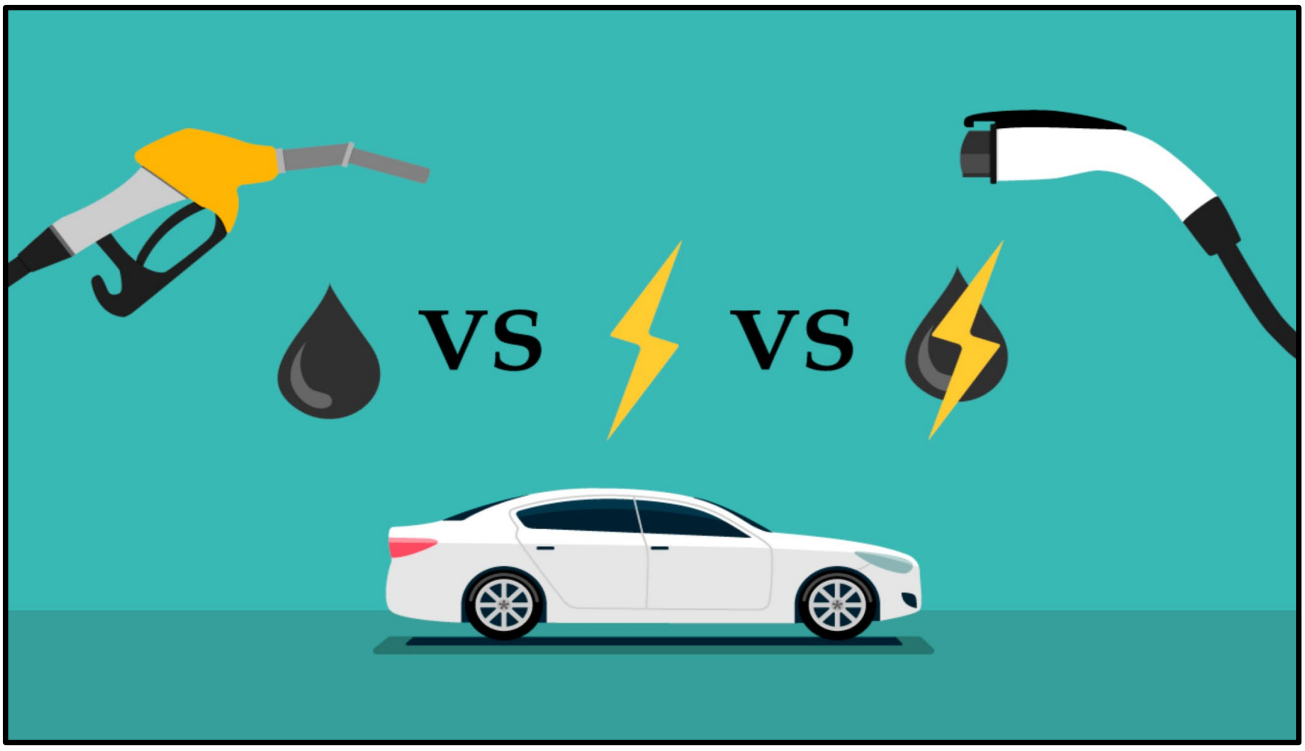
CAL STATE EAST BAY

Economic Analysis of Internal Combustion Engine Car, Hybrid Car and Electric Vehicle

Economic and Life cycle analysis over 12 years



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1 Introduction

Vehicles defined in this analysis are Conventional vehicles (Internal combustible engine), Hybrid Electric vehicles (HEV) and Electric vehicles (EV). This report will provide economic analysis, life cycle cost analysis for the three mutually exclusive alternatives. A typical “conventional” type of vehicle is powered by a regular internal combustion engine (ICE). ICEV cars use fuel which combusts inside a combustion chamber with the help of oxidizers. Our ICE car model is a Volvo S60 2021 luxury car that has 25 mpg mileage on an average. It can go up to 398 miles on fully filled gas tank. Hybrid (HEV) vehicle is a mixture of combustion and electric engines which speak to each other with the use of technology and sensors. The hybrid car model selected for analysis is Volvo S60 2021 Plug-in Hybrid is a luxury sedan that has the combustion engine and supercharger and adds an electric motor, plus a nominal 9.1-kWh lithium-ion battery pack for up to 22 miles of pure-electric driving. It has 30 mpg mileage on an average. Average electric mileage per kwh is 0.47/mile. Electric Vehicle (EV) is a vehicle without a combustion engine and a big battery bank, also referred to as an electric motor. The Electric vehicle chosen for this analysis is Volvo XC40 recharge 2021. On full charge it travels up to 208 miles. This vehicle’s range is controlled by the capacity and charge of the battery. Volvo XC40 EV has a nominal 78-kwh battery. The average electric mileage is 0.43/mile.

The third category of vehicle (EV) has gained widespread attention since the introduction of these vehicles only four years ago. Plugin Hybrids are a smarter alternative to a regular combustion engine vehicle as they use the best combination of electric and combustion technologies. Hybrid electric vehicle is a huge improvement in terms of mileage and carbon emissions over a regular combustion engine vehicle. As batteries and technologies are currently

enough to satisfy most human driving patterns and with advancements happening every day, electric vehicles are set to become the preferred way to transport humans, goods and services. The purpose of this analysis is to figure out economic option among the three vehicles and determine their environmental impact.

2 Mutually Exclusive Alternatives

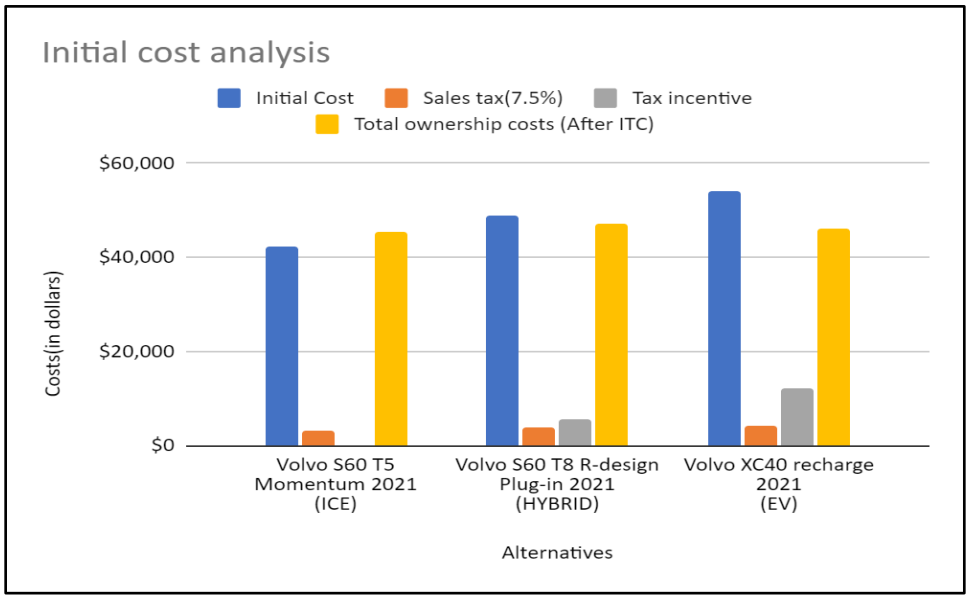
We have considered 3 vehicles that are mutually exclusive and have an equal useful life of 12 years each. The service life of our alternatives are 12 years each. We are comparing alternatives that have different initial investments. As a rule of thumb, the analysis period is also the same as the service life of our alternatives. To evaluate the best alternative, we have used the effective analysis methods to compare the mutually exclusive alternatives using Break-even analysis (Sensitivity), Net present worth (NPW) and Annual equivalent worth (AEW) analysis. In our analysis process, the analysis period equals the service life of the alternatives. We compare the present worth, annual equivalent cost and cost per mile of each alternative to determine the best option based on economy and environmental impact.

Alternative	Volvo S60 2021 (ICE)	Volvo S60 Plug-in 2021 (HYBRID)	Volvo XC40 Recharge 2021 (EV)
Initial costs	$42,295.00	$48,919.00	$53,990
Average O&M costs	$5518.30	$4641.44	$3848.88
Useful life (in years)	12	12	12
Tax incentives	$0	$5419	$12000

Table 1- Mutually exclusive alternatives

3 Initial Costs

The national average cost of gasoline powered cars (using conventional combustion engines) is currently $35,000 in the United States, cheaper than most Hybrid and electric cars. The current Sales tax for California is 7.5%. Many states in the U.S have implemented federal tax incentives to promote the adoption of electric vehicles (EVs), including plug-in hybrid vehicles (PHEVs) and battery electric vehicles (BEVs). The federal tax incentives account for about 10% of the net price you would have paid for plug-in hybrid cars and electric cars. In addition to federal tax credits, some states like California offer the Electric car tax credit program. However, there is a limitation - if a manufacturer sells more than 2,00,000 EV vehicles, no matter which model it was, federal tax incentives will be phased out for that brand. For example, the Tesla cars are no longer eligible for federal/state tax rebate. There is also a small amount of incentive by PG&E for plug-in electric charging. As per our analysis it is not significant to consider it in calculations.



Graph 1: Initial Costs

4 Operating and Maintenance Costs

The operating and maintenance costs are the costs required for a car to operate. Depending upon the use of car by the owner defines it's overall operating and maintenance costs over the period of car owned. The maintenance and operational cost analysis depend on the type of car (ICE or Hybrid or EV) hence it is difficult to quantify exact costs due to the car owner's selective maintenance and operation.

This analysis considers the Annual operating and maintenance costs for 15000 miles per year. The costs considered are Forecasted fuel prices, Average maintenance and repairs, License and Registration/Renewal Fees and Average insurance. The cost of insurance is highly volatile and depends on the owner's driving record, the owner's accident rate, and the type of car and its initial cost. For this reason, the maintenance costs were reduced by the cost of tires and then averaged over a 5-year period to yield an annual maintenance cost estimate. For this analysis, the data provided by kbb.com is used for maintenance and insurance cost estimates. If there is a need for battery replacement for PHEV and EV cars, the average cost of battery replacement runs about $5,500 ~ $12,000 on an average, which is not considered in this analysis. The battery replacement is generally required after 180,000 miles or beyond 12 years after buying. Following figures show operating and maintenance costs for each of the three mutually exclusive alternatives of this analysis. The operating and maintenance costs are shown below. The calculations for forecasted fuel prices, License and Registration/Renewal Fees, Loan repayments is shown in the next section of this report. Refer to ICE, Hybrid, EV tabs of the excel model for calculations of operating and maintenance costs.

4.1 Operating and maintenance cost for S60 2021 (ICE)

*Graph 2:*Calculated O&M cost for Volvo S60 ICE car

4.2 Operating and maintenance cost for S60 2021 (PHEV)

Graph 3: Calculated O&M costs for Volvo S60 Hybrid Plug-in car

4.3 Operating and maintenance cost for XC40 Recharge 2021(EV)

Graph 4: Calculated O&M costs for Volvo XC40 Recharge EV

5 Loan Repayments

Basically, there are several options for purchasing cars. In this purchase, we would be looking into the most common household option - loan payment. The first option is to purchase a vehicle, which can cost between $45,000-$53,000 estimated total for Volvo luxury cars, excluding the ITC rebate. The second option would be taking a loan to purchase from a local bank, credit union. The average interest rate with a good credit score is about 4.16% annual interest rate currently in California. Also, the number for years of repayments chosen is 5 years. This analysis considers 10% of total car price (car price + taxes – tax credits) as down payment. Considering the current cost of owning a conventional ICE Volvo car to be $ 42,295. The down payment is 10% of the total purchase price (after deducting sales tax and tax credit). Therefore, the financed loan amount runs about $40,920.41 with an effective annual interest rate (APR%)

of 0.0416%. Since the loan period is 5 years, our number of monthly payment periods is 60, the monthly payment size is $776.68, and the total interest amount paid is $4473.78. The total amount paid is the sum of the total Interest payment (IP) plus the loan amount. For instance, the below table shows the breakdown of loan payment for monthly payment calculations of ICEV financed for 5 years. Refer to 'ICE', 'Hybrid' and 'EV' tabs of the excel model for in detail calculations of Loan repayments for each of the car.

Calculation for (e)	
Total Price	$45,467.13
Down Payment	$4,546.71
Financed Amount	$40,920.41
Inputs:	
Loan Amount	$40,920.41
Loan period(years)	5
APR (%)	0.0416
Payments per year	12
i (payment period)	0.35%
N(periods)	60

Calculations:	
Monthly payment %	$756.57
Interest paid	$4,473.78
Total Amount Paid	$45,394.19

Table 2: Finance Calculations

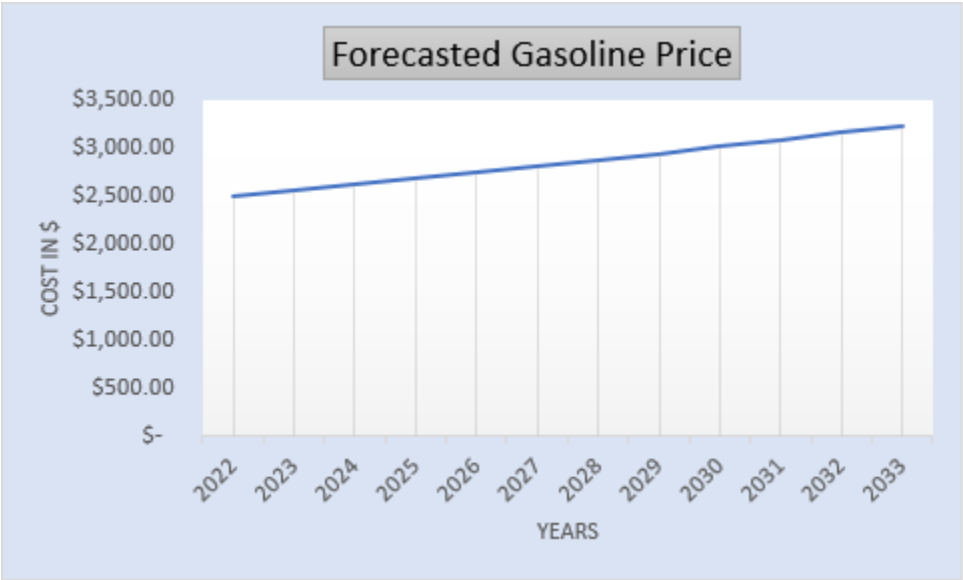
6 Historical, Financial and Cost Data

The historical data used for this economical cost analysis include fuel prices from year 2010 to 2011(11 years), electricity prices from year 2010 to 2021(11 years). Also, car fuel economy calculations and maintenance costs from past models of similar cars. Considering annual mileage of 15,000 miles, the average retail price of electricity annually (in dollars per KwH) in

California for the last decade was $0.081, much cheaper compared to the fuel prices (Dollars per Gallon) over the last decade which was $3.07 on average. Spending an extra $200 per month in financing or lease payments compared to saving about $60 per month in fuel and electric recharge costs should be a great deal for car owners. In this analysis model, yearly inflation rates are computed the gasoline and electricity prices obtained from the U.S energy information portal. The table below shows the changes in inflation rate over the last decade and helped in forecasting the fuel prices for the next computation period.

Periods/Years	Date	U.S. All Grades All Formulations Retail Gasoline Prices (Dollars per Gallon)	Calculated Average Inflation rate
0	2010	$ 3.14	
11	2021	$ 4.07	
Calculation for average inflation rate	Initial Value	$ 3.14	
	Latest Value	$ 4.07	
	Initial val/Latest Val	1.297	
[initial value (1+f)^N= Latest Value]	Solving LHS of eqn	0.01027	
where f = average inflation rate	Solving RHS of eqn	1.023923254	**2.4%**

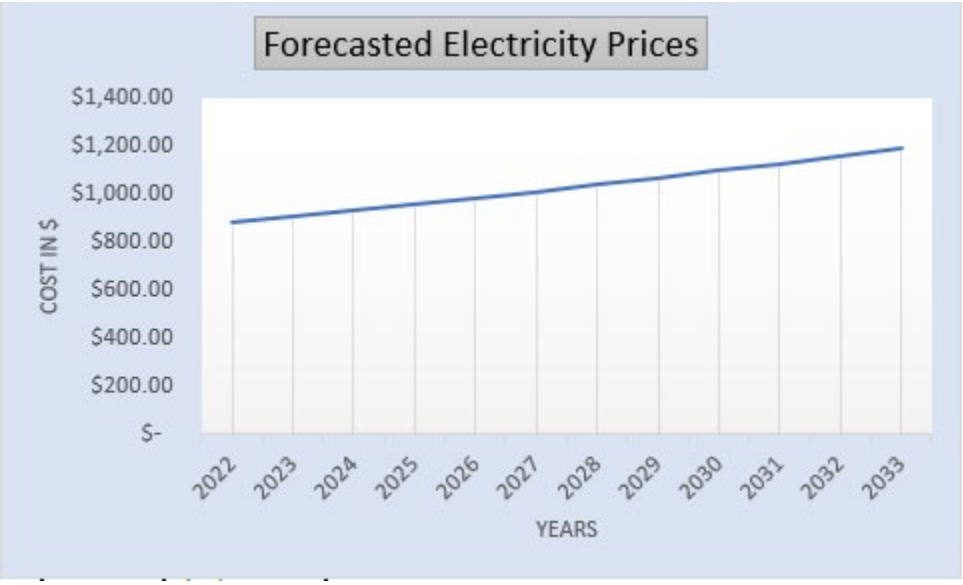
Table 3: Calculation for inflation of gasoline



Graph 5: Forecasted Gasoline prices

Periods/Years	Date	U.S. California : Average retail price of electricity annual (Dollars per KwH)	Average Inflation rate
0	2010	0.0983	
11	2021	0.1331	
Calculation for average inflation rate [initial value (1+f)^N= Latest Value] where f = average inflation rate	Initial Value	$ 0.10	
	Latest Value	$ 0.13	
	Initial val/Latest Val	1.35402	
	Solving LHS of eqn	0.01197	
	Solving RHS of eqn	1.02794	**2.8%**

Table 4: Calculation for inflation of electricity



Graph 6: Forecasted Electricity prices

Our economic analysis of Volvo S6 ICE, hybrid and EV model shows that the fuel expenses for combustion engine cars are more compared to our hybrid and EV alternatives. Although electric vehicle technology is higher in first cost, the operating and maintenance cost savings provide lower life cycle costs than conventional ICE cars. Choosing electric cars over conventional cars reduces the energy cost and is more sustainable. Refer to 'ICE', 'Hybrid', 'EV' tabs for calculations of forecasted gasoline and electricity prices. Over the period, electric cars can help to save a lot of money on fuel cost, our further analysis below shows that.

7 Analysis Model

The analysis methods used for economic analysis of ICEV, HEV and EV in this model are Present worth Analysis and Annual Equivalent worth. As the mutually exclusive alternatives are considered as service projects, minimum costs are considered to find out the economic option. Refer to excel model 'PW Analysis' tab for present worth analysis and 'AE Analysis' for Annual equivalent worth (costs) analysis. The model also calculates cost per mile each year.

7.1 Findings

The main finding of this study is that the selected electric vehicle, Volvo XC40 recharge, performs the best in terms of total lifecycle costs compared to its alternatives S60 ICEV and PHEV. Based on the LCC simulation results, the LCC results show that for all three lifetime cases that's reasonably priced, battery-powered/recharge vehicles (HEV/EV) are lower in annual costs than conventional ICE vehicles.

Comparing the other three most popular Volvo luxury cars for analysis, the S60 T5, S60 T8 plug-in hybrid and the XC40 recharge, the after-costs for both ICEV and PHEV are resulting in higher annual costs than the XC40 recharge pure electric car. The results of varying miles per year driven changes the annual cost positions of the three alternatives. The inputs of most impact have been identified as: 1) The initial vehicle cost, 2) Insurance Cost, 3) Fuel/energy Cost, 4) Inflation rate. Also, for the hybrid S60 plug-in car to achieve break-even point with the XC40 EV over its service period in terms of fuel, the price of fuel must be equivalent to $1.20 per mile. The net present worth of EV's is consistently higher than ICEV and HEV. The AEW analysis shows that EV's have comparatively less costs than HEV and ICE. HEV's have slightly more cost than EV but less than gasoline. As for the initial costs, EV & PHEV appears to be high, but the operating and maintenance costs are low over the periods. The environmental impact of ICEV is more than PHEV and EV. The savings due to the EV's lower annual energy and maintenance costs may gradually decline over the lifecycle, depending on if insurance prices spike, along with additional replacement costs.

8 Questions - Project Analysis

a) What are the main outflows and inflows?

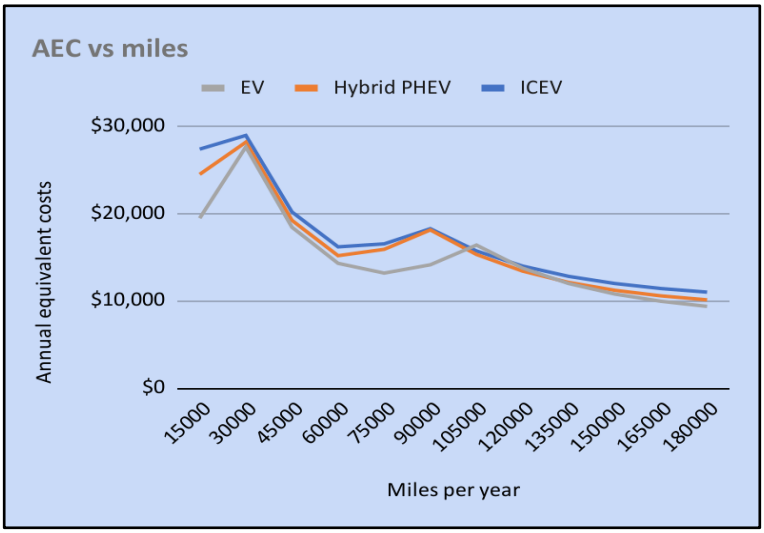
The main outflows for our project are initial cost, taxes, operational and maintenance costs. The inflows are tax incentives.

b) Determine the optimal replacement age for each vehicle. Calculate the capital recovery cost.

Optimal replacement age: As per research, a vehicle with a maintenance cost that is 30% or more of the vehicle's residual value should be assessed for replacement. In our analysis considering the annual maintenance/repair costs and salvage values, the optimal replacement age for ICE is before year 7, similarly for PHEV the ideal replacement age is at year 7 and for EV before year 8.

c) What are the key financial variables you are using? Like MARR, Interest rate, and inflation? Justify your inputs.

The key financial variables we used for this project are mainly, interest rate (as per bank interest rate), inflation, net present value (NPV), Annual equivalent worth (AEW). Following figure shows the AEC vs Miles graph for each of the alternative.



Graph 7: AEC

d) Show the mileages at which different alternatives become more attractive. Does your model show you any optimal balance between extra cost of sustainable systems and the saved cost associated with the use of less resources?

As per our analysis using per mile cost vs number of miles, the alternative that has the lowest yearly per mile cost (EV in this case) is the most attractive and economical choice due to its saved after-costs despite high initial cost.

e) If a CARBON TAX increases the cost of Gas by 100% and electricity by 20%. How do the answers for items (a) to (d) change?

Below tables depict the change in fuel and electricity prices due to increased carbon tax %. On a 20% increase in electricity price, the electricity price per kwh spikes to $0.1597. However, when fuel is increased by 100%, the resultant price is $8.14, which increases the total O&M costs of the ICEV and PHEV. However, even with increased cost prices of fuel and electricity, Volvo XC40 recharge turns out to be the best alternative due to its reduced ownership costs over the years in comparison to Volvo S60 ICE and Volvo S60 plug-in hybrid.

Car	Volvo S60 ICE	Volvo S60 PHEV	Volvo XC40 EV
Fuel Prices in current year	$ 4.07	$ 4.07	-
	$ -	$ 0.1331	$ 0.1331

Input Parameters	Current Fuel Prices	Current Electricity Prices
Carbon Tax	100%	20%
Prices after applying carbon tax	$ 8.14	$ 0.1597

Table 5: Effect of carbon tax on prices

Effect of carbon tax & fuel price hike on question 7(a)

- If the carbon tax increases fuel & electricity prices by 100% and 20% respectively, the outflows are the annual operating costs (fuel/electricity prices), carbon tax%. The inflows are still the tax incentives.

Effect of carbon tax & fuel price hike on question 7(b)

- There would be no change in the optimal replacement age and capital recovery costs due to the change in Fuel/electricity prices.

Effect of carbon tax & fuel price hike on question 7(c)

- The financial variables remain the same as 7(c).

Effect of carbon tax & fuel price hike on question 7(d)

- The total operational costs (cost per mile, fuel/energy prices) for all the three alternatives would spike and the present worth (PW) and annual equivalent costs (AEW) costs would increase, however EV is the most attractive alternative due to the lesser cost per mile charges and higher net present worth (NPW).

9 Sensitivity Analysis

The economic sensitivity analysis (or what-if analysis) measures how the output variables are affected based on changes to key input variables. In this LCC model, one-way sensitivity analysis investigates the effect of change in initial costs, mileage, interest rates on the total LCC. To build a decision-making model for adoption of the best alternative, we define costs and

benefits parameters of this model and devise a comprehensive plan for car owners. Hence, economic parameters such as annual equivalent worth, capital recovery costs, net present value, will determine the feasibility of this model through critical analysis of real time data and references.

The optimal balance between the high initial costs of the sustainable alternative and the saved costs have been calculated by predicting the annual equivalent costs and its present value annually. Upon comparing the alternatives, the higher the number of miles, lower the total LCC cost becomes, for Electric vehicles compared to the other two alternatives. Hybrid models have a slow rate of cash flows due to their dependency on conventional energy systems compared to an EV. Refer to the 'Inputs' tab in excel model to set the parameters of sensitivity analysis.

10 Impact on Environment due to Carbon Emissions

To determine the environmental impact of each alternative, we have gathered the estimated carbon emission in pounds and multiplied it by the provided 15,000 miles per year to determine the total CO2 emissions. The carbon footprint shows emissions for EV which are not considered in this analysis. They are still lower than ICEVs and HEVs. Refer to 'Carbon Emission' tab in the excel model.

11 Conclusion

Which is worth buying- an ICEV or PHEV or BEV? It rests on what you can afford and how well you maintain the vehicle. In addition, an electric vehicle can give you up to 21% tax break in the first year and is also good for the environment. If you decide to buy a car, shop around and search for federal and state tax incentives. There are separate tax credits offered such as the one offered PG&E for zero carbon emission vehicles. And if you do not want to purchase it

upfront, you can take a loan as well which is a feasible choice, with the current loan interest rates in California at 4.16%. That offers a lower upfront cost. Though EV looks cost-effective, the buyer needs to consider other factors such as refill range of the car, availability of refill stations, power of the car required for frequent driving terrain, environmental impact along with the economic analysis to make the right choice.

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