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An Analysis of Total Cost of Ownership and Cost Competitiveness of Privately-Owned Electric Vehicles in Nepal

by

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The undersigned certify that they have read, and recommended to the institute of engineering for acceptance, a thesis entitled **"An Analysis of Total Cost of Ownership and Cost Competitiveness of Privately-Owned Electric Vehicles in Nepal"** submitted by Anuj Pathak in partial fulfillment of the requirements for the degree of Master in Engineering in Energy System planning and Management.

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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 which is associated with negative environmental effects, 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 in the country. Since EV 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 and electricity prices. Also, the separate tax policies for EVs posed by the government plays another important role in the purchase price and annual costs. In this study, a model to calculate the total ownership cost of battery electric vehicles (BEVs) 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 ownership cost per km (TCO/km)for the two wheeler and four wheeler EVs and ICEVs. The model shows that two wheeler EVs (E2W) have a comparable and even lower TCO/km than the two wheeler ICEVs (ICE2W), while four wheeler EVs (E4W) have lower TCO/km than the ICEV counterparts (ICE4W) only for the lower ends of vehicle segments (hatchbacks) but not for the SUVs and MUVs. Also, the sensitivity analysis shows purchase price and AKT as the most sensitive parameters among others in the TCO/km calculation. The breakdown in the total costs shows that EVs have higher capital cost and lower operational cost over all the segments of vehicles. The estimation of breakeven AKT that makes EVs economical than ICEVs counterparts by comparing specific models in those segments shows that low priced petrol vehicle (hatchback) have lower TCO/km at 7760 km whereas in the case of SUV segment, it is more than 2000 km. For the diesel vehicles, the breakeven AKT in case of hatchback is less than 5000 km due to the high price of diesel fueled vehicles, whereas for the higher ends (MUV), the breakeven AKT is 8840 km. In case of two wheelers, it is found that 75% of E2Ws are economical at AKT of 2000 km and all the E2Ws are economical at the AKT of 5000 km.

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List of Abbreviations

ARAI	Automotive Research Association of India
BEV	Battery Electric Vehicle
DCF	Discounted cash flow
EV	Electric Vehicle
E2W	Electric Two Wheeler
E4W	Electric Four Wheeler
ICEV	Internal Combustion Engine Vehicle
ICE2W	Internal Combustion Engine Vehicle Two Wheeler
ICE4W	Internal Combustion Engine Vehicle Four Wheeler
Km	kilometer
KL	Kiloliter
kWh	Kilo Watt hour
MUV	Multi Utility Vehicle
NPR	Nepalese Rupees
Rs.	Rupees
SUV	Sport Utility Vehicle
TCO	Total Cost of Ownership

CHAPTER ONE: INTRODUCTION

1.1 Background

The fossil fuel has been the dominant power source of the transportation all over the world in the past centuries. This trend, if continued, would increase the demand for oil in the coming years and it would be an unaffordable commodity for all. The other side of the fossil fuel is the greenhouse gas emission which is associated with negative environmental effects. The production and use of energy mostly from fossil fuel sources have contributed significantly to the historic increase in greenhouse gas concentration in the atmosphere (Edenhofer, et al., 2011). On the other hand, the unwanted circumstances of fossil fuel in transportation can be a good opportunity for the adoption of more environmentally and economically dependable source of energy form such as electricity. In later years, the use of electric vehicles for transportation is getting growing attention and support for the same reason.

There were only about 17000 electric cars on the world's roads in 2010. By 2019, that number had increased to 7.2 million, 47% of which were in China (IEA, 2020). In the current scenario, different countries have already started making vision and plans of sustainable and clean energy sources for transportation sector. In order to promote EVs on the market, president Obama on March, 2012 launched an EV program which dedicates to using clean energy. It has embraced a goal of having one million electric powered vehicles on U.S. roads by 2015 (Obama White House Archives, 2012). Similarly, the Indian government started Faster Adoption and Manufacturing of Hybrid and Electric vehicles (FAME) scheme which provides incentives for purchasing electric vehicles. The vehicle is covered under this scheme that offers incentives to the electric and hybrid vehicles ranging from Rs. 1,800 to Rs. 29,000 for scooters and motorcycles and Rs.1.38 Lac for cars. FAME is a part of National Electric Mobility Mission Plan of Government of India (Economic Times, 2015).

To stimulate EV adoption, many countries have set subsidies and tax rebates for low-emission vehicles. The Clean vehicle rebate project in California (California Air Resources Board, 2016), the Plug-in vehicle grant in the UK (GOV.UK, 2015) and the Green vehicle purchasing promotion measures in Japan (Japan Automobile Manufacturers Association, 2016) etc. are the few examples.

1.2 Context of Nepal

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 (Baral, Parajuli, & Aryal, 2000). 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 (Maharjan, 2002).

Since Nepal is a country with huge hydropower potential with a theoretical potential of 83,000 MW, of which 42,000 MW is reported to be economically feasible (NEA, 2008) hydropower being a relatively cleaner source of electricity, electrification of transport sector can significantly reduce the burden of greenhouse gases in the environment.

In a study to assess the effects of meeting a part of the land transport service demand through electrified mass transport system and electric vehicles with the help of bottom up energy system model of Nepal based on the MARKAL framework (Shakya & Shrestha, 2011) 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 CO2e) in the same scenario during 2015–2050.

According to the data from Nepal Oil Corporation Limited (NOCL, 2020), 566,827 KL of petrol and 1714,917 KL of diesel were imported in the fiscal year 2018–2019, which was more than the previous year by 16% and 8% respectively. The main purposes of these imports were for the transport sector and this shows the possibility of reducing trade deficit by the electrification of transport sector.

The government of Nepal has also set goals for emission control through Nationally Determined Contributions (NDC) which was submitted to UN Framework on

Convention of Climate Change (UNFCCC) secretariat. The first NDC was focused on reducing the dependency on fossil fuel by increasing the share of electric vehicles by up to 20 percent by 2020 with the commitment to decrease the dependency on fossil fuels in the transport sector by up to 50 percent by 2050 (Ministry of Population and Environment, 2016).

The second NDC was submitted to UNFCCC on 8th December, 2020 with the focus on making shares of EV sales 25% of all private passenger vehicles, including two wheelers and 20% of all four wheelers public passenger vehicles by 2025 (Ministry of Population and Environment, 2020).

In order to achieve these goals, the government of Nepal started to inspire people towards the electric mobility. While the retail price of petrol and diesel reached up to 261% above the cost price, electric vehicles carried just a 10% tax on the purchase price. Electric cars were exempt from road tax, which can be Rs. 30-50,000 per year for fossil-fuel cars. Nepal was the only country in the world with such a huge relative tax difference (Nepali Times, 2019) but there were recent policy changes in EVs tax and policies (Minstry of Finance, 2020) which rather increased the excise, custom duties and also set annual vehicle tax on EV making it costlier than before in terms of capital and operational cost.

On the other hand, Nepal Electricity Authority (NEA) is also focusing on increasing domestic demand through the promotion of electric vehicles by building charging station infrastructures in the different parts of the country (NEA, 2020).

As of 2019 (Sherchan, 2019), the number of reported EVs in Nepal were about 700 private cars, 7 buses, 35000 e-rickshaws, 5000 two wheelers and 710 three wheelers (safa tempo). According to the data of the department of customs, electric vehicles that have passed the customs inspection in fiscal year 2019/20 were 574. It was more than the number in previous fiscal year which was 361 (Department of Customs, 2020) .

Even though, the government has set ambitious goals on emission control and EV adoption, there has not been any assessment and evaluation of the current status of completion of such goals and the reasons for the deviation from the goals.

1.3 Problem Statement/Research Questions

Although the government has set the national plan of increasing electric mobility with incentives, the fossil fuel vehicles still holds the major market share. In order to increase the sales of electric vehicles, this disparity should come to equilibrium in the form of cost and benefits.

However, there are still challenges to overcome for the EV adoption like lesser public awareness and acceptance, including the lack of charging stations and adequate maintenance showrooms, undependable electricity supply, and inadequate parking lots. Electric mobility is not a new technology but is still in the developing phase as compared to the conventional fossil fueled transportation systems. In the developing countries like Nepal which primarily depends on foreign imports to fulfill the demand of vehicles, the electric mobility here is greatly affected by the EV production, research and development and plan and policies of the other countries.

Despite of the challenges, the technological developments are delivering substantial cost reductions of electric vehicles. Advances in technology and cost cutting are expected to continue. The key enablers are developments in battery chemistry and expansion of production capacity in manufacturing plants.

Having been set the national goals and tax incentives, are electric vehicles going to flourish in the market? If not, then what would be the bottleneck parameters and what effective policy should be implemented in order to overcome the barriers against the EV adoption? These questions were the major factors which motivated to search for the appropriate research topic.

There are multiple parameters that affect the EV adoption in a country. A research (Adhikari, Ghimire, Kim, Aryal, & Khadka, 2020) used analytical hierarchy process (AHP) and survey to rank the seventeen different barriers against the EV use in Nepal. The research ranked the lack of charging stations, relatively higher purchase price of EVs compared to internal combustion vehicles, and poor long-term planning and goal setting on the part of the government as the top three barriers against EV uptake in Nepal. There are multiple factors that affect the EV adoption. The behavioral aspect of buyers, perceived values, network effect, availability of infrastructure etc.

Among these different barriers, the purchase price of EVs has been taken in interest in this study. The purchase price is the cost that the buyer pays for the vehicle. But purchase price is not the only cost associated with the vehicle ownership. There are multiple types of cost associated with it during the total ownership period. The electricity cost, annual tax, insurance premium, maintenance cost etc. are the other cost components.

Let's say an EV costs more during the purchase time than the conventional types of vehicles but it costs lesser than the other conventional powertrain vehicles during the operation phase making the overall ownership cost lower, the purchase price is no longer a barrier here. In a much clear way, the total cost of vehicle across the total period of ownership makes greater sense than just the purchase price of the vehicles. The purchase price is just the initial expenditure. The operational expenditure also makes another chunk of the cost associated with the vehicle ownership.

Different previous literatures were studied in the case of Nepal regarding the EV adoption and there seemed a gap in research in the aspect of vehicle ownership cost. To the knowledge of the author, no study so far has been carried out a comprehensive analysis of the total cost of ownership of EVs and its comparison with ICEV counterparts in the case of Nepal. The lack of research to appropriately assess the total cost of vehicle ownership, its cost competitiveness with ICEVs and the effects of different parameters associated with it clearly pointed towards the needed research topic.

1.4 Research Objectives

The research objectives are divided as follows:

1.4.1 Main Objective

- To analyze the total cost of ownership and cost competitiveness of privately-owned electric vehicles in Nepal

1.4.2 Specific Objectives

- To estimate and compare the life cycle cost (cost of ownership) of privately-owned electric vehicle with that of fossil fuel vehicle
- To analyze the current economic policies and perform sensitivity analysis of parameters affecting the cost of vehicle ownership

CHAPTER TWO: LITERATURE REVIEW

A case study from the USA market (Feng & Figliozzi, 2013), 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 (Bjerkan, Nørbech, & Nordtømme, 2016) 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 (Nykvist & Nilsson, 2015) 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 analysis of economic competitiveness of EVs in Chinese market (Zhao, Doering, & Tyner, 2015) by comparing the life-cycle private costs (LCPCs), life-cycle social costs (LCSCs) and vehicle emission costs of existing BEV models with comparable conventional ICEVs showed that BEVs in the Chinese market likely will not be economically competitive in the before the year 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 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 (Proff & Kilian, 2012).

While some results reveal that because of their high price, electric four-wheelers are not a feasible option in developing countries, on the other hand, electric two-wheelers may be beneficial as they have a lower purchase price (Rajper & Albrecht, 2020). A linear regression model analyzing the electric vehicle adoption of 30 countries in 2012 showed that financial incentives, charging infrastructure and local presence of production facilities to be significant and positively correlated to a country's electric vehicle market share (Sierzchula, Bakker, Maat, & van Wee, 2014). 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. The several key driving forces, on the one hand, associated with the adoption of EVs, are such as the reduction in greenhouse gas emissions (GHG), efficient energy use, gasoline savings and low operational cost. The resisting forces, on the other hand, that influence the acceptance of EVs include high purchase price, inadequate range, slow charging and the anxiety of new production adoption (Carley, Krause, Lane, & Graham, 2013).

The TCO/km for the market of Germany (Wu, Inderbitzin, & Bening, 2015) for years 2014, 2020 and 2025 using Monte Carlo simulations to analyze distributions and probabilities of outcomes concluded that comparative cost efficiency of EV highly depends on the annual driving distance and the vehicle class. Another study (Palmer, Tate, Wadud, & Nellthorp, 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 study focused in Germany (Letmathe & Suares, 2017) analyzed the TCO model and 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 examined the principal factors that can uplift the growth of electric vehicles in Nepal using system dynamics (Paudel, Govinda, Bhattrai, & Shrestha, 2019). Based on public expectations from government in terms of vehicle infrastructure and attributes, situation and policies, the research concluded that choice of policies and infrastructure development from the government side could significantly raise the EVs adoption in Kathmandu valley.

A case study (Krupa, 2019) 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.

A TCO/km model developed in India (Kumar & Chakrabarty, 2020) calculated the TCO of EVs with different fuel variants (petrol, diesel and compressed natural gas [CNG]) of ICE counterparts. 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.

CHAPTER THREE: METHODOLOGY

In order to carry out the process of obtaining the targets as mentioned in the objectives, a systematic process of research framework has been followed which consists of the key concepts of the research project. The purpose of the research in to analyze and compare the total cost of ownership of EVs as compared to that of traditional fossil fueled vehicles, commonly known as internal combustion engine vehicles (ICEVs). The different parameters associated with the total cost of ownership were first of all identified and the values and relations were then collected and estimated with the help of literature reviews and data collection methods. The calculation model was prepared in spreadsheet. The current as well as previous government policies were also analyzed based on these data. The results obtained were analyzed and compared using different graphical methods.

The research framework is summarized in the chart below.

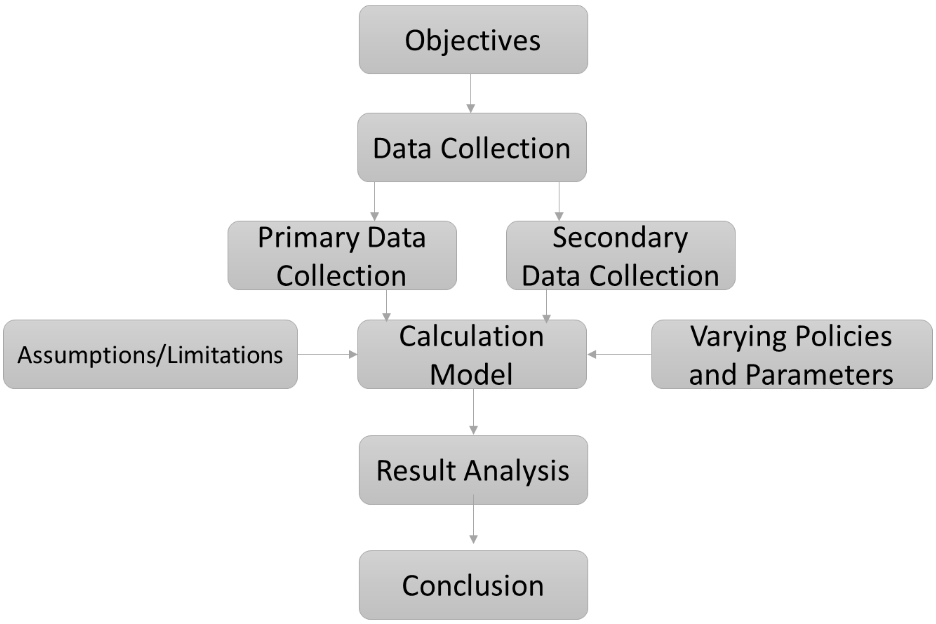

Figure 3.1: Research Framework

The primary data consist of vehicle driving statistics and maintenance cost for both fuel and battery-operated vehicles. The secondary data consist of vehicle purchase price, vehicle specifications, and government tax and incentives figures. The data obtained has been used to evaluate the life cycle cost of both battery operated and fossil fuel vehicles.

2.1 Data Collection

The approaches used for data collection are primary data collection and secondary data collection. The primary data collection includes the data from surveys and interviews.

2.1.1 Primary Data Collection

In order to analyze the vehicle ownership cost, the driving statistics of the user is important. Also, the maintenance cost of the fuel operated vehicles and battery operated vehicles is needed to approximate the ownership cost. The survey form was created in *google form* and distributed among the vehicle owners. The survey questionnaire consisted of different parameters needed for life cycle cost calculation. The sample of questionnaires for Electric Vehicle is in Appendix1.

Similarly, questionnaire was prepared for ICEVs and distributed among the ICEV owners. The sample of questionnaires for IC Engine Vehicle is shown in Appendix2.

The questionnaires were distributed among the vehicle owners for the data collection. The total sample size was 120. Among them, 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 major data collected from primary data collection were vehicle models, annual driving statistics and annual maintenance cost. The collected data was then taken into spreadsheet for the calculation.

2.1.2 Secondary Data Collection

The secondary data collection was done in order to obtain the government tax rates, vehicle prices, fuel and electricity prices and different policies established for the EV sustainability.

With the aim of flourishing EVs in the country, EVs were exempt from road tax; however the road tax for fossil fuel cars ranged from NPR.30000 to 50000 depending upon the CC (cubic centimeters) of vehicle and the province. Unlike other countries, such as Sweden, the Netherlands and Norway, Nepal does not have direct carbon tax policy. However, the government started collecting 50 paisa per liter on diesel and petrol since the fiscal year 2008-09 (The Kathmandu Post, 2019), with a view to spending the fund on programs and activities aimed at tackling air pollution in the

Valley. 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 were Rs. 112 per liter and Rs. 95/liter respectively (Nepal Oil Corporation Limited, 2021). The electricity charge per unit for the charging stations was updated by NEA from Rs. 10 to Rs. 5.6 (ERC, 2020) and the same value was taken for the TCO calculation.

The battery used in EVs also seems to have great effect on the price of EV. Because of the increased research and production of battery systems, the price seems to fall down in future. In a battery price projection done by Bloomberg New Energy Finance showed that from the observed historical values, the learning rate of around 18%. This means that for every doubling of cumulative volume, an 18% reduction in price is observed. The realized price of battery system was $176/KWh in 2018. The projection showed that the price will fall down to be around $94/kWh by 2024 and $62/kWh by 2030. This trend of battery price can be fit to predict the cost of EV in the future. In this calculation, the price of $94/kWh has been used in the battery replacement cost at the 5th year after the ownership. There was no excise duty levied on the electric motor vehicles (Inland Revenue Department, 2002) and the government had levied only 10% customs duty and 13 % VAT. But amid the coronavirus pandemic in 2020, the government of Nepal amended the excise duty on EVs with the Budget of FY 2020/21 delivered on May 28, 2020. The amended excise duty was set according to the motor capacity of the EVs which is shown in table 3.1. Again after few months the cabinet meeting revised the excise duty on October 1st. After public outrage, government reversed its hefty hike in taxes on electric vehicles (Nepali Times, 2020).

Table 3.1: Excise Duty on EVs, Finance Act 2020/21

Motor Capacity	Excise Duty (%) [May 28, 2020]	Excise Duty [Revised on Oct 1, 2020]
50 KW	30%	6%
50-100 KW	40%	10%
100-150 KW	50%	15%
150-200 KW	60%	45%
200-300 KW	70%	52.2%
Above 300 KW	80%	60%

Along with this amendment, the 80% customs duty was also introduced with 50% discount. The pollution control fee has been also set on the petrol and diesel sold within Nepal at Rs 1.50 per liter. The same act also introduced 5% road development fee which was previously only 3.5% of the purchase price (Finance Act, 2017/18). The current road development fee structures for the two wheeler and four wheeler internal combustion engine vehicles (ICE2W and ICE4W) and two wheeler and four wheeler electric vehicles (E2W and E4W) are shown in the table 3.2.

Table 3.2: Road Development Fee for EVs and ICEVs (Finance Act 2020/21)

Category	Road Development Fee
ICE2W (upto 155 cc)	Rs. 15,000
ICE2W (156 cc – 250 cc)	Rs. 18,000
ICE2W (251 cc – 400 cc)	Rs. 50,000
ICE2W (above 401 cc)	Rs. 2,00,000
E2W	Rs. 12,000
ICE4W (upto 2000 cc)	8% of purchase price
ICE4W (above 2000 cc)	10% of purchase price
E4W	5% of purchase price

EVs enjoyed the free annual vehicle tax provision for the past years but the current finance act of 2020/21 has imposed the annual tax on EVs according to the motor capacity of the vehicles. The annual vehicle tax for EVs is shown in table 3.3.

Table 3.3: Annual Vehicle Tax Rate for EVs (DOTM, Fiscal Act 2020)

Two Wheeler Motor Power (watt)	Annual Vehicle Tax (Rs.)	Four Wheeler Motor Power (kW)	Annual Vehicle Tax (Rs.)
350 to 1000	1500	50 to 125	15000
1001 to 1500	2000	126 to 225	20000
1501 and higher	3000	226 and higher	30000

Similarly, the annual vehicle tax rates for ICEVs in the categories of car, jeep, van and microbus are presented in table 3.4.

Table 3.4: Annual Vehicle Tax Rate for ICEVs (DOTM, Fiscal Act 2020)

Two Wheeler (CC)	Annual Vehicle Tax (Rs.)	Four Wheeler (CC)	Annual Vehicle Tax (Rs.)
up to 125	2800	up to 1000	21000
125 to 160	4500	1001 to 1500	23500
161 to 250	5500	1501 to 2000	25500
251 to 400	9000	2001 to 2500	35500
401 to 650	20000	2501 to 2900	41000
above 651	30000	above 2901	58500

2.1.3 Vehicles Selection

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 for the TCO calculation. The selected EVs are listed in table 3.5.

Table 3.5: Four Wheeler and Two Wheeler EVs Selection

	Vehicle Model	Type	Purchase Price (Rs.)	Battery kWh	Range (km)
Four Wheeler	The Go e8	Hatchback	2494000	15.2	150
	Mahindra e20 Plus P4	Hatchback	2950000	10.08	110
	MG ZS EV	SUV	5999000	44.5	340
	BYD M3 Van (7 seater)	Van	6200000	50.3	310
	Hyundai KONA Electric (39.2 kWh)	SUV	7696000	39.2	312
	Kia Niro EV 2020	SUV	9000000	64	385
Two Wheeler	NIU N Series	scooter	269000	1.74	80
	Super Soco CUx	scooter	239900	1.92	85
	Terra Eco(Li-ion)	scooter	215000	2.3	100
	TAILG Leopard	scooter	210000	3.2	130

The vehicles were primarily categorized into EVs and ICEVs and further sub-categorized into two wheelers and four wheelers. The four wheelers vehicles were again divided into two sub-categories according to the fuel type, petrol and diesel. However, for the two wheelers vehicles, only scooters were considered because of their prevalence in the market. The EVs includes two wheelers and four wheelers vehicles that use electric power for the driving. There are different variants in four wheeler vehicle category like hatchback, van and SUV (Sports Utility Vehicle).

The prices of the vehicles were collected from the respective dealers for the year of 2020/21. For the vehicle specifications, different brochures and official websites provided by the companies were taken as reference.

In case of four wheeler EVs, their prices before the finance act 2020/21 were also collected in order to observe the effect of policy change in EV's taxes. The before and after policy prices of E4Ws are shown in the table 3.6.

Table 3.6: EVs price before and after finance act 2020/21

Four Wheeler EV Model	Purchase Price Before Finance Act 2020/21 (Rs.)	Purchase Price After Finance Act 2020/21 (Rs.)	Change %
The Go e8	1950000	2494000	27.90%
Mahindra e20 Plus P4	2265000	2950000	30.24%
MG ZS EV	4999000	5999000	20.00%
BYD M3 Van (7 seater)	5200000	6200000	19.23%
Hyundai KONA Electric (39.2 kWh)	5596000	7696000	37.53%
Kia Niro EV 2020	6690000	9000000	34.53%

Similarly, ICEVs were selected based upon the models obtained from questionnaires which were again filtered and ranked according to different price range and vehicle specifications in order to reflect the diversity. For the four wheeler ICEVs, vehicles selection is also based upon the fuel types i.e. petrol and diesel. The vehicles segments are divided according to the body types and utility i.e. hatchbacks, SUVs and MUVs. For the two wheelers, only scooters were selected as the counterparts of the two wheeler EVs. The ARAI mileage has been used for the calculation. The four wheelers and two wheelers ICEVs selected for this research are listed in the table 3.7. The detailed vehicle specifications are listed in Appendix 3 and 4.

Table 3.7: Four wheeler and Two Wheeler ICEVs Selection

Vehicle Model		Type	Purchase Price (Rs.)	CC	Mileage (km/l)
Four Wheeler (Petrol)	Suzuki S-Presso	Hatchback	2299000	998	21.5
	volkswagen polo Trendline	Hatchback	2745000	1198	16.5
	Hyundai Grand i10 Sportz AT	Hatchback	3396000	1197	17.3
	Ford EcoSport Trend	SUV	3899000	1497	14.75
	Kia Sportage (LX PTL)	SUV	6990000	1999	14.42
	Hyundai Tucson GL MT 4WD (Petrol)	SUV	8496000	1999	12.5
Four Wheeler (Diesel)	Tata Tiago	Hatchback	3400000	1047	27.28
	Maruti Suzuki S Cross Delta	SUV	4299000	1248	24
	Ford EcoSport Trend	SUV	4399000	1497	21.7
	Hyundai Creta SX	SUV	5996000	1582	20.5
	KIA Carnival	MUV	8190000	2199	14.11
	Toyota Innova Crysta GX	MUV	8950000	2393	13
Two Wheeler (Petrol)	Hero Pleasure	scooter	177500	110	65
	Honda Dio	scooter	212900	109.5	56
	TVS NTorq (Race Edition)	scooter	249900	125	51
	Aprilia SR	scooter	291900	150	50

2.1.3 Assumptions and Limitations

The location, price of vehicles, fuel and electricity cost, tax rates and driving habits were assumed to be of Kathmandu valley only. The buying habit of people depends on many factors such as quality, comfort, influences, availability, equipment and services, etc. All these factors were assumed fixed and only the price criteria were taken for the comparison. 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.

From primary data collection through survey forms, the average travel distance per year of the vehicle was assumed to be 10,000 km. The vehicle ownership time was fixed at 10 years and the discounting rate in discounted cash flow model was assumed to be 10% for the base case scenario.

2.2 TCO model

TCO analysis helps in understanding the true cost of buying goods or services over its useful life (Roda & Garetti, 2016). In case of EVs, the TCO model plays an important role in assessing the total vehicle cost for the specific time period taking account of multiple parameters affecting the cost. It also helps policy makers to analyze the current policies and incentives on EVs and also helps in deciding whether EVs need further incentives or tax rebates for its economic competitiveness with traditional fossil fuel vehicles.

The formula used to evaluate the life cycle cost is:

Life Cycle Cost = Capital Cost + Operational Cost

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 the vehicles whiles the operational expenditure includes operational and maintenance (O&M) cost, annual vehicle taxes, vehicle renewal cost, fuel or electricity cost, insurance premium per year etc. In this study, TCO per km of travel is calculated by using the model (Wu, Inderbitzin, & Bening, 2015). The equation (1) represents the TCO/km.

$$\frac{\text{TCO}}{\text{km}} = \frac{\left(\text{PC} - \frac{\text{RV}}{(1+\text{r})^{\text{N}}}\right) * \text{CRF} + \frac{1}{\text{N}} \sum_{\text{n}=1}^{\text{N}} \frac{\text{AOC}}{(1+\text{r})^{\text{N}}}}{\text{AKT}}$$

Equation 3.1

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 for capital recovery factor is shown in equation 2 (Wu, Inderbitzin, & Bening, 2015).

$$\text{CRF} = \frac{\text{r}(1+\text{r})^{\text{N}}}{(1+\text{r})^{\text{N}} - 1}$$

Equation 3.2

2.2.1 Capital Expenditure

The capital expenditure represents the price of vehicle at the time of purchase. In this study, the purchase prices of vehicles provided by the respective sellers/dealers have been used as the capital expenditure. Since Nepal is a country which imports vehicles in order to fulfill its demand, the government taxes like custom duty, excise, VAT etc. play major role while setting the price of the vehicles. Also, the government's schemes of subsidies and seller's discount help to reduce the price to some extent.

Although, there is no provision of subsidies for EVs at the time of purchase, sellers may provide certain discount on their own judgments. This discount has not been included in this study as the percentage of discount may vary from sellers to sellers but the effect of change in price of vehicle in TCO/km has been analyzed for all the categories of vehicles considered in this study.

The capital expenditure (Capex) has been calculated after deducting the present value of residual value (RV) from the initial purchase price (PC) annualized by the capital recovery factor (CRF). The annualized value represents the annual repayments. The equation 3 represents the calculation formula for the capital expenditure.

$$\text{Capital Expenditure} = \left(\text{PC} - \frac{\text{RV}}{(1+\text{r})^{\text{N}}}\right) * \text{CRF}$$

Equation 3.3

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 (Inland Revenue Department, 2002). The reducing balance method is used to calculate the amount of depreciation in each successive year.

2.2.2 Operating Expenditure

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 equation 4 represents the formula to calculate operating expenditure in present value.

$$\text{Present value of total AOC} = \frac{1}{\text{N}} \sum_{\text{n}=1}^{\text{N}} \frac{\text{AOC}}{(1+\text{r})^{\text{n}}}$$

Equation 3.4

Here, the present value of total annual operating cost is divided by total years of vehicle ownership (N) in order to represent the cost for each year.

Annual Fuel/Electricity Price

Fuel price is calculated based on yearly travel statistics. The daily travel activities as well as special long-range travel data is obtained from the questionnaire. The travel statistics (in km) is used with fuel price to evaluate total annual cost of fuel. The mileage per liter of fuel is also considered for the fossil fueled vehicle. For the electric vehicles, the total units of electricity consumed in a year are multiplied with electricity price in order to obtain the yearly electricity price.

Maintenance Cost

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.

Annual Vehicle Tax

The vehicle renewal cost and Road Tax varies for the different specification of vehicles and the province. After choosing the vehicle models for the comparison, the annual vehicle renewal cost was taken according to the vehicle specification as shown in table 3 and 4.

Insurance Yearly Premium

There are multiple insurance policies available in the market for the wheeler and four wheeler private vehicles and these policies differ in the case of EVs and ICEVs. The insurance is necessary to cover any damage caused to the vehicle as well as to the third party due to the various circumstances like accidents and natural disasters. The full coverage (comprehensive package) includes the insurance of both the vehicle and any third party damage caused by the vehicle and its choice fully depends up on the vehicle owner. In this study, only the third party insurance is taken into the calculation model which is made mandatory by the government (Motor Vehicles and Transport Management Act, 1993).

In order to understand and estimate the current rates of the third party insurance, an online calculator provided by an insurance company (Shikhar Insurance, 2021) is used. The current rates of third party insurance premium for EVs and ICEVs are shown in table 3.8, 3.9, 3.10 and 3.11.

Table 3.8: Third Party Insurance Rate for Four Wheeler ICEVs

Engine (cc)	Price (Rs.)
Up to 1000	7365
1001 to 1500	8495
1601 and higher	10747

Table 3.9: Third Party Insurance Rate for Two Wheeler ICEVs

Engine (cc)	Price (Rs.)
Up to 150	1715
151 to 250	1941
251 and higher	2167

Table 3.10: Third Party Insurance Rate for Four Wheeler EVs

Motor Power (kW)	Price (Rs.)
Up to 20	3000
21 and higher	4000

Table 3.11: Third Party Insurance Rate for Two Wheeler EVs

Motor Power (Watt)	Price (Rs.)
Up to 800	1715
801 to 1200	1941
1201 and higher	2167

In case of four wheelers EVs, the insurance price also depends on the numbers of seat in the vehicle. There is additional Rs. 700 per seat which is added in the price mentioned in the table 9. The final price of the third party insurance is calculated by adding 13% tax.

Battery and Tyre Replacement Cost

The vehicles were assumed to be purchased on the current year and ownership cost for the next years were calculated. Since the battery cost for the coming years was not available, different literatures were used for the future price of battery. The predicted price of the Li-ion battery packs in general would fall around $94/kWh by 2024 and $62/kWh by 2030 (Claire, 2017) as shown in figure 3.2. The battery cost in the future was calculated using the same projection. 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 price. 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.

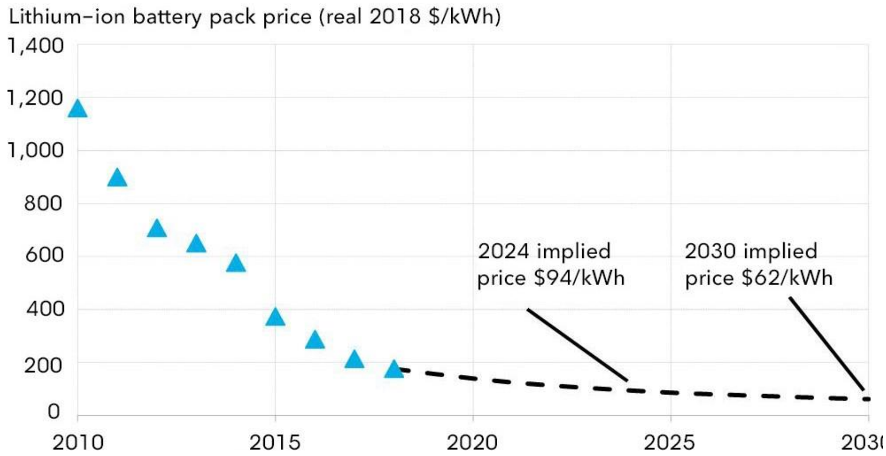

Figure 3.2: Lithium-ion battery price outlook (BNEF)

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.

2.2.3 Discounted Cash Flow (DCF) Model

A discounted cash flow model was prepared considering the present and future cash flow assumed in this calculation. The main motive of using DCF model is to determine the value of an investment based on its future cash flows considering all the yearly payments, discount rate and total number of years. The operating expenditures in this study are calculated at present value by discounting all the future operating costs by the discounting rate (r). For the 10 years of ownership period, an overview of DCF model is presented in table 3.12.

In the table, numbers 1 to 10 represents the total years of ownership. The left side column shows the vehicle types used in the calculation. The different types of cost for those vehicles are written in their respective boxes. Here, the abbreviations used for the costs are as follows:

TOC: Total operating cost (annual fuel/electricity cost + annual maintenance cost + annual tax + insurance)

TRC: Tyre replacement cost (once in every four year for all types of vehicles)

BRC: Battery replacement cost (for all EVs at the 5^{th} year of ownership)

The present value of the cost for each year is calculated using equation 4 as shown in section 2.2 of the same chapter.

Table 3.12: DCF Model Cash flow

Vehicle Type	1	2	3	4	5	6	7	8	9	10
E2W	TOC	TOC	TOC	TOC + TRC	TOC + BRC	TOC	TOC	TOC + TRC	TOC	TOC
E4W	TOC	TOC	TOC	TOC + TRC	TOC + BRC	TOC	TOC	TOC + TRC	TOC	TOC
ICE2W (petrol)	TOC	TOC	TOC	TOC + TRC	TOC	TOC	TOC	TOC + TRC	TOC	TOC
ICE4W (petrol)	TOC	TOC	TOC	TOC + TRC	TOC	TOC	TOC	TOC + TRC	TOC	TOC
ICE4W (diesel)	TOC	TOC	TOC	TOC + TRC	TOC	TOC	TOC	TOC + TRC	TOC	TOC

2.2.4 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.

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 as follows:

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.

Multiple Policies

In this scenario, TCO/km of four wheeler EVs with respect to the government policy before and after finance act 2020/21 was 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. The change in EVs TCO/km in these two scenarios was obtained and analyzed.

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.

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 (Willenbockel, 2008). The average lending rate of commercial banks in Nepal was 10.3 % per annum from Nov 2013 to Nov 2018 as estimated by CEIC (CEIC , 2021). Even though discount rates are subject 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.

2.3 Calculation

After the completion of data collection from primary and secondary sources, the analysis portion was carried out in a spreadsheet. A discounted cash flow model (DCF) was prepared to calculate the life cycle cost. A DCF model is shown in figure 2.

2.4 Analysis

The total vehicle ownership cost of EVs was compared against that of ICEVs. The TCO was broken down into capital cost and operational cost and the comparative analysis was done between EVs and ICEVs. Also, the TCO between previous and current government policy was compared. The analysis contains the TCO/km comparison between different vehicle segments categorized by vehicle types (two wheelers and four wheelers) and fuel types used (electric, petrol and diesel). For the two wheelers, only scooters with electric and petrol operated are considered.

The base case scenario was estimated with the fix set of variables and later they were modified in order to analyze the TCO/km in multiple scenarios. The varying cases include the change in government policies, change in annual kilometer travel (AKT) and change in discount rates. The sensitivity analysis was performed to determine the change in TCO/km while changing the input parameters. The different parameters like purchase price of vehicles, per unit fuel price (petrol and diesel), per unit electricity price and annual kilometer travel were taken in consideration for the sensitivity analysis.

CHAPTER FOUR: RESULTS AND DISCUSSION

The TCO/km values for all the selected four wheeler and two wheeler EVs and ICEVs were calculated based on the annualized total lifecycle cost method. 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 4.1. 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.

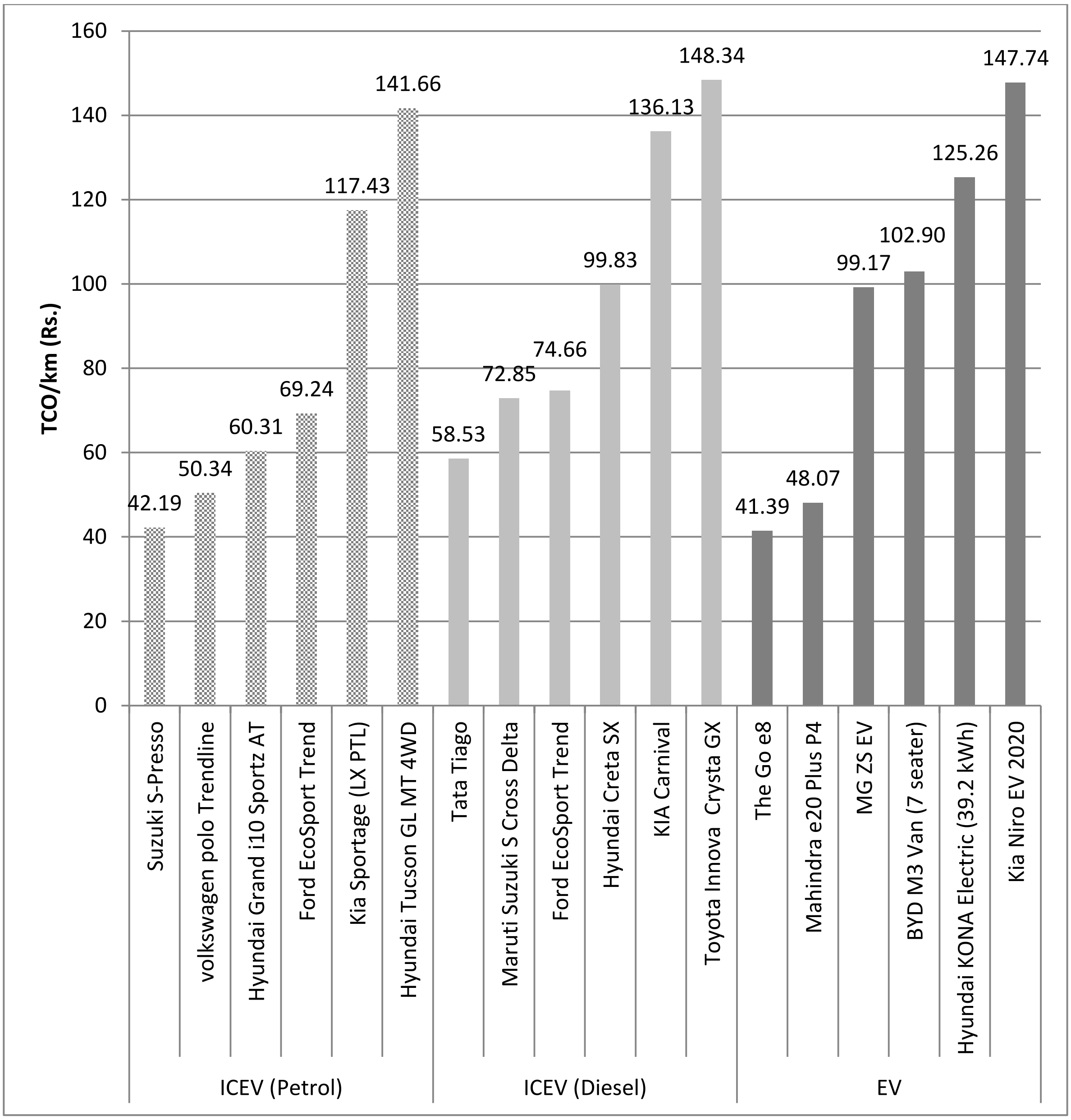

Figure 4.1: TCO/km of four wheeler EVs and ICEVs

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 4.2.

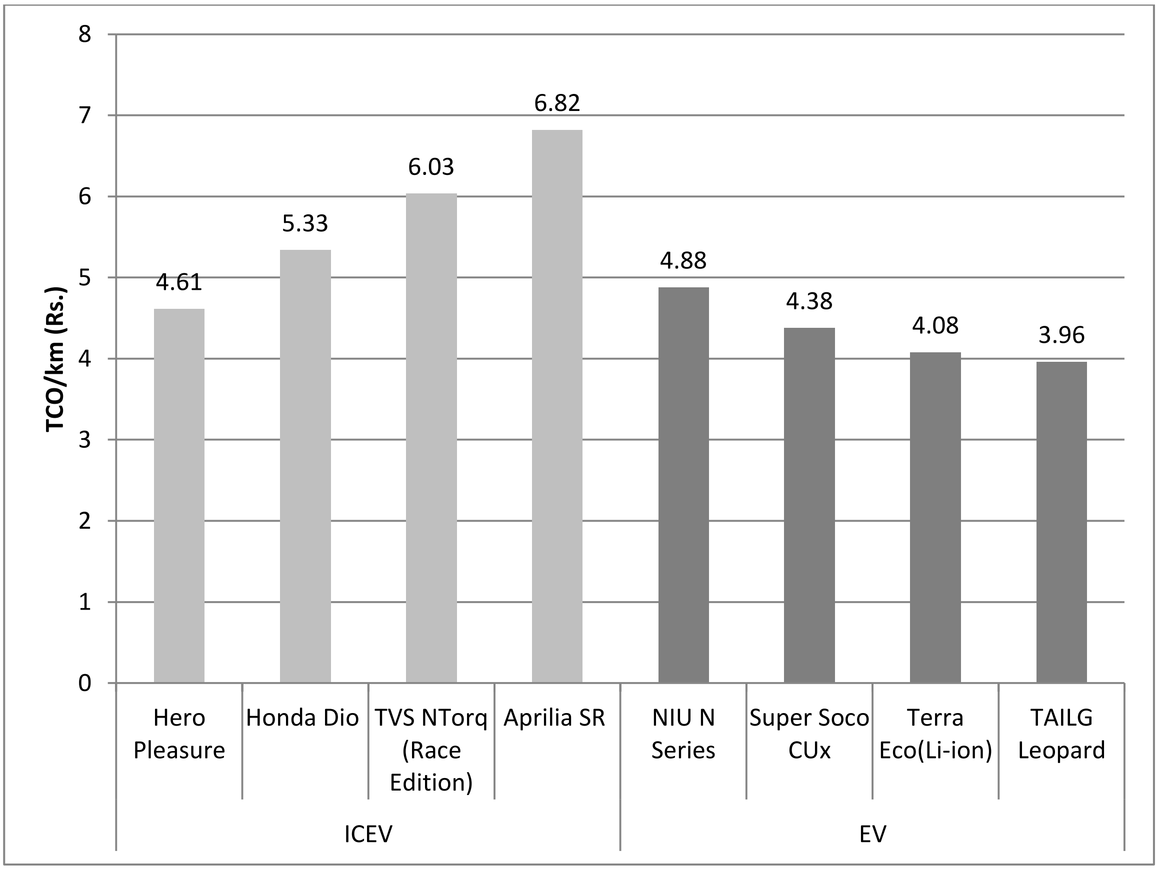

Figure 4.2: TCO/km of two wheeler EVs and ICEVs

At the current government policies, it was seen that two wheeler EVs were economical than the two wheeler ICEVs.

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 (as shown in table 6) 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. The comparison is presented in figure 4.3. The EVs of different price range were relatively cheaper at the previous tax policy.

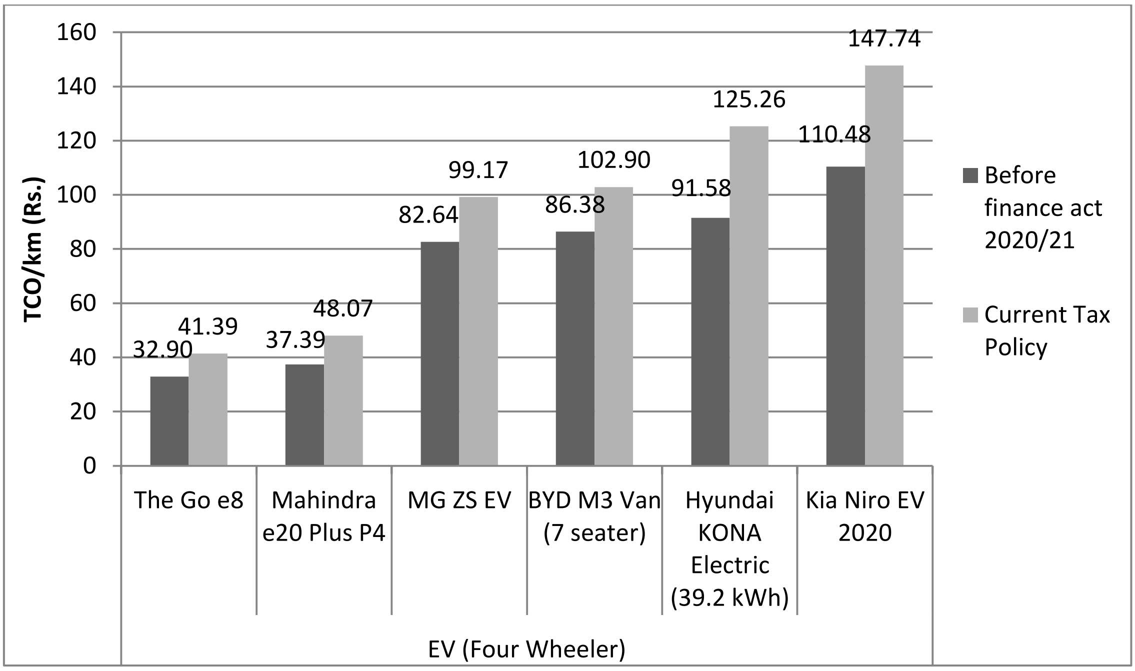

Figure 4.3: Change in TCO/km of EVs due to policy change

The change in the tax policies has influenced and negatively impacted the total cost of EV ownership. The EVs total ownership cost has been increased by 20%-37%. The percentage change in TCO/km of EVs for these two policy scenarios are shown in the table 4.1.

Table 4.1: Percentage change in TCO/km of EVs due to policy change

E4W Models	% Change in TCO/km
The Go e8	25.79%
Mahindra e20 Plus P4	28.58%
MG ZS EV	19.99%
BYD M3 Van (7 seater)	19.13%
Hyundai KONA Electric (39.2 kWh)	36.78%
Kia Niro EV 2020	33.73%

The results show that the disparity in the cost is even higher for the higher end vehicles than the lower ends.

The TCO/km of four wheeler EVs at the policy before finance act 2020/21 was also compared with their ICEV counter parts. As shown in figure 4.4, EVs seem to have lower TCO/km compared to their ICEV counterparts across all the segments.

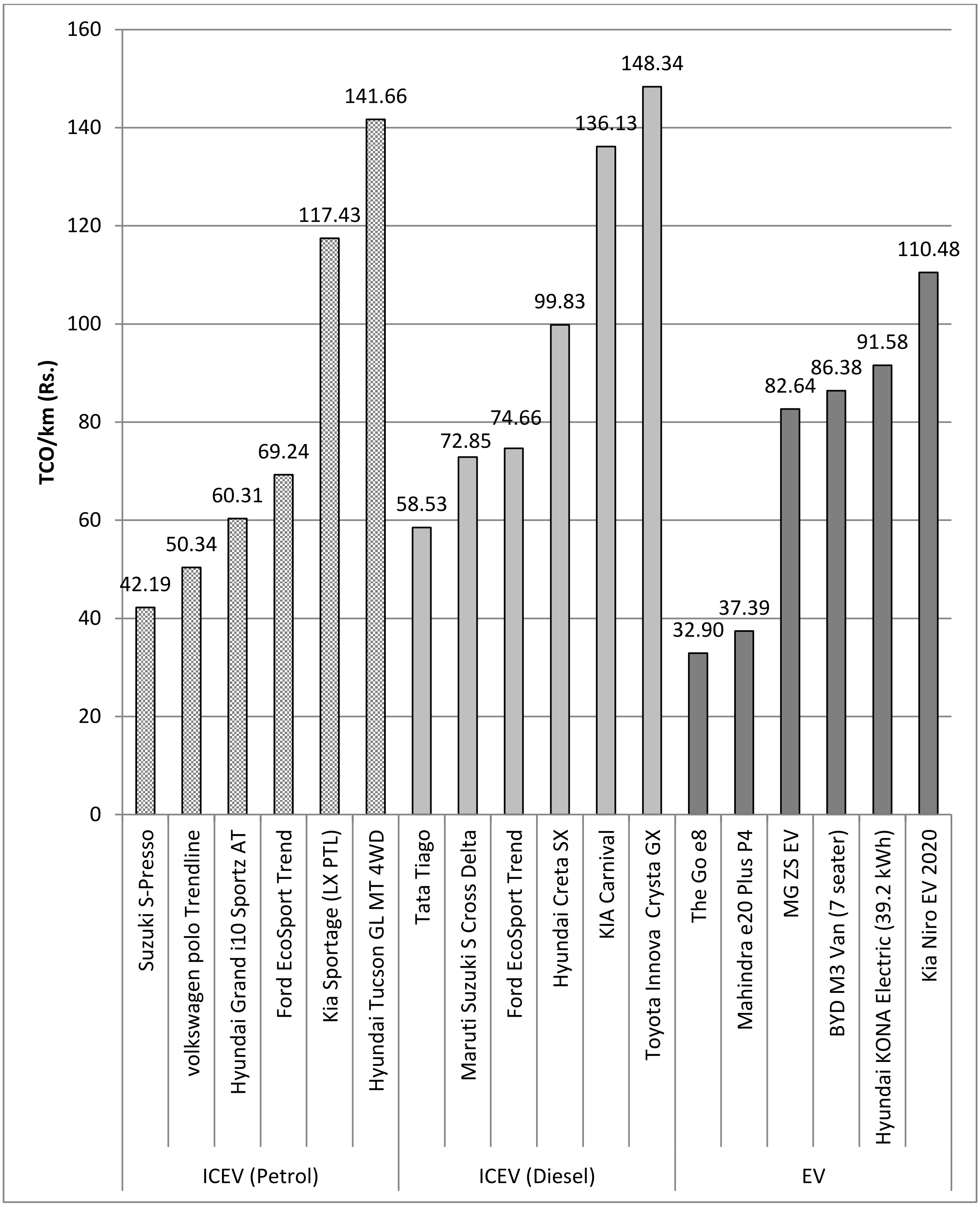

Figure 4.4: TCO/km of four wheeler EVs and ICEVs before the finance act 2020/21

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 maintenance and electricity cost of EVs. The comparison is shown in figure 4.5. 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.

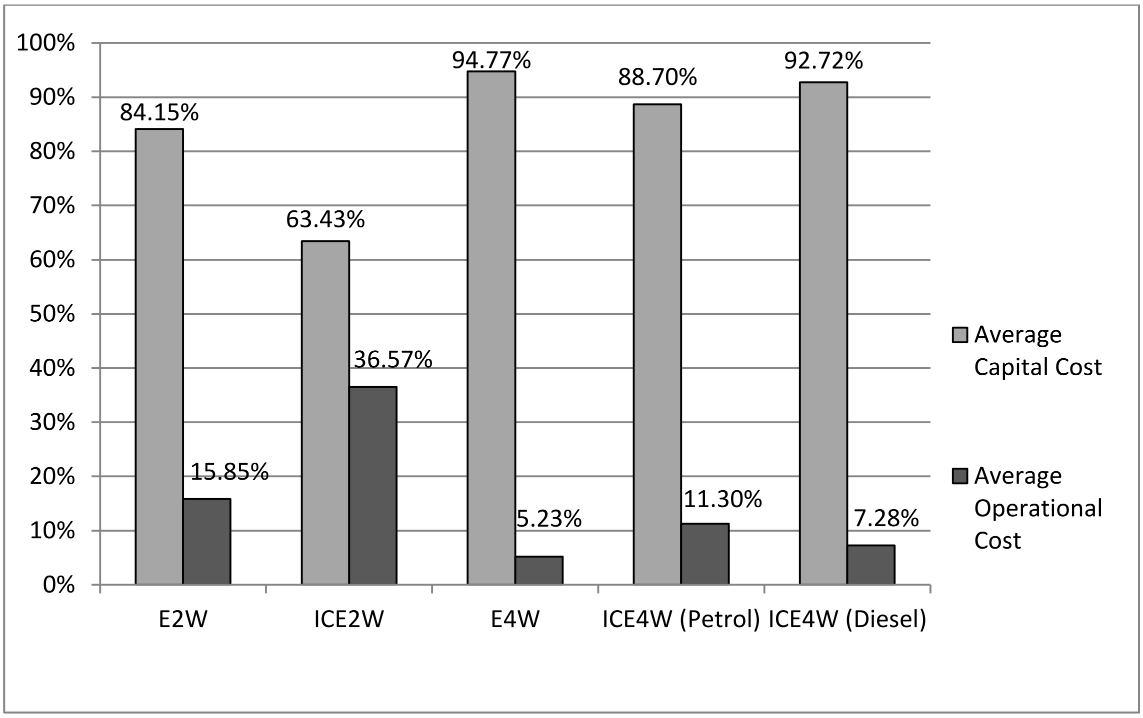

Figure 4.5: Comparison between Capital Cost and Operational Cost

The further breakdown in the cost composition was done in order to identify the individual cost contribution of each component. 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. For the two wheelers, the average capital cost was found to be comparable (equal in this calculation), whereas for four wheelers, the average capital cost of EVs was found to be in between that of ICEV (Petrol) and ICEV (Diesel). The cost breakdown is presented in table 4.2.

Table 4.2: Average TCO/km distribution in Rs. for EVs and ICEVs

Vehicle Type	Capital Cost	Fuel/Electricity Cost	Annual Maintenance Cost	Annual Tax and Insurance	Tyre Replacement	One Time Battery Replacement Cost
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	-

Table 4.3 presents the average cost breakdown in percentage for all the vehicles considered in calculation. 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.

Table 4.3: Average cost breakdown in percentage

Vehicle Type	Capital Cost	Fuel/Electricity Cost	Annual Maintenance Cost	Annual Tax and Insurance	Tyre Replacement Cost	One Time Battery Replacement Cost
E2W	84.27%	1.83%	2.84%	6.38%	1.06%	3.62%
ICE2W	63.79%	21.99%	8.09%	5.33%	0.81%	-
E4W	94.79%	0.47%	0.20%	1.35%	0.49%	2.70%
ICE4W (Petrol)	90.22%	5.46%	1.15%	2.60%	0.57%	-
ICE4W (Diesel)	93.11%	3.17%	0.94%	2.31%	0.47%	-

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 4.6 and 4.7.

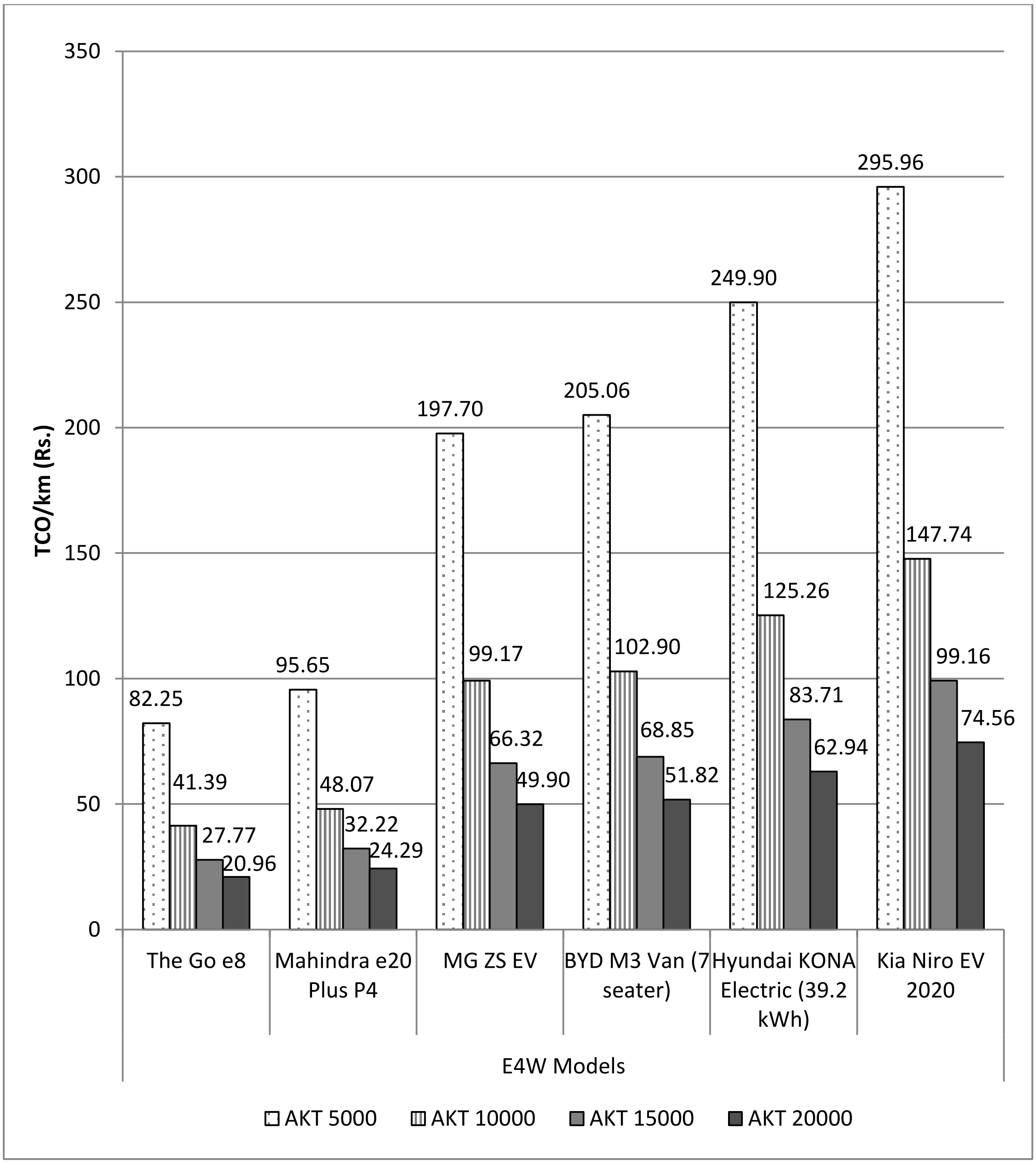

Figure 4.6: TCO/km for multiple AKT for E4W

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. As it can be seen from the figure 8, 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. It can be observed from the figure 8 that E4Ws have lower TCO/km at 15000 and higher AKT than the ICEV counterparts at the base case scenario.

In the case of two wheelers EV, the AKT was changed for different scenarios of low travel and high travel similar to the cases of E4W. The change in TCO/km with the change in AKT is shown in figure 9 for E2W. From the chart, it is visible that as the AKT increases, TCO/km decreases and the values are nearly equal for the high travel scenario of 20000 km.

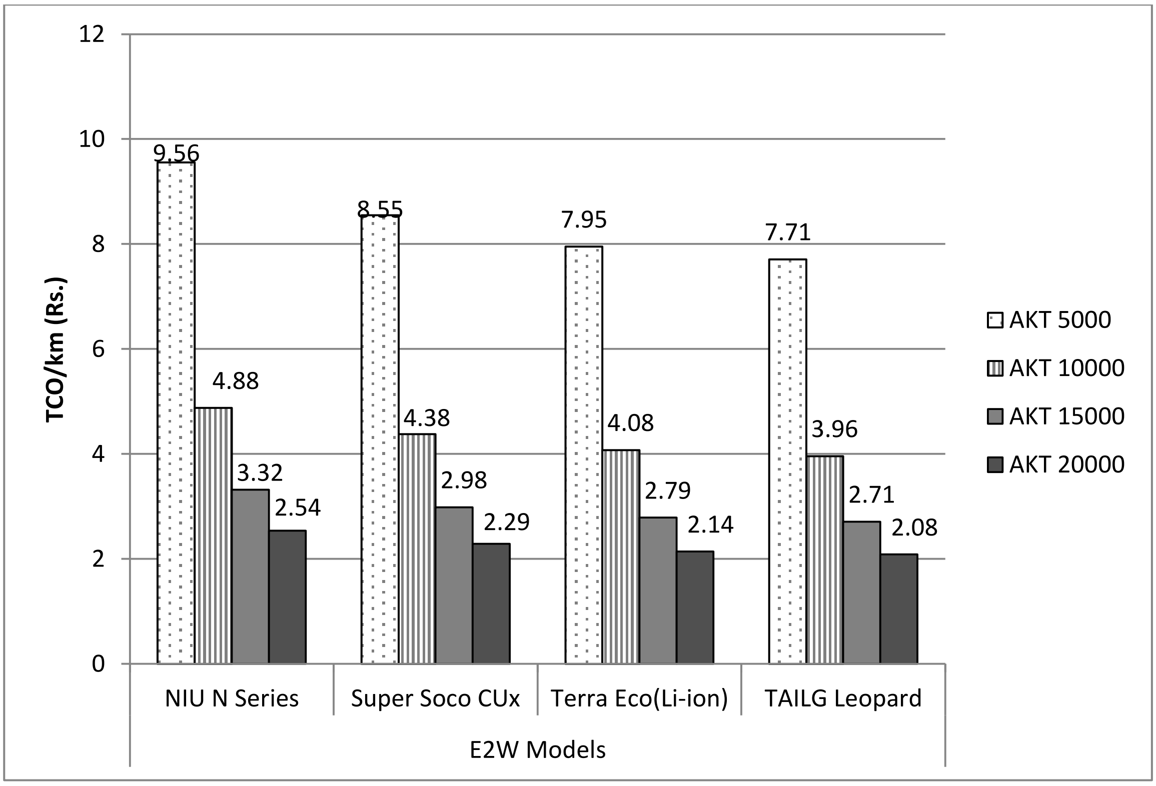

Figure 4.7: TCO/km for multiple AKT for E2W

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 and the rate of decrease is low at higher AKT values.

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 figure 4.8. The high discount rate shows high TCO/km and the degree of change is higher for 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 4.9 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.

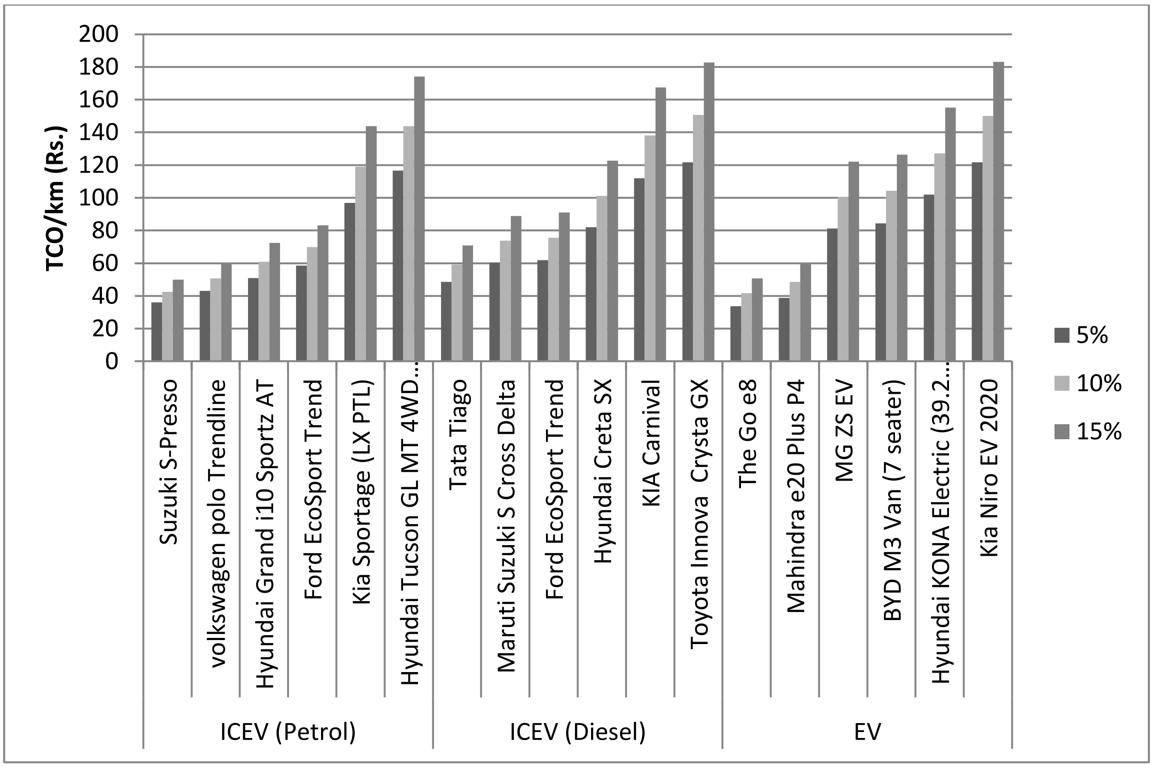

Figure 4.8: TCO/km of E4W and ICE4W for different discount rates

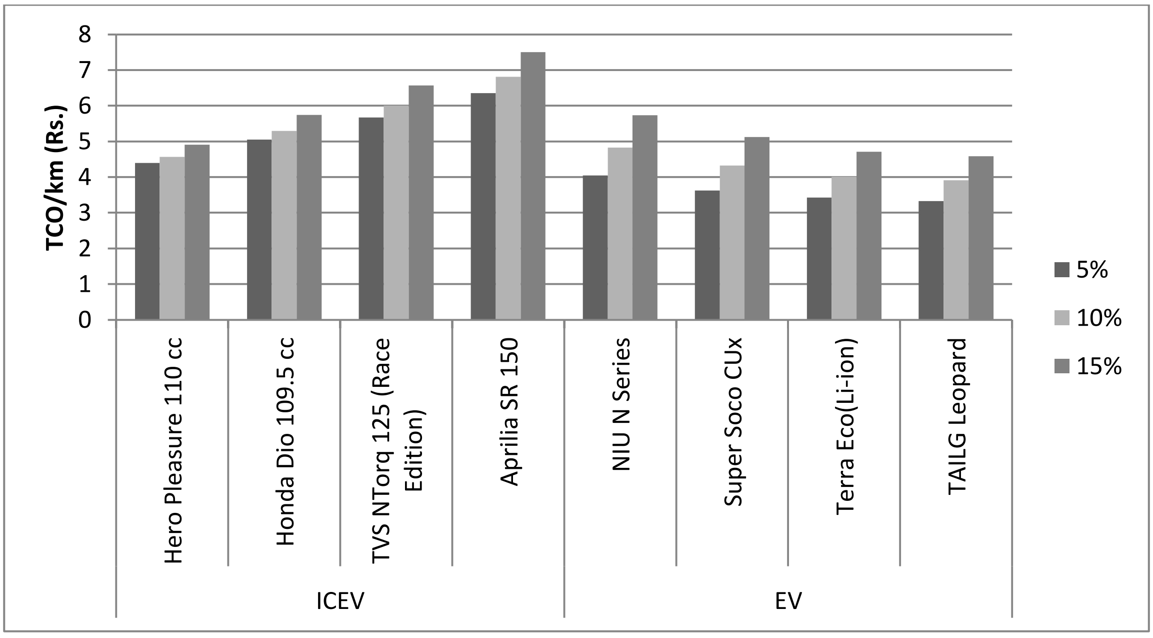

Figure 4.9: TCO/km of E2W and ICE2W for different discount rates

4.5 Sensitivity Analysis

In order to analyze the effects of change in input parameters in TCO/km, sensitivity analysis was done. The major input parameters like purchase price, annual kilometer travel (AKT), electricity price and fuel price were chosen for the sensitivity analysis. The input parameters were changed by certain percentages and the change in outputs were noted. All the considered parameters were changed by 5%, 10% and 15% successively and the rates of change were compared with the base case scenario.

4.5.1 Purchase Price

Purchase price is the capital expenditure. There are scenarios when purchase price may change while purchasing the vehicle. The seller's discount, government subsidies etc. are the possible cases of change in purchase price. In order to find out the effect of change in purchase price in TCO/km of the vehicles, sensitivity analysis was done by changing the purchase price by 5%, 10% and 15% and the resulted TCO/km values were compared with the base case scenario. The results are shown in table 4.4.

Table 4.4: Sensitivity analysis of purchase price

Vehicle Categories		Change in Purchase Price	Change in TCO/km
Four Wheeler	ICEV (Petrol)	5%	4.39%
		10%	8.79%
		15%	13.18%
	ICEV (Diesel)	5%	4.69%
		10%	9.39%
		15%	14.08%
	EV	5%	4.72%
		10%	9.44%
		15%	14.16%
Two Wheeler	ICEV	5%	3.23%
		10%	6.46%
		15%	9.69%
	EV	5%	4.30%
		10%	8.61%
		15%	12.91%

The purchase price was decreased by 5%, 10% and 15% from the current price. This resulted in decrease in total ownership cost. It can be seen 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 which varied linearly. 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. The trend shows a linear relationship between purchase price and TCO/km for all the categories of the vehicles as shown in figure 4.10.

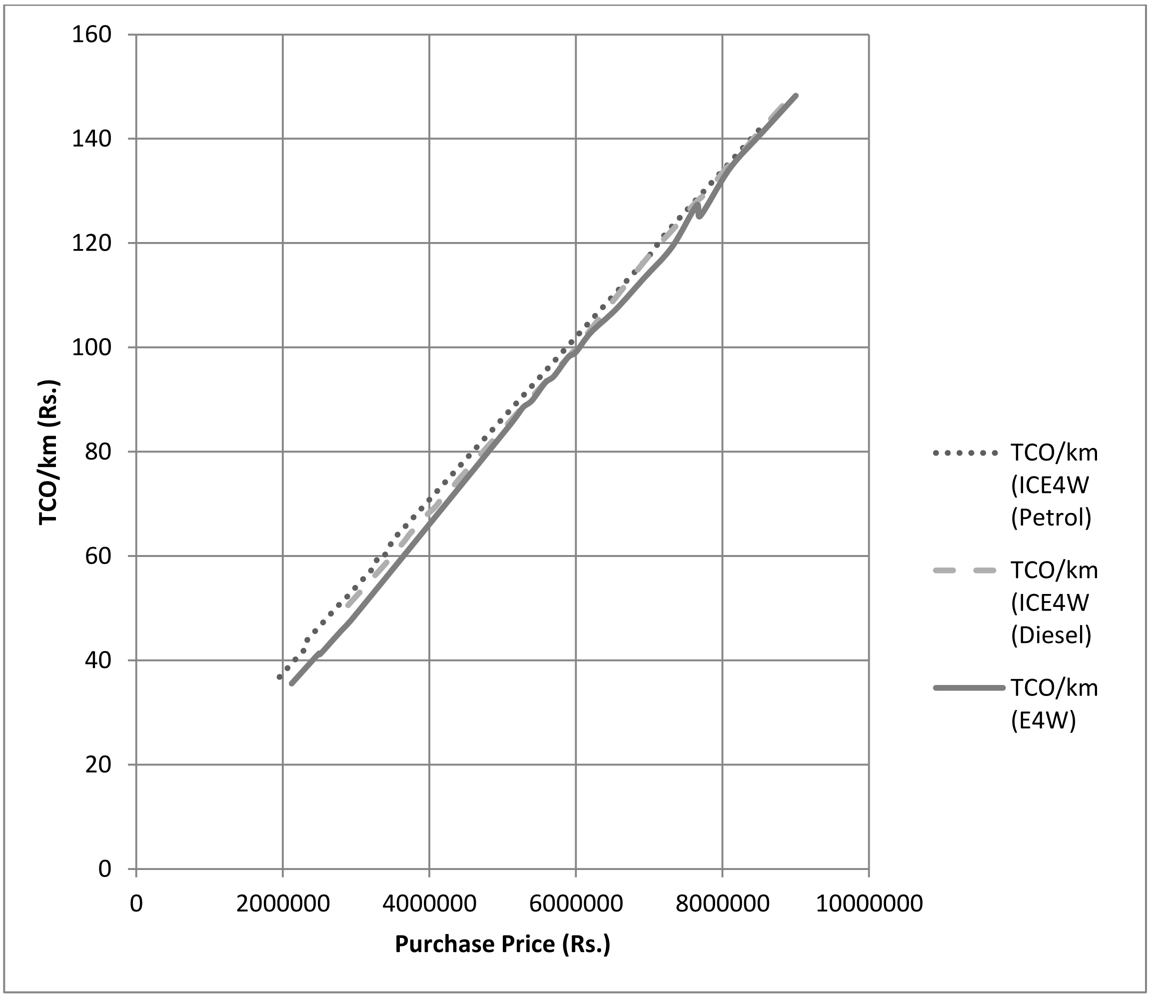

Figure 4.10: TCO/km change with purchase price

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 4.5. The annual kilometer travel was decreased by 5%, 10% and 15% from the base case scenario of 10000 km.

Table 4.5: Sensitivity analysis of AKT

Vehicle Categories		Change in AKT	Change in TCO/km
Four Wheeler	ICEV (Petrol)	5%	4.84%
		10%	10.21%
		15%	16.21%
	ICEV (Diesel)	5%	5.06%
		10%	10.69%
		15%	16.98%
	EV	5%	5.23%
		10%	11.04%
		15%	17.53%
Two Wheeler	ICEV	5%	3.68%
		10%	7.78%
		15%	12.35%
	EV	5%	5.05%
		10%	10.66%
		15%	16.93%

It was already seen from figure 8 in section 4.3 that the change of TCO/km with AKT was not linear and the rate of change depends on the specific point on the graph for the respective AKT value. Hence, to observe the nature of change of TCO/km with distance travelled, separate analysis of TCO/km with distance was done. Figure 4.11 shows the nature of change of TCO/km with AKT for four wheelers vehicles. In this analysis only lower ends (hatchback) and higher ends (SUV, MUV) of vehicles were considered for both EVs and ICEVs.

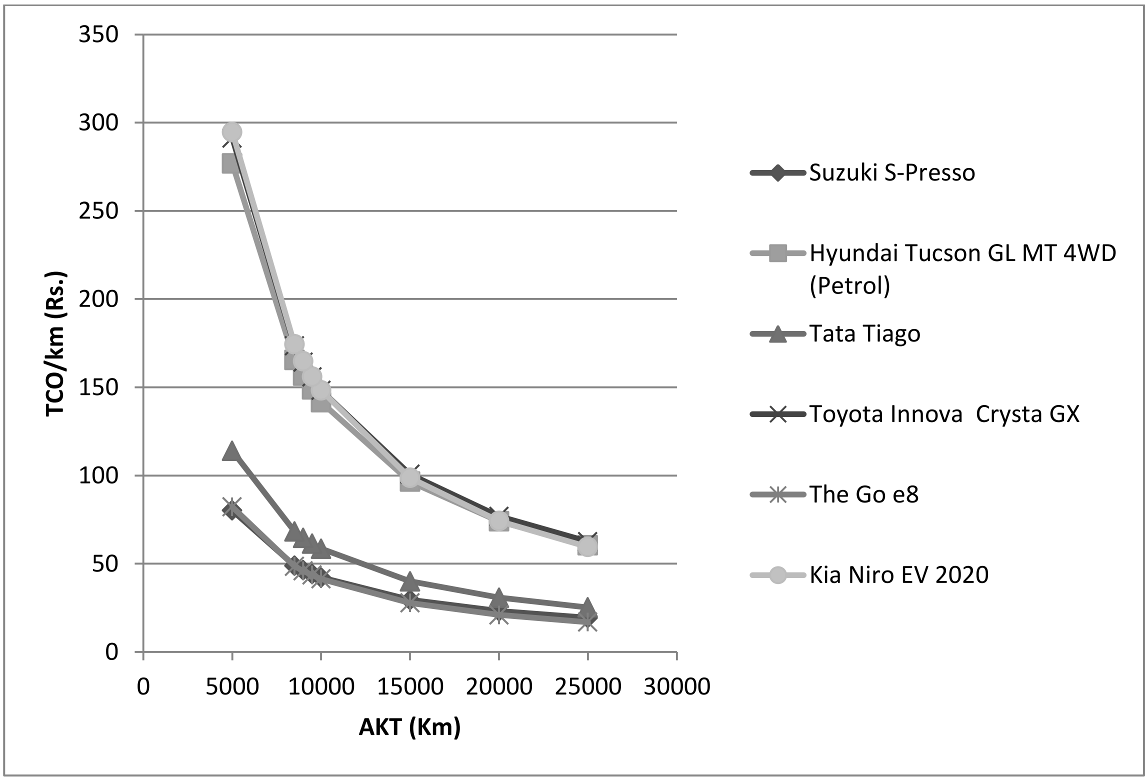

Figure 4.11: Relationship between TCO/km and AKT for four wheeler vehicles

The trend of TCO/km with AKT in figure 4.11 shows that higher AKT values helps to get the lower costs of the vehicles. 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 segments (hatchback and SUV) for the four wheelers. The breakeven distances are shown in table 4.6 for different vehicle segments of hatchback and SUV.

Table 4.6: Breakeven AKT in Km that makes E4W economical than ICE4W

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

Similarly, for the two wheelers, the TCO/km was compared with multiple AKT values across all the models. The trend of change of TCO/km values of two wheelers vehicles (as shown in figure 4.12) was found to be similar with that of four wheelers.

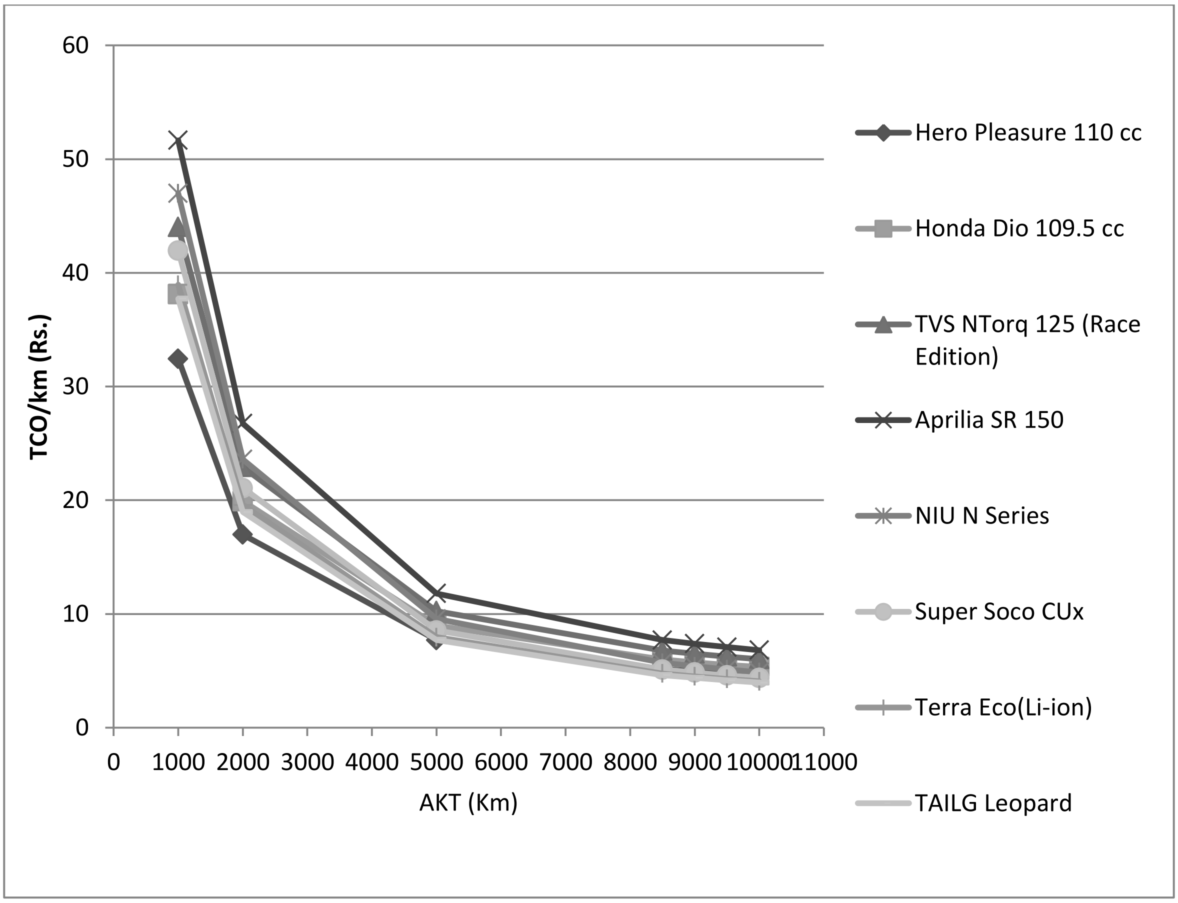

Figure 4.12: Relationship between TCO/km and AKT for two wheeler vehicles

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.

4.5.3 Per Unit Electricity Price

The per unit price of electricity affects the total cost of ownership of EVs. In Nepal, Nepal Electricity Authority and Electricity Regulatory Commission control the price of electricity. In order to observe the effects of change in electricity price on TCO/km of vehicles, the unit price was changed by 5%, 10% and 15% and the respective TCO/km values were compared with the base case scenario. The table 4.7 shows the sensitivity of electricity price on TCO/km of E2W and E4W.

Table 4.7: Sensitivity analysis of Electricity Price

EV	Change in Electricity Price	Change in TCO/km
Four Wheeler	5%	0.023%
	10%	0.045%
	15%	0.068%
Two Wheeler	5%	0.08%
	10%	0.15%
	15%	0.23%

The unit price of electricity was decreased by 5%, 10% and 15% and the corresponding decrease in TCO/km values were obtained as tabulated in table 12. 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 15.

Also, the nature of change in TCO/km due to the variation of per unit electricity price was analyzed. The figure 4.13 and figure 4.14 show the nearly constant nature of TCO/km while changing per unit electricity price from Rs. 5 to Rs. 10.

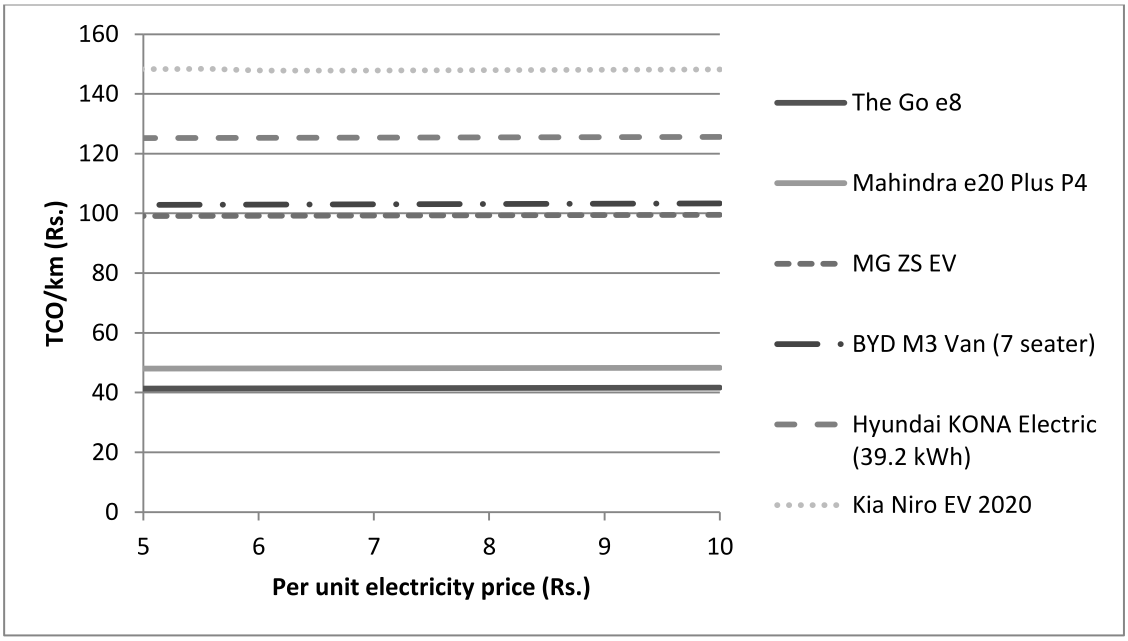

Figure 4.13: Relationship between TCO/km and per unit electricity price for E4W

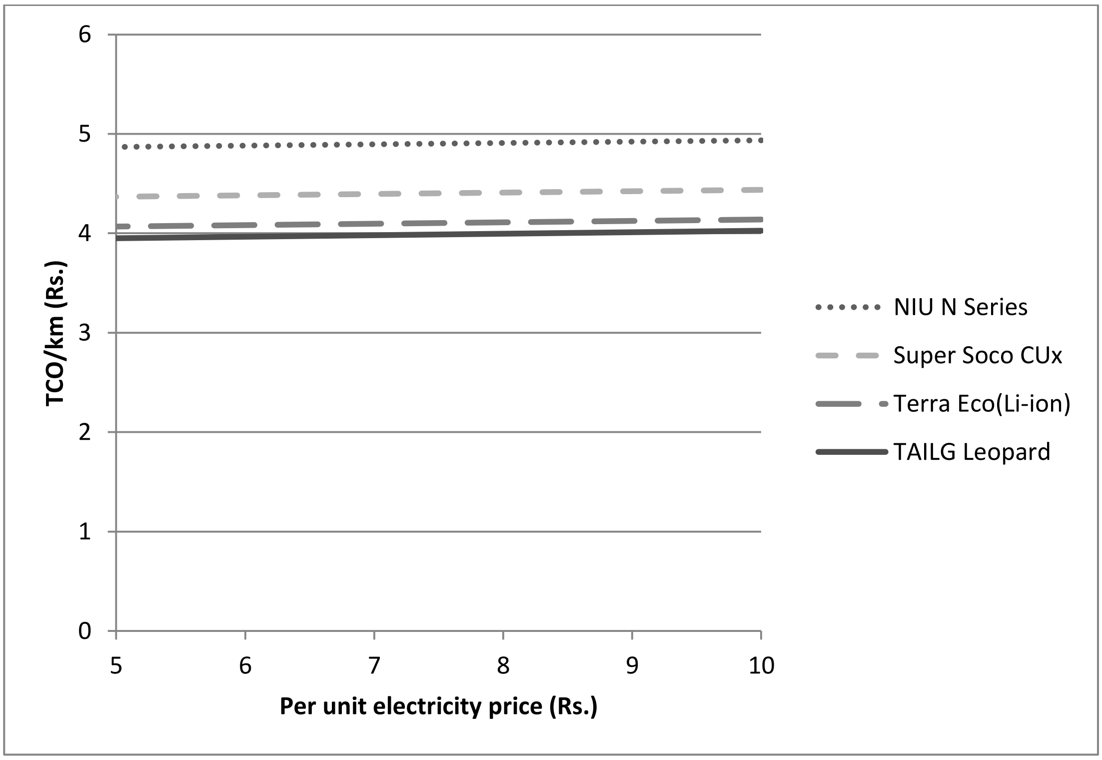

Figure 4.14: Relationship between TCO/km and per unit electricity price for E2W

The figures 4.13 and 4.14 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 low as shown in table 14. 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.

4.5.4 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 by 5%, 10% and 15% and respective TCO/km were compared against the base case scenario.

The table 4.8 shows the sensitivity of fuel prices on TCO/km. It can be observed that increase in fuel price increases the TCO/km but the effect was very low in case of ICE4W. The effect was higher in ICE2W.

Table 4.8: Sensitivity analysis of Fuel Price

Vehicle Categories		Change in Fuel Price	Change in TCO/km
Four Wheeler	ICEV (Petrol)	5%	0.33%
		10%	0.66%
		15%	0.99%
	ICEV (Diesel)	5%	0.14%
		10%	0.29%
		15%	0.43%
Two Wheeler	ICEV	5%	1.12%
		10%	2.24%
		15%	3.36%

While decreasing the fuel price by 5%, 10% and 15%, 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 4.15, 4.16 and 4.17.

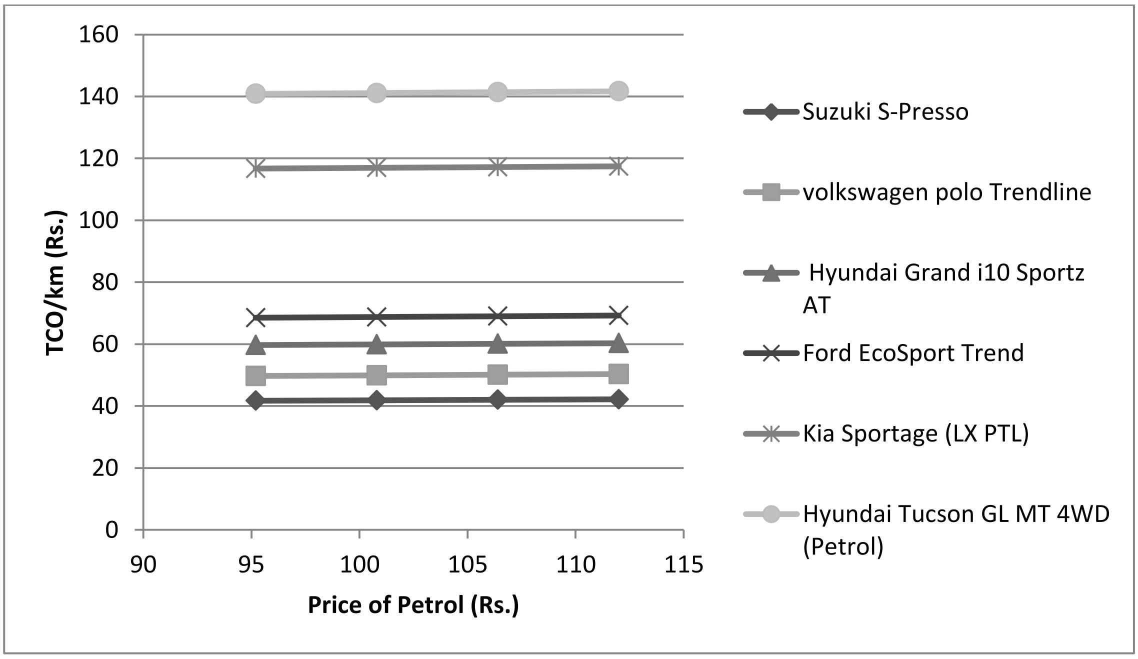

Figure 4.15: Relationship between TCO/km and price of petrol for ICE4W

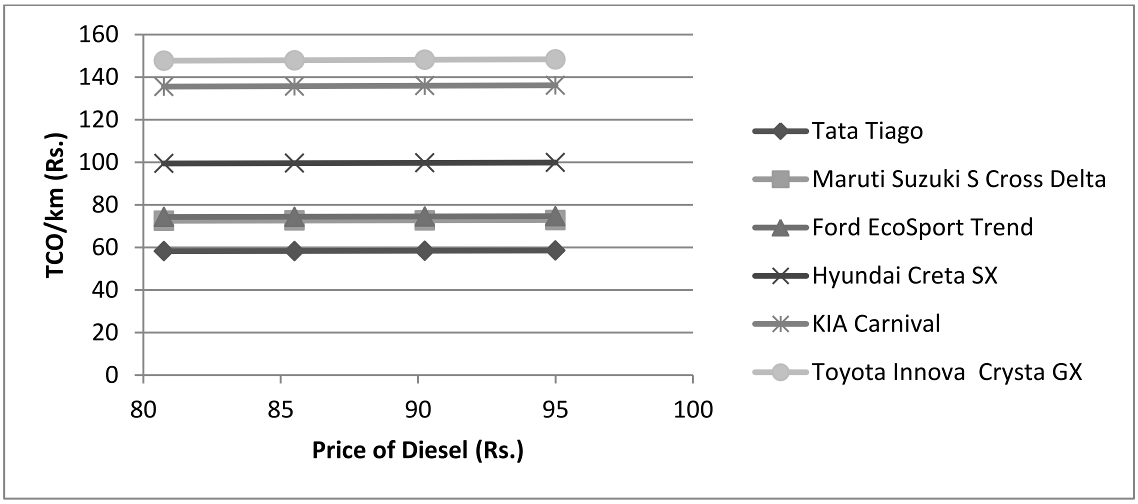

Figure 4.16: Relationship between TCO/km and price of diesel for ICE4W

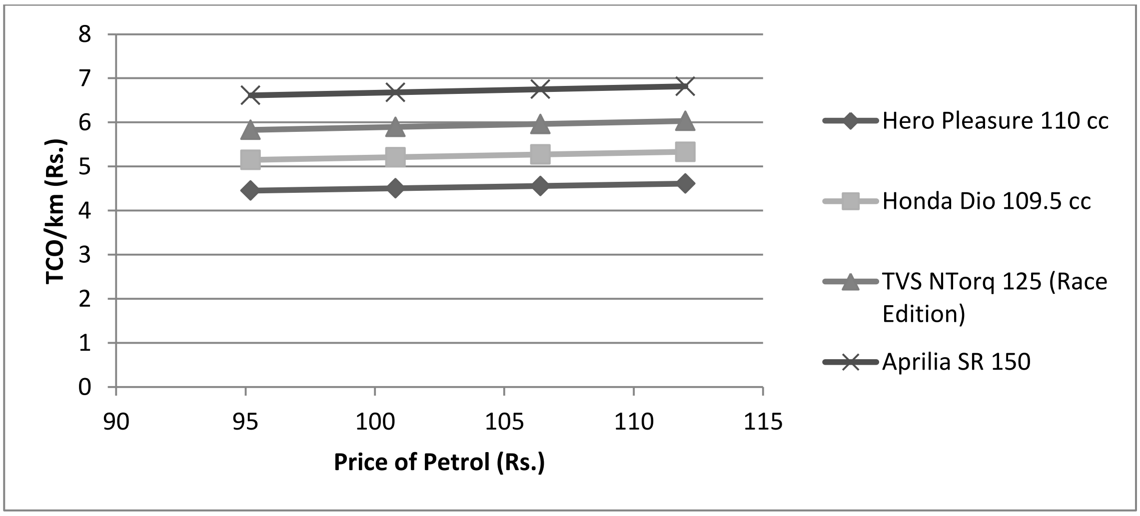

Figure 4.17: Relationship between TCO/km and price of petrol for ICE2W

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

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

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) 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.

Different previous researches Krupa (2019) and Adhikari et al., (2020) regarded purchase price or affordability as an important barrier against the uptake of EVs in Nepal, this study showed that the notion was not true before the promulgation of finance act 2020/21. However, at the current scenario, four wheeler EVs in some segments seem to be unaffordable as compared to ICEVs. In this condition, government should either reconsider the new tax policy or subsidize the EVs in order to make them affordable in comparison to ICEVs.

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.

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Appendix 1: Questionnaire for Electric Vehicle

Topic	Question	Answer
Vehicle Information	Type of Vehicle	Two Wheeler/Four Wheeler
	Model	
	Purchase Price (NRs.)	
	Owned Since	
	Distance Traveled in a full charge in Km	
	Battery Capacity (kWh)	
Yearly Travel Trend	Daily Travel Distance (Km)	
	Medium Range Travel Distance (Km)	
	Number of Medium Range Travel in a Year	
	Long Range Travel Distance (Km)	
	Number of Long Range Travel in a Year	
Maintenance	Total Number of Maintenance Period in a Year	
	Average Maintenance Cost per Period	

Appendix 2: Questionnaire for IC Engine Vehicle

Topic	Question	Answer
Vehicle Information	Type of Vehicle	Two Wheeler/Four Wheeler
	Fuel Type	Petrol/Diesel/Other
	Model	
	Purchase Price (NRs.)	
	Owned Since	
	Mileage per liter of fuel in Km	
Yearly Travel Trend	Daily Travel Distance (Km)	
	Medium Range Travel Distance (Km)	
	Number of Medium Range Travel in a Year	
	Long Range Travel Distance (Km)	
	Number of Long Range Travel in a Year	
Maintenance	Total Number of Maintenance Period in a Year	
	Average Maintenance Cost per Period	

Appendix 3: Vehicle Specifications of Four Wheelers

Four Wheeler		Engine CC (or Motor kW for EV)	Type	Battery kWh	Purchase Price (Rs.)	Seats	Driving Range (km)	Average Mileage (km/liter)	Battery Warrant from Manufacturer
ICEV (Petrol)	Suzuki S-Presso	998	Hatchback	0	2299000	5	-	21.5	-
	volkswagen polo Trendline	1198	Hatchback	0	2745000	5	-	16.5	-
	Hyundai Grand i10 Sportz AT	1197	Hatchback	0	3396000	5	-	17.3	-
	Ford EcoSport Trend	1497	SUV	0	3899000	5	-	14.75	-
	Kia Sportage (LX PTL)	1999	SUV	0	6990000	5	-	14.42	-
	Hyundai Tucson GL MT 4WD (Petrol)	1999	SUV	0	8496000	5	-	12.5	-
ICEV (Diesel)	Tata Tiago	1047	Hatchback	0	3400000	5	-	27.28	-
	Maruti Suzuki S Cross Delta	1248	SUV	0	4299000	5	-	24	-
	Ford EcoSport Trend	1497	SUV	0	4399000	5	-	21.7	-
	Hyundai Creta SX	1582	SUV	0	5996000	5	-	20.5	-
	KIA Carnival	2199	MUV	0	8190000	7	-	14.11	-
	Toyota Innova Crysta GX	2393	MUV	0	8950000	7	-	13	-
EV	The Go e8	15	Hatchback	15.2	2494000	5	150	-	4
	Mahindra e20 Plus P4	19	Hatchback	10.08	2950000	4	110	-	3
	MG ZS EV	105	SUV	44.5	5999000	5	340	-	8
	BYD M3 Van (7 seater)	70	Van	50.3	6200000	7	310	-	8
	Hyundai KONA Electric (39.2 kWh)	100	SUV	39.2	7696000	5	312	-	8
	Kia Niro EV 2020	147.8	SUV	64	9000000	5	385	-	7

Appendix 4: Vehicle Specifications of Two Wheelers

Two Wheeler		Engine CC (or Motor kW for EV)	Type	Battery kWh	Purchase Price (Rs.)	Driving Range (km)	Average Mileage (km/liter)	Battery Warrant from Manufacturer
ICEV	Hero Pleasure 110 cc	110	scooter	0	177500	-	65	-
	Honda Dio 109.5 cc	109.5	scooter	0	212900	-	56	-
	TVS NTorq 125 (Race Edition)	125	scooter	0	249900	-	51	-
	Aprilia SR 150	150	scooter	0	291900	-	50	-
EV	NIU N Series	2.4	scooter	1.74	269000	80	-	2
	Super Soco CUx	1.3	scooter	1.92	239900	85	-	3
	Terra Eco(Li-ion)	3	scooter	2.3	215000	100	-	-
	TAILG Leopard	1	scooter	3.2	210000	130	-	-