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Comparative Analysis of the Total Cost of Ownership (TCO) Between Electric Vehicles (EVs), Hybrid Electric Vehicles (HEVs) and Internal Combustion Engine (ICE) Vehicles in India

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ABSTRACT

The automotive industry is undergoing a dramatic shift from the traditional internal combustion engine to an electric mobility solution for a sustainable environment and the conservation of fossil fuel resources. Although the environmentally advantageous aspects of Electric Vehicles and Hybrid Electric Vehicles are quite clear, consumer sentiment regarding the adoption of such modes of transportation has been governed largely by the economics of use, or the Total Cost of Ownership (TCO) value. This research seeks to present an evidence-based comparative analysis of the TCO costs for Electric Vehicles, Hybrid Electric Vehicles, and Internal Combustion Engine vehicles in the Indian context through an analytical framework of cost assessment of critical parameters such as acquisition costs, fuel consumption costs, servicing costs, government taxation subsidies, and other deprecation costs over the proposed period of five years. Through an integration of industry reports, this paper seeks to present a scientific analysis of the feasibility of the above automobile options from an economic use prospective.

KEYWORDS

Electric vehicles (EVs), hybrid electric vehicles (HEVs), internal combustion engine (ICE) vehicles, total cost of ownership (TCO), purchase price, operating costs, economic analysis.

1. Introduction

The world's transportation sector is actually going through a paradigm shift induced by the need to reduce greenhouse gas emissions as well as combat global warming. In the context of India, for a nation so heavily dependent on imported crude oil as well as finding itself confronting increasingly adverse conditions concerning urban air quality [1], such a paradigm shift is highly imperative. As such, there has been a great push from the governing authority as well as the automotive sector to move away from the conventional Internal Combustion Engines towards a clean option: mainly Electric Vehicles and Hybrid Electric Vehicles. This switchover marks not only the technological but also the economic shift. While it's clear that EVs have significant environmental benefits, it's important to consider whether it's economically viable for adoption to pick up pace in price-sensitive countries such as the Indian market. As it stands, one expects people to express interest in buying EVs but are driven back by the sticker price, largely due to the battery technology involved. But assessing the cost of a car from a narrow focus on purchase price alone provides no clarity. The Total Cost of Ownership, TCO, approach takes into consideration a more realistic financial calculation, which includes costs such as the cost of purchase, operating costs, which could be in terms of fuel/energy, the cost of maintenance, the cost of insurance, the value of any government subsidy, as well as the salvage value for disposal [2].

An initiative to close the cost gap has been launched by the Government of India with Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) schemes. Fiscal measures, along with favorable Good and Services Tax (GST) rates, are being implemented to make the total cost of ownership (TCO) for EVs equivalent to, or better than, that for ICE vehicles. HEVs, with a combustion engine and electric propulsion system, provide a hybrid solution where fuel efficiency improves without being bound by range restrictions, with less fiscal incentives from the government [3]. Additionally, increased

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infrastructure for electrical distribution and charging points remain a critical part of this environment [4].

This study encompasses a precise quantitative analysis and comparison of the TCO for EVs, HEVs, and conventional ICE vehicles in a manner that is relevant to the Indian economic scenario. This study steers away from a generic and theoretical analysis and uses a sophisticated mathematical model to estimate and calculate the cost associated with a 5-year ownership cycle. Through this rigorous study, it has been possible to estimate and calculate various "break-even" points associated with economical savings offered through electrical mobility for a smoother and better transitional experience for individuals and policymakers interested in adopting sustainable transport solutions.

2. Literature Survey

In the last decade, the financial evaluation of alternative fuel vehicles using the Total Cost of Ownership approach has garnered a lot of interest within the academic community. Owing to the steady evolution of battery technology and the approach adopted by governments globally, the financial calculations related to car ownership keep fluctuating.

2.1 *TCO and Economic Viability*

Many studies have been conducted in order to set up a basic framework for the comparison study. Sheppard et al. [2] and Singh et al. [5] pointed out the initial high cost associated with EVs, which in turn is largely compensated for by lower running costs. For the case of India, a study conducted by Kumar and Sharma [3] gave a life-cycle costing calculation, which stated that the financial benefits of EVs would result in the future due to a substantial price gap for gasoline when compared with the lower prices of electricity. Singh et al. [6] validated this study for the Indian scenario, while Bansal and Gupta [7] pointed out the need for high daily use cycles in the case of a metropolitan city, which would increase the return on investment for EV owners.

2.2 *Role of Government Policy*

Government intervention is a critical parameter in the evaluation of the TCO. Studies by Chandra and Kumar [8] and Tiwari et al. [9] analyzed the impact of the subsidy offered by the FAME scheme on the penetration of electric vehicles in the market. It is clear from the analysis that without the help of fiscal supports in the form of subsidy and taxation benefits, the TCO of EGVs will find it difficult to reach parity with the well-established technology of internal combustion engine vehicles.

Table 1. Key findings and results from the studies on TCO

Study	*Key Findings*	*Vehicle Types*	*Key Result*
Dhingra (2019) [10]	TCO of EVs in India	EVs	EVs exhibit lower OpEx despite higher entry price
Ghosh et al. (2020) [11	TCO in urban India	EVs, HEVs, ICE	HEVs and EVs show reduced OpEx.
Gupta et al. (2020) [12]	Maintenance costs	EVs, HEVs, ICE	EVs incur 50-60% lower service costs than ICE.
Mahajan & Joshi (2020) [13]	Operational cost analysis	EVs, ICE	EVs offer 50-70% reduction in OpEx.
Patel et al. (2021) [14]	Feasibility of HEVs	HEVs, ICE	HEVs save fuel but trail EVs in efficiency.
Rajesh & Verma (2021) [15]	Depreciation trends	EVs, ICE	EV depreciation im proving with infras tructure.
Saini et al. (2021) [16]	Fuel cost savings	HEVs, ICE	HEVs achieve 30-40% fuel savings vs ICE.
Sharma & Kumar (2021) [17]	EV adoption & TCO	EVs, ICE	Long-term TCO favors EVs with subsidies.
Tiwari et al. (2020) [9]	Government incentives	EVs	Subsidies significantly lower EV TCO.

Study	*Key Findings*	*Vehicle Types*	*Key Result*
Singh et al. (2022) [6]	Urban TCO comparison	EVs, HEVs, ICE	EVs provide lowest overall TCO
Sharma & Rajput (2022) [18]	Rural vs Urban TCO	EVs, HEVs, ICE	HEVs are suited for rural, while EVs are popular.

2.3 *Operational Costs and Depreciation*

One of the exclusive benefits of EVs highlighted in the existing body of work is the considerable decrease in Operational Expenditure (OPEX). Saini et al. [16] and Patel et al. [19] compared the variability in fuel costs in ICEs with the stability in electricity charges for this purpose. Moreover, Gupta et al. [12] broke down service cost analysis to establish that due to their simpler power train with fewer components, there is a 50-60% reduction in maintenance costs in EVs in comparison with their ICEs.

“Resale value is one of the least known factors in TCO. Rajesh and Verma [15] discussed the depreciation dynamics and found that EVs had a faster depreciation trajectory due to concerns over battery longevity and replacement costs. But as battery technology matures and second-hand EVs gain more traction in the market, such a divergence is likely to narrow down. Sarkar and Bhowmick [20] further elaborate that although HEVs help to provide a transition path, having two powertrains multiplies factors of depreciation that fall somewhere in between that of ICE and EVs.

2.4 *Gaps in Existing Literature*

Although different aspects of TCO have already been investigated individually, a requirement prevails regarding a contemporary comparative study that incorporates the prevailing market prices in the Indian market. A majority of the existing literature has used static values, whereas the current study fills that gap by employing a model of a 5-year TCO.

3. Parameters of TCO

Total Cost of Ownership (TCO) is a collective measurement that calculates the cost-effectiveness of car ownership from a price perspective, aside from its purchase price. This section breaks down the five critical factors that have been identified for comparative analysis.

3.1 *Vehicle Purchase Price*

The acquisition or purchase cost is expected to be the biggest challenge in adopting Electric Vehicles in larger numbers in India. The biggest contribution to the cost of EVs is made by the Lithium Ion batteries, which could constitute 30% to 40% of the total price of any vehicle, as purely analytically described in Dixit et al. [21]. Though there is an overall declining trend in global battery costs, high import costs and ESL manufacturing in India make it costly in comparison to proven ICE. On the flip side, ICE cars have benefitted from decades of automotive manufacturing in their own country and thus have set a cost premium; this is currently at its lowest price point. The premium for Hybrid Electric Vehicles is highest for incorporating two power systems.

Vehicle Purchase Price = Base Price + Optional Features +Taxes + Registration Fees + Other Charges (1)

Table 2. Breakdown of the initial purchase price and cost drivers

Vehicle Type	*Avg. Price (Rs.)*	*Key Cost Components & Drivers*	*Examples*
EV	15,00,000	High: Battery Pack (30-40%),Import Duties. Offset by: Lower GST (5%).	Tata Nexon EV
HEV	12,00,000	Medium-High: Dual Powertrain complexity. Impact: Higher production cost.	Honda City e:HEV
ICE	9,00,000	Base/Lowest: Mature supply chain. Impact: Lowest acquisition cost.	Maruti Swift

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3.2 *Fuel/Energy Costs*

Operational Cost (OPEX), fuelled largely by energy use, is the most fluctuating component of TCO. Electric Vehicles exploit fully the high tank-to-wheel efficiency of Electric Motors (est. 77% to 82%), which is considerably higher than that of Internal Combustion Engines (ICE) and just 12% to 30%. In the present Indian economy, such thermodynamic advantage is further amplified by the huge spread between government-controlled electricity prices and dotted petroleum prices (petrol & diesel).

Annual energy cost (C_E) is obtained as a function of annual distance (D_{annual}), efficiency (η), and unit fuel price (P_{unit}):

$$C_E = D_{annual} \times \eta \times P_{unit} \quad (2)$$

Where, $\boldsymbol{D_{annual}}$ is set to 15,000 km for all cases.

For Electric Vehicles (EV): Assuming an efficiency of $\boldsymbol{\eta EV = 0.2\ kWh/km}$ and electricity tariff $\boldsymbol{P_{elec} = Rs.7/kWh}$:

$$\boldsymbol{C_{E(EV)} = 15000 \times 0.2 \times 7 = Rs.21,000} \quad (3)$$

For Hybrid Electric Vehicles (HEV): With a fuel economy of $\boldsymbol{4.5\ L/100km}$ ($\boldsymbol{\eta HEV = 0.045\ L/km}$) and petrol price $\boldsymbol{P_{fuel} = Rs.110/L}$:

$$\boldsymbol{C_{E(HEV)} = 15000 \times 0.045 \times 110 = Rs.74,250} \quad (4)$$

For Internal Combustion Engines (ICE): With a standard fuel economy of $\boldsymbol{7\ L/100km}$ ($\boldsymbol{\eta ICE = 0.07\ L/km}$) and petrol price $\boldsymbol{P_{fuel} = Rs.110/L}$:

$$\boldsymbol{C_{E(ICE)} = 15000 \times 0.07 \times 110 = Rs.1,15,500} \quad (5)$$

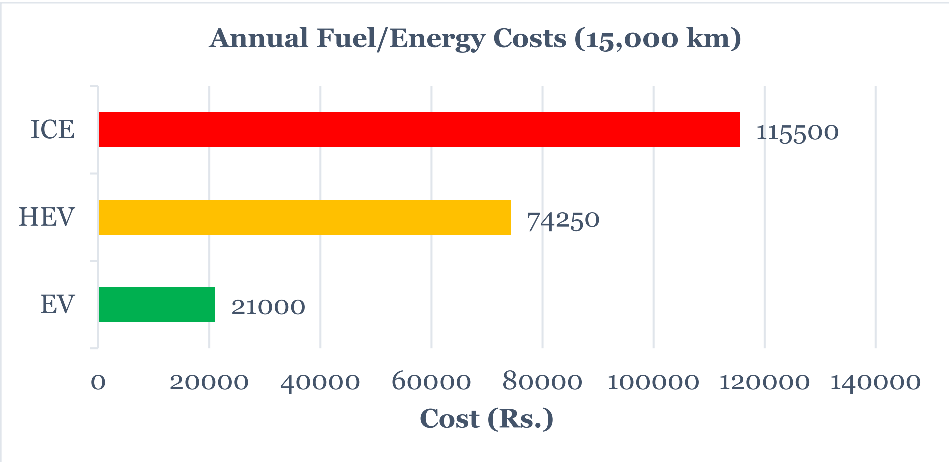

Fig. 1.Comparison of Annual Fuel/Energy Costs based on 15,000 km usage

3.3 *Maintenance Costs*

The level of variation for the cost of maintenance is driven by the level of complexity presented by the engine. A conventional ICE car contains more than 2,000 moving parts requiring a rigorous program of oil changes and filter replacements. On the other hand, the number of moving parts required in the drivetrain of EVs is below 20. A key consideration from the cost angle is the regenerative braking aspect of the technology that extends the life of the mechanical brake pad.

The annual maintenance cost (C_M) can thus be estimated by taking the average of the scheduled service cost (S_C) over the lifespan of a vehicle tenure (T):

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$$C_M = \frac{\sum_{t=1}^{T} S_c(t)}{T} \quad (6)$$

Calculated Annual Averages:

$$C_{M(EV)} \approx Rs.7,500 \text{ (Minimal fluids, tires, wipers)} \quad (7)$$

$$C_{M(HEV)} \approx Rs.15,000 \text{ (ICE maintenance + Electricals)} \quad (8)$$

$$C_{M(ICE)} \approx Rs.22,500 \text{ (Full engine/trans. service)} \quad (9)$$

Table 3: Annual Maintenance Cost And Complexity Analysis

Vehicle Type	*Annual Cost (Rs.)*	*Complexity*	*Key Service Requirements*
EV	7,500	Low: <20 moving parts. No engine	Cabin air filter, tires, coolant. Brake pads have an increased lifespan.
HEV	15,000	High: Dual powertrain.	Engine oil/filter, battery check, transmission
ICE	22,500	High: >2,000 moving parts.	Engine oil, spark plugs, Timing belt, Exhaust.

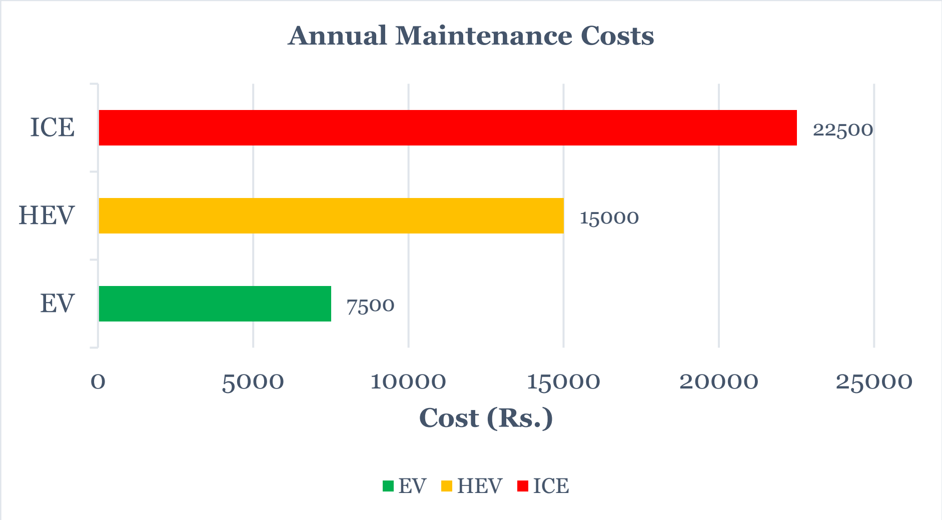

Fig. 2. Comparison of Annual Maintenance Costs. EVs show minimal expenditure due to lower mechanical complexity.

3.4 *Depreciation*

Depreciation is defined as the reduction in asset value due to time and is an essential factor in calculating the resale or residual value of the vehicle (V_res). Notably, conventional electric vehicles have traditionally followed steeper depreciation patterns compared to ICE vehicles because of market doubts about SoH. This is, however, becoming normalized.

Table 4: Depreciation Analysis and Residual Value Projections (5 Years)

Vehicle Type	*Initial Price (Rs.)*	*Residual (50%)*	*Economic Implications*
EV	15,00,000	7,50,000	Risk: Battery health anxiety. Benefit: Low mechanical wear.
HEV	12,00,000	6,00,000	Risk: Dual-powertrain aging.
ICE	9,00,000	4,50,000	Benefit: High market liquidity. Risk: Regulatory bans.

Assuming a straight-line depreciation model for comparative clarity over a tenure T of 5 years with a depreciation rate r_{dep}:

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$$V_{res} = P_{initial} \times (1 - (r_{dep} \times T)) \tag{10}$$

For a rate of r_{dep}= 10% per annum over 5 years, the owner retains 50% of the asset value.

Table 5: Government Fiscal Incentives and Taxation Structure

Parameter	*EV*	*HEV*	*ICE*
GST Rate	5% (Lowest)	43% (Total)	Up to 50%
Subsidies	FAME II + State	Minimal	None
Road Tax	100% Waiver	Standard	Standard (High)
Impact	Reduces TCO	High tax burden	Highest tax burden

3.5 *Government Incentives*

The Indian taxation regime supports EVs with the help of the FAME II scheme and the supporting Goods and Services Tax (GST) regime. The GST for EVs is only 5%, while for ICE cars, they are labeled as a 'Luxury Goods' category with a headline GST rate of 28%, including the Compensation Cess, increasing the overall tax incidence to 50%.

The effective cost to the consumer (P_{eff}) is represented by the expression:

$$P_{eff} = P_{base} + T_{tax} - S_{gov} \tag{11}$$

Where $Ttax$ is the tax component and $Sgov$ represents total subsidies ($S_{FAME} + S_{State}$).

4. Total Cost of Ownership (TCO)

The primary contribution of this paper is the establishment of the calculation of the above-mentioned parameters into a single financial indicator, namely the Total Cost of Ownership (TCO) metric. The section below outlines the methodology utilized within the analytical framework to obtain the 5-year cost breakdown.

4.1 *Methodology and Analytical Model*

In order to calculate a true and accurate cost of car ownership, this study computes a Net Total Cost of Ownership (Net TCO). This is different from a simple cash flow analysis because it takes a true residual value at the end of a car ownership period.

The Net TCO is represented by:

$$Net\ TCO = CapEx + OpEx_n - V_{res} \tag{12}$$

Where:

- *CapEx is the Final Purchase Price (P_{final}) after subsidies.*
- *OpEx is the sum of Fuel (C_E) and Maintenance (C_M)costs.*
- *V_{res} is the Residual (Resale) Value at the end of tenure T = 5.*

4.2 *Detailed Calculation Breakdown (EV Scenario)*

In order to understand the analytical reasoning, a description of the calculation process for the Electric Vehicle case will be provided.

1. Capital Expenditure (CapEx):
$$CapEx = 15,00,000 - 1,50,000 = Rs. 13,50,000$$
2. Operational Expenditure (OpEx - 5 Years):
$$OpEx_{5yr} = 5 \times (21{,}000 + 7{,}500) = Rs. 1{,}42{,}500$$
3. Residual Value ($Vres$):
$$Vres = 15{,}00{,}000 \times 0.50 = Rs. 7{,}50{,}000$$
4. Net Total Cost of Ownership:
$$Net\ TCO_{EV} = 13{,}50{,}000 + 1{,}42{,}500 - 7{,}50{,}000 = Rs. 7,42,500$$

This calculation shows how, because of high resale value retention and low OpEx, the real price is much lower than what it looks at first when you buy it.

4.3 *Comparative Results*

Using similar reasoning for HEVs and ICE vehicles, one can derive comparable considerations as follows:

HEV Calculation:

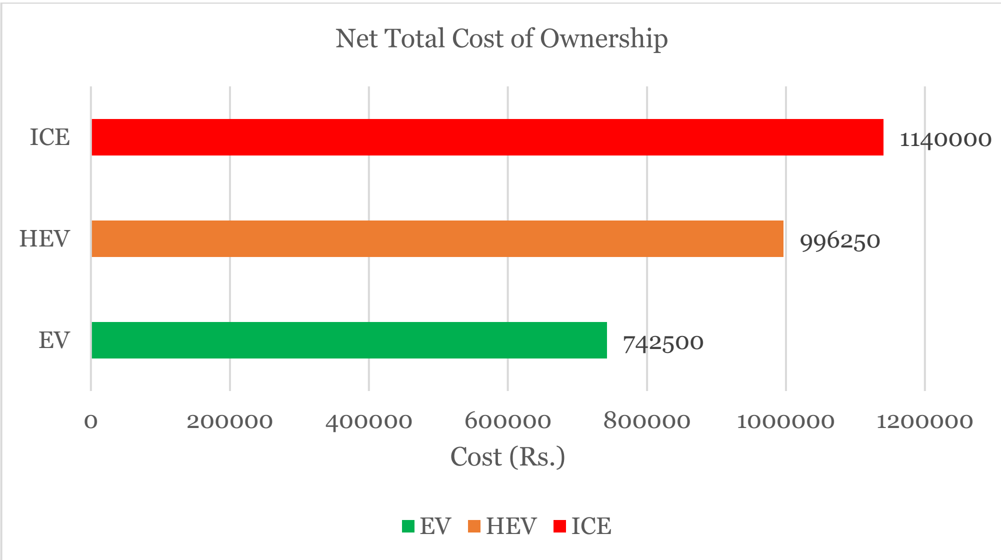
$$\boldsymbol{CapEx = Rs. 11,50,000}$$
$$\boldsymbol{OpEx_{5yr} = Rs. 4,46,250}$$
$$\boldsymbol{Vres = Rs.\ 6,00,000}$$
$$\boldsymbol{Net\ TCO_{HEV} = Rs. 9,96,250}$$

ICE Calculation:

$$\boldsymbol{CapEx = Rs. 9,00,000}$$
$$\boldsymbol{OpEx_{5yr} = Rs. 6,90,000}$$
$$\boldsymbol{Vres = Rs. 4,50,000}$$
$$\boldsymbol{Net\ TCO_{ICE} = Rs. 11,40,000}$$

Table 6: Net TCO Summary of 5 Years: True Cost of Ownership (In Rs.)

Cost Component	*EV*	*HEV*	*ICE*
A. Cash Outflow Components			
Net Purchase Price	13,50,000	11,50,000	9,00,000
Total OpEx (5 Yrs)	1,42,500	4,46,250	6,90,000
Total Cash Spent	14,92,500	15,96,250	15,90,000
B. Asset Recovery			
(-) Resale Value	7,50,000	6,00,000	4,50,000
C. Net Total Cost of Ownership (A - B)			
NET TCO	7,42,500	9,96,250	11,40,000



5. Conclusion

A comparative analysis indicates that there exist dissimilar financial patterns for different vehicles. Even with a relatively lower purchase price, ICE vehicles have the highest Net TCO due to their high running and maintenance costs for a period of five years. This is opposed to the Electric Vehicles, which have a relatively higher purchase price with a remarkably lower Net TCO. Hybrids act as a compromise solution. Finally, with respect to financial sustainability, EVs are deemed better options depending upon government support.

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