ECONOMIC ANALYSIS OF HFCV, BEV AND ICEV IN INDIAN CONTEXT

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Abstract: Governments across the globe are trying their best to be more and more carbon neutral. One known way to it is Hydrogen Economy, where clean power can be produced with zero emissions. Transportation sector being one of the major contributor in the greenhouse gases, it is impossible to cut noticeable carbon footprints without its being carbon neutral. So there is a sheer requirement of Automobiles to be carbon neutral which is leading the automobile sector to other clean alternative fuel like hydrogen. Hydrogen Fuel Cell Vehicles is the initiative taken by certain automobile manufacturers and governments of respective countries is supporting the initiative by giving subsidies and other incentives to the end user. India being a piece sensitive market for automobiles, this paper will help: manufactures to price their product and provide schemes accordingly; government to decide subsidies so that HFCV can be competitive to other BEV and ICEV; people to analyze the life cycle cost of all three products without any hypothetical subsidy. Using a trend analysis model this paper analyses the future cost of fuels like petrol, diesel and electricity and the cost associated of each fuel in lifecycle of the respective vehicle. For calculation of hydrogen prices, a well to wheel model, which is constructed taking Indian scenario in mind, is used. HFCV being a new technology, its lifecycle cost is more than BEV and ICEV, if we don’t take any manufacturer provided scheme and government provided subsidies into consideration. But if we will analyze other market, where free Hydrogen for certain amount of time is provided by manufacturers and there are government provided subsidies and incentives, Indian consumers would be very attracted toward this new segment of vehicles.

IndexTerms – Economic, Economic Analysis, Hydrogen, Hydrogen fuel cell vehicle, battery electric vehicle, India.

1. INTRODUCTION
The fast rate of adoption of alternate fuel vehicles around the world over recent years has proved their reliability factor. Alongside with the increase in their number, the myths and the fear of unknown has decreased from the people’s mind due to which they are now less hesitant to buy alternate Fuel Vehicle. In the recent years in India, electric vehicles have made their path clear by proving themselves equally competent both economically and environmentally. The increasing number of recharging stations has also helped reducing range anxiety of electric vehicle buyers and increasing the distance, that can be travelled by vehicle.

But the alternate fuel vehicles doesn’t end here. Hydrogen Fuel Cell vehicles are proving themselves around the world, an alternative to electric vehicles. These vehicles are environmental friendly as they have zero tail pipe emissions and they can be truly carbon neutral if hydrogen is produced by green energy. Their refuelling time is an added advantage over the Electric vehicles. A hydrogen Fuel Cell vehicle can be refuelled in 3 to 5 minutes.

This paper focusses on the Life cycle cost of Hydrogen Fuel Cell vehicle in comparison with electric vehicles and conventional Internal Combustion engine vehicle with respect to Indian scenario. This analysis plays an important role as Indian consumers being very much price sensitive. Like other governments, Indian government has also focussed on their hydrogen missions. India can soon expect a hydrogen fuel cell vehicle in upcoming years. This paper will throw some light on the economic aspect of owning a hydrogen fuel cell vehicle in upcoming years in India.

2. REVIEW OF LITERATURES

2.1 ECONOMICS OF HYDROGEN
In the fast few decades, when global warming became an international concern, scientists and researchers started research on alternate fuels and their economic feasibility. Amos 1998 [1] calculated the cost of storing and transporting hydrogen and reviewed each possible aspect for the same. It further proposed that the cost of hydrogen depends on several factors or combination of factors such as production rate, storage capacity, storage time, delivery distance. It is widely used by many authors who provided a well-to-wheel cost of hydrogen to the end user. Franco Barbir 2005 [2] focussed on the economic aspect of producing hydrogen from electrolysis. An economic analysis describing 19 pathways of producing and delivering hydrogen was done by Simbeck and Cheng 2002 [3]. The data and the calculations for production, storage and delivery were backed up by Air Products and Chemicals, BOC and Praxair. It proposed that onsite hydrogen production becomes expensive because of lower production rates.

Morris 2003 [4] stated “A Hydrogen Economy Is Not A Renewable Energy Economy”. It proposed that wind Electricity is 20 to 40 percent expensive than electricity from fossil fuel whereas wind generated hydrogen is approximately 200 percent expensive than hydrogen generated from fossil fuel sources Casten et.al 2000 [5] analysed different methods to use hydrogen as a fuel in automobile such as on-board reforming and off-boarding. They proposed central production of hydrogen would not be favourable as storage and transporting to a network of refuelling stations can be risky. They further proposed that hydrogen from local electrolyser would be expensive because of high cost of electricity in California. Berry 1996 [6] proposed that hydrogen generated from natural gas can do more emissions than an efficient gasoline or natural gas vehicle. One reason for this is fuel cell electric vehicles requires electricity intensive storage like liquefaction and compression. Turner 2004 [7] proposed that it would need 150 million tonnes of hydrogen to power whole transport sector of United States.

A well-to-wheel economic as well as environmental analysis on hydrogen as transportation fuel in context with Shanghai is done in Huang et.al 2006 [8]. It also considered the weight to weight energy efficiency of different processes into the account. Another well to wheel economic analysis for hydrogen technology is Balachandra and Reddy 2007 [9] in Indian Context. A central plant is
considered which has a capacity of 150 tonnes of hydrogen per day with a load capacity of 90%. Hydrogen can be supplied from
steam methane reforming of natural gas for hydrogen fuel cell trucks whereas t
production from steam methane reforming of natural gas for hydrogen fuel cell trucks whereas tail pipe emissions were eminent
forces o

2.2 HYDROGEN INFRASTRUCTURE

Many authors also attempted to solve the problem of planning and designing the hydrogen refuelling infrastructure. One of which,
Greene et al. 2020 [12], discusses about the methods to plan hydrogen refuelling stations like p-median model and California
Shanghai with the help of compendium of hydrogen refueling equipment costs (CHREC), hydrogen station cost model (HSCM) and
Tongji hydrogen delivery cost model (THDCM). The study proposed that the on-site production of hydrogen by SMR was less
expensive than delivery from a centralized plant since the price of natural gas was much lower at the station than the feedstock at the
centralized plant. Further, it compared the costs incurred by the plant at Shanghai with one in California. From which it was proposed that
the price of hydrogen produced by on-site electrolysis is much less in Shanghai than in California because of lower cost of
electricity in Shanghai. Ogeden 1997 [14] analysed the cost of hydrogen to end user and the cost of hydrogen infrastructure in
California proposed that off-peak power from 6 pm to 10 pm can be available which can produce 440-660 million square cubic foot
of hydrogen per day. There are several energy surplus nations who can produce electrolytic hydrogen from the excess available
renewable energy

2.3 VEHICLE COMPARISONS

Buzoverov et al. [15] discusses the economic as well as environmental impact of various electric vehicles such as Battery Electric
Vehicles (BEVs), Fuel Cell Vehicles (FCVs) and Aluminium Air Electrochemical Generator vehicles (AAEGC). AAEGC was considered
the least environmental friendly among all because refining aluminium (A995) out of alumina is also an energy intensive
process and emits comparatively huge amount of CO2. Gim 2015 [16] provides a treasure of Information regarding the economic
comparison between hydrogen fuel cell vehicle (HFCV) and conventional internal combustion engine vehicle in respect to Korean
scenario. This paper deals with the economic analysis of domestic fuel cell vehicles (Hyundai Tucson FCV) and conventional ICE
vehicles (Hyundai Tucson) considering subsidy and hydrogen price in 2015 and 2025. It stated that the cost of fuel cell vehicle and
hydrogen prices must be kept less for its being competitive with conventional ICE vehicles. Granovskyi et al. 2005 [17] proposed
natural gas can provide the same range as that of hydrogen with storage pressure two times less than that of hydrogen. It also stated
that fuel cell vehicle remains uncompetitive because of high price of the vehicle and fuel. Richard Raustad 2017 [18] provides a
life cycle cost analysis of several conventional internal combustion engine, plug-in hybrid and battery electric vehicles. It was stated
in the paper that although the conventional internal combustion vehicles are having a cheap price tag they comes out to be most
expensive in terms of 10 year ownership followed by plug-in hybrids and battery electric vehicles. Gilmore and Patwardhan 2016
[19] performs the cost of ownership analysis of the 4 door passenger cars in India on the basis of private cost and societal cost. It
proposed that the lower societal and fuel cost of EVs is insufficient to compensate for its higher capital cost. It found out that CNG
vehicles have the least ownership cost among all drive train vehicles as of their least private and societal cost.

DY Lee et al. 2018 [20] performed life-cycle analysis of diesel and hydrogen powered medium and heavy duty vehicles (2h to 8b
gross vehicle weight category) in which the analysis was break down in two categories namely well to pump and pump to wheel
analysis. Paper proposed that almost all of the CO2 emissions are produced from Well to pump part and that too in hydrogen
production from steam methane reforming of natural gas for hydrogen fuel cell trucks whereas tail pipe emissions were eminent
source of CO2 emissions for diesel powered trucks. Ajamovic and Haas 2018 [21] has compared conventional ICE vehicles, battery
electric vehicles and fuel cell vehicles for three scenarios – pessimistic, average and optimistic. The pessimistic scenario was the
worst case scenario where prices and emissions were exaggerated. The optimistic scenario was rather supported by least prices and
emissions. It stated that using only coal for electricity generation or hydrogen production would do more emissions then convention
ICE vehicles. Kaa et al. 2017 [22] makes a comparison between battery electric vehicle and hydrogen fuel cell vehicle to analyse
which technology will dominate the market. It made use of linear BMW model and certain factors such as technological superiority,
compatibility and brand reputation & credibility. Battery electric vehicles scored more on all the factors than hydrogen fuel cell
vehicles.

2.4 OTHER LITERATURES

Zorrilla 2018 [23] describes the trend analytics feature of Tableau and how important it is to choose correct trend line feature. It
also compares 5 trend line models: Linear, Exponential, Logarithmic, Power and Polynomial, on a data source and explains which
model parameter to give emphasis while selecting a perfect fit for your trend. Jenna 2017 [24] proposes the methods to use the
forecast feature of analytics in Tableau. The implementation of forecast feature was presented on ‘Sample Superstore’ dataset which
is default available dataset in Tableau package.

Manoharan et al. [25] reviewed to inspect closely the feasibility of using hydrogen as a major fuel in transportation systems. All
composites (Type IV) are primarily used, and sometimes metal lined composites (Type III) are used. The fill time of these tanks is
competitive with fossil fuels when the hydrogen is pre-cooled. An alternative to traditional compressed H2 tanks that is still being
researched is a tank with an internal skeleton, which is a complex design of struts in tension within the tank to resist the forces of
the compressed gas. Goel et al. 2014 studied the driving characteristic data of three cities in India – Delhi, Rajkot and Vishakhapatnam.
The research proposed that daily average mileage has no direct relation with the city’s area or the population. The paper stated that
the annual mileage of a car in Delhi is 12,200 km. Naveen et al. 2021 [26] performed a survey on Indian consumers to find out whether
they would like to buy hydrogen fuel cell vehicle over a battery electric vehicle and conventional internal combustion engine
vehicle. The result came out to be battery electric vehicle winning over the two other choices. The study proposed that the
respondents were quite concerned about the price of alternate fuel vehicles. The price of hydrogen fuel cell vehicle was INR 4500000
in the survey, which was quite how as compared to respondent’s then owned car.
3. CALCULATIONS

3.1 ASSUMPTIONS

- Life of vehicle is assumed to be 10 years.
- No maintenance/service cost is included in the analysis.
- Each year vehicle would be driven 12,200 km.
- Degradation of mileage with time will not happen.
- Battery degradation factor is also not considered in the analysis as that won’t affect the analysis.
- No subsidies or insurance being considered in the paper as none is mentioned by the government for HFCV. And subsidies on the BEV vary from state to state in India.
- The cost of hydrogen is calculated using electrolysis of water method of production of hydrogen.

3.2 ASSUMPTIONS

The vehicles chosen for analysis are conventional internal combustion engine (ICE), Battery Electric Vehicle (BEV) and Hydrogen Fuel Cell Vehicle (HFCV). The model year is selected as 2021. The prices considered in the report are ex-showroom prices of the top variants of each model.

<table>
<thead>
<tr>
<th>Model Year</th>
<th>Year</th>
<th>MAKE</th>
<th>MODEL</th>
<th>PRICE (INR)</th>
<th>TYPE</th>
<th>RANGE</th>
<th>Kmph/kmile</th>
</tr>
</thead>
<tbody>
<tr>
<td>2021</td>
<td>Tata Nexon</td>
<td>XZA+ DT(0)</td>
<td>11.46</td>
<td>ICE</td>
<td>300 km</td>
<td>17 km/l</td>
<td></td>
</tr>
<tr>
<td>2021</td>
<td>Tata Nexon EV</td>
<td>XZ+ LUX</td>
<td>16.40</td>
<td>BEV</td>
<td>300 km</td>
<td>92.7 km/Le</td>
<td></td>
</tr>
<tr>
<td>2021</td>
<td>Hyundai Nexo</td>
<td>65.00</td>
<td>HFCV</td>
<td>593 km</td>
<td></td>
<td>93.7 km/Le</td>
<td></td>
</tr>
</tbody>
</table>

3.3 DAILY MILEAGE

To evaluate the daily mileage, it is necessary to specify the number of kilometres a vehicle is driven per year. For this analysis, the data is taken from Assessment of Motor Vehicle Use Characteristic in Three Indian Cities by Goel et.al. [26]. The data belongs to the year 2014. According to the data provided, each personal car is driven 12200 km on an average.

3.4 CALCULATING ELECTRICITY, PETROL AND HYDROGEN PRICES

The most important thing that we needed to consider before calculating the fuel consumption is the price of each fuel over the years. For the fuel pieces we have considered various parameters from various sources.

3.4.1 ELECTRICITY COST

For the cost of electricity, we considered data from statista.com. The data available was from 2009 to 2019, on the basis of which, we estimated the upcoming 11 years from 2020 to 2030, which is stated in the table 2. For the prediction of the upcoming years (2020 to 2030), we used exponential trend line model, as it was providing the best quality results as compared to other models. The equation of the curve is: 1.9398e-48*exp(0.0553263*year). Pictorial depiction of the curve is in Figure 3 with dark maroon breaking lines.
3.4.2 Petrol Prices

The estimation of Petrol prices (2018 to 2030) is done on the basis of data of Petrol Prices (2002 to 2017) available from Petroleum Planning and Analysis Cell site. For the prediction of the upcoming years (2018 to 2030), we used exponential trendline model, as it was providing the best quality results as compared to other models in Tableau Data Visualization Tool. The equation of the trend line curve can be seen in figure 4, i.e. $7.15449 \times 10^{-49} \times \exp(0.0571139 \times \text{Year})$.

Table 3. Actual and Forecasted Petrol Cost

<table>
<thead>
<tr>
<th>YEAR</th>
<th>ACTUAL AVERAGE PRICE (INR)</th>
<th>FORECASTED AVERAGE PRICE (INR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>29.22</td>
<td>2018</td>
</tr>
<tr>
<td>2003</td>
<td>31.65</td>
<td>2019</td>
</tr>
<tr>
<td>2004</td>
<td>35.78</td>
<td>2020</td>
</tr>
<tr>
<td>2005</td>
<td>40.24</td>
<td>2021</td>
</tr>
<tr>
<td>2006</td>
<td>45.68</td>
<td>2022</td>
</tr>
<tr>
<td>2007</td>
<td>43.02</td>
<td>2023</td>
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<tr>
<td>2008</td>
<td>47.23</td>
<td>2024</td>
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<td>2009</td>
<td>42.65</td>
<td>2025</td>
</tr>
<tr>
<td>2010</td>
<td>51.56</td>
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<tr>
<td>2011</td>
<td>63.92</td>
<td>2027</td>
</tr>
<tr>
<td>2012</td>
<td>68.83</td>
<td>2028</td>
</tr>
<tr>
<td>2013</td>
<td>69.13</td>
<td>2029</td>
</tr>
<tr>
<td>2014</td>
<td>69.38</td>
<td>2030</td>
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<td>2015</td>
<td>61.78</td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>62.74</td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td>68.06</td>
<td></td>
</tr>
</tbody>
</table>
3.4.3 DIESEL PRICES

The estimation of Diesel prices (2018 to 2030) is done on the basis of data of Diesel Prices (2002 to 2017) available from Petroleum Planning and Analysis Cell site. For the prediction of the upcoming years (2018 to 2030), we used exponential trend line model, as it was providing the best quality results as compared to other models in Tableau Data Visualization Tool. The equation of the trend line curve can be seen in figure 5, i.e. $8.5761e-62 \times \exp(0.0717496 \times \text{Year})$.

Table 4: Actual and Forecasted Diesel Cost

<table>
<thead>
<tr>
<th>YEAR</th>
<th>ACTUAL AVERAGE PRICE (INR)</th>
<th>FORECASTED AVERAGE PRICE (INR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>18.35</td>
<td>2018</td>
</tr>
<tr>
<td></td>
<td></td>
<td>65.33</td>
</tr>
<tr>
<td>2003</td>
<td>20.30</td>
<td>2019</td>
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<tr>
<td></td>
<td></td>
<td>70.19</td>
</tr>
<tr>
<td>2004</td>
<td>23.07</td>
<td>2020</td>
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<tr>
<td></td>
<td></td>
<td>75.40</td>
</tr>
<tr>
<td>2005</td>
<td>28.39</td>
<td>2021</td>
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<tr>
<td></td>
<td></td>
<td>81.01</td>
</tr>
<tr>
<td>2006</td>
<td>31.61</td>
<td>2022</td>
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<tr>
<td></td>
<td></td>
<td>87.04</td>
</tr>
<tr>
<td>2007</td>
<td>30.31</td>
<td>2023</td>
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<tr>
<td></td>
<td></td>
<td>93.51</td>
</tr>
<tr>
<td>2008</td>
<td>32.97</td>
<td>2024</td>
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<tr>
<td></td>
<td></td>
<td>100.47</td>
</tr>
<tr>
<td>2009</td>
<td>31.88</td>
<td>2025</td>
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<tr>
<td></td>
<td></td>
<td>107.95</td>
</tr>
<tr>
<td>2010</td>
<td>38.12</td>
<td>2026</td>
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<tr>
<td></td>
<td></td>
<td>115.98</td>
</tr>
<tr>
<td>2011</td>
<td>40.27</td>
<td>2027</td>
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<tr>
<td></td>
<td></td>
<td>124.60</td>
</tr>
<tr>
<td>2012</td>
<td>43.52</td>
<td>2028</td>
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<td></td>
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<td>133.87</td>
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<tr>
<td>2013</td>
<td>50.62</td>
<td>2029</td>
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<tr>
<td></td>
<td></td>
<td>143.83</td>
</tr>
<tr>
<td>2014</td>
<td>55.49</td>
<td>2030</td>
</tr>
<tr>
<td></td>
<td></td>
<td>154.53</td>
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<tr>
<td>2015</td>
<td>57.64</td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>50.93</td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td>56.78</td>
<td></td>
</tr>
</tbody>
</table>
HYDROGEN PRICES

The prices of hydrogen are calculated from the model mentioned by Balachandra et.al [9]. The prices mentioned in table 5 are calculated by taking in mind the production is done by Electrolysis in a central plant having production capacity of 150 tonnes per day, stored in compressed form and transported by truck to refuelling stations. Each trip is considered to be of 300 km each side. All other costs are kept constant in the model except the kWh cost and diesel costs, which are taken according to our forecasted values. Following are the methods used to calculate:

- TEC ~ Total Electricity Consumption
- VNFC ~ Variable Non-Fuel O&M Cost
- FOC ~ Fixed Operating Cost per year
- CC ~ Capital Charges per year
- HPR/H ~ Hydrogen Production Rate per hour
- CWC ~ Cooling Water Cost
- AFU ~ Annual Fuel Usage
- NT ~ Number of Trips
- ALC ~ Annual Labour Cost
- VOC ~ Variable Operating Cost
- TNS ~ Total Number of Stations

**PRODUCTION COST**

\[
\text{PRODUCTION COST} = \frac{\text{TEC} \times \text{kWh cost} \times \frac{\text{Days/year}}{1000000} + \text{VNFC} + \text{FOC} + \text{CC} \times \frac{\text{HPR/H} \times 24 \times \text{Days/year}}{1000000}}{1000000}
\]

Where,

- TEC = 8218500 kWh/Day
- VNFC = 205 Million INR/year
- FOC = 617 Million INR/year
- CC = 2468 Million INR/year
- HPR/H = 6250 kg/hr
- Days/year = 328

*The above values for production cost calculation are taken from Table 2 of “Hydrogen Energy For Indian Transport Sector: A Well-To-Wheel Techno-Economic and Environmental Feasibility Analysis” [9] except HPR/H which is taken from Table 1 of same paper.

**STORAGE COST**

\[
\text{STORAGE COST} = \frac{(\text{TEC} \times \text{kWh cost} + \text{VNFC} + \text{FOC} + \text{CWC}) \times \frac{\text{CC}}{\text{HPR/H} \times 24 \times \text{Days/year}}}{1000000}
\]

Where,

- TEC = 108640000 kWh/year
- VNFC = 34.5 Million INR/year
- FOC = 103.5 Million INR/year
- CWC = 2.05 Million INR/year
- CC = 414.2 Million INR/year
- HPR/H = 6250 kg/hr
- Days/year = 328

*The above values for storage cost calculation are taken from Table 3 of “Hydrogen Energy for Indian Transport Sector: A Well-To-Wheel Techno-Economic and Environmental Feasibility Analysis” [5] except HPR/H which is taken from Table 1 of same paper.

**TRANSPORTATION COST**

\[
\text{TRANSPORTATION COST} = \frac{\text{AFU} \times \text{1.5} \times \text{1000DIESEL COST}}{\text{HPR/H} \times 24 \times \text{Days/year}} \times 1000000
\]

*The above values for transportation cost calculation are taken from Table 3 of “Hydrogen Energy for Indian Transport Sector: A Well-To-Wheel Techno-Economic and Environmental Feasibility Analysis” [5] except HPR/H which is taken from Table 1 of same paper.
To calculate the annual cost of fuel for Hyundai Nexo, annual mileage (km), range (km) from Table 1 and hydrogen prices from Table 3 are considered. Firstly, the fuel consumed per year is calculated by “Annual Mileage (12,200 km)/mileage (17 kmpL)”. To get annual cost, “(fuel consumed per year) * (petrol price of particular year)” is used.

**AFC = \( \frac{\text{TEC} + \text{VOC} + \text{FOC}}{\text{TNS} \times \text{Days/year}} \)**

Where,

- TEC = 1,20,075 kWh/year
- VOC = 1,04,695 INR/year
- FOC = 6,28,170 INR/year
- CC = 25,12,679 INR/year

To calculate the annual cost of fuel for Tata Nexon EV, annual mileage (km), mileage (kmpl) from Table 1 and kWH prices from Table 2 are considered. Firstly, number of charges per year is calculated by “Annual mileage (12,200 km)/Range per charge(300km)”, which came out to be 40.67. To calculate annual cost, “40.67 * 30 * kWh price” is used. Here, 30 is the battery capacity of Tata Nexon EV in kWh. ss

**AFC = \( \frac{\text{TEC} + \text{VOC} + \text{FOC}}{\text{Range (km)}} \)**

To calculate the annual cost of fuel for Hyundai Nexo, annual mileage (km), range (km) from Table 4 are considered. Firstly, number of refuelling per year is calculated by “Annual mileage (12,200 km)/Range (593 km)”, which came out to be 20.57. To calculate annual cost, “20.57 * 6.33 * hydrogen price” is used. Here, 6.33 is the fuel tank capacity of Hyundai Nexo in kg.

**AFC = \( \frac{\text{CC} + \text{VNF} + (\text{TEC} \times \text{KWH COST}) + \text{VOC} + \text{FOC}}{\text{TNS} \times \text{Days/year}} \)**

Where,

- TEC = 4,64,950 INR/year
- VOC = 6,28,170 INR/year
- FOC = 6,250 INR/hr
- Days/year = 328

The annual cost of fuel per year is shown in the Table 6. To calculate the annual cost of fuel for Tata Nexon, annual mileage (km), mileage (kmpl) from Table 1 and petrol prices from Table 3 are considered. Firstly, the fuel consumed per year is calculated by “Annual Mileage (12,200 km)/mileage (17 kmpL)”. To get annual cost, “(fuel consumed per year) * (petrol price of particular year)” is used.

**AFC = \( \frac{\text{TEC} + \text{VOC} + \text{FOC}}{\text{Days/year}} \)**

Where,

- TEC = 1,20,075 kWh/year
- VOC = 1,04,695 INR/year
- FOC = 6,28,170 INR/year
- CC = 25,12,679 INR/year

To calculate the annual cost of fuel for Hyundai Nexo, annual mileage (km), range (km) from Table 1 and hydrogen prices from Table 4 are considered. Firstly, number of refuelling per year is calculated by “Annual mileage (12,200 km)/Range (593 km)”, which came out to be 20.57. To calculate annual cost, “20.57 * 6.33 * hydrogen price” is used. Here, 6.33 is the fuel tank capacity of Hyundai Nexo in kg.

**AFC = \( \frac{\text{TEC} + \text{VOC} + \text{FOC}}{\text{Range (km)}} \)**

**Table 5. Cost of Hydrogen in segments**

<table>
<thead>
<tr>
<th>YEAR</th>
<th>PRODUCTION (INR/kg)</th>
<th>STORAGE (INR/kg)</th>
<th>TRANSPORT (INR/kg)</th>
<th>REFUELLING (INR/kg)</th>
<th>TOTAL (INR/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2021</td>
<td>453.14</td>
<td>26.83</td>
<td>120.87</td>
<td>33.70</td>
<td>634.54</td>
</tr>
<tr>
<td>2022</td>
<td>475.06</td>
<td>27.72</td>
<td>128.57</td>
<td>34.06</td>
<td>665.39</td>
</tr>
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<td>2023</td>
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<td>28.64</td>
<td>136.83</td>
<td>34.43</td>
<td>697.97</td>
</tr>
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<td>2024</td>
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<td>29.64</td>
<td>145.71</td>
<td>34.83</td>
<td>732.90</td>
</tr>
<tr>
<td>2025</td>
<td>548.47</td>
<td>30.67</td>
<td>155.27</td>
<td>35.25</td>
<td>769.66</td>
</tr>
<tr>
<td>2026</td>
<td>576.42</td>
<td>31.80</td>
<td>165.52</td>
<td>35.70</td>
<td>809.44</td>
</tr>
<tr>
<td>2027</td>
<td>604.91</td>
<td>32.95</td>
<td>176.53</td>
<td>36.16</td>
<td>850.54</td>
</tr>
<tr>
<td>2028</td>
<td>635.59</td>
<td>34.19</td>
<td>188.36</td>
<td>36.66</td>
<td>894.80</td>
</tr>
<tr>
<td>2029</td>
<td>667.92</td>
<td>35.49</td>
<td>201.08</td>
<td>37.18</td>
<td>941.67</td>
</tr>
<tr>
<td>2030</td>
<td>702.43</td>
<td>36.88</td>
<td>214.74</td>
<td>37.74</td>
<td>991.80</td>
</tr>
</tbody>
</table>

To calculate the annual cost of fuel for Tata Nexon EV, annual mileage (km), range (km) from Table 2 are considered. Firstly, number of charges per year is calculated by “Annual mileage (12,200 km)/Range per charge(300km)”, which came out to be 40.67. To calculate annual cost, “40.67 * 30 * kWh price” is used. Here, 30 is the battery capacity of Tata Nexon EV in kWh.ss

**AFC = \( \frac{\text{TEC} + \text{VOC} + \text{FOC}}{\text{Range (km)}} \)**

Where,

- TEC = 4,64,950 INR/year
- VOC = 6,28,170 INR/year
- FOC = 6,250 INR/hr
- Days/year = 328

**Table 6. Fuel Cost /Year**

<table>
<thead>
<tr>
<th>YEAR</th>
<th>TATA NEXON</th>
<th>TATA NEXON EV</th>
<th>HYUNDAI NEXO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Petrol price</td>
<td>Annual Cost</td>
<td>kWh Price</td>
</tr>
<tr>
<td>2021</td>
<td>96.38</td>
<td>69,166.82</td>
<td>7.05</td>
</tr>
<tr>
<td>2022</td>
<td>102.04</td>
<td>73,228.71</td>
<td>7.45</td>
</tr>
<tr>
<td>2023</td>
<td>108.04</td>
<td>77,534.59</td>
<td>7.87</td>
</tr>
<tr>
<td>2024</td>
<td>114.39</td>
<td>82,091.65</td>
<td>8.32</td>
</tr>
<tr>
<td>2025</td>
<td>121.11</td>
<td>86,914.24</td>
<td>8.79</td>
</tr>
<tr>
<td></td>
<td>3,889,36</td>
<td>48,165.6</td>
<td>44,55,788.26</td>
</tr>
<tr>
<td>2026</td>
<td>128.23</td>
<td>92,023.88</td>
<td>9.30</td>
</tr>
<tr>
<td>2027</td>
<td>135.77</td>
<td>97,434.94</td>
<td>9.82</td>
</tr>
<tr>
<td>2028</td>
<td>143.75</td>
<td>1,03,161.77</td>
<td>10.38</td>
</tr>
<tr>
<td>2029</td>
<td>152.20</td>
<td>1,09,225.88</td>
<td>10.97</td>
</tr>
</tbody>
</table>
Table 7. 5 year ownership cost

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Vehicle Price</th>
<th>Fuel Cost</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tata Nexon</td>
<td>11,46,000</td>
<td>3,88,936</td>
<td>15,34,936</td>
</tr>
<tr>
<td>Tata Nexon EV</td>
<td>16,40,000</td>
<td>48,165.6</td>
<td>16,88,165.6</td>
</tr>
<tr>
<td>Hyundai Nexo</td>
<td>65,00,000</td>
<td>4,55,788</td>
<td>69,55,788</td>
</tr>
</tbody>
</table>

Table 8. 10 year ownership cost

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Vehicle Price</th>
<th>Fuel Cost</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tata Nexon</td>
<td>11,46,000</td>
<td>8,02,347</td>
<td>19,48,347</td>
</tr>
<tr>
<td>Tata Nexon EV</td>
<td>16,40,000</td>
<td>1,11,690</td>
<td>17,51,690</td>
</tr>
<tr>
<td>Hyundai Nexo</td>
<td>65,00,000</td>
<td>10,40,195</td>
<td>75,40,195</td>
</tr>
</tbody>
</table>

4. RESULTS

Tata Nexon comes out to be the cheapest option when vehicle price is considered as compared to the other two cars. But when total cost of ownership (vehicle price along with fuel prices) is considered, figure 6 shows that Tata Nexon’s and Tata Nexon EV’s total ownership cost becomes pretty much same in seventh year of ownership (see 2027 in figure 6). This can equal up in fifth or sixth year if one consider the subsidies by the government and maintenance costs. Fuel prices would be a major concern for conventional ICE vehicle buyer, because the fuel price may see a hike in future above our predicted price as government has to keep up to Paris Agreement 2016 as mentioned by Gilmore and Patwardhan 2016 [19]. But at the end of ten years Tata Nexon EV appears to be the most economical option. Hyundai Nexo comes out to be the most expensive option without any subsidies or incentive from manufacturer. It seems from figure 6 that Nexo is a luxury vehicle competing with some compact SUV class.

Figure 6. Ownership Costs of vehicles

5. CONCLUSION

Although the ownership cost of Tata Nexon EV comes out to be more than that of Tata Nexon in 5 years but after considering the subsidies by government, the total cost of ownership will equal up in fifth or sixth year instead of seventh. So, it is quite clear from the figure 6 that those who want to own a car for short time period (<5years) they must consider Tata Nexon a better choice from our analysis. But if a buyer wants to own a vehicle for 10 years Nexon EV comes out to be the best option.

Hyundai Nexo seems to be the out of league at the end of analysis as its ownership cost comes out to be approximately 4 folds than the two competitors. If Hyundai launches the Nexo at the estimated price in India, it would be out of reach of any middle class Indian. Government has to wave of import taxes on the Nexo along with providing a hefty subsidy to promote this vehicle. Along with all these financial helps, it requires a network of hydrogen refuelling stations. Right now there is only two refuelling stations in India – one at Indian Oil R&D Centre, Faridabad and the other at National Institute of Solar Energy, Gurugram. As per Sierzchula et al 2014 [30], these factors can be opposing Hyundai Nexo in Indian Market – little presence of refuelling Infrastructure, foreign vehicle manufacturer etc.
REFERENCES


