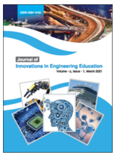

Journal of Innovations in Engineering Education
JIEE 2021, Vol. 4, Issue 2, pp 16-31.

https://doi.org/10.3126/jiee.v4i2.35359

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Analysis of total cost of ownership and cost competitiveness of privately-owned electric vehicles in Nepal

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ARTICLE INFO

Article history:

Received 01 Mar 2021
Received in revised form
30 Aug 2021
Accepted 02 Sept 2021

Keywords:

Electric vehicle
Cost comparison
Electric vehicle policy
Electric vehicles adoption
Total ownership cost (TCO)

Abstract

The fossil fuel has been the dominant power source of the transportation all over the world in the past centuries. With the development of electric powertrain technology and growing concern over the detrimental effects of fossil fuel like greenhouse gas emission, the transport sector is transforming to electric globally. The Government of Nepal has also announced different policy measures as well as national plans to adapt to this growing trend of electric vehicle (EV) adoption. Since EVs are considered to have higher capital cost compared to the internal combustion engine vehicles (ICEV), the operational cost differs significantly due to the different maintenance cost, electricity prices and separate tax policies. In this study, a model to calculate the total ownership cost of EVs and their ICEV counterparts is developed. The different parameters like purchase price, annual kilometer travel (AKT), annual tax and insurances, fuel and electricity prices, annual maintenance cost etc. are used to estimate the total cost of ownership per km (TCO/km) for the two wheeler EVs and ICEVs (E2W, ICE2W) and four wheeler EVs and ICEVs (E4W, ICE4W) along with different policies imposed by the government for such vehicles in two different scenario (i.e., before and after finance act 2020/2021). The sensitivity analysis of input parameters and the breakeven distance that makes EVs economical than ICEVs is also calculated.

Abbreviations and acronyms

Rs. : Rupees

Km : Kilometer

HB : Hatchback

kWh : Kilo Watt Hour

EV : Electric Vehicle

NPR : Nepalese Rupees

MUV : Multi Utility Vehicle

SUV : Sport Utility Vehicle

E2W : Electric Two Wheeler

DCF : Discounted Cash Flow

E4W : Electric Four Wheeler

BEV : Battery Electric Vehicle

TCO : Total Cost of Ownership

ICEV : Internal Combustion Engine Vehicle

ICE2W : Internal Combustion Engine Vehicle Two Wheeler

ICE4W : Internal Combustion Engine Vehicle Four Wheeler

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1. Introduction

The history of electric vehicles in Nepal dates back to 1970s when the trolley bus operation was started in Kathmandu with Chinese help but the real growth and diversification of EVs took in 1993 with the initiative of the GRI (Global Resources Institute) which proposed to convert all diesel or petrol powered tempos into battery powered electric tempos [1]. But the opposition from fossil-fuel interest groups, failed management, and the lack of support networks without long-term vision and commitment from all EV stakeholders, EV development couldn't be sustainable and played a large role in creating impediments. The analysis of these impediments revealed some of the policy and player dynamics of EV technology development [2].

A study [3] to assess the effects electrified mass transport system and electric vehicles with the help of bottom up energy system model of Nepal based on the MARKAL framework showed that if the share of electricity based transport services was to grow from 10% in 2015 to 35% by 2050, the hydropower generation capacity would have to increase by 495 MW by 2050. The same study also concluded that the cumulative total imported energy would decrease by 14.6% in the 35% transport electrification scenario as compared to the base case during 2015–2050. In addition, the cumulative greenhouse gas emissions would be reduced by 12.9% (74.7 million tons CO_2e) in the same scenario during 2015–2050. A case study from the USA market [4], with economic and technological analysis of the key factor affecting the competitiveness electric commercial vehicles showed that only in scenarios with high utilization (over 60 miles driven per day or 16,000 miles per year per truck) the electric vehicles are competitive. This is especially valid if a battery replacement is required before the electric commercial vehicle is replaced. The breakeven analysis results show that a 9% to 27% EV price reduction can greatly increase their competitiveness when vehicles are driven over 12,000 miles per year, even if the diesel truck fuel economy is as high as 13.46 Miles per Gallon. The study on incentives for promoting battery electric vehicles in Norway [5] was done in order to investigate the role of incentives based on data with a diverse group of BEV users from a market with relatively high BEV penetration. The analyses showed that there were clear delineations between incentive groups, both in terms of age, gender, and education. Income was a less prominent predictor, which probably results from the competitive price of BEVs in the Norwegian market. Another study done on the cost of batteries for electric vehicles [6] showed that the costs of Li-ion battery packs continue to decline and that the costs among market leaders are much lower than previously reported. The economic competitiveness of electric vehicles in Chinese market by comparing the life-cycle private costs (LCPCs), life-cycle social costs (LCSCs) and vehicle emission costs of existing BEV models with comparable conventional internal combustion engine vehicles (ICEVs) [7] showed that BEVs likely will not be economically competitive in the Chinese market before 2031. Although, the time horizon projected by the research is too far, these studies can be beneficial for lowering that predicted the benchmark through technological advancement and proper policy implementation. The study on the competitiveness of EU automotive industry [8] in electric vehicles underlines that the European automotive industry will play a major role in the transition to electro-mobility. According to the results of the market model, about 7 percent of the EU 27, new vehicle registrations will be electric vehicles in 2020, while a share of 31 percent can be expected in 2030, including passenger cars and light commercial vehicles. While some results reveal that electric four-wheelers are not a feasible option in developing countries [9] due to their high purchase price, on the contrary, electric two-wheelers may be beneficial as they come with a lower purchase price. A linear regression model analyzing the electric vehicle adoption of 30 countries in 2012 [10] showed that financial incentives, charging infrastructure and local presence of production facilities to be significant and positively correlated to a countr's electric vehicle market share. According to the same research, socio-demographic variables e.g., income and education level were not significant and country specific factors help to explain diversity in national adoption rates. There are numerous factors that push and pull the equilibrium state of the established market of EVs as compared to traditional ICEV. There are several driving forces associated with EVs' adoption, such as the reduction in greenhouse gas emissions (GHG), efficient energy use, gasoline savings and low operational cost. The resisting forces influencing the acceptance of EVs include high purchase price, inadequate range, slow charging and new production adoption anxiety [11]. A probabilistic model [12] calculated the TCO/km for the market of Germany for years 2014, 2020 and 2025 using Monte Carlo simulations to analyze distributions and probabilities of outcomes which concluded that comparative cost efficiency of EV highly depends on the annual driving distance and the vehicle class. Another team of researchers [13] in 2018 calculated and compared TCO for electric, hybrid, petrol and diesel vehicles for UK, USA and Japan from 1997 to 2015 and concluded that hybrids were cheaper in 2015 than the year of introduction which showed strong correlation with their relative TCO. Also, for the fuel price of that time in UK, hybrids reached cost parity at 16,000 miles. A TCO model targeted in Germany [14] demonstrated its validity comparing it with ICEVs (BEVs and HEVs) including the battery resale value for the second use and second life. Using Monte Carlo simulation under various scenarios, the result revealed that only few EVs were economical without subsidies and concluded that subsidies support competitiveness of EVs but fail to lead to favorable TCO within several vehicle segments.

Regarding the promotion of EVs in Nepal, the country is still in the early phase of the adoption. Hence there are only few literatures available regarding the comprehensive analysis of cost and public perception of EVs. A research conducted in 2019 [15] examined the principal factors that can uplift the growth of electric vehicles in Nepal using system dynamics. Based on public expectations from government in terms of vehicle infrastructure and attributes, situation and policies, the research concluded with the simulation that choice of policies and infrastructure development from the government side could significantly raise the EVs adoption in Kathmandu valley. A case study [16] to explore the barriers and opportunities to electric vehicle development in Nepal summarized the development of EVs by the failure to appeal to a wider demographic and lack critical infrastructure for mass public participation. Although there are opportunities of economic independence and environmental benefits, there are major technological barriers like infrastructure, misconception and unaffordability for the market penetration of EVs and mass participation. The Global Green Growth Institute has worked in the sector of electric mobility in Nepal, based inside the Kathmandu valley. One of its works focuses on the financial feasibility of operating electric mid-sized buses in routes servicing the UNESCO world heritage sites in Kathmandu valley [17]. The study was conducted on non-profit public transport operator (NPTO) and private sector transport operator (PSTO) considering capital expenditure (CAPEX), operating expenses (OPEX) and passenger demand and fare. It concluded that the NPTO will be able to accrue saving to purchase replacement batteries at the 8th year of operation but will not be able to extend the life of the vehicle beyond 15 years. On the other hand, it will be an attractive proposition for private sector operators (PSTO) to invest in the electric buses with the projected internal rate of return (IRR) estimated to be 14% and the equity internal rate of return (EIRR) estimated to be 18%. A TCO model developed for the Indian transportation sector [18] calculated the TCO of EVs with different fuel variants (petrol, diesel and compressed natural gas [CNG]) of ICE counterparts in India. The TCO model showed that the TCO per km of electric two-wheelers (e-2Ws) and electric three-wheelers (e-3Ws) was less than their ICE counterparts whereas the TCO per km of electric cars (e-cars) was higher than their ICE counterparts in case of hatchback and sedan cars. Also, the TCO per km of electric bus (e-bus) was higher than diesel and CNG buses because of high initial purchase cost.

2. Limitations

The location, price of vehicles, fuel and electricity cost, tax rates and driving habits were assumed to be of Kathmandu valley only. All the discounts while purchasing the vehicles and the free vehicle servicing were ignored. While estimating the life cycle cost of vehicles, the efficiency and performance parameters were assumed fixed over the vehicle ownership time. Due to the resource constraint on the total numbers of registered or sold EVs in Kathmandu valley (official records of registered vehicles according to the fuel types was unavailable from the Department of Transport Management and some EVs dealers refused to provide their sales records), the primary data collection was done in order to gather as many numbers of respondents as possible within the time frame of the research period and the number was 120. From primary data collection through survey forms, the average travel distance per year of the two wheelers and four wheelers vehicle was estimated to be 10,000 km. The vehicle ownership time was fixed at 10 years.

3. Methodology

3.1. Scope and Data

The scope of study is focused in the market of Nepal with the costs, policies and driving statistics of Kathmandu valley specifically. Due to the lack of official records of vehicle driving statistics, a survey was conducted with the sample size of 120 people living inside Kathmandu valley in order to calculate the driving statistics of people and common two wheelers and four wheelers EVs and ICEVs available in the market. In the sample size, 16.67% were two wheeler EV owners, 38.33% were two wheelers ICEV owners, 13.33% were four wheeler EV owners, 10.83% were four wheelers ICEV owners with diesel fuel and 20% were four wheeler ICEV owners with petrol fuel. The average annual kilometer travel was estimated to be 10000 km. Using the answers from questionnaire, personal judgment and currently available and most preferred vehicles according to the dealers, EVs and ICEVs of different price range and specifications were selected. The four wheeler vehicles (E4W and ICE4W) were selected with the different price range and specifications (hatchbacks, SUV, MUV) in order to reflect the diversity. In the case of two wheelers (E2W and ICE2W), only scooters were selected due to their prevalence in the EV segment. The different types and segments of vehicles selected for the study are shown in Table 1 and 2. The vehicle prices and specifications provided by the dealers are used as the reference for the different vehicle performance parameters and categorization. Regarding the tax policy of policy of government for different segments of EVs and ICEVs, the rate varies according to the engine capacity (cc) for ICEVs whereas for EVs, it's the motor power of the vehicle. The different annual vehicle tax rates are presented in Table 3 and 4. The other specifications of the vehicles are shown in **Appendix A** and **Appendix B**.

Table 1: EV selection

Four Wheeler	The Go e8	Hatchback
	Mahindra e20 Plus P4	Hatchback
	MG ZS EV	SUV
	BYD M3 Van (7 seater)	Van
	Hyundai KONA Electric (39.2 kWh)	SUV
	Kia Niro EV 2020	SUV
Two Wheeler	NIU N Series	scooter
	Super Soco CUx	scooter
	Terra Eco(Li-ion)	scooter
	TAILG Leopard	scooter

Table 2: ICEV selection

Four Wheeler (Petrol)	Suzuki S-Presso	Hatchback
	Volkswagen polo Trendline	Hatchback
	Hyundai Grand i10 Sportz AT	Hatchback
	Ford EcoSport Trend	SUV
	Kia Sportage (LX PTL)	SUV
	Hyundai Tucson GL MT 4WD (Petrol)	SUV
Four Wheeler (Diesel)	Tata Tiago	Hatchback
	Maruti Suzuki S Cross Delta	SUV
	Ford EcoSport Trend	SUV
	Hyundai Creta SX	SUV
	KIA Carnival	SUV
	Toyota Innova Crysta GX	SUV
Two Wheeler (Petrol)	Hero Pleasure	scooter
	Honda Dio	scooter
	TVS NTorq (Race Edition)	scooter
	Aprilia SR	scooter

Table 3: Annual vehicle tax for EVs [19]

TWMP (watt)	**AVT** (Rs.)	**FWMP** (kW)	**AVT** (Rs.)
350 - 1000	1500	50 - 125	15000
1001 - 1500	2000	126 - 225	20000
$\geqslant$ 1501	3000	$\geqslant$ 226	30000

Where,

TWMP : Two Wheeler Motor Power

AVT : Annual Vehicle Tax

FWMP : Four Wheeler Motor Power

Where,

Table 4: Annual vehicle tax for ICEVs [19]

TW (CC)	**AVT** (Rs.)	**FW** (CC)	**AVT** (Rs.)
$\leqslant$ 125	2800	$\leqslant$ 1000	21000
125 - 160	4500	1001 - 1500	23500
161 - 250	5500	1501 - 2000	25500
251 - 400	9000	2001 - 2500	35500
401 - 650	20000	2501 - 2900	41000
$\geqslant$ 651	30000	$\geqslant$ 2901	58500

TW : Two Wheeler

AVT : Annual Vehicle Tax

FW : Four Wheeler

For the price of petrol and diesel, Kathmandu region has been taken into consideration. The price of petrol and diesel as of 2021-02-11 has been taken into consideration which are Rs. 112 per liter and Rs. 95/liter respectively [20]. The electricity charge per unit for the charging stations was updated by ERC (Electricity Regulatory Commission) from Rs. 10 to Rs. 5.6 [21] and the same value was taken for the TCO calculation.

3.2. TCO model

TCO analysis helps in understanding the true cost of buying goods or services over its useful life [22]. There are two important components of the TCO model: Capital Expenditure (Capex) and Operational Expenditure (Opex). The capital expenditure represents one-time buying cost of EVs whiles the operational expenditure includes operational and maintenance (O& M) cost, labor cost, fuel etc. In this report, TCO per km of travel is calculated by using the model of Geng et al., [12]. The following equation represents the TCO/km.

$$\begin{aligned}\frac{\mathrm{TCO}}{\mathrm{km}} &= \frac{\mathrm{CRF}}{\mathrm{AKT}}\left[\left(\mathrm{PC}-\frac{\mathrm{RV}}{(1+\mathrm{r})^{\mathrm{N}}}\right)\right] \\ &+ \frac{1}{\mathrm{AKT}}\left[\frac{1}{\mathrm{N}}\sum_{N=1}^{N}\frac{\mathrm{AOC}}{(1+\mathrm{r})^{\mathrm{N}}}\right]\end{aligned} \tag{1}$$

Where,

PC : Purchase cost of the vehicle

RV : Residual value of the vehicle at the end of vehicle life

CRF : Capital recovery factor

AOC : Annual operating cost of the vehicle

r : Discount factor

N : Lifetime of the vehicle (years)

AKT : Annual kilometer travel

The calculation formula [12] for capital recovery factor is shown in Eq. 2.

$$RF = \frac{r(1+r)^N}{(1+r)^N - 1} \tag{2}$$

In order to calculate the residual value, depreciation rate of 20% is taken as reference which is set by the Inland Revenue Department for the category of automobiles, buses and minibuses [23]. The reducing balance method is used to calculate the amount of depreciation in each successive year.

The operational cost involves the cost occurred in different operational activities like fuel/electricity, maintenance, taxes and insurance, battery replacement (for EVs), tyre replacement etc. over the life-time of the vehicle ownership. The average annual operating cost (AOC) includes all those future cost into account with the use of a discount rate.

The yearly maintenance cost was estimated from the questionnaire. Total maintenance period in a year was multiplied with average maintenance cost per period to get the total maintenance cost in a year. The annual maintenance cost was divided by the annual kilometer travel in order to calculate the maintenance cost per kilometer. Since more travel distance also causes more maintenance cost, the ratio of maintenance cost per kilometer was used for the estimation of maintenance cost in various annual kilometer travel (AKT) scenarios. The annual maintenance cost per km for the different vehicle segments were found to be Rs. 0.3/km for E4W, Rs. 1.5/km for ICE4W, Rs. 0.2/km for E2W and Rs. 0.75/km for ICE2W. The maintenance costs of EVs are lower because of fewer moving parts and saves on oil and lubrication costs. The annual maintenance cost for the total vehicle ownership period was assumed to be constant.

In this study, only the third party insurance is taken into the calculation model which is made mandatory by the government [24]. In order to understand and estimate the current rates of the third party insurance, an online calculator provided by an insurance company [25] was used.

Since the battery cost for the future years are not available currently, different literatures were used for the future price of battery. A research by Bloomberg New Energy Finance (BNEF) [26] predicted that the price of Li-ion battery packs in general would fall around \$94/kWh by 2024 and \$62/kWh by 2030. The same battery price was used in the calculation. For the tyre cost, there are differently priced tyres available by different manufacturers for the same vehicle model. So, the cost was estimated by taking a reasonable value among the current market prices. The four wheeler's tyre price was fixed at Rs. 10000 per piece for all the vehicles. For the two wheelers, it was set at Rs. 2000 per piece.

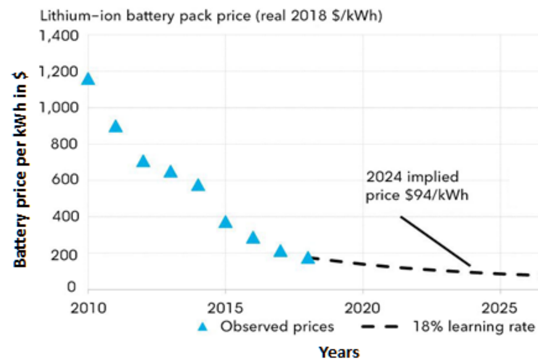

Figure 1: Lithium-ion battery price outlook (BNEF)

The battery replacement time for EVs was fixed at the 5th year of ownership taking the average of battery warranty from manufacturers 2 years to 8 years for different EV models. The tyre replacement time was fixed at 4th and 8th year of ownership for both EVs and ICEVs.

3.3. Multiple scenarios

In order to estimate the effects of different government policies, driving conditions, operating prices and interest rates, multiple scenarios were prepared by changing the input parameters.

3.3.1. Base case scenario

This scenario represents the basic case of the calculation with which other scenarios are compared. This scenario consists of current purchase price of vehicles with current governmental policies. Other parameters set in this scenario are shown in Table 5.

Table 5: Parameters set in scenario

Annual Kilometer Travel (AKT)	10000 km
Discount Rate (r)	10%
Total ownership period (N)	10
Residual Value Factor	10.74%
Per Unit Electricity Price	Rs. 5.6
Fuel Price (Petrol)	Rs. 112
Fuel Price (Diesel)	Rs. 95

The annual tax rates as stated in Table 3 and Table 4 are used in this scenario.

3.3.2. Multiple policies

In this case, the values of TCO/km of EVs with respect to the government policy before and after finance act 2020/21 were compared. Before the finance act 2020/21, there was no annual vehicle tax set on EVs and they used to cost lesser because of no excise duty, only 10% custom duty and 13% VAT [27]. But amid the coronavirus pandemic in 2020, the government of Nepal amended the excise duty on EVs with the Budget of FY 2020/21 (Finance Act, 2020) delivered on May 28, 2020. The amended excise duty was set according to the motor capacity of the EVs. Again after few months, the cabinet meeting revised the hefty hike in taxes on electric vehicles [28]. The change in EVs TCO/km in these two scenarios (before and after the finance act 2020/21) was obtained and analyzed.

3.3.3. Multiple AKT

The total annual kilometer travel (AKT) was changed for different driving statistics. Low, medium and high driving scenarios were set at 5000 km, 10000 km, 15000 km and 20000 km per year respectively. The purpose of this scenario was to observe the change in TCO/km with the change in AKT.

3.3.4. Multiple discount rates

The discount rate is used to reflect the time value of money from future to the present in the discounting model. The choice of the appropriate social discount rate remains a controversial issue [29]. The average lending rate of commercial banks in Nepal was 10.300% per annum from Nov 2013 to Nov 2018 as estimated by CEIC [30]. Even though discount rates are subjected to change over time, in this calculation, 10% discounting rate was assumed for the DCF model. However, varying discount rates (5% and 15%) were also used in order to analyze its effects on the total cost of ownership.

4. Result and discussion

The TCO/km values for all the selected four wheeler and two wheeler EVs and ICEVs were calculated based on the above mentioned TCO model. The calculation was carried out in a spreadsheet model with multiple scenarios.

The TCO/km for base case scenario (current tax policy) for the E4W and ICE4W is presented in the Figure 2. It can be seen that TCO/km of diesel fueled vehicles were greater than that of petrol fueled vehicles across all the vehicle segments. It's because diesel fueled vehicles are relatively higher in capital cost. The EVs shows comparable TCO/km with lower end petrol fueled vehicles while higher end EVs are near to the higher end of diesel fueled vehicle segments. That means four wheeler EVs are cheaper in hatchback section for petrol fueled ICEVs while they are expensive in SUV section. In case of the diesel fueled ICEVs, the EVs are way cheaper in hatchback section but are comparable in SUVs and MUVs section. In the case of two wheelers, the TCO/km values of EVs are relatively lower than that of ICEVs as shown in Figure 3.

4.1. Government policy analysis

The TCO/km of the four wheeler vehicles were calculated at the current government taxes with increased excise, customs duty and annual vehicle tax and also at the tax rates before the finance act 2020/21. The increase in these parameters has increased the capital cost of EVs, and also the operational cost because of the introduction of annual vehicle tax. For the given set of parameters in the base case, the TCO/km of EVs at current policy has increased as compared to the TCO/km of EVs before finance act 2020/21 as presented in Table 5. EVs of different price range were relatively cheaper at the previous tax policy.

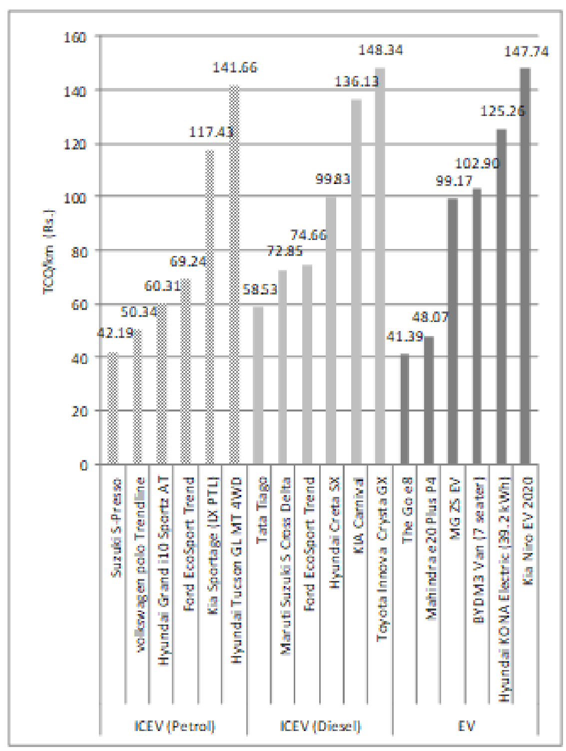

Figure 2: TCO/km of four wheeler EVs and ICEVs

4.2. TCO/km Breakdown

The TCO of EVs and ICEVs were broken down into capital cost and operational cost. The comparative analysis showed that ICEVs have lower average capital cost as compared to EVs, while EVs have lower average operational cost than ICEVs. It's because of lower main-

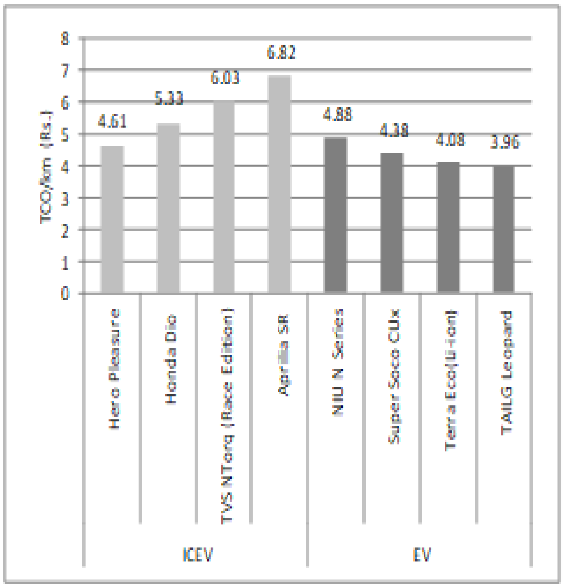

Figure 3: TCO/km of two wheeler EVs and ICEVs

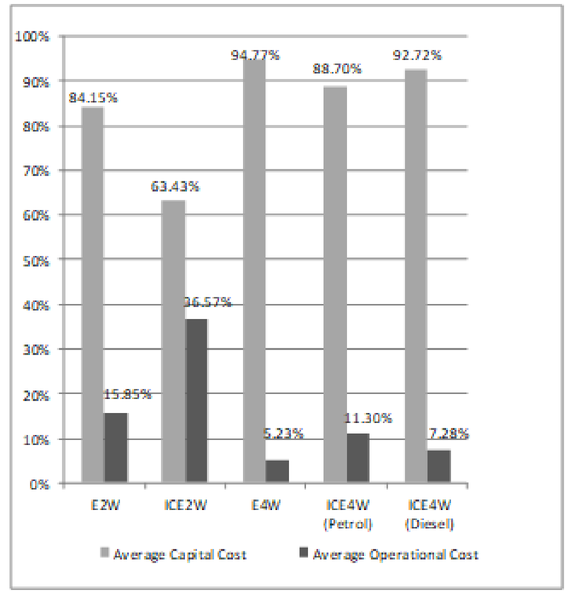

Figure 4: TCO/km breakdown

Table 6: Change in TCO/km of E4Ws due to policy change

E4W Models	TCO/km after finance act 20/21	TCO/km before finance act 20/21	% Change in TOC/km
The Go e8	41.39	32.90	25.79%
Mahindra e20 Plus P4	48.07	37.39	28.58%
MG ZS EV	99.17	82.64	19.99%
BYD M3 Van (7 seater)	102.90	86.38	19.13%
Hyundai KONA Electric (39.2 kWh)	125.26	91.58	36.78%
Kia Niro EV 2020	147.74	110.48	33.73%

tenance and electricity cost of EVs. The comparison is shown in Figure 4. For the same years of ownership, same annual kilometer travel and same factor of residual value of vehicles, EVs seem to be economical during the operational phase while ICEVs seem economical during the time of purchase.

The further breakdown in the cost composition was done in order to identify the individual cost contribution of each parameter. The operational cost was further divided into maintenance cost, fuel or electricity cost, annual tax and insurance, tyre replacement cost and one time battery replacement cost for EVs. Table 7 presents the average cost breakdown for all the vehicles considered in calculation.

Table 7: TCO/km (in Rs.) breakdown for each parameter

A	B	C	D	E	F	G
E2W	3.64	0.08	0.12	0.28	0.05	0.16
ICE2W	3.64	1.25	0.46	0.30	0.05	-
E4W	89.29	0.45	0.18	1.28	0.46	2.54
ICE4W (Petrol)	72.35	4.38	0.92	2.08	0.46	-
ICE4W (Diesel)	91.61	3.12	0.92	2.27	0.46	-

Where,

A : Vehicle Type

B : Capital Cost

C : Fuel/Electricity Cost

D : Annual Maintenance Cost

E : Annual Tax and Insurance

F : Tyre Replacement Cost

G : One Time Battery Replacement Cost

The highest portion of cost in TCO/km is taken by the capital cost for both EVs and ICEVs. The second highest contributor in cost for EVs was found to be annual tax and insurance cost and the third highest cost contributor was battery replacement cost. But for the ICEVs, the second highest cost contributor was fuel cost for the petrol fueled vehicles, whereas it was annual tax and insurance for the diesel fueled vehicles. It was due to the selection of higher engine capacity (cc) of diesel fueled vehicles in this study. It makes them fall in the higher tax category due to the higher engine capacity.

4.3. Multiple annual kilometer travel (AKT)

The TCO of vehicles depends up on the annual travel distances. The increase in travel distances increases the electricity or fuel cost and maintenance cost and the TCO/km ratio changes. In order to understand the effect of AKT, multiple driving statistics were implemented in the model as shown in Figure 5 and 6.

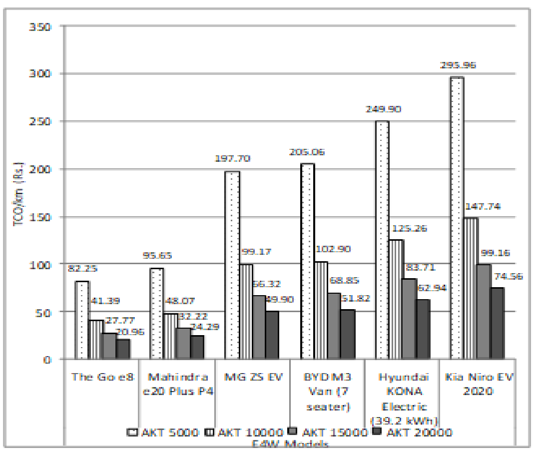

Figure 5: TCO/km for multiple AKT for E4W

The AKT of 10000 km was used in the base case scenario. Furthermore, the lower and higher AKT of 5000 km, 15000 km and 20000 km were used for the varying AKT scenario for four wheelers and two wheelers. As it can be seen from the Figure 5, TCO/km is very high and the rate of change is also sharp at the lower values of AKT. As the AKT increases, the TCO/km decreases and the rate of change is slow. In the case of two wheelers EV, TCO/km decreases and the values are nearly equal for the high travel scenario of 20000 km.

The nature of change of TCO/km with AKT is similar to that of E4W. At the lower values of AKT, TCO/km is very high but decreases sharply with the increase in AKT.

4.4. Multiple discount rates

In the base case scenario, 10% discount rate was used. In order to analyze the effects of changing discount rates, low rate of 5% and high rate of 15% were used. The TCO/km for all the four wheeler EVs and ICEVs are shown in chart 6. The high discount rate shows high TCO/km and the degree of change is higher for

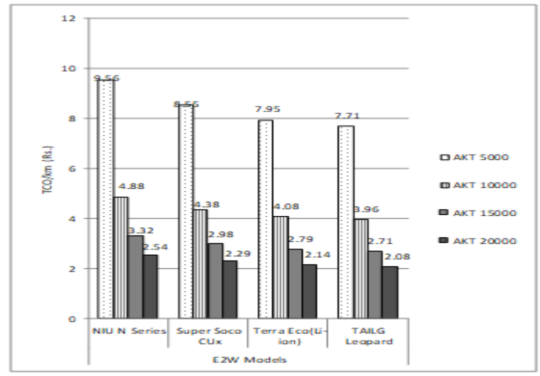

Figure 6: TCO/km for multiple AKT for E2W

the vehicles with higher purchase price for all the three categories. The E4Ws along with all the ICE4Ws are economical in lower discount rates. Similarly, Figure 7 shows the effect of different discount rates for two wheeler EVs and ICEVs. The similar effect is seen also for two wheelers. The higher interest rates caused the higher TCO/km.

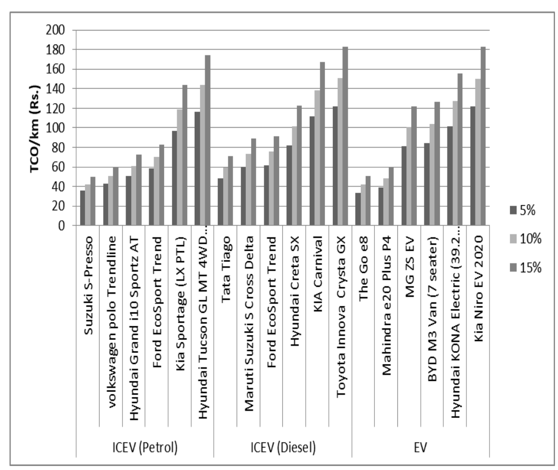

Figure 7: TCO/km of E4W and ICE4W for different discount rates

4.5. Sensitivity analysis

In order to analyze the effects of change in input parameters in TCO/km, sensitivity analysis was done. The input parameters like purchase price, annual kilometer travel (AKT), electricity price and fuel price were changed and the rates of change of TCO/km values were compared with the base case scenario.

4.5.1. Purchase price

There are scenarios when purchase price may change while purchasing the vehicle like seller's discount, government subsidies etc.

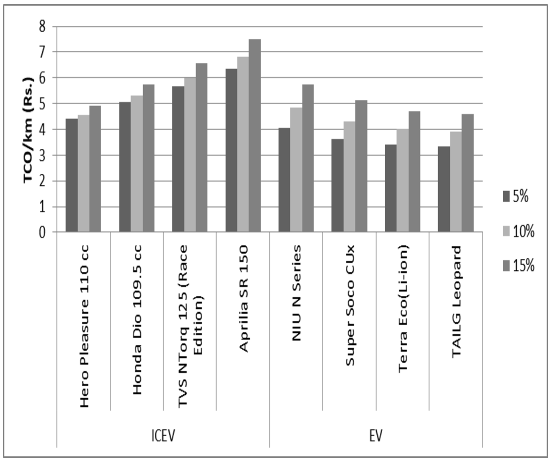

Figure 8: TCO/km of E2W and ICE2W for different discount rates

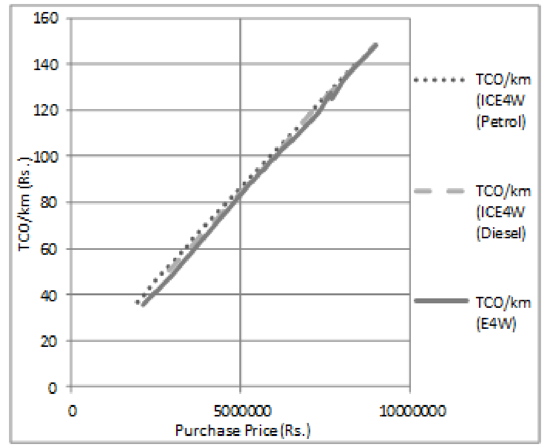

Figure 9: TCO/km change with purchase price

Table 8: Sensitivity analysis of purchase price

Vehicle Categories	Change in Purchase Price	Change in TCO/km
ICE4W (Petrol)	5%	4.44%
ICE4W (Diesel)	5%	4.72%
E4W	5%	4.73%
ICE2W	5%	3.31%
E2W	5%	4.43%

Table 9: Sensitivity analysis of purchase price

Vehicle Categories	Change in AKT	Change in TCO/km
ICE4W (Petrol)	5%	4.84%
ICE4W (Diesel)	5%	5.06%
E4W	5%	5.23%
ICE2W	5%	3.68%
E2W	5%	5.05%

It can be seen from the Table 8 that change in purchase price has significant effect on the TCO/km of the both EVs and ICEVs. The effect of change in purchase price across all the segments of vehicle was found to be similar. The percentage change in output was slightly less than the percentage change in the input.

Also, in order to understand the trend of change of TCO/km with the change in purchase price, the absolute values of TCO/km were plotted against the purchase price for all the vehicle segments of four wheelers.

4.5.2. Annual kilometer travel (AKT)

The annual driving statistics of the vehicle owner is never constant over the vehicle ownership period. It usually depends on the daily routines and different circumstances of the users. As presented in the section 4.3, the change in AKT also changed the TCO/km. People may choose to drive differently in order to make the TCO/km economical over the vehicle ownership period. As it was already seen that decrease in AKT increases the TCO/km, the percentage of increase in TCO/km is listed in Table 9.

It was already seen from Figure 5 and 6 that the change of TCO/km with AKT was not linear and the rate of change also changed for the different value of AKT. In order to understand the trend of change of TCO/km with the change in AKT, the absolute values of TCO/km were plotted against the AKT for all the EV segments as shown in Figure 10 and 11.

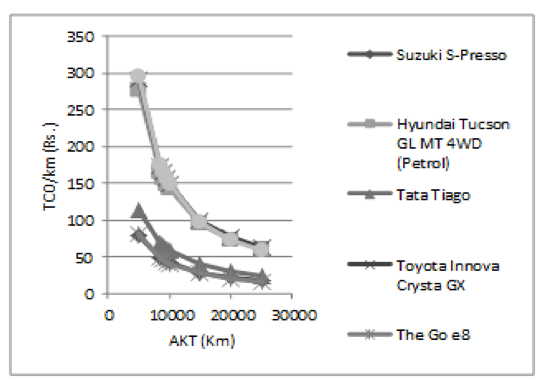

Figure 10: Relationship between TCO/km and AKT for four wheeler vehicles

The trend of TCO/km with AKT shows that higher AKT values helps to get the lower TCO/km. For some values of AKT, the ownership of EVs might not be economical but for some higher values of AKT, the same EV might be economical. The breakeven distance that makes EVs economical were also calculated for the different seg-

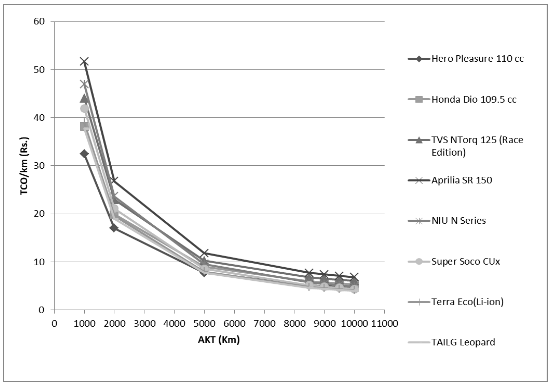

Figure 11: Relationship between TCO/km and AKT for two wheeler vehicles

ments (hatchback and SUV) for the four wheelers. The breakeven distances are shown in Table 10 for the specific models.

The breakeven distance (AKT) that makes E2Ws economical than ICE2W was calculated and it was found that 75% of E2Ws were economical at AKT of 2000 km and all the E2Ws were economical at the AKT of 5000 km.

Table 10: Sensitivity analysis of purchase price

EV Model	ICE4W (Petrol) Suzuki S-Presso (HB)	ICE4W (Petrol) Hyundai Tucson GL MT 4WD (SUV)	ICE4W (Diesel) Tata Tiago (HB)	ICE4W (Diesel) Toyota Innova Crysta GX (MUV)
The Go e8 (HB)	7760	-	< 5000	-
Kia Niro EV 2020 (SUV)	-	20800	-	8840

Table 11: Sensitivity analysis of Electricity Price

Vehicle Categories	Change in Electricity Price	Change in TCO/km
E4W	5%	0.023%
E2W	5%	0.080%

The change in electricity price had very low effect on the TCO/km of the E4W while the effect was much larger in case of E2W. It was because of the reason that higher portion of TCO/km was contributed by the cost of electricity in E4W than in the E2W. This is visible in the cost breakdown of vehicles as shown in Table 7.

Also, the nature of change in TCO/km due to the variation of per unit electricity price was analyzed. The Figure 12 and 13 show the nearly constant nature of TCO/km while changing per unit electricity price from Rs. 5 to Rs. 10.

According to the Electricity Regulatory Commission (ERC) [21], charging station can add a maximum of 20% profit on the per unit electricity price of Rs. 5.6 and sell it to the general public which can be Rs. 6.72/kWh at maximum. As we can see from the Figure 12 and 13, there is no significant change in TCO/km even with the allowable 20% profit margin.

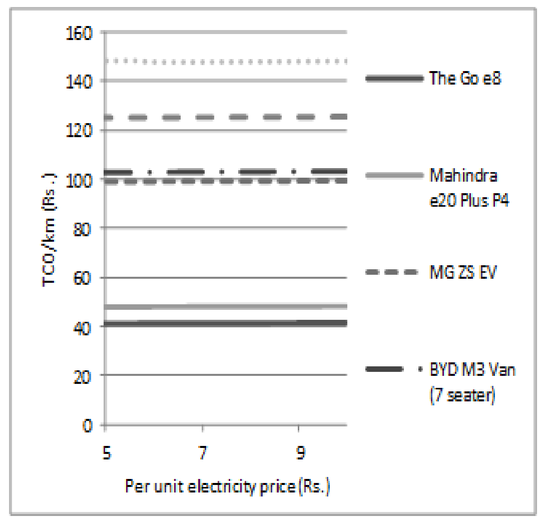

Figure 12: Relationship between TCO/km and per unit electricity price for E4W

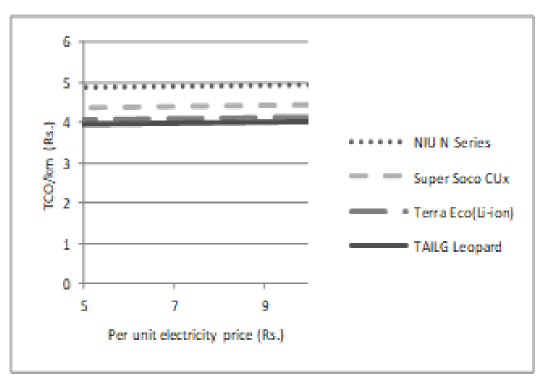

Figure 13: Relationship between TCO/km and per unit electricity price

The Figures 12 and 13 clearly show that changing electricity price has very little effect in the TCO/km values. The reason is that the EVs already have low operating cost and the contribution of electricity price in total

TCO/km was. These figures might be seen bigger while analyzing the total annual cost (TCO) but changing the total annual cost into total annual cost per km (TCO/km) significantly lowers its values.

4.5.3. Change in fuel price

The types of fuel considered in this calculation are petrol and diesel. The Nepal Oil Corporation Limited, a monopoly state owned trading enterprise of Nepal, sets the price of these fuels in Nepal. The change in fuel prices affects the TCO/km of ICEVs. In order to see the effects of change in fuel prices on TCO/km of ICEVs, these input parameters were changed and respective TCO/km were compared against the base case scenario as shown in Table 12.

Table 12: Sensitivity analysis of Electricity Price

Vehicle Categories	Change in Electricity Price	Change in TCO/km
ICE4W (Petrol)	5%	0.33%
ICE4W (Diesel)	5%	0.14%
ICE2W	5%	1.12%

While decreasing the fuel price by 5%, the corresponding decrease in TCO/km of four wheelers was lower as the fuel price contributed lesser portion in TCO/km of ICE4W. When compared to the EVs and the sensitivity of electricity prices, the sensitivity of fuel price in the TCO/km of ICEVs was found to be higher. The nature of relationship between fuel price and TCO/km was found to be linear as shown in Figures 14, 15 and 16.

It can be observed that the change in fuel price is more sensitive to TCO/km of ICE2W than the ICE4W.

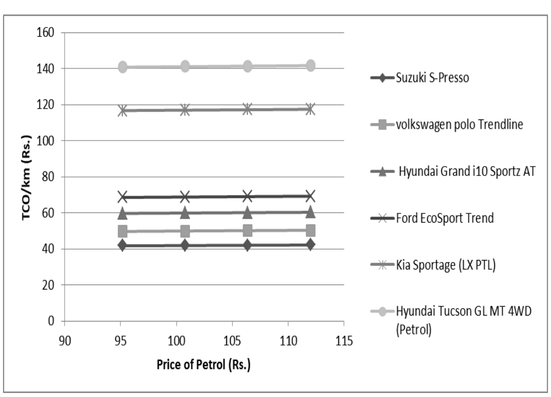

Figure 14: Relationship between TCO/km and price of petrol for ICE4W

The sensitivity analysis of these four parameters showed that the highly sensitive parameters were purchase price and AKT. The electricity price and fuel price only affected the TCO/km in lesser extent. This information might be helpful for the vehicle users and policy makers as they can evaluate and tweak appropriate parameters in order to make EVs more economical.

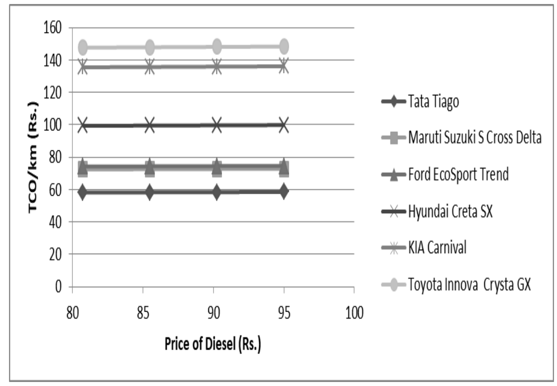

Figure 15: Relationship between TCO/km and price of diesel for ICE4W

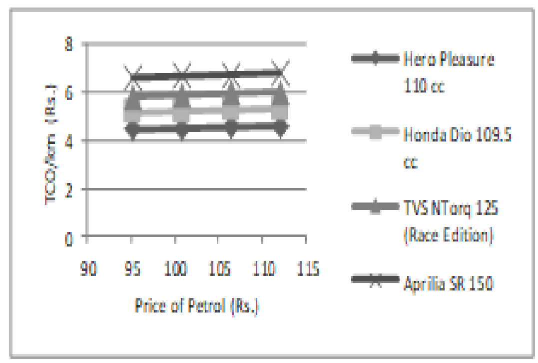

Figure 16: Relationship between TCO/km and price of petrol for ICE2W

5. Conclusion

The study calculated the TCO/km of two wheeler and four wheeler vehicles with electric and conventional powertrain technologies and analyzed it's variation in multiple scenarios. The results indicate that the two wheeler EVs are more economical at the current government policies than the four wheeler EVs. In the four wheeler EVs segments, only the hatchbacks have comparable and even lower TCO/km than the ICEV counterparts. In case of SUV segment, EVs have much higher TCO/km than the petrol fueled SUVs but show some agreements with the diesel fueled SUVs and MUVs considered in this study.

In case of two wheeler EVs (scooters), the TCO/km is comparable or even less than that of the two wheeler ICEVs (scooters). The results are in coherence with the conclusion of Rajper, S.Z. and Albrecht (2020) in the prospects of EVs in developing countries that two wheeler EVs are beneficial in developing countries due to their lower purchase price. The results also show the similar trend with the research done by Kumar and Chakrabarty (2020) in the Indian market that two wheeler EVs have lower TCO/km as compared to their ICEV counterparts.

The analysis of recent government policy change (finance act 2020/21) regarding EVs showed that the current policy has increased the TCO/km of four wheelers EVs by 20%-37%. Also, EVs were cheaper and the TCO/km was lower in the scenario before the finance act 2020/21. Hence, it can be said that the current tax policies regarding EVs are retrogressive for the adoption of EVs.

The cost breakdown of TCO/km showed that both two wheelers and four wheelers EVs have higher capital cost and lower operational cost than their ICEV counterparts. The calculation with multiple discount rates showed that lower rate engendered lower TCO/km.

The sensitivity analysis showed that the most sensitive parameters in TCO/km were purchase price and AKT. The change in fuel and electricity prices didn't show significant change in the per km cost of ownership. The multiple annual kilometer travel (AKT) analysis showed that EVs in the SUV segments can be cheaper than the ICEV counterparts if driven more. The breakeven AKT that makes EVs economical than ICEVs counterparts was estimated by comparing specific models in those segments. In case of low priced petrol vehicle (hatchback) the breakeven AKT was 7760 km whereas in the case of SUV segment, it was more than 2000 km. For the diesel vehicles, the breakeven AKT in case of hatchback was less than 5000 km due to the high price of diesel fueled vehicles, whereas for the higher ends (MUV), the breakeven AKT was 8840 km. In case of two wheelers, it was found that 75% of E2Ws were economical at AKT of 2000 km and all the E2Ws were economical at the AKT of 5000 km.

The research can be further extended by developing a probabilistic model to represent a more accurate driving and vehicle ownership scenario by considering the uncertain (stochastic) variables like fuel economy, maintenance cost over time, future electricity and oil prices etc.

Acknowledgment

The author(s) would like to express gratitude towards the faculties of the Department of Mechanical and Aerospace Engineering (IOE) and the editors and reviewers of JIEE whose valuable comments and suggestions were very important for the work.

The author(s) received no financial support for the research, authorship, and/or publication of this article.

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Appendix A. Vehicle Specifications of Four Wheelers

Four Wheeler		Engine CC (or Motor kW for EV)	Type	Battery kWh	Purchase Price (in Rs. 1000)	Seats	Driving Range (km)	Avg. Mileage (km / liter)	Battery War-rant from Manuf.
ICEV (Petrol)	Suzuki S-Presso	998	HB	0	2299	5	-	21.5	-
	Volkswagen polo Trendline	1198	HB	0	2745	5	-	16.5	-
	Hyundai Grand i10 Sportz AT	1197	HB	0	3396	5	-	17.3	-
	Ford EcoSport Trend	1497	SUV	0	3899	5	-	14.75	-
	Kia Sportage (LX PTL)	1999	SUV	0	6990	5	-	14.42	-
	Hyundai Tucson GL MT 4WD (Petrol)	1999	SUV	0	8496	5	-	12.5	-
ICEV (Diesel)	Tata Tiago	1047	HB	0	3400	5	-	27.28	-
	Maruti Suzuki S Cross Delta	1248	SUV	0	4299	5	-	24	-
	Ford EcoSport Trend	1497	SUV	0	4399	5	-	21.7	-
	Hyundai Creta SX	1582	SUV	0	5996	5	-	20.5	-
	KIA Carnival	2199	MUV	0	8190	7	-	14.11	-
	Toyota Innova Crysta GX	2393	MUV	0	8950	7	-	13	-

Four Wheeler		Engine CC (or Motor kW for EV)	Type	Battery kWh	Purchase Price (in Rs. 1000)	Seats	Driving Range (km)	Avg. Mileage (km / liter)	Battery Warrant from Manuf.
EV	The Go e8	15	HB	15.2	2494	5	150	-	4
	Mahindra e20 Plus P4	19	HB	10.08	2950	4	110	-	3
	MG ZS EV	105	SUV	44.5	5999	5	340	-	8
	BYD M3 Van (7 seater)	70	Van	50.3	6200	7	310	-	8
	Hyundai KONA Electric (39.2 kWh)	100	SUV	39.2	7696	5	312	-	8
	Kia Niro EV 2020	147.8	SUV	64	9000	5	385	-	7

Appendix B. Vehicle Specifications of Two Wheelers

Four Wheeler		Engine CC (or Motor kW for EV)	Type	Battery kWh	Purchase Price (in Rs. 1000)	Driving Range (km)	Avg. Mileage (km / liter)	Battery Warrant from Manuf.
ICEV (Petrol)	Hero Pleasure 110 cc	110	scooter	0	177.5	-	65	-
	Honda Dio 109.5 cc	109.5	scooter	0	212.9	-	56	-
	TVS NTorq 125 (Race Edition)	125	scooter	0	249.9	-	51	-
	Aprilia SR 150	150	scooter	0	291.9	-	50	-
ICEV (Diesel)	NIU N Series	2.4	scooter	1.74	269	80	-	2
	Super Soco CUx	1.3	scooter	1.92	239.9	85	-	3
	Terra Eco(Li-ion)	3	scooter	2.3	215	100	-	-
	TAILG Leopard	1	scooter	3.2	210	130	-	-