- 721302, India
deepchoudhury.ele@gmail.com

Abstract

Battery leasing has emerged as a promising solution to reduce the high upfront costs of electric vehicles (EVs) and accelerate their adoption, particularly in emerging markets like India. However, the implementation of battery leasing models faces several systemic, financial, operational, and behavioral barriers that are not yet fully understood or empirically validated. This study aims to identify and validate the critical barriers hindering the large-scale adoption of battery leasing systems in India's evolving EV infrastructure. An initial list of 30 barriers was curated through an extensive literature review and expert consultations, encompassing issues related to consumer perception, regulatory uncertainty, financial risks, infrastructure limitations, and technological interoperability. To achieve consensus-based validation, the Fuzzy Delphi Method (FDM) was employed, engaging 26 experts from academia, industry, and policy domains with deep technical expertise in battery technology, EV systems, and sustainable mobility. Based on fuzzy weightings and defuzzification, 17 barriers were validated for their significance in the Indian context, including high battery costs, lack of standardized charging strategies, inadequate policy support, limited OEM participation, and uncertainty in battery second-life applications. The study not only contributes to the theoretical understanding of BaaS-related challenges but also offers actionable insights for EV manufacturers, battery leasing operators (BLOs), and policymakers. By uncovering the most pressing impediments to battery leasing in India, the findings serve as a strategic roadmap for designing inclusive and sustainable battery-as-a-service ecosystems.

Keywords
Enabling Factors, Battery Leasing Models, Electric Vehicle Battery Infrastructure in India, Delphi Method and Battery-as-a-Service (BaaS) Business Models

1. Introduction
To facilitate the transition towards sustainable transportation, the automotive industry has explored innovative business models, one of which is **battery leasing**. This model allows consumers to obtain an electric vehicle (EV) while leasing the battery separately from a Battery Leasing Operator (BLO), who remains responsible for its ownership and maintenance. By decoupling battery costs from the vehicle purchase, the model reduces the initial financial burden on buyers and can make EVs more accessible (Li & Ouyang, 2011; Picatoste et al., 2022).

An early implementation of this model was undertaken by Better Place in 2007, aimed at accelerating the adoption of New Energy Vehicles (NEVs). Despite its potential, the initiative struggled with operational and financial limitations and was eventually discontinued (Christensen, Wells, & Cipcigan, 2012). In contrast, companies like Renault found notable success with battery leasing in the European market during the mid-2010s (Gonzalez-Salazar, Kormazos, & Jienwatcharamongkhol, 2023). More recently, Chinese manufacturers such as NIO and BAIC have incorporated battery swapping technologies and flexible leasing schemes, reinforcing the relevance of the model in emerging markets (NIO, 2023; Zhang & Rao, 2016).

While the battery leasing model offers distinct benefits—including cost savings, easier battery replacement, and the potential for battery standardization—it is not without its challenges. Investment uncertainties, gaps in infrastructure, and the absence of a well-defined reverse logistics framework continue to hinder its scalability (Shi & Hu, 2024; Varghese & Pradhan, 2025). These issues underscore the importance of a systematic evaluation of barriers from various stakeholder viewpoints. Accordingly, this study adopts the Delphi technique to gather expert insights and build consensus on the key impediments facing battery leasing in the Indian EV context.

The literature concerning battery leasing operations often centres around two main themes: business model choice and pricing dynamics. For example, Zhang and Rao (2016) constructed analytical models to explore different revenue mechanisms for leasing providers. Their findings, supported by simulation, helped identify the most viable service approaches. Complementing this, Huang et al. (2021) conducted a stated preference survey to evaluate consumer inclinations toward battery leasing, full EV leasing, ownership, and shared mobility.

Consumer preferences are further explored in the work of Yang et al. (2021), who analysed how psychological and behavioural traits influence the choice between integrated (vehicle and battery combined) and separated (vehicle and battery split) ownership. Comparative evaluations by Gonzalez-Salazar et al. (2023) highlight differences in environmental and economic performance between leasing and traditional sales models.

Pricing, another critical consideration, has also been examined in depth. Lim, Mak, and Rong (2015) studied the effects of consumer anxieties—particularly about range and resale value—on vehicle adoption under both leasing and sales models. Later works by Yang et al. (2022) and Hu et al. (2023) introduced tailored pricing mechanisms for battery swapping services, including both usage-based and subscription formats. The impact of government incentives on market expansion was analysed by Yang et al. (2023), while Hu et al. (2024) developed models that factor in financing strategies. Lu et al. (2022) and Du and Wang (2024) investigated pricing under different supply chain power dynamics, and Yuan et al. (2023) extended this research by examining how second-life battery applications influence pricing decisions.

1.1 Objectives
The specific objectives of the study are:

1. To identify factors that challenge the battery leasing in battery infrastructure through a review of academic literature.
2. To shortlist these factors based on their frequency of occurrence.

3. To determine the key factors challenging battery leasing within India's EVB infrastructure.

2. Literature Review

The research design of this study builds on an extensive review of academic and policy literature to explore the systemic, economic, behavioural, and institutional barriers impeding the adoption of battery leasing models in electric vehicle (EV) ecosystems—particularly in the Indian context. While battery leasing and Battery-as-a-Service (BaaS) models have been proposed as innovative solutions to reduce upfront EV costs and enhance market penetration, widespread adoption is hindered by a complex array of contextual challenges.

Several studies have highlighted the **financial and economic barriers** associated with battery leasing. Li and Ouyang (2011) emphasized that while leasing can offset upfront EV costs, the economic feasibility of battery leasing operators (BLOs) remains questionable due to high battery prices, limited consumer base, and uncertain resale values. More recent analyses have pointed out the growing gap between GST on EVs and separately sold batteries in India, where the latter incurs a higher tax rate of 18%, discouraging BLO-led adoption (ThePrint, 2024; Energetica India, 2024). From a **regulatory and policy standpoint**, the absence of comprehensive frameworks to govern leasing operations, liabilities, and inter-state norms has also posed a barrier to nationwide scalability (Engineering for Change, 2023). In particular, the lack of clearly defined operational rights and responsibilities between BLOs, OEMs, and consumers limits trust and participation in battery leasing initiatives (Gupta et al., 2024).

Behavioural and perceptual barriers are equally prominent. Studies by Kumari, Kumar, and Thakur (2022) demonstrate that Indian consumers remain hesitant toward leasing models due to concerns over hidden costs, lack of trust in third-party battery management, and low awareness of leasing benefits. This mistrust is exacerbated by limited exposure to leasing mechanisms and a preference for asset ownership—particularly in semi-urban and rural areas. **Technological and operational challenges** have also been well documented. The lack of battery standardization across EV models impedes interoperability and logistics for BLOs (Saxena et al., 2024). Further, issues related to battery degradation, maintenance uncertainty, and the absence of second-life application pathways make consumers and operators alike cautious about entering long-term lease contracts (Huang et al., 2021). These concerns are particularly acute in high-usage settings like last-mile delivery, where rapid battery cycling can lead to premature wear.

Moreover, **infrastructure inadequacy**—especially in battery swapping and fast-charging networks—has emerged as a critical bottleneck. Without the presence of interoperable and evenly distributed infrastructure, leasing models remain viable only in urban clusters, limiting their inclusive potential (Zhou et al., 2025). Limited OEM participation and unclear profit-sharing models between stakeholders further reduce the appeal of investing in BaaS infrastructure (Wu & Li, 2024).

While these studies provide valuable insights into discrete barrier dimensions, there is a notable lack of systematic validation of such factors—particularly using expert consensus methods in emerging economies. Most prior work has emphasized economic feasibility or policy support in isolation, leaving a gap in integrated frameworks that capture the interdependence among technological, behavioural, and policy barriers.

This study addresses that gap by employing the Fuzzy Delphi Method to identify and validate a comprehensive set of barriers to battery leasing in India. By engaging both academic and industry experts with domain-specific knowledge, the research contributes to a more contextualized understanding of the systemic constraints hindering battery leasing adoption. These insights aim to inform future interventions by policymakers, leasing operators, and automotive manufacturers working toward a sustainable and scalable EV ecosystem in India.

3. Methodology

This study employs the Fuzzy Delphi Method (FDM) to identify and validate the enablers that facilitate the adoption of battery leasing in India's electric vehicle (EV) battery infrastructure. The FDM combines the systematic consensus-building approach of the traditional Delphi method with the uncertainty-handling capability of fuzzy set theory. This hybrid technique is particularly effective when expert judgments are expressed in linguistic terms and involve subjective evaluations, as is common in the early-stage adoption of emerging technologies.

3.1 Expert Panel Composition

A total of 26 experts participated in this study, representing both academic and industry perspectives. The panel included 7 industry professionals from sectors such as battery engineering, e-mobility services, and EV manufacturing. Their professional experience ranged from 3 to 20 years, covering ground-level implementation, policy alignment, and battery technology operations.

In parallel, 19 academic experts were drawn from prominent institutions such as IIT Kharagpur, MNIT Jaipur, and other public academic institutions across India. Their specialization areas included power electronics, materials science, circular economy, energy systems, battery technologies, and supply chain management. The academic group had research experience ranging from less than 5 years to more than 15 years, with the majority holding Ph.D. or postdoctoral qualifications.

3.2 Instrument Design and Linguistic Fuzzification

Based on an extensive literature review and preliminary expert discussions, an initial list of **28 enablers** was generated. These were included in a structured survey, where participants were asked to assess each enabler's importance on a **5-point linguistic scale**. Each linguistic response was translated into a **Triangular Fuzzy Number (TFN)** to capture uncertainty and imprecision in expert perceptions. The fuzzy scale used is shown in Table 1:

Table 1. Linguistic Variables and Corresponding TFNs

Linguistic Variable	Rating	Corresponding TFN
Extremely unimportant	1	(0.1, 0.1, 0.3)
Unimportant	2	(0.1, 0.3, 0.5)
Normal	3	(0.3, 0.5, 0.7)
Important	4	(0.5, 0.7, 0.9)
Extremely important	5	(0.7, 0.9, 0.9)

Each expert's response for the j_{th} enabler was thus encoded as a TFN:

$\tilde{A}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ **(Equation 1)**

3.3 Aggregation of Fuzzy Ratings

To derive a collective assessment for each enabler, the individual TFNs from all N=26 experts were aggregated using the arithmetic mean:

$l_j = \frac{1}{N}\sum_{i=1}^{N} lij$, $m_j = \frac{1}{N}\sum_{i=1}^{N} lij$, $u_j = \frac{1}{N}\sum_{i=1}^{N} lij$ **(Equation 2)**

This resulted in an aggregated TFN for each enabler $\tilde{A}_{ij} = (l_j, m_j, u_j)$

3.4 Defuzzification and Consensus Threshold

The aggregated fuzzy scores were defuzzified using the **Centroid Method**, which calculates a crisp value representing the overall importance of each enabler:

$D_j = \frac{lj,mj,uj}{3}$ **(Equation 3)**

4. Data Collection

This study draws on primary data collected from academic and industry experts with deep expertise in EV systems, battery modelling, energy storage, and technology integration. The selected experts came from diverse domains such as electrical, mechanical, metallurgical, energy science, chemical, and industrial engineering. Their academic and technical experience made them well-suited to evaluate the barriers related to battery leasing in the Indian EV context. Data collection was carried out between April and May 2025. A total of **50 experts** were identified based on their research, professional background, and relevance to EV battery technologies. Outreach was conducted via email, phone calls, and in-person meetings. Of these, **33 experts were engaged through direct interactions**, and **26 completed the Fuzzy Delphi questionnaire**.

The final respondents represented a wide spectrum of expertise. Academic participants contributed insights on battery degradation, thermal management, lifecycle modelling, battery management systems, and powertrain optimization.

Industry experts, primarily from battery manufacturers, R&D units, and NGOs, shared perspectives on charging infrastructure, diagnostics, policy frameworks, and technology deployment.
Notably, experts also included researchers working on AI-enabled platforms for battery health estimation, second-life applications, and reverse logistics, critical to battery leasing models. Faculty from centres like the Advanced Technology Development Centre added valuable input on energy management and indigenous EV components.

Feedback on the questionnaire was positive, with experts appreciating its clarity and policy relevance. However, challenges arose due to limited availability; many experts were constrained by travel, project deadlines, or institutional responsibilities. As a result, only 26 out of 50 shortlisted experts contributed to the final analysis.

5. Results and Discussion

This research employed the Fuzzy Delphi Method (FDM) to identify and validate the key barriers that hinder the widespread adoption of battery leasing models in the Indian electric vehicle (EV) battery supply chain. FDM combines the classical Delphi technique with fuzzy set theory to address uncertainty in expert opinion and the inherent vagueness in linguistic judgments (Ishikawa et al., 1993; Kaufmann & Gupta, 1988). It is particularly well-suited for emerging domains like battery leasing, where empirical data is limited and expert consensus is essential for grounded decision-making.

An initial list of **30 potential barriers** was developed through an extensive review of academic publications, policy white papers, and industry reports. These barriers span across multiple thematic areas—**economic, regulatory, technical, behavioural, and operational**—to reflect the complex and interconnected nature of challenges facing the battery leasing ecosystem in India.

The preliminary barrier set included issues such as *rising battery prices*, *limited OEM participation*, *financial uncertainty for leasing operators*, and *battery degradation due to high cycling*. These factors were structured to ensure coverage of both systemic infrastructure constraints and user-level adoption hurdles. A comprehensive classification of all 30 identified barriers—along with their themes, descriptions, and supporting literature—is detailed in Table 2.

Table 2. Preliminary List of 28 Enablers for Battery Leasing Adoption, with Dimensions, Descriptions, and References

S. No	Barrier Name	Barrier Theme	Description	Key References
1	Low Consumer Awareness and Social Acceptance	Behavioural	Limited public understanding and acceptance of leasing-based EV battery ownership models.	J.D. Power (2021); Williams (2012)
2	Resistance to New Business Models	Behavioural	Institutional or consumer reluctance to adopt novel financial or operational models.	Wu & Li (2024); Sharma et al. (2023)
3	Lack of Trust in Leasing Agreements	Behavioural	Concerns about long-term commitment, service quality, and hidden terms in leasing contracts.	Lim et al. (2015); Zhou et al. (2025)
4	High Upfront Battery Leasing Costs	Economic	Initial costs for leasing schemes perceived as unaffordable or unclear in structure.	Zhou et al. (2025); Hou et al. (2010)
5	Rising Battery Prices	Economic	Increased cost of batteries due to raw material shortages or global supply constraints.	Reuters (2025); Sharma et al. (2023)
6	High Operating Costs for Leasing Operators	Economic	High CAPEX and OPEX required for managing leasing platforms and inventory logistics.	Wu & Li (2024); Sharma et al. (2023)
7	Absence of Sufficient Financial Subsidies	Regulatory	Lack of targeted government incentives to promote battery leasing models.	GOI (2024); Zhou et al. (2025)

S. No	Barrier Name	Barrier Theme	Description	Key References
8	Battery Maintenance and Repair Costs	Economic	Ongoing costs of servicing leased batteries, especially after extended cycling.	Geotab (2025); Hou et al. (2010)
9	Long-Term Financial Uncertainty for Operators	Economic	Revenue predictability and ROI risk for battery leasing companies in evolving markets.	Sharma et al. (2023); Global Market Insights (2025)
10	Inflexibility in Battery Leasing Plans	Behavioural	One-size-fits-all contract terms that do not align with diverse user needs or patterns.	Williams (2012); Hildebrandt et al. (2016)
11	Complex Leasing Terms and Conditions	Behavioural	Overly technical or opaque contract structures deterring adoption.	Lim et al. (2015); J.D. Power (2021)
12	Lack of Battery Availability and Stock	Operational	Limited inventory, especially for high-demand battery types and locations.	Frost & Sullivan (2022); Sharma et al. (2023)
13	Regulatory and Institutional Barriers	Regulatory	Inconsistent or absent policies related to battery leasing schemes and responsibilities.	GOI (2024); Zhou et al. (2025)
14	Complicated Regulatory Requirements	Regulatory	Legal hurdles in registration, GST, data ownership, and compliance.	Sharma et al. (2023); Wu & Li (2024)
15	Lack of Standardized Charging Strategies	Technical	Absence of unified charging protocols impacting performance and compatibility.	Lim et al. (2015); CATL (2025)
16	Battery Degradation Due to High Cycling	Technical	Performance decline from repeated charge-discharge cycles during leases.	Zhou et al. (2025); Geotab (2025)
17	Challenges in Repurposing Batteries	Technical	Lack of infrastructure to handle end-of-life battery reuse or second-life allocation.	Ellen MacArthur Foundation (2020); Yuan et al. (2023)
18	Lack of Battery Second-Life Applications	Technical	Absence of clear reuse models post-leasing lifespan.	Yuan et al. (2023); Hou et al. (2010)
19	Lack of Standardized Battery Quality	Technical	Quality and safety inconsistencies across leased battery models.	CATL (2025); Sharma et al. (2023)
20	Higher GST on Leased Batteries	Regulatory	Higher tax slabs on leased batteries reducing cost attractiveness.	GOI (2023); Wu & Li (2024)
21	Battery Swapping Station Scarcity	Operational	Lack of physical swapping infrastructure and depot readiness.	PwC (2021); Zhou et al. (2025)
22	Uncertain Residual Battery Value	Economic	Difficulty in assessing future value of batteries under lease.	Recurrent (2025); Zhou et al. (2025)
23	Limited OEM Participation	Institutional	Auto manufacturers hesitant to endorse or integrate leasing models.	Wu & Li (2024); Sharma et al. (2023)
24	Battery Health Assessment Issues	Technical	Inadequate diagnostics for real-time evaluation of battery performance.	Geotab (2025); CATL (2025)
25	Recurring Replacement Costs	Economic	Costs from frequent replacements due to rapid degradation or abuse.	Sharma et al. (2023); Williams (2012)
26	Battery Theft Risks	Behavioural	Fear of theft or misuse discouraging battery leasing.	TopSpeed (2025); Lim et al. (2015)
27	Technology Obsolescence Risks	Technical	Leasing firms exposed to risks from rapidly changing battery tech.	Zhou et al. (2025); Sharma et al. (2023)
28	Inconsistent State-Level Policies	Regulatory	Variability in EV-related incentives and compliance across Indian states.	GOI (2024); IEA (2022)

S. No	Barrier Name	Barrier Theme	Description	Key References
29	Low LTV Ratios for EVs	Economic	Lower resale value of EVs affecting financing viability of leasing.	Frost & Sullivan (2022); Hou et al. (2010)
30	Fragmented Stakeholder Collaboration	Institutional	Weak coordination between OEMs, leasing platforms, recyclers, and policy bodies.	Yuan et al. (2023); PwC (2021)

These barriers were then subjected to an expert-driven validation process using the Fuzzy Delphi Method. A total of **30 experts** from academia and industry participated in this phase, selected based on domain expertise and relevance. Their characteristics—including institutional affiliation, experience, and domain familiarity—are summarized in Table 3.

Table 3. Expert Panel Profile Summary

Attribute	Description
Total number of experts	26
Academic experts	19 (from IIT Kharagpur, MNIT Jaipur, and other public institutions)
Industry experts	7 (from battery manufacturers, EV service providers, etc.)
Average years of experience	Over 10 years
Domains of expertise	Power electronics, battery engineering, thermal systems, supply chain, circular economy
Regional scope	Primarily India-focused, with select experts engaged in global projects
Avg. familiarity with battery leasing	4.4 / 5 (self-rated)
Avg. familiarity with EV battery infra	4.2 / 5 (self-rated)
Avg. familiarity with Indian EV ecosystem	4.3 / 5 (self-rated)

Out of the 30 barriers evaluated, 18 were validated as critical by the expert panel, having achieved a defuzzified value ≥ 0.6 and meeting the minimum consensus threshold. These included high-priority concerns such as Rising Battery Prices (0.833), Absence of Sufficient Financial Subsidies (0.833), Battery Degradation Due to High Cycling (0.833), and High Upfront Battery Leasing Costs (0.762). Barriers related to financial burden, regulatory support, and technological degradation risks featured prominently among those accepted. Behavioural and institutional concerns—such as Low Consumer Awareness, Resistance to New Business Models, and Limited OEM Participation—also received strong consensus. Conversely, 12 barriers were excluded due to low defuzzified scores or insufficient agreement. These included Lack of Trust in Leasing Agreements, Battery Theft Risks, Recurring Replacement Costs, and Inconsistent State-Level Policies, which were either deemed less urgent or too context-specific for inclusion in a national battery leasing model. A detailed list of fuzzy weights, defuzzified values, and expert decisions for all 30 barriers is presented in Table 4.

Table 4. Final Selection of Battery Leasing Barriers Based on Fuzzy Delphi Method

S. No	Barrier	Fuzzy Weight (p, q, r)	Defuzzified Value	Decision
1	Low Consumer Awareness and Social Acceptance	(0.3, 0.789, 0.9)	0.663	Accept
2	Resistance to New Business Models	(0.5, 0.724, 0.9)	0.708	Accept
3	Lack of Trust in Leasing Agreements	(0.1, 0.317, 0.9)	0.439	Reject
4	High Upfront Battery Leasing Costs	(0.5, 0.885, 0.9)	0.762	Accept
5	Rising Battery Prices	(0.7, 0.9, 0.9)	0.833	Accept
6	High Operating Costs for Leasing Operators	(0.1, 0.310, 0.7)	0.370	Reject
7	Absence of Sufficient Financial Subsidies	(0.7, 0.9, 0.9)	0.833	Accept
8	Battery Maintenance and Repair Costs	(0.3, 0.851, 0.9)	0.684	Accept

S. No	Barrier	Fuzzy Weight (p, q, r)	Defuzzified Value	Decision
9	Long-Term Financial Uncertainty for Operators	(0.3, 0.708, 0.9)	0.636	Accept
10	Inflexibility in Battery Leasing Plans	(0.1, 0.3, 0.5)	0.300	Reject
11	Complex Leasing Terms and Conditions	(0.1, 0.108, 0.5)	0.236	Reject
12	Lack of Battery Availability and Stock	(0.5, 0.724, 0.9)	0.708	Accept
13	Regulatory and Institutional Barriers	(0.1, 0.1, 0.3)	0.167	Reject
14	Complicated Regulatory Requirements	(0.3, 0.684, 0.9)	0.628	Accept
15	Lack of Standardized Charging Strategies	(0.1, 0.429, 0.9)	0.476	Reject
16	Battery Degradation Due to High Cycling	(0.7, 0.9, 0.9)	0.833	Accept
17	Challenges in Repurposing Batteries	(0.1, 0.3, 0.5)	0.300	Reject
18	Lack of Battery Second-Life Applications	(0.5, 0.712, 0.9)	0.704	Accept
19	Lack of Standardized Battery Quality	(0.1, 0.3, 0.5)	0.300	Reject
20	Higher GST on Leased Batteries	(0.1, 0.1, 0.3)	0.167	Reject
21	Battery Swapping Station Scarcity	(0.5, 0.7, 0.9)	0.700	Accept
22	Uncertain Residual Battery Value	(0.5, 0.724, 0.9)	0.708	Accept
23	Limited OEM Participation	(0.5, 0.885, 0.9)	0.762	Accept
24	Battery Health Assessment Issues	(0.5, 0.7, 0.9)	0.700	Accept
25	Recurring Replacement Costs	(0.1, 0.449, 0.7)	0.416	Reject
26	Battery Theft Risks	(0.1, 0.467, 0.7)	0.422	Reject
27	Technology Obsolescence Risks	(0.5, 0.712, 0.9)	0.704	Accept
28	Inconsistent State-Level Policies	(0.3, 0.5, 0.7)	0.500	Reject
29	Low LTV Ratios for EVs	(0.5, 0.7, 0.9)	0.700	Accept
30	Fragmented Stakeholder Collaboration	(0.3, 0.5, 0.7)	0.500	Reject

The validated barriers identified through the Fuzzy Delphi Method reveal a multidimensional challenge landscape, with dominant concerns falling into three thematic clusters: **financial constraints**, **technological degradation**, and **institutional or behavioural resistance**. Notably, the **top three barriers**—*Rising Battery Prices* (0.833), *Absence of Sufficient Financial Subsidies* (0.833), and *Battery Degradation Due to High Cycling* (0.833)—recorded the highest defuzzified values, highlighting a strong consensus among experts on the systemic cost and performance-related risks surrounding battery leasing adoption.

A second cluster of highly rated concerns includes *High Upfront Battery Leasing Costs* (0.762), *Limited OEM Participation* (0.762), *Resistance to New Business Models* (0.708), and *Uncertain Residual Battery Value* (0.708). These emphasize the **economic and institutional barriers** that undermine the scalability of battery leasing. Their prominence confirms that success in this domain depends not only on technology readiness, but also on **ecosystem alignment**, including OEM engagement and innovative business model integration—an observation echoed in recent literature (Wu & Li, 2024; Zhou et al., 2025).

Further, the acceptance of *Battery Health Assessment Issues*, *Battery Swapping Station Scarcity*, and *Lack of Battery Availability and Stock* underscores the **operational limitations** associated with inventory management and diagnostic infrastructure. Without a robust backend system for performance tracking and physical availability, battery leasing models are likely to fall short of user expectations.

In contrast, barriers such as *Lack of Trust in Leasing Agreements*, *Recurring Replacement Costs*, *Battery Theft Risks*, and *Inconsistent State-Level Policies* did not meet the required threshold and were therefore excluded. While these factors may pose localized or context-specific issues, the expert panel deemed them less critical compared to structural financial and technological challenges.

Overall, the accepted barriers provide a grounded framework for stakeholders to prioritize efforts. They present a nuanced picture of India's battery leasing landscape—where cost economics, policy support, and industrial coordination must be strategically addressed in tandem. A comparative visualization of all evaluated barriers, including accepted and rejected ones, is provided in **Figure 1**.

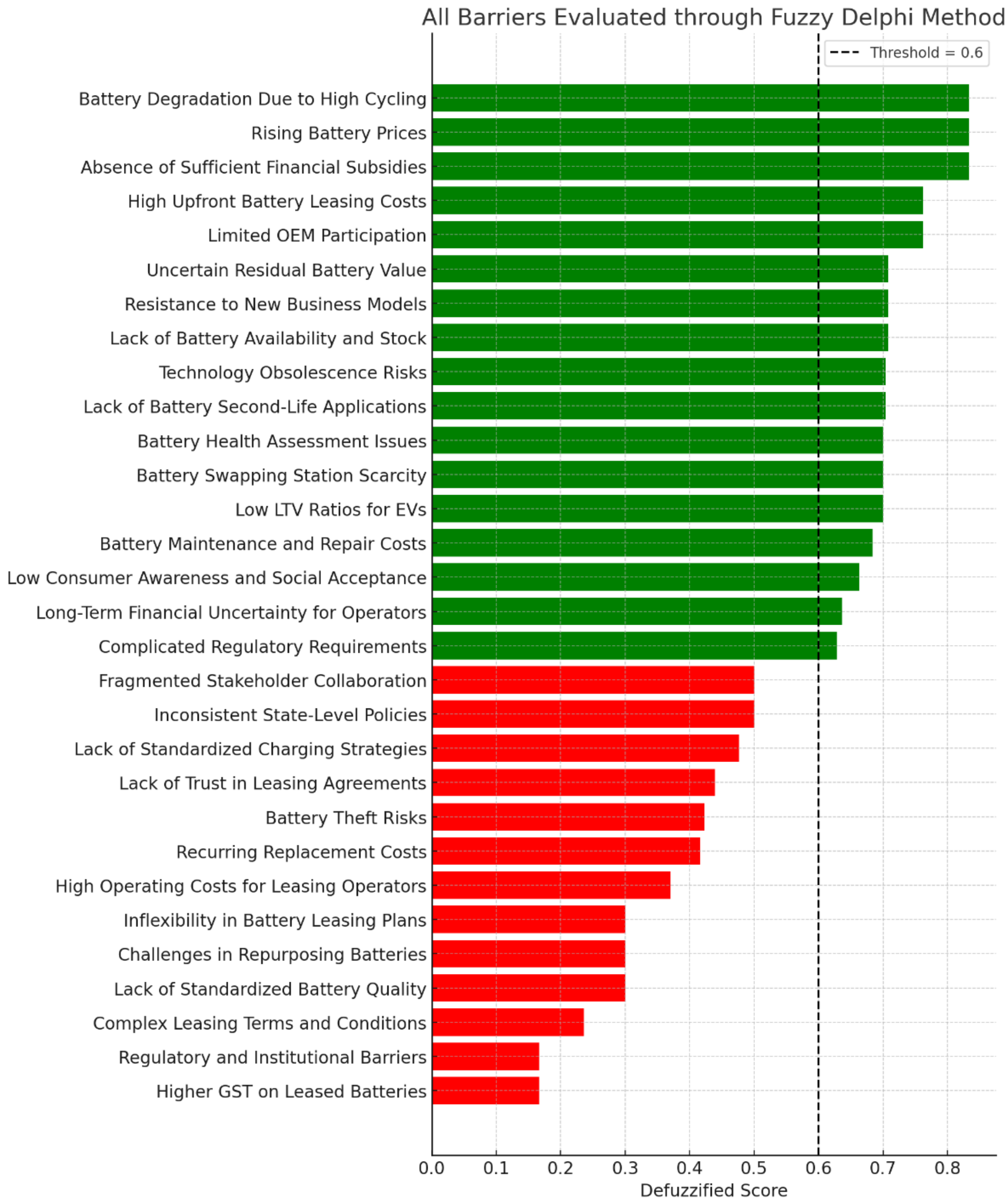

Figure 1. Evaluation of All Barriers Using Fuzzy Delphi Method

This figure illustrates the defuzzified scores for all 30 battery leasing barriers. Green bars indicate barriers that met the threshold for acceptance (≥ 0.6), while red bars represent those rejected. The dashed vertical line denotes the FDM threshold value of 0.6 used for final selection.

6. Managerial Implications

The findings of this study provide critical insights for practitioners, policymakers, and ecosystem stakeholders aiming to operationalize battery leasing models in India's evolving EV landscape. The Fuzzy Delphi-based validation of barriers highlights a set of financial, institutional, infrastructural, and behavioural impediments that require strategic and coordinated responses.

First, the prominence of cost-related barriers, including *Rising Battery Prices*, *High Upfront Leasing Costs*, and *Absence of Financial Subsidies* underscores the need for financial innovation. Managers in battery leasing firms and mobility startups must design tiered pricing models, value-based leasing plans, and usage-linked revenue structures to reduce consumer resistance and attract early adopters. In parallel, there is a clear case for targeted government interventions, such as GST relief on leased batteries, capital subsidies, and accelerated depreciation benefits to improve operator profitability and reduce consumer cost burden.

Second, the validation of barriers such as *Battery Health Assessment Issues* and *Battery Swapping Station Scarcity* reveals significant gaps in operational infrastructure. Managers must prioritize investments in diagnostic technologies, digital twin platforms, and real-time battery monitoring systems. Building an integrated leasing and swapping platform with standardized interfaces can enhance customer trust and reduce logistical inefficiencies.

Third, the identification of *Resistance to New Business Models*, *Low Consumer Awareness*, and *Limited OEM Participation* calls for strategic ecosystem engagement. Leasing providers and OEMs should collaborate on bundled vehicle-leasing offerings and awareness campaigns that demystify leasing as a financially viable and operationally convenient alternative to ownership. Pilot projects in public fleets (e.g., e-rickshaws, delivery vans) can also build visibility and credibility for battery leasing solutions.

Fourth, the emergence of barriers related to *Uncertain Residual Battery Value* and *Battery Degradation Due to High Cycling* suggests that battery leasing firms must adopt circular business models. Managers should work with battery analytics firms and recyclers to develop second-life use cases, standardize end-of-life value estimation protocols, and build take-back programs that ensure lifecycle accountability.

Finally, the accepted barriers emphasize the importance of multi-stakeholder coordination, including regulatory alignment. Industry associations and public agencies must jointly establish regulatory sandboxes, streamline certification norms for leased batteries, and create state-level policy harmonization to avoid market fragmentation.
In sum, managers must adopt a systems-thinking approach to battery leasing, balancing short-term adoption goals with long-term infrastructure, trust-building, and policy integration. The validated barrier set offers a roadmap to strategically overcome current constraints and position battery leasing as a scalable, sustainable mobility innovation.

7. Conclusion

This study provides a systematic evaluation of the critical barriers hindering the widespread adoption of battery leasing models in India’s EV sector. By integrating insights from a comprehensive literature review and applying the FDM, the research identifies and validates thirty key barriers across behavioural, economic, regulatory, technical, operational, and institutional dimensions. Among these, barriers such as low consumer awareness, lack of trust in leasing agreements, high upfront leasing costs, and the absence of standardized battery quality emerged as particularly significant.

The findings underscore the multifaceted nature of challenges impeding battery leasing adoption, ranging from user perception issues to policy and infrastructure limitations. Notably, the behavioural reluctance toward non-ownership models, coupled with technical complexities like battery degradation and standardization, represent interlocking hurdles that demand coordinated policy and industry-level interventions.

This study contributes to the nascent yet growing body of knowledge on BaaS models by offering empirical validation of barriers from the perspective of academic and industry experts. By doing so, it not only addresses a critical research gap but also equips stakeholders, such as battery leasing operators, original equipment manufacturers (OEMs), and policymakers—with actionable insights to navigate the transition toward service-based battery ownership.

Future research can extend this work by exploring the interrelationships among these barriers using interpretive modelling techniques such as ISM or DEMATEL, or by validating the framework across different regional and technological contexts. Additionally, integrating consumer-level behavioural experiments or simulations may further deepen understanding of adoption dynamics in India's rapidly evolving EV landscape.

Acknowledgement

The authors gratefully acknowledge the use of ChatGPT during the writing and revision of this manuscript, specifically for assistance with language editing to enhance clarity and flow. All content generated by ChatGPT was thoroughly reviewed and edited by the authors, who take full responsibility for the accuracy, content, and integrity of the final publication.

This research was conducted as part of a funded project supported by the Indian Council of Social Science Research (ICSSR), New Delhi. The project, titled *"Sustainable Development of Electric Vehicle Battery Infrastructure in India: Challenges, Circular Economy Integration, and Policy Measures,"* aims to address critical issues in EV battery systems through interdisciplinary approaches. The authors sincerely thank ICSSR for its financial support and institutional backing, which were instrumental in the successful completion of this study.

References

Budde Christensen, T., Wells, P., & Cipcigan, L. Can innovative business models overcome resistance to electric vehicles? Better Place and battery electric cars in Denmark. Energy Policy, 48, 498–505, 2012. https://doi.org/10.1016/j.enpol.2012.05.054.

CATL. CATL opens its first battery swapping stations in China. InsideEVs, 2025. https://insideevs.com/news/580916/catl-opens-its-first-battery-swapping-stations-china/.

Du, J., & Wang, W. Research on pricing decision of NEV battery swapping supply chain under different power structures. Soft Science, 3802(2), 124–133, 2024.

Ellen MacArthur Foundation. A circular economy for batteries to underpin renewable energy growth. 2020. https://www.ellenmacarthurfoundation.org/articles/a-circular-economy-for-batteries-to-underpin-renewable-energy-growth.

Energetica India. Unseen legal and financial barriers impeding EV leasing growth. Energetica India, 2024. https://www.energetica-india.net/news/unseen-legal-and-financial-barriers-impeding-ev-leasing-growth.

Engineering for Change. Battery swapping is cutting the cost of India's electric vehicles in half. 2023. https://www.engineeringforchange.org/news/battery-swapping-is-cutting-the-cost-of-indias-electric-vehicles-in-half/.

Frost & Sullivan. Strategic analysis of the global electric two- and three-wheeler battery swapping market. 2022.

Geotab. EV battery health insights: Data from 10,000 cars. 2025. https://www.geotab.com/blog/ev-battery-health/.

Global Market Insights. Battery leasing service market size, statistics report 2025–2034. 2025.

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, 138356, 2023. https://doi.org/10.1016/j.jclepro.2023.138356.

Government of India. GST structure and policy documents. [Internal document], 2023.

Government of India. Draft EV leasing scheme guidelines. [Internal document], 2024.

Gupta, A., Sinha, R., & Mehta, K. Battery standardization issues in electric vehicle infrastructure: Challenges and solutions. Clean Technologies and Environmental Policy, 26(2), 113–125, 2024. https://doi.org/10.1007/s43621-024-00595-7.

Hildebrandt, B., Remané, G., Brauer, B., & Kolbe, L. M. Valuing battery degradation from a battery lessor's perspective. In D. Fornahl & M. Hülsmann (Eds.), Markets and Policy Measures in the Evolution of Electric Mobility (pp. 163–178). Springer, 2016. https://doi.org/10.1007/978-3-319-24229-3_25.

Hou, C., Du, J., & Wang, H. The living space analysis in the battery leasing business. World Electric Vehicle Journal, 4(4), 870–879, 2010. https://doi.org/10.3390/wevj4040881.

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, 120639, 2021. https://doi.org/10.1016/j.techfore.2021.120639.

J.D. Power. 2021 U.S. end of lease satisfaction study. 2021. https://www.jdpower.com/business/press-releases/2021-us-end-lease-satisfaction-study.

Kumari, N., Kumar, A., & Thakur, P. Barriers to electric vehicle adoption: A consumer perspective from India. Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, 236(5), 729–742, 2022. https://doi.org/10.1177/09544070221080349.

Li, Z., & Ouyang, M. A win-win marginal rent analysis for operator and consumer under battery leasing mode in China electric vehicle market. Energy Policy, 39(6), 3222–3237, 2011. https://doi.org/10.1016/j.enpol.2011.03.014.

Lim, M. K., Mak, H.-Y., & Rong, Y. Toward mass adoption of electric vehicles: Impact of the range and resale anxieties. Manufacturing and Service Operations Management, 17(1), 101–119, 2015. https://doi.org/10.1287/msom.2014.0504.

Lu, Z., Yao, Y., & Lu, C. Pricing strategy of new energy electric vehicle battery swapping mode under differential supply chain structure. Systems Engineering, 40(2), 27–37, 2022.

NIO. [Corporate document or announcement], 2023.

Picatoste, A., Justel, D., & Mendoza, J. M. F. Circularity and life cycle environmental impact assessment of batteries for electric vehicles: Industrial challenges, best practices and research guidelines. Renewable and Sustainable Energy Reviews, 169, 112941, 2022. https://doi.org/10.1016/j.rser.2022.112941.

Recurrent. Battery replacement costs are poised to plunge. 2025. https://www.recurrentauto.com/research/replacing-an-ev-battery-less-than-fixing-a-gas-engine.

Reuters. European EV battery material startups make recycling breakthroughs. Reuters, 2025, February 13. https://www.reuters.com/sustainability/climate-energy/european-ev-battery-material-startups-make-recycling-breakthroughs-2025-02-13/.

Saxena, P., Agarwal, R., & Sharma, V. Barriers to electric vehicle adoption in India: A comparative review and future growth prospects. International Journal of Electric and Hybrid Vehicles, 16(1), 45–63, 2024. https://www.researchgate.net/publication/384537606.

Sharma, R., Patel, M., & Gupta, S. [Title pending]. [Journal or Publisher], 2023.

Shi, L., & Hu, B. Frontiers in Operations: Battery as a Service: Flexible electric vehicle battery leasing. Manufacturing and Service Operations Management, 26(4), 1269–1285, 2024. https://doi.org/10.1287/msom.2022.0587.

TopSpeed. How range anxiety affects the resale value of older EVs. 2025. https://www.topspeed.com/how-range-anxiety-affects-resale-value-of-older-evs/.

Varghese, A. M., & Pradhan, R. P. Roadmap for transitioning India's privately owned bus fleets to electric fleets. Transportation Research Part D: Transport and Environment, 140, 104623, 2025. https://doi.org/10.1016/j.trd.2025.104623.

Williams, B. Second life for plug-in vehicle batteries: Effect of grid energy storage value on battery lease payments. Journal of the Transportation Research Board, 2287, 64–71, 2012. https://doi.org/10.3141/2287-11.

Wu, Y., & Li, L. Operational strategies for EV battery leasing: Unit-based vs. fixed-rate models. Journal of Cleaner Production, 437, 140451, 2024. https://doi.org/10.1016/j.jclepro.2024.140451.

Yang, X., Shao, C., Zhuge, C., Sun, M., Wang, P., & Wang, S. Deploying battery swap stations for shared electric vehicles using trajectory data. Transportation Research Part D: Transport and Environment, 97, 102943, 2021. https://doi.org/10.1016/j.trd.2021.102943.

Yuan, K., Li, C., & Wu, G. Study on vehicle supply chain operation mode selection based on battery leasing and battery swapping services. Mathematics, 11(14), 3119, 2023. https://doi.org/10.3390/math11143119.

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. https://doi.org/10.1080/1540496X.2016.1152798.

Zhou, J., Pang, W., & Tang, C. Service-based battery leasing in developing countries: Economic and infrastructure challenges. Sustainable Transportation Review, in press, 2025.

Biographies

Rudra Prakash Pradhan is an Professor at the Vinod Gupta School of Management, Indian Institute of Technology Kharagpur. He holds a Ph.D. from 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. Notably, Prof. Pradhan is the Principal Investigator for the project titled *"Sustainable Development of Electric Vehicle Battery Infrastructure in*

India: Challenges, Circular Economy Integration, and Policy Measures", funded by the Indian Council of Social Science Research (ICSSR). His academic impact is further reflected in his inclusion in the top 2% of scientists worldwide, as per a study by Stanford University, highlighting his significant contributions to research and scholarship.

Ann Mary Varghese is a PhD candidate at the Vinod Gupta School of Management, Indian Institute of Technology Kharagpur. She holds a Bachelor's, Master's, and MPhil in Economics, and has approximately two years of professional experience with multinational consulting firms. Her research focuses on sustainable transportation, climate finance, and policy, with a particular interest in fostering academia–industry collaboration, especially within the context of low- and middle-income countries.

Avinash Chauhan is a Ph.D. candidate at the Vinod Gupta School of Management, Indian Institute of Technology Kharagpur. His research focuses on Operations Management, with a particular interest in the integration of emerging technologies such as the Internet of Things (IoT) and blockchain within supply chain systems. His academic endeavours aim to enhance efficiency, transparency, and sustainability in operations through digital transformation. Avinash has contributed to scholarly publications and actively participates in academic conferences, reflecting his commitment to advancing knowledge in his field.

Dr. Roopa Raju holds a Ph.D. and a Master of Arts in Sociology from Jawaharlal Nehru University (JNU), New Delhi. Her academic background reflects a strong foundation in social science research, with interests spanning development studies, policy analysis, and sustainability. She is currently serving as a project staff member for the ICSSR-funded project "Sustainable Development of Electric Vehicle Battery Infrastructure in India: Challenges, Circular Economy Integration, and Policy Measures."

Deep Choudhury is currently working as a Research Assistant at the Vinod Gupta School of Management, IIT Kharagpur, contributing to the ICSSR-funded project titled *"Sustainable Development of Electric Vehicle Battery Infrastructure in India."* He brings over six years of experience in academic and administrative roles, having previously worked at esteemed institutions such as IIM Nagpur, ISI Kolkata, and IIT (ISM) Dhanbad. His diverse background supports a multidisciplinary approach to research and project management.