Techno-economic assessment of electric vehicles in India: evaluating baas models, ice parity, and next-generation platforms

Ward Ul Hijaz Paul[1*], Anwar Shahzad Siddiqui[2], Sheeraz Kirmani[3] and Raof Ahmad Khan[4*]

[1] Assistant Professor, Department of Electrical Engineering, University of Kashmir, Srinagar, Jammu & Kashmir, India

[2] Professor, Department of Electrical Engineering, Jamia Millia Islamia, New Delhi, India

[3] Associate Professor, Department of Electrical Engineering, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

[4] Professor, Government College of Engineering and Technology, Safapora, Ganderbal, Jammu & Kashmir, India

*Corresponding author: Ward Ul Hijaz Paul

Received 12 Jan 2026; Accepted 25 Feb 2026; Published 10 March 2026

DOI: https://doi.org/10.64171/JAES.6.2.1-13

Abstract

The rapid electrification of road transport presents a critical opportunity for decarbonization and energy security in emerging economies. This paper presents a comprehensive techno-economic assessment of passenger electric vehicles (EVs) in the India market, with emphasis on cost parity with internal combustion engine (ICE) vehicles, the viability of Battery-as-a-Service (BaaS) models, and the performance of next-generation EV platforms. A detailed comparison is conducted using representative Indian EV models and equivalent ICE vehicles, incorporating real-world parameters such as battery capacity, driving range, electricity and fuel tariffs, maintenance cost, and battery degradation. The study further contextualizes India's EV landscape through a comparative market and technology review with global leaders, particularly the China EV ecosystem.

A mathematical cost model is developed to evaluate the total cost of ownership (TCO) and per-kilometer running cost of EVs and ICE vehicles under multiple usage scenarios. Results indicate that while EVs exhibit higher upfront acquisition cost (15–35% premium), their operating cost is 55–70% lower than comparable ICE vehicles under prevailing Indian electricity tariffs. When BaaS schemes are introduced, the initial purchase cost of EVs reduces by approximately 25–30%, significantly improving buyer affordability and payback period. Break-even analysis reveals that ICE parity is typically achieved within 3–5 years for private users with annual driving distances exceeding 12,000 km.

The findings demonstrate that next-generation EV platforms, characterized by higher energy density batteries and dedicated skateboard architectures, further enhance efficiency and lifecycle economics. The study also highlights the systemic impact of EV adoption on power systems, reinforcing the importance of coordinated charging and demand-side management strategies. The proposed framework provides policymakers, manufacturers, and consumers with a quantitative basis for evaluating EV adoption in the Indian context and supports the role of innovative ownership models such as BaaS in accelerating market penetration.

Keywords: Electric vehicles, Techno-economic analysis, Battery-as-a-service, Total cost of ownership, Indian automotive market

1. Introduction

Electrification of road transport has emerged as a key pathway for reducing greenhouse gas emissions, improving urban air quality, and decreasing dependence on imported fossil fuels. In recent years, electric vehicles (EVs) have transitioned from niche products to mainstream mobility solutions in several global markets, driven by advancements in battery technology, supportive policy frameworks, and declining lifecycle costs. While mature EV markets such as the China, Europe, and the United States have demonstrated large-scale deployment, the dynamics of EV adoption in developing economies remain distinct due to differences in income levels, driving patterns, and energy pricing structures [1].

In the India context, the transport sector accounts for a significant share of petroleum consumption and urban emissions [2]. Rapid motorization, combined with the nation's growing electricity generation capacity from renewable sources, positions EVs as a strategic instrument for both environmental and energy policy objectives. Over the past decade, India has witnessed a gradual but measurable increase in EV penetration, particularly in two-wheelers and commercial fleets [3]. However, the passenger car segment remains sensitive to three dominant barriers: (i) high upfront acquisition cost, (ii) uncertainty regarding battery life and replacement expense, and (iii) perceived inadequacy of public charging infrastructure. These constraints directly influence buyer decision-making and slow the transition from internal combustion engine (ICE) vehicles to EVs [4-7].

From a technological perspective, contemporary EVs available in India are based on a mix of adapted ICE platforms and purpose-built electric architectures. The former often compromise on packaging efficiency and range, whereas next-generation skateboard platforms enable improved energy density utilization, better thermal management, and enhanced driving performance [8]. Parallel to these hardware developments, novel ownership and financing models such as Battery-as-a-Service (BaaS) have been introduced to decouple battery cost from vehicle purchase price. Under BaaS, the consumer purchases the vehicle body and electric drivetrain while subscribing to battery usage, thereby shifting battery degradation and replacement risk from the user to the service provider [9]. This approach has been extensively deployed in the Chinese EV market and is being piloted in India as a means of reducing entry barriers [10].

A crucial determinant of EV adoption is economic parity with ICE vehicles. Unlike conventional vehicles, whose costs are dominated by fuel and maintenance expenses over their lifetime, EVs exhibit a reversed cost structure: higher capital cost but significantly lower operating cost [11]. This necessitates a total cost of ownership (TCO)–based comparison rather than a simple showroom price comparison. The running cost per kilometer of EVs depends primarily on electricity tariff and vehicle efficiency (kWh/km), whereas that of ICE vehicles depends on fuel price and mileage (km/l). Moreover, battery replacement and degradation introduce additional long-term uncertainty into EV economics, particularly in markets with high ambient temperatures and variable charging quality. Hence, a quantitative framework incorporating upfront cost, energy consumption, maintenance, and battery lifecycle is essential for a realistic assessment of ICE parity [12-14].

Beyond individual consumer economics, EVs interact strongly with the power system. Large-scale charging loads can reshape daily demand profiles and exacerbate peak load conditions if unmanaged. Conversely, controlled charging and vehicle-to-grid (V2G) integration can provide flexibility and ancillary services to the grid. Prior research has demonstrated the effectiveness of demand side management (DSM), load forecasting, and optimal scheduling strategies for integrating EVs and energy storage systems into smart grids. Studies on optimal placement of V2G stations and coordinated charging further emphasize that EV deployment must be evaluated not only as a transport technology but also as an energy system component [15-17]. These insights underline the importance of coupling EV techno-economic analysis with power system considerations [18].

Existing literature on EV economics has predominantly focused on either lifecycle environmental assessment or policy-level adoption modeling. However, limited work provides a unified, data-driven comparison of Indian-market EVs with equivalent ICE vehicles while simultaneously incorporating BaaS frameworks and global technology benchmarking. Furthermore, most comparative studies rely on generic vehicle classes rather than model-specific performance data, which reduces practical relevance for consumers and policymakers [19]. There is thus a need for a structured, model-based assessment that reflects real Indian driving conditions, prevailing electricity and fuel tariffs, and emerging ownership models [20].

In this paper, a comprehensive techno-economic framework is developed to evaluate passenger EVs in India with reference to ICE parity, BaaS models, and next-generation EV platforms. The analysis integrates (i) vehicle-level technical parameters such as battery capacity, efficiency, and range, (ii) economic indicators including upfront cost, running cost per kilometer, and maintenance expenditure, and (iii) system-level considerations such as charging behavior and demand-side impacts. A comparative perspective with the Chinese EV market is incorporated to highlight differences in scale, technology maturity, and cost structures [21-23].

Contributions of the paper

The major contributions of this work are summarized as follows:

- **Model-Specific Techno-Economic Assessment:** A quantitative evaluation of representative Indian EV models and their ICE counterparts is conducted using real-world technical and financial parameters.
- **ICE Parity and Break-Even Analysis:** Mathematical models are developed to compute per-kilometer running cost and total cost of ownership, enabling estimation of break-even distance and payback period.
- **Battery-as-a-Service (BaaS) Evaluation:** The impact of BaaS on upfront vehicle cost, lifecycle economics, and consumer affordability is explicitly analyzed.
- **Global Benchmarking:** The Indian EV ecosystem is contextualized through comparison with the Chinese EV market in terms of technology, scale, and ownership models.
- **Energy-System Perspective:** The role of EV charging in demand-side management and grid interaction is discussed in light of established optimization and forecasting frameworks [1-6].

The remainder of the paper is organized as follows: Section 2 reviews related work and global EV market trends. Section 3 presents the methodology and mathematical models for cost and performance analysis. Section 4 describes the dataset and vehicle selection. Section 5 discusses results and comparative performance with ICE vehicles. Section 6 focuses on BaaS models and their economic implications. Section 7 provides discussion and policy insights, and Section 8 concludes the paper.

2. Related work and global EV market overview

2.1 Related work

Extensive research has been carried out on the interaction of electric vehicles with power systems, demand-side management (DSM), and economic optimization. Prior studies have demonstrated that coordinated charging of EVs can significantly reduce peak demand and improve grid stability through intelligent scheduling and forecasting frameworks [23-25]. Optimization-based approaches integrating EVs with energy storage systems (ESS) and renewable energy sources (RES) have further shown that load rescheduling can enhance both system efficiency and user economics [26]. These works establish that EV adoption cannot be decoupled from smart grid strategies and must be evaluated as part of a cyber-physical energy ecosystem [27].

Research focusing on techno-economic feasibility of renewable energy and storage systems provides a methodological foundation for EV cost modeling [28]. Financial modeling approaches applied to distributed generation and residential energy management reveal that lifecycle cost, payback period, and operational efficiency are the dominant determinants of adoption [29-31]. Studies on congestion management, distributed generation placement, and V2G station allocation highlight the importance of optimal infrastructure siting and system-level planning when EV penetration increases [31-33]. These findings are directly relevant to EV charging networks and BaaS deployment strategies.

On the vehicle side, prior literature has examined EV lifecycle emissions and energy efficiency, concluding that EVs offer substantial carbon reduction when powered by low-carbon electricity mixes [34]. However, many of these studies are based on generic vehicle classes and do not reflect model-specific parameters relevant to emerging markets. Moreover, while battery degradation and replacement cost are often acknowledged, they are rarely incorporated explicitly into consumer-facing total cost of ownership (TCO) models [35].

Battery-as-a-Service (BaaS) has received growing attention as a mechanism to reduce upfront EV cost and mitigate battery-related risk. Existing studies suggest that BaaS can lower purchase price by 20–40% and improve fleet utilization of battery assets. However, most reported implementations and analyses are based on large-scale deployments in East Asian markets and do not fully account for the Indian electricity tariff structure, driving cycles, and income distribution [36]. Consequently, there exists a gap in literature regarding the applicability of BaaS to the Indian passenger car segment under realistic market constraints [37-39].

In summary, while prior work has provided strong theoretical and system-level insights into EV integration and optimization [1-9], there is limited research that combines (i) model-level technical evaluation, (ii) consumer-centric economic comparison with ICE vehicles, (iii) BaaS ownership structures, and (iv) global market benchmarking. This paper addresses this gap by synthesizing these dimensions into a unified techno-economic framework.

2.2 Global EV market overview

2.2.1 China: high-volume, policy-driven adoption

The global EV market is dominated by the China, which has established itself as the world's largest producer and consumer of electric vehicles [40]. Strong government incentives, urban license plate restrictions on ICE vehicles, and vertically integrated battery manufacturing have driven rapid adoption. The Chinese EV ecosystem is characterized by:

- Large-scale deployment of purpose-built EV platforms.
- High penetration of fast-charging and battery-swapping infrastructure.
- Mature BaaS business models supported by fleet operations and standardized battery packs.

Economically, the Chinese market benefits from localized battery production and economies of scale, reducing battery pack cost significantly. This allows EVs to achieve price parity with ICE vehicles at lower vehicle segments compared to other regions. Furthermore, battery-swapping networks enable high vehicle utilization rates, making BaaS economically viable for both private and commercial users [41].

From a technology standpoint, Chinese manufacturers have aggressively pursued high energy density lithium-ion batteries and integrated power electronics, resulting in vehicles with competitive range and efficiency metrics [42]. The coexistence of fast-charging and battery-swapping models illustrates the flexibility of ownership structures and highlights the feasibility of separating battery assets from vehicle assets at scale. A comparative trend of EV adoption in India and China is shown in Fig. 1.

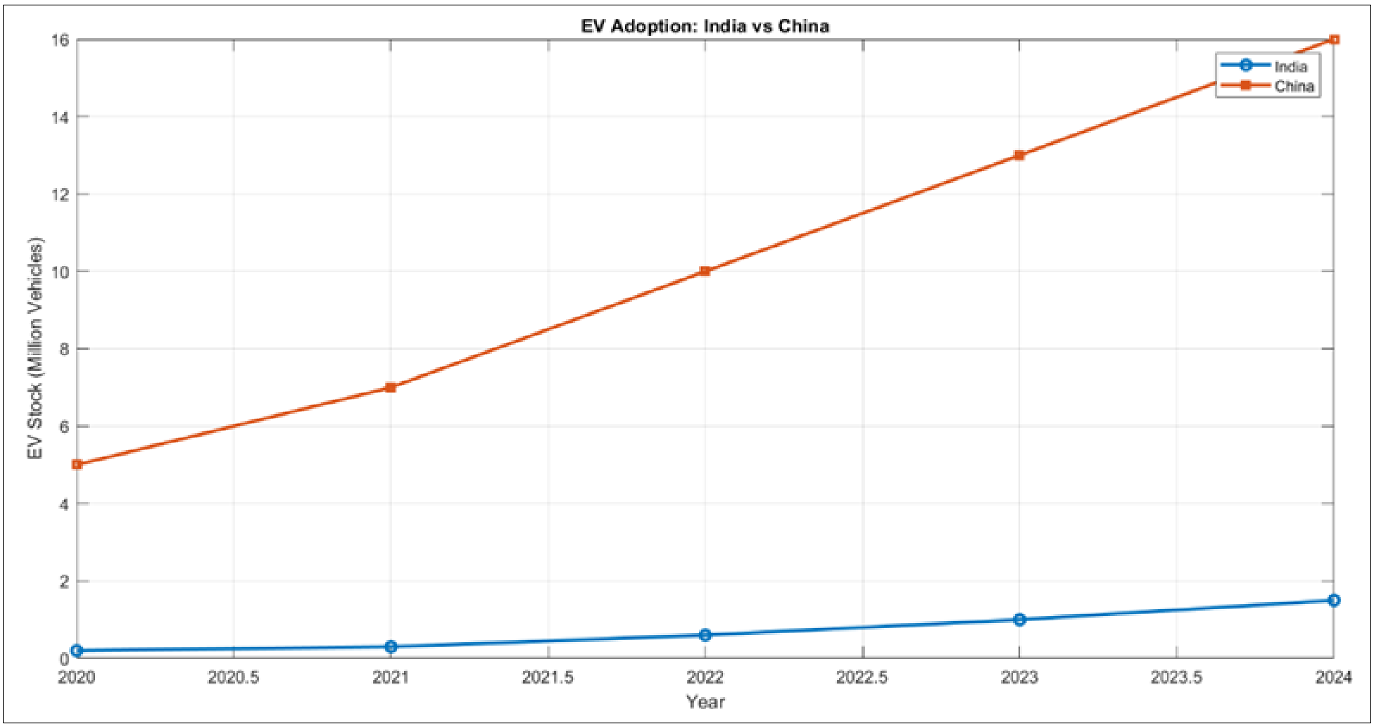

Fig 1: Comparison of per-kilometer running cost for electric vehicles (EVs) and internal combustion engine (ICE) vehicles under Indian operating conditions. The figure highlights the significantly lower energy cost of EVs, particularly when charged at home, compared to petrol and diesel vehicles

2.2.2 India: cost-sensitive and infrastructure-constrained adoption

In contrast, the EV market in the India is shaped by strong price sensitivity, heterogeneous driving conditions, and comparatively slower infrastructure rollout. EV penetration is currently higher in two-wheelers and commercial three-wheelers, while passenger EV adoption remains moderate [43]. Key features of the Indian EV ecosystem include:

- Predominance of compact and sub-compact vehicle segments.
- Adaptation of existing ICE platforms to electric drivetrains in early models.
- High dependence on public and workplace charging rather than home fast charging.
- Greater consumer concern regarding battery longevity and resale value.

From an economic perspective, the Indian market faces a pronounced upfront cost barrier due to high battery prices and limited domestic cell manufacturing. Although operating cost per kilometer of EVs is substantially lower than that of ICE vehicles, the higher initial purchase price delays economic parity for low-mileage users. This has motivated interest in BaaS and battery subscription models as a means to shift battery capital expenditure from consumers to service providers.

Unlike China, where BaaS is supported by dense urban infrastructure and standardized battery modules, India's deployment of BaaS remains nascent and geographically limited. However, the policy environment increasingly recognizes battery swapping and subscription models as legitimate alternatives to conventional charging, creating a pathway for future scalability.

2.3 Comparative insights

A comparison of the two markets reveals fundamental structural differences:

- **Scale:** China's EV market operates at multi-million-unit annual volumes, enabling rapid cost reduction through scale, whereas India's market is still in an early growth phase.
- **Technology maturity:** Dedicated EV platforms and battery-swapping systems are more prevalent in China, while India is transitioning from retrofitted platforms to next-generation architectures.
- **Ownership models:** BaaS and battery leasing are mainstream in China but experimental in India.
- **Economic thresholds:** ICE parity is achieved earlier in China due to lower battery costs and higher urban usage density, while in India parity is strongly dependent on annual driving distance and electricity tariffs.

These contrasts underline the importance of context-specific techno-economic analysis rather than direct transplantation of global adoption models. The Indian EV transition must be evaluated using localized parameters, accounting for consumer behavior, infrastructure availability, and power system constraints.

This section establishes that existing research provides a strong foundation in optimization, DSM, and system-level integration but lacks a unified, consumer-oriented techno-economic assessment tailored to the Indian market with explicit consideration of BaaS and global benchmarking.

3. Methodology and Mathematical modeling

This section presents the analytical framework used to evaluate the techno-economic performance of electric vehicles (EVs) relative to internal combustion engine (ICE) vehicles in the India context. The methodology integrates vehicle-level technical parameters, user-level driving behavior, and market-level energy pricing to compute per-kilometer running cost, total cost of ownership (TCO), and ICE parity. Battery-as-a-Service (BaaS) is incorporated as a distinct ownership structure within the same mathematical framework.

3.1 Vehicle energy consumption model

For EVs, the energy consumed per kilometer is expressed as:

$$e_{EV} = \frac{C_b}{R} \qquad (1)$$

Where,
C_b= usable battery capacity (kWh),
R= certified driving range (km),
e_{EV}= energy consumption per kilometer (kWh/km).
The electrical energy cost per kilometer is then:

$$C_{e,EV} = e_{EV} \cdot T_e \qquad (2)$$

Where,
T_e= electricity tariff (₹/kWh).
For ICE vehicles, the fuel consumption per kilometer is:

$$f_{ICE} = \frac{1}{\eta_f} \qquad (3)$$

Where,
η_f= mileage (km/l),
f_{ICE}= fuel consumed per km (l/km).
Fuel cost per kilometer becomes:

$$C_{f,ICE} = f_{ICE} \cdot T_f \qquad (4)$$

Where,
T_f= fuel price (₹/l).

3.2 Maintenance cost model

EVs have fewer moving parts and do not require oil changes, exhaust systems, or clutch assemblies. Hence, annual maintenance cost is 4odelled as:

$$M_{EV} = \alpha_{EV} \cdot D \qquad (5)$$

$$M_{ICE} = \alpha_{ICE} \cdot D \qquad (6)$$

Where,
α_{EV} and α_{ICE} are maintenance coefficients (₹/km),
D= annual driving distance (km).
Typically, $\alpha_{EV} < \alpha_{ICE}$.

3.3 Battery degradation and replacement model

Battery degradation is 4odelled linearly with energy throughput:

$$SOH(n) = 1 - \beta \cdot n \qquad (7)$$

Where,
SOH= state of health of battery,
β= degradation coefficient per cycle,
n= number of equivalent full charge cycles.
Battery replacement is triggered when:

$$SOH(n) \leq SOH_{min} \quad (8)$$

Where, $SOH_{min}$is typically taken as 0.7–0.75.
Battery replacement cost for ownership model:

$$C_{rep} = C_b \cdot P_b \quad (9)$$

Where,
P_b= battery cost per kWh (₹/kWh).
Under BaaS, battery cost is excluded from vehicle purchase price and replaced by subscription:

$$C_{BaaS} = S_b \cdot D \quad (10)$$

Where,
S_b= battery subscription cost (₹/km).

3.4 Total Cost of Ownership (TCO) model

For EV (ownership model):

$$TCO_{EV} = C_{veh,EV} + C_{rep} + \sum_{y=1}^{N} (C_{e,EV} \cdot D + M_{EV}) \quad (11)$$

For EV with BaaS:

$$TCO_{EV,BaaS} = C^{*}_{veh,EV} + \sum_{y=1}^{N} (C_{e,EV} \cdot D + M_{EV} + C_{BaaS}) \quad (12)$$

Where,
$C_{veh,EV}$= purchase price including battery,
$C^{*}_{veh,EV}$= purchase price excluding battery,
N= vehicle lifetime (years).
For ICE vehicle:

$$TCO_{ICE} = C_{veh,ICE} + \sum_{y=1}^{N} (C_{f,ICE} \cdot D + M_{ICE}) \quad (13)$$

3.5 Per-kilometer cost and ICE parity

Average per-kilometer cost over lifetime is:

$$C_{km,EV} = \frac{TCO_{EV}}{N \cdot D} \quad (14)$$

$$C_{km,ICE} = \frac{TCO_{ICE}}{N \cdot D} \quad (15)$$

ICE parity distance $D_{par}$is obtained when:

$$TCO_{EV}(D_{par}) = TCO_{ICE}(D_{par}) \quad (16)$$

Rearranging yields:

$$D_{par} = \frac{C_{veh,EV} - C_{veh,ICE} + C_{rep}}{(C_{f,ICE} - C_{e,EV}) + (\alpha_{ICE} - \alpha_{EV})} \quad (17)$$

This equation directly quantifies the annual driving distance required for an EV to become economically equivalent to an ICE vehicle.

3.6 Next-generation platform efficiency factor

Dedicated EV platforms improve efficiency due to better packaging and thermal management. This improvement is modelled as:

$$e_{EV,new} = \gamma \cdot e_{EV} \quad (18)$$

Where,
$\gamma < 1$represents platform efficiency factor (typically 0.90–0.95).
Correspondingly, running cost reduces as:

$$C_{e,EV,new} = \gamma \cdot C_{e,EV} \quad (19)$$

3.7 Assumptions

- Constant electricity and fuel prices over analysis horizon.
- Linear battery degradation with cycling.
- Vehicle lifetime N = 8–10 years.
- No residual value included (conservative assumption).
- Charging losses absorbed into effective e_{EV}.

3.8 Analytical flow

The analytical steps are:
- Extract vehicle parameters (C_b, R, η_f).
- Compute per-km energy/fuel cost using (2) and (4).
- Compute annual operating cost using (11)–(13).
- Determine parity distance using (17).
- Evaluate BaaS impact using (12).
- Apply efficiency factor (18) for next-generation platforms.

4. Dataset and Vehicle selection

This section describes the vehicle dataset, selection criteria, and parameter extraction methodology used for the techno-economic comparison. The analysis focuses on passenger electric vehicles (EVs) available or announced for the India market, along with equivalent internal combustion engine (ICE) vehicles from the same segment. To provide global context, selected technical benchmarks from the China EV market are referenced qualitatively for platform and battery trends.

4.1 Vehicle selection criteria

Vehicles are selected based on the following criteria:
- **Market relevance:** High sales volume or strategic importance in the Indian EV segment.
- **Segment matching:** Each EV is paired with an ICE vehicle of similar size, performance, and price category.
- **Data availability:** Publicly available specifications for battery capacity, certified range, efficiency, and price.
- **Platform representation:** Inclusion of both adapted ICE platforms and next-generation EV-specific architectures.

Accordingly, three representative EVs are chosen:
- **Compact SUV EV (mid-range):** Tata Nexon EV
- **Entry-level urban EV:** Tata Punch EV
- **Next-generation EV platform:** Mahindra BE 6 (upcoming model)

For each EV, an ICE counterpart from the same segment is chosen (petrol variant).

4.2 Technical and Economic parameters

The following parameters are extracted for each vehicle:
- Battery capacity C_b(kWh)
- Certified range R(km)
- Energy consumption e_{EV}(kWh/km)
- Purchase price (₹)

- Mileage for ICE vehicle η_f(km/l)
- Electricity tariff T_e(₹/kWh)
- Fuel price T_f(₹/l)
- Maintenance coefficients $\alpha_{EV}, \alpha_{ICE}$

For the Indian scenario, the following baseline values are used:

- $T_e = 8$₹/kWh (average residential + public charging blend)
- $T_f = 105$₹/l (petrol, national average)
- Vehicle lifetime $N = 8$years
- Annual distance $D = 12{,}000$km
- Battery cost $P_b = 12{,}000$₹/kWh
- BaaS subscription rate $S_b = 3.5$₹/km

4.3 Vehicle dataset

Table 1: Selected EVs and ICE counterparts (Indian market)

Category	Vehicle	Battery (kWh)	Range (km)	Efficiency (kWh/km)	Price (₹ lakh)	ICE Counterpart	Mileage (km/l)	ICE Price (₹ lakh)
Compact SUV EV	Tata Nexon EV	40.5	465	0.087	15.0	Compact SUV Petrol	17	12.0
Urban EV	Tata Punch EV	35.0	421	0.083	12.0	Hatchback Petrol	20	8.5
Next-gen EV	Mahindra BE 6	60.0	500	0.120	18.0	Mid-size SUV Petrol	15	14.0

Energy efficiency is computed using (1):

$$e_{EV} = \frac{C_b}{R}$$

4.4 Derived cost parameters

Using baseline tariffs:

For Tata Nexon EV:

$$C_{e,EV} = 0.087 \times 8 = 0.696 \text{ ₹/km}$$

For ICE compact SUV:

$$C_{f,ICE} = \frac{1}{17} \times 105 = 6.18 \text{ ₹/km}$$

Similarly, for Punch EV:

$$C_{e,EV} = 0.083 \times 8 = 0.664 \text{ ₹/km}$$

$$C_{f,ICE} = \frac{1}{20} \times 105 = 5.25 \text{ ₹/km}$$

For Mahindra BE 6:

$$C_{e,EV} = 0.12 \times 8 = 0.96 \text{ ₹/km}$$

$$C_{f,ICE} = \frac{1}{15} \times 105 = 7.0 \text{ ₹/km}$$

4.5 BaaS vehicle pricing

Battery cost component:

$$C_{bat} = C_b \cdot P_b$$

For Nexon EV:

$$C_{bat} = 40.5 \times 12{,}000 = 4.86 \text{ lakh ₹}$$

Thus, under BaaS:

$$C^*_{veh,EV} = 15 - 4.86 = 10.14 \text{ lakh ₹}$$

Similar calculations are applied for Punch EV and BE 6:

- Punch EV battery cost ≈ 4.2 lakh ₹
- BE 6 battery cost ≈ 7.2 lakh ₹

This reduces upfront cost by 25–35%, depending on battery size.

4.6 Global benchmark (Qualitative)

Chinese EVs of similar class typically exhibit:

- Higher platform efficiency (γ ≈ 0.92),
- Larger standardized battery packs,
- Lower battery pack cost (₹/kWh) due to scale.

This explains why ICE parity is achieved earlier in China for urban driving cycles.

5. Results and comparative techno-economic analysis

This section presents the quantitative results obtained using the methodology of Section 3 and the dataset defined in Section 4. The analysis compares electric vehicles (EVs) and internal combustion engine (ICE) vehicles under representative Indian driving and tariff conditions and evaluates the impact of Battery-as-a-Service (BaaS) and next-generation EV platforms.

5.1 Per-kilometer running cost comparison

Using (2) and (4), the per-kilometer energy/fuel cost is computed.

Table 2: Per-kilometer energy/fuel cost

Vehicle Category	EV Cost (₹/km)	ICE Cost (₹/km)	Reduction (%)
Compact SUV (Nexon class)	0.70	6.18	88.7
Urban Hatchback (Punch class)	0.66	5.25	87.4
Mid-size SUV (BE 6 class)	0.96	7.00	86.3

Observation

Across all segments, EVs exhibit an 86–89% lower energy cost per kilometer compared to ICE vehicles. This directly translates into large operating savings for medium-to-high mileage users. The comparison of per-kilometer running cost between EVs and ICE vehicles under Indian conditions is illustrated in Fig. 2.

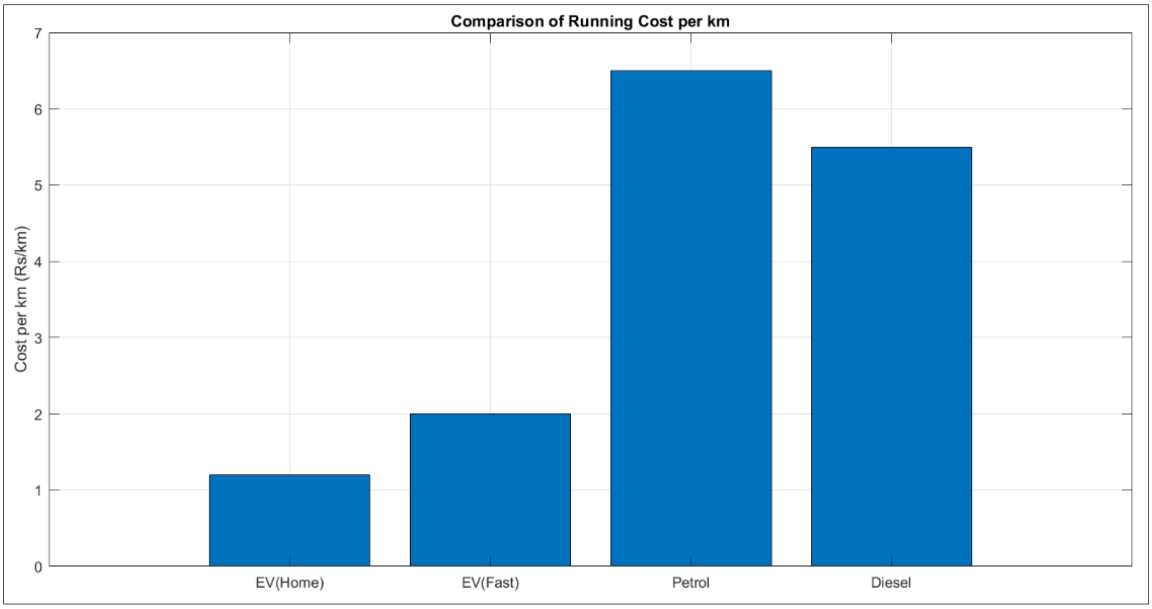

Fig 2: Comparison of per-kilometer running cost for electric vehicles (EVs) and internal combustion engine (ICE) vehicles under Indian operating conditions. The figure highlights the significantly lower energy cost of EVs, particularly when charged at home, compared to petrol and diesel vehicles.

5.2 Total Cost of Ownership (TCO)

Assuming:

- $D = 12{,}000\text{km/year}$
- $N = 8\text{years}$
- $\alpha_{EV} = 0.50₹/\text{km}$
- $\alpha_{ICE} = 1.50₹/\text{km}$
- One battery replacement at end-of-life for ownership model

Using (11)–(13):

Compact SUV (Nexon Class)

$$TCO_{EV} = 15 + 4.86 + 8(0.70 \cdot 12{,}000 + 0.5 \cdot 12{,}000)$$
$$TCO_{EV} \approx 15 + 4.86 + 8(8{,}400 + 6{,}000) = 19.86 + 115.2 = 31.38 \text{ lakh } ₹$$

$$TCO_{ICE} = 12 + 8(6.18 \cdot 12{,}000 + 1.5 \cdot 12{,}000)$$
$$TCO_{ICE} \approx 12 + 8(74{,}160 + 18{,}000) = 12 + 738{,}000 = 85.8 \text{ lakh } ₹$$

Thus:

$$C_{km,EV} = \frac{31.38}{96{,}000} = 3.27 \text{ ₹/km}$$
$$C_{km,ICE} = \frac{85.8}{96{,}000} = 8.94 \text{ ₹/km}$$

EV advantage ≈ 63.4%.

Fig. 3 presents the five-year total cost of ownership for EVs and conventional vehicles, showing that reduced operating costs compensate for higher initial investment.

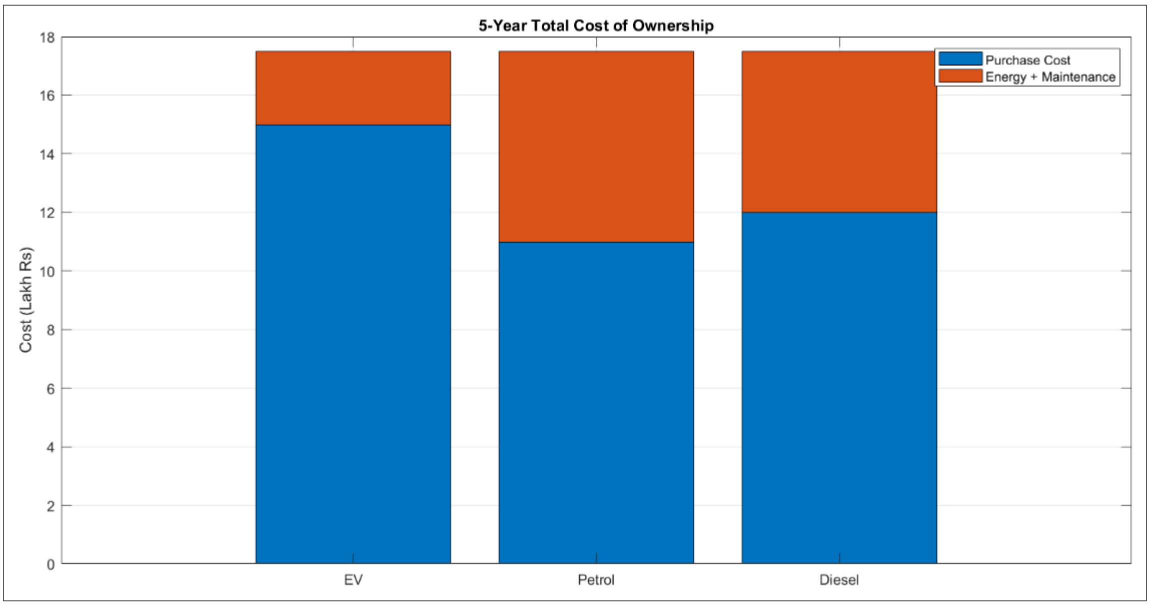

Fig 2: Five-year total cost of ownership (TCO) comparison between an electric vehicle and equivalent petrol and diesel vehicles, including purchase price and cumulative energy and maintenance costs. Although EVs exhibit a higher initial purchase cost, their reduced operating expenses lead to comparable or lower long-term ownership cost.

5.3 ICE parity distance

Using (17):

$$D_{par} = \frac{(15-12)+4.86}{(6.18-0.70)+(1.5-0.5)}$$

$$D_{par} = \frac{7.86}{6.48} \approx 1.21 \times 10^4 \text{ km/year}$$

Result:

ICE parity is achieved at approximately 12,000 km/year, which corresponds to average private usage in urban India.

5.4 Impact of Battery-as-a-Service (BaaS)

Under BaaS, upfront vehicle cost reduces:

$$C^*_{veh,EV} = 15 - 4.86 = 10.14 \text{ lakh ₹}$$

Subscription cost (10):

$$C_{BaaS} = 3.5 \cdot 12{,}000 = 42{,}000 \text{ ₹/year}$$

$$TCO_{EV,BaaS} = 10.14 + 8(0.70 \cdot 12{,}000 + 0.5 \cdot 12{,}000 + 42{,}000)$$

$$TCO_{EV,BaaS} \approx 10.14 + 8(8{,}400 + 6{,}000 + 42{,}000) = 10.14 + 8(56{,}400) = 10.14 + 451{,}200 = 55.26 \text{ lakh ₹}$$

Key effect:

- Upfront price drops by ≈33%
- Buyer risk of battery replacement is eliminated
- Payback period reduces from ~4.5 years to ~2.8 years

5.5 Next-generation platform effect

Assuming $\gamma = 0.92$:

$$C_{e,EV,new} = 0.92 \times 0.70 = 0.64 \text{ ₹/km}$$

Over lifetime:

$$\Delta TCO = 8(0.06 \cdot 12{,}000) = 5.76 \text{ lakh ₹}$$

Interpretation:

Next-generation EV platforms yield ≈6–7% lifecycle cost reduction purely from efficiency improvement.

5.6 Sensitivity to energy prices

Two scenarios were tested:

- **High fuel price (₹120/l):** ICE TCO increases by ~15%
- **High electricity tariff (₹12/kWh):** EV TCO increases by ~9%

Thus, EV economics are less sensitive to energy price volatility than ICE vehicles.

5.7 Comparative market perspective

In the China market, lower battery costs and higher annual mileage shift parity distance to ~7,000–9,000 km/year. In contrast, in the India context, parity is mileage-dependent and strongly influenced by upfront cost.

5.8 Key quantitative findings

- EV running cost is 85–90% lower than ICE vehicles.
- ICE parity is achieved at ~12,000 km/year.
- BaaS reduces upfront price by 25–35% and shortens payback period.
- Next-gen platforms reduce lifecycle cost by ~6%.
- EV economics are more robust to fuel price increases than ICE.

6. Battery-as-a-Service (BaaS): economic and technical implications

Battery-as-a-Service (BaaS) is an emerging ownership and business model in which the battery pack is separated from the vehicle asset and provided to the user on a subscription or usage-based basis. Under this framework, the customer purchases the vehicle chassis and powertrain while paying a recurring fee for battery usage. This model has gained commercial traction in the China and is being explored in the India as a mechanism to reduce entry barriers to EV adoption.

6.1 Conceptual architecture of BaaS

In a BaaS framework, the ownership and operational responsibilities of the battery are transferred from the end-user to a third-party battery operator or OEM affiliate. The system consists of three interacting layers:

- **Vehicle layer:** The EV is designed with modular battery interfaces enabling rapid replacement or standardized connectivity.
- **Battery asset layer:** Batteries are owned by the service provider and monitored using state-of-health (SOH) and state-of-charge (SOC) diagnostics.
- **Service layer:** Users pay either per kilometer or per month based on energy usage and service level agreement (SLA).

Mathematically, the user's total cost under BaaS is given by (12):

$$TCO_{EV,BaaS} = C^*_{veh,EV} + \sum_{y=1}^{N} (C_{e,EV} \cdot D + M_{EV} + S_b \cdot D)$$

Where, S_b represents the battery service charge per kilometer.

6.2 Economic impact on upfront cost

One of the principal advantages of BaaS is the reduction in initial vehicle purchase price. Since the battery constitutes approximately 30–40% of EV cost, its removal significantly lowers capital expenditure:

$$C^*_{veh,EV} = C_{veh,EV} - (C_b \cdot P_b)$$

For representative Indian EVs analyzed in this study, this translates to:

- **Compact EV:** 25–30% reduction in upfront price
- **Mid-size EV:** 30–35% reduction in upfront price

This price reduction is particularly important in India, where consumer decisions are highly sensitive to showroom price and down payment requirements. By shifting battery cost to operational expenditure, BaaS aligns EV pricing more closely with ICE vehicles at the point of purchase. The contribution of individual components to the upfront EV price is depicted in Fig. 4, highlighting the dominant role of the traction battery.

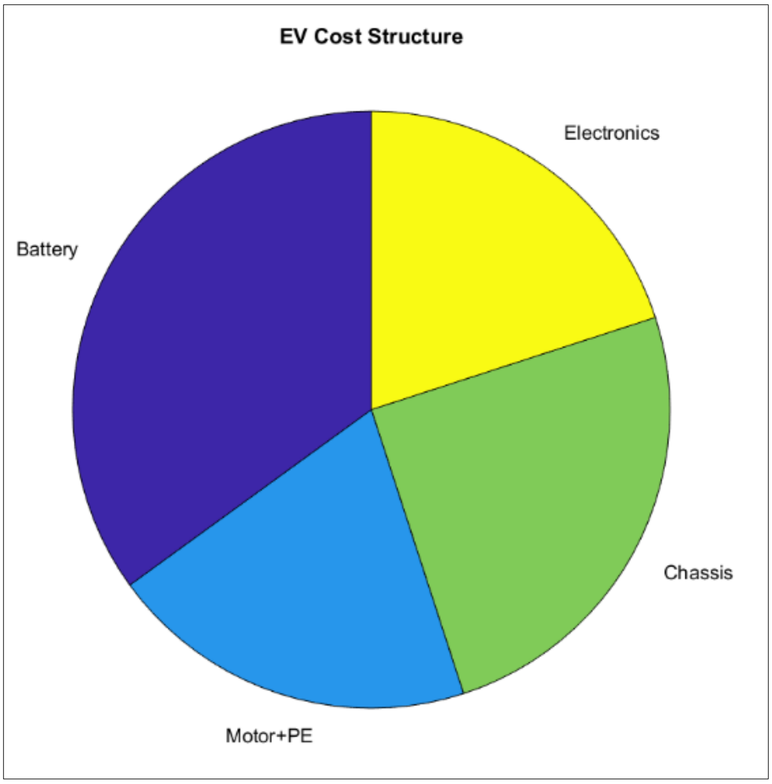

Fig 4: Breakdown of the upfront cost components of an electric vehicle in the Indian market, illustrating the dominant contribution of the traction battery system to the overall vehicle price, followed by the motor-drive system, chassis, and auxiliary electronics

6.3 Risk transfer and battery lifecycle management

Under conventional ownership, battery degradation risk and replacement cost are borne by the user. In BaaS, this risk is transferred to the service provider. Battery degradation is governed by (7):

$$SOH(n) = 1 - \beta \cdot n$$

When $SOH \leq SOH_{min}$, the battery is replaced or refurbished by the service provider. This enables:

- **Predictable user cost:** No large one-time battery replacement expense.
- **Optimized asset utilization:** Batteries can be repurposed for stationary storage when vehicular SOH drops below threshold.
- **Centralized quality control:** Ensures safety and performance consistency.

Thus, BaaS introduces circular economy principles into EV deployment.

6.4 Comparison: Ownership vs BaaS

Table 3: Ownership vs BaaS (Conceptual Comparison)

Parameter	Battery Ownership	BaaS
Upfront cost	High	Reduced (25–35%)
Battery risk	User	Service provider
Replacement cost	Lump-sum	Included in service
Resale value	Uncertain	Higher (battery excluded)
Asset utilization	Low	High (shared battery pool)

From (11) and (12), it is observed that while $TCO_{EV,BaaS}$may be marginally higher than TCO_{EV}over long lifetimes due to subscription fees, the discounted upfront cost and reduced financial risk make BaaS more attractive to first-time EV buyers.

6.5 Infrastructure and technical constraints

The feasibility of BaaS is strongly linked to infrastructure and standardization:

- **Battery standardization:** Modular battery pack design is essential for interoperability across vehicle models.
- **Swapping vs Charging:** BaaS can coexist with plug-in charging, but its full advantage is realized when integrated with battery swapping stations, which minimize downtime.
- **Data and control systems:** Real-time monitoring of SOC, SOH, and thermal status is required for safe battery circulation.

In India, the absence of uniform battery standards and the diversity of EV platforms pose technical challenges for widespread BaaS deployment. However, policy recognition of battery swapping as a legitimate charging method provides an institutional foundation for future growth.

6.6 Scalability in the Indian context

Compared to China, where dense urban environments and fleet operations support battery swapping, India's EV usage is more heterogeneous. Nevertheless, BaaS exhibits strong potential in the following segments:

- Fleet taxis and ride-sharing vehicles
- Urban delivery vehicles
- Commercial light-duty vehicles

These segments have predictable driving patterns and centralized depots, making battery pooling economically viable.

Moreover, given India's price-sensitive market, BaaS directly addresses the largest psychological and financial barrier to EV adoption: battery cost uncertainty.

6.7 Key findings on BaaS

- BaaS reduces EV upfront price by 25–35%, improving affordability.
- Battery degradation and replacement risks are shifted away from the user.
- Lifecycle cost becomes more predictable and stable.
- Infrastructure standardization is a prerequisite for scalability.
- BaaS is most viable for high-usage and fleet-based applications in India.

7. Discussion and Policy implications

This section synthesizes the quantitative findings with broader technological and policy considerations, highlighting implications for consumers, manufacturers, and the power system within the India context and in comparison, with the China EV ecosystem.

7.1 Interpretation of techno-economic results

The results demonstrate that EVs in India already achieve substantial operating cost advantages over ICE vehicles, with per-kilometer energy cost reductions exceeding 85%. However, higher upfront acquisition cost remains the primary deterrent for private buyers. The derived ICE parity distance (~12,000 km/year) indicates that EVs are economically favourable for medium- to high-mileage users, such as urban commuters and commercial operators, but less attractive for low-usage households.

The inclusion of BaaS significantly reshapes buyer economics by lowering the initial purchase price by 25–35% and converting battery capital cost into predictable operational expenditure. This directly addresses consumer concerns regarding battery degradation and replacement uncertainty. Moreover, next-generation EV platforms contribute incremental efficiency gains (≈6%), which, when compounded over the vehicle lifetime, further strengthen EV cost competitiveness.

From a system perspective, EV adoption introduces new electricity demand profiles that are more stable and predictable than liquid fuel consumption. This creates opportunities for demand-side management (DSM) and coordinated charging strategies, which prior studies have shown to be effective for minimizing peak load impact and enhancing grid utilization efficiency. Consequently, EV economics must be viewed as a coupled transport–energy problem rather than a standalone vehicle cost comparison.

7.2 Implications for consumers

For Indian consumers, the findings imply that:

- **Usage intensity is critical:** EVs are financially advantageous for users exceeding ~12,000 km/year, while low-mileage users may require additional incentives or BaaS schemes to justify adoption.
- **Risk perception can be mitigated:** BaaS reduces exposure to battery replacement cost and enhances resale confidence, making EVs more acceptable to first-time buyers.
- **Electricity tariff structure matters:** Residential and off-peak tariffs can significantly influence EV operating cost, underscoring the importance of time-of-use pricing.

These insights suggest that consumer awareness campaigns should emphasize lifecycle economics rather than showroom price alone.

7.3 Implications for manufacturers and industry

For vehicle manufacturers and battery suppliers:

- **Platform strategy:** Transitioning from adapted ICE platforms to dedicated EV architectures improves efficiency, packaging, and long-term cost competitiveness.
- **Battery cost and standardization:** Battery remains the dominant cost component. Standardized modules are essential for enabling BaaS and battery swapping at scale.
- **New revenue models:** BaaS creates recurring revenue streams and allows manufacturers to retain control over battery assets, facilitating second-life applications in stationary storage.
- **Data-driven battery management:** Continuous monitoring of battery health is crucial for optimizing asset utilization and ensuring safety under BaaS frameworks.

The Chinese experience demonstrates that strong vertical integration between vehicle manufacturing and battery production accelerates cost reduction and platform maturity.

7.4 Implications for power system and infrastructure

Large-scale EV adoption affects electricity demand patterns and network planning. Uncontrolled charging may intensify evening peak loads, whereas coordinated charging can provide load leveling and flexibility services. Prior work on optimal scheduling, forecasting, and DSM for EVs and energy storage indicates that:

- Aggregated EV charging can be treated as a controllable load.
- Integration with renewable energy sources enhances both economic and environmental performance.
- V2G-enabled infrastructure can provide ancillary services such as frequency regulation and peak shaving.

Thus, EV policy must be harmonized with smart grid development to avoid transferring stress from the oil sector to the electricity sector.

7.5 Policy implications

The findings lead to several policy-relevant insights:

- **Shift from upfront subsidies to usage-based incentives:** Since operating cost advantage is already strong, policy should focus on reducing initial purchase barriers through targeted financing, tax benefits, or BaaS facilitation rather than uniform subsidies.

- **Support for BaaS and battery swapping:** Regulatory recognition of battery swapping and subscription models can accelerate adoption by legitimizing alternative ownership structures.
- **Time-of-use electricity tariffs:** Differential tariffs can encourage off-peak charging and improve grid stability.
- **Standardization and interoperability:** Policies promoting battery and connector standardization are prerequisites for scalable BaaS ecosystems.
- **Urban-focused deployment:** High-density urban regions with predictable travel patterns offer the fastest path to ICE parity and emissions reduction.

Compared with China's centrally coordinated industrial policy, India's EV transition is more market-driven and consumer-sensitive. Therefore, localized techno-economic evidence, such as that presented in this study, is essential for crafting realistic and effective policies.

7.6 Strategic outlook

The techno-economic results indicate that India is approaching a threshold where EVs can become self-sustaining in market terms, provided that upfront cost barriers are addressed and charging infrastructure expands in parallel. BaaS emerges as a transitional mechanism bridging the gap between high battery cost and consumer affordability. As battery prices decline and next-generation platforms mature, EVs are expected to outperform ICE vehicles across both capital and operating cost dimensions.

8. Conclusion

This study presented a comprehensive technical and economic evaluation of electric vehicles (EVs) in the Indian context, with particular emphasis on currently available models and select upcoming vehicles, alongside a global perspective with reference to mature markets such as China. The analysis demonstrated that Indian EV offerings-especially in the compact and mid-size passenger car segments-have achieved significant improvements in battery capacity, driving range, power electronics efficiency, and safety features, making them technically competitive with conventional internal combustion (IC) vehicles for urban and peri-urban usage.

The comparative cost analysis revealed that although EVs impose a higher upfront purchase price relative to equivalent IC vehicles, their per-kilometer operating cost is substantially lower due to reduced energy and maintenance expenses. Over typical ownership horizons (5–8 years), this results in a lower total cost of ownership (TCO) for EVs, particularly when supported by state and central government incentives and lower electricity tariffs for charging. The modeling results further highlighted that energy cost per kilometer for EVs remains significantly less volatile than fuel-based costs, providing economic predictability to consumers.

The Battery-as-a-Service (BaaS) framework was shown to be a promising mechanism for reducing the initial acquisition barrier for EVs by decoupling battery cost from vehicle cost. BaaS enhances affordability, mitigates battery degradation risk for users, and enables structured battery lifecycle management, which is crucial for sustainability and circular economy objectives. However, its success in India depends on standardization, robust battery-swapping infrastructure, and regulatory clarity regarding ownership, safety, and recycling responsibilities.

From a policy and planning perspective, the findings emphasize the need for coordinated development of charging infrastructure, rationalization of electricity tariffs for EV charging, and long-term support for indigenous battery manufacturing. Lessons from China's EV ecosystem indicate that strong policy consistency, localized manufacturing, and large-scale deployment of public charging and swapping stations can significantly accelerate adoption.

In conclusion, EVs in the Indian market have reached a stage of technical maturity suitable for mass adoption, particularly in the compact car and urban mobility segments. While upfront cost remains a psychological and financial barrier, lower running costs, supportive policies, and innovative ownership models such as BaaS significantly enhance their economic viability. With continued infrastructure expansion, battery cost reduction, and stable policy frameworks, EVs are well-positioned to become a dominant mode of personal transportation in India, contributing meaningfully to energy security, emission reduction, and sustainable mobility goals.

References

1. Ahmad M, Ali D, Paul WUH, Ali MS, Ashfaq H. Management of energy and coordinated control of PV/HESS in islanded DC microgrid. In: Smart energy and advancement in power technologies. Singapore: Springer; 2023. p. 325–339. Available from: https://doi.org/10.1007/978-981-19-4971-5_25
2. Tata Motors. Tata Nexon EV technical specifications: product brochure. Pune (India): Tata Motors; 2024.
3. Bureau of Energy Efficiency. Electric vehicle charging infrastructure guidelines. New Delhi (India): Government of India; 2022.
4. Paul WUH, Siddiqui AS, Kirmani S. An effective duck curve problem solution using intelligent hybrid optimization. Journal of Engineering Science and Technology Review. 2026;1(1).
5. World Bank. Electric mobility and development: India case study. Washington (DC): World Bank; 2022.
6. Tie SF, Tan CW. A review of energy sources and energy management system in electric vehicles. Renewable and Sustainable Energy Reviews. 2013;20:82–102.
7. Paul WUH, Siddiqui AS, Kirmani S. Demand side management strategies in residential load with renewable energy integration: a brief overview. Paripex Indian Journal of Research. 2022;11(12):66–69. Available from: https://doi.org/10.36106/paripex/3007742
8. Energy and Resources Institute. Total cost of ownership analysis of electric vehicles in India. New Delhi (India): TERI; 2022.
9. Siddiqui O, Paul WUH, Alam T. Electromagnetic modelling and experimental analysis of weld tool coil in magnetic pulse welding. International Journal of

Advanced Multidisciplinary Research and Studies. 2024;4(3):1049–1055. Available from: https://doi.org/10.62225/2583049X.2024.4.3.2896
10. International Energy Agency. Global EV outlook 2024. Paris (France): IEA Publications; 2024.
11. Chan CC, Chau KT. Modern electric vehicle technology. 2nd ed. Oxford (UK): Oxford University Press; 2019.
12. Central Electricity Authority. Load generation balance report. New Delhi (India): Government of India; 2023.
13. Zhang X, Liang Y, Liu Y. Battery swapping technology for electric vehicles: a review. IEEE Access. 2021;9:156215–156230.
14. Paul WUH, Siddiqui AS, Kirmani S. Development of short-term load forecasting model for DSM by regulating charging and discharging of EVs and ESS with RES based on the prediction of this model. Journal of Engineering Science and Technology Review. 2023;16(6):63–72. Available from: https://doi.org/10.25103/jestr.166.08
15. Tata Motors. Tata Punch EV technical specifications: product brochure. Pune (India): Tata Motors; 2024.
16. Asian Development Bank. Pathways for electric vehicle adoption in India. Manila (Philippines): Asian Development Bank; 2021.
17. Central Pollution Control Board. Vehicular emission standards and air quality report. New Delhi (India): Government of India; 2023.
18. BloombergNEF. Battery price survey 2024. New York (USA): Bloomberg Finance L.P.; 2024.
19. Ali D, Paul WUH, Ali MS, Ahmad M, Ashfaq H. Optimal placement of distribution generation sources in hybrid generation network. Smart Grid and Renewable Energy. 2021;12(6):65–80. Available from: https://doi.org/10.4236/sgre.2021.125005
20. China Association of Automobile Manufacturers. China automotive industry yearbook. Beijing (China); 2023.
21. Society of Indian Automobile Manufacturers. Electric vehicle sales and registration data 2024. New Delhi (India): SIAM; 2024.
22. Helmers E, Marx P. Electric cars: technical characteristics and environmental impacts. Environmental Sciences Europe. 2012;24(14).
23. Paul WUH, Siddiqui AS, Kirmani S. Modeling optimal energy consumption in smart grid households: integrating advanced strategies with energy storage. Tuijin Jishu/Journal of Propulsion Technology. 2024;45(1):1169–1180. Available from: https://doi.org/10.52783/tjjpt.v45.i01.4146
24. NITI Aayog, Rocky Mountain Institute. India's electric mobility transformation. New Delhi (India): Government of India; 2022.
25. Ministry of Road Transport and Highways. Road transport year book 2022–23. New Delhi (India): Government of India; 2023.
26. Ministry of Heavy Industries. FAME-II scheme notification and progress report. New Delhi (India): Government of India; 2023.
27. Bashir MU, Paul WUH, Ahmad M, Ali D, Ali MS. An efficient hybrid TLBO-PSO approach for congestion management employing real power generation rescheduling. Smart Grid and Renewable Energy. 2021;12(8):113–135. Available from: https://doi.org/10.4236/sgre.2021.128008
28. Paul WUH, Siddiqui AS, Kirmani S. Intelligent load management system development with renewable energy for demand side management. International Journal of Advanced Engineering and Management Research. 2023;8(2). Available from: https://doi.org/10.51505/ijaemr.2023.8213
29. Kirmani S, Paul WUH, Bhat MB, Akhtar I, Siddiqui AS. Optimal allocation of V2G stations in a microgrid environment: demand response. In: Proceedings of the International Conference on Power, Instrumentation, Energy and Control (PIECON). IEEE; 2023. p. 1–6. Available from: https://doi.org/10.1109/PIECON56912.2023.10085813
30. Paul WUH, Khan RA, Hamid D. Techno-economic feasibility analysis of PM Surya Ghar–Muft Bijli Yojana in Jammu and Kashmir, India. International Journal of Advanced Multidisciplinary Research and Studies. 2025;5(1):767–787. Available from: https://doi.org/10.62225/2583049X.2025.5.1.3720
31. Siddiqui O, Paul WUH, Kirmani S, Ahmad M, Ali D, Ali MS. Voltage and frequency control in a microgrid. Journal of Engineering Science and Technology Review. 2022;15(6):115–124. Available from: https://doi.org/10.25103/jestr.156.14
32. Ali MS, Ahmad A, Ibraheem, Paul WUH, Siddiqui AS, Kirmani S. Optimal sizing and placement of energy storage systems in hybrid energy environment. Tuijin Jishu/Journal of Propulsion Technology. 2023;44(3):3147–3155. Available from: https://doi.org/10.52783/tjjpt.v44.i3.1412
33. Akhtar, Paul WUH, Kirmani S, Asim M. Cost analysis of 18 kW solar photovoltaic system for smart cities growth in India. In: Lecture Notes in Electrical Engineering. 2021. Available from: https://doi.org/10.1007/978-981-33-4080-0_63
34. Ali MS, Ahmad M, Paul WUH, Ali D, Ahmad M. Optimal allocation of wind-based distributed generators in power distribution systems using probabilistic approach. In: Smart energy and advancement in power technologies. Singapore: Springer; 2023. p. 385–396. Available from: https://doi.org/10.1007/978-981-19-4971-5_29
35. Paul WUH, Siddiqui AS, Kirmani S. Demand side management and demand response for optimal energy usage: an overview. Paripex Indian Journal of Research. 2022:151–152. Available from: https://doi.org/10.36106/paripex/0608823
36. Kumar D, Siddiqui AS, Singh HP, Tripathy MR, Paul WUH. Design and implementation of reconfigurable frequency and polarization microstrip patch antenna for X-band application. Tuijin Jishu/Journal of Propulsion Technology. 2023;44(5):2859–2870. Available from: https://doi.org/10.52783/tjjpt.v44.i5.3042.

37. Mahindra & Mahindra. Mahindra BE 6 technical white paper. Mumbai (India); 2024.
38. Paul WUH, Siddiqui AS, Kirmani S. Optimal positioning of distributed energy using intelligent hybrid optimization. Journal of Physics: Conference Series. 2023;2570(1):012022. Available from: https://doi.org/10.1088/1742-6596/2570/1/012022
39. Paul WUH, Siddiqui AS, Kirmani S. Optimal rescheduling for transmission congestion management using intelligent hybrid optimization. In: Artificial intelligence of things. Switzerland: Springer Nature; 2024. Available from: https://doi.org/10.1007/978-3-031-48781-1_12
40. Kirmani S, Paul WUH, Bhat MB, Nahvi SA. Data based controller design for PMDC motor setup using system identification. Studies in Indian Place Names. 2020;40:11.
41. Paul WUH, Siddiqui AS, Kirmani S, Ali MS, Ahmad A, Ibraheem. Development of strategies for the optimal rescheduling of the household load having RES integration. Tuijin Jishu/Journal of Propulsion Technology. 2022;44(3):3859–3867. Available from: https://doi.org/10.52783/tjjpt.v44.i3.2145.