Electrifying UC Davis Light Duty Fleet: Total Cost of Ownership and Greenhouse Gas Emissions Calculator

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Jonathan Boyd
Julia Hoffman
Oleksandr Syrovoi

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1. Project Background

As the harmful consequences of fossil fuels are becoming more evident, people, regions, and organizations are stepping up. The University of California has taken great leadership in combating climate change. To guide research and change system wide, the university pledged to become carbon neutral by 2025 [1]. Utilizing the universities research potential, The UC Carbon Neutrality Initiative strives to reduce campus related emissions and illustrate the path toward decarbonization [1]. Greater than 95% of campus emissions are scope 1 and scope 2 emissions, from the direct burning of fossil fuels, and emissions related to fossil fuel consumption for electricity generation [1]. This leaves ample room to address campus emissions right from the source.

As a contributor to scope 1 emissions, campus Fleet Services is looking at ways to reduce their greenhouse gas (GHG) emissions through electrification. Currently campus fleet is comprised of light duty vehicles: sedans, SUVs, vans, and trucks. Fleet Services offers hourly, daily, and departmental rentals. With direction from Gil Tal, the Transportation Research Director of the Plug-in Hybrid and Electric Vehicle Research Center, we created a Total Cost of Ownership (TCO) and GHG emissions calculator to assist the campus fleet manager in navigating vehicle replacements to transition to a more electric fleet.

2. Considerations

2.1. High Occupancy Vehicle Lane use for Eligible Clean Air Vehicles

UC Davis's geographic position along interstate highway 80 and vicinity to the Bay Area places the campus in a unique position for utilizing High Occupancy Vehicle (HOV) lanes. HOV lanes require a certain number of passengers in the car or a Clean Air Vehicle (CAV) decal in order to use the lane. The Department of Motor Vehicles (DMV) and the California Air Resources Board (CARB) partnered to create the CAV program, allowing electric vehicles that meet certain air quality standards to be eligible for HOV lane use, with only a single occupant [5]. The decals are inexpensive, costing a one time fee of $22 [5]. The Bay Area HOV lanes hold these guidelines during main commute hours and created the lanes to encourage carpooling and incentivize CAV use over single occupant and conventional vehicles, with the goal of reducing transportation related pollution. In addition to the comparisons identified in the Fleet Electrification Tool, fleet managers can consider purchasing a CAV decal eligible vehicle for the benefits of the HOV lane and in hopes of reducing travel time for users. CAV decals expire on the first day of the calendar year, four years after originally purchased, ensuring the decals can be used for a minimum of three years [4]. The program in its entirety will conclude on September 30th, 2025 making the benefits of the program time sensitive and temporally limited [4]. In case studies detailed later in this paper, each one compared a vehicle/vehicles to a CAV eligible vehicle, the 2020 Chevy Bolt, the 2020 Hyundai Kona Electric Vehicle (EV), and the 2020 Chrysler Pacifica Plug-in Hybrid Electric Vehicle (PHEV)[6].

2.2. Potential Tax Credits

While the Fleet Electrification Tool we produced accounts for many UC Davis specific attributes, there are other considerations that can impact the TCO of UC Davis vehicles. The federal government and California state government offer tax incentives for purchasing qualifying new electric or plug-in hybrid electric vehicles [8]. The federal tax credit for new electric vehicles can reach up to $7,500 [8]. The California state program, the Clean Air Vehicle Rebate Project, offers rebates of up to $7,000 for new, qualifying, EV and PHEVs [10]. Some vehicles in our case studies detailed later in this paper qualify to varying degrees for the federal tax credit and state rebate as detailed in the table below [8 and 10].

Vehicle	Federal Tax Credit	State Tax Rebate
2019 Chevrolet Volt	$1,875	$1,000
2020 Chevrolet Bolt	$1,875	$2,000
2020 Hyundai Kona EV	$7,500	$2,000
2020 Chrysler Pacifica PHEV	$7,500	$1,000

Table 1: Vehicle tax credits [8 and 10]

Utilizing tax credits as a tax exempt public university is not a streamlined task. When a tax-exempt organization purchases a vehicle eligible for a tax credit, the dealer can take the credit as long as the organization is notified during purchasing [9]. Organizations and dealerships can negotiate a percent of the tax credit to become a discount on the vehicle purchase price [9]. UC Davis has experience using the tax credit to negotiate a lower purchasing price, establishing familiarity in the area [9].

3. Calculation considerations

The methods and considerations associated with the deployment of EVs in the fleet environment are inherently different than considerations of assessing a conventional fleet vehicle. The biggest difference to account for is added benefits of zero emissions to health and the environment, and consequently, the reversal of harm that would otherwise be caused by conventional vehicles. In general, vehicle selection for replacement of existing units involves matching a certain type of vehicle to a specific use, in case with UC Davis it will be either a department rental vehicle, daily rental vehicle or a facility maintenance truck. As presented in this report, compelling arguments for the replacement of conventional vehicles with EVs can be made when the appropriate vehicle is selected for the task [2].

Operational considerations for EVs are quite different compared to conventional vehicles since they use a pre-stored energy source rather than physical fuel being transferred into the tank and burned in a fuel converter. Fundamentally different power and drivetrains lead to decisively different maintenance considerations, producing more predictable fuel expenses as well as generally much lower vehicle maintenance cost [2].

More often than not, the upfront capital cost of an EV is higher than a comparable internal combustion vehicle yet state, local and federal tax credits in addition to various financial incentives routinely result in a lower purchase price for an EV. Further financial benefit with adopting EV in the fleet environment is the fact that usual maintenance items such as coolants, lubricants and filters as well as the tools and accessories are no longer needed and do not have to be stocked any longer [2]. Lower operating expenses of EVs are an attractive reason to consider their deployment in a fleet environment. EVs are mechanically simpler than CFVs, having no transmission, cooling and lubrication systems results in much lower maintenance cost and significantly improves the viability of EVs as fleet vehicles.

Specifically with UC Davis, fleet deployment calculation must account for no interest or financial charges, since vehicles are being acquired bypassing loans which subsequently eliminate these charges. Additionally, University is self-insured therefore no insurance charges need to be factored in compared to a usual Total Cost of Ownership evaluation scenario that is often used in various tools designed for similar purposes.

When it comes to emissions reduction potential, the electricity source can have a large impact. An additional benefit to electrification at UC Davis, is the cleaner electrical grid. The University electricity mix is quite different from the average California grid, specifically, only 27% of electrical supply comes from carbon-based generation. Vehicle emission reduction benefits calculated using the Fleet Electrification Tool developed as part of this report presents environmental benefits for both electrical grid scenarios: the California average grid and UC Davis-specific grid.

Calculations presented in this report were performed against two paramount metrics of the vehicle evaluation process: total cost of ownership (TCO) in $ and total greenhouse (GHG) emissions in lbs of CO2-equivalent over the analysis period of vehicle use phase. The Fleet Electrification Tool was built around the metrics mentioned. Analysis presented in this report was over a 9-year analysis period, the typical lifespan of a UC Davis light-duty fleet vehicle.

Accounting for idling impact is another factor that has its effect on both TCO and GHG emissions which was included in analysis performed as part of this report. Idling of an internal combustion engine (ICE) can have negative effects on cost of ownership as well as undesirable health effects. Whenever the vehicle is on, it builds up its exhaust when it idles, emitting GHG and sometimes getting inside the vehicle. Comparison of idle-free and 2-hour a day idling vehicle was performed to evaluate impact of idling on GHG emissions and TCO. Results of the analysis are presented in a graph below. It appears that conventional vehicles are quite sensitive to idling time over their lifetime to the point that if a vehicle idles extensively (like facility maintenance vehicles do) TCO ends up being significantly higher than EV and PHEV alternatives.

No idling **2-hour a day idling**

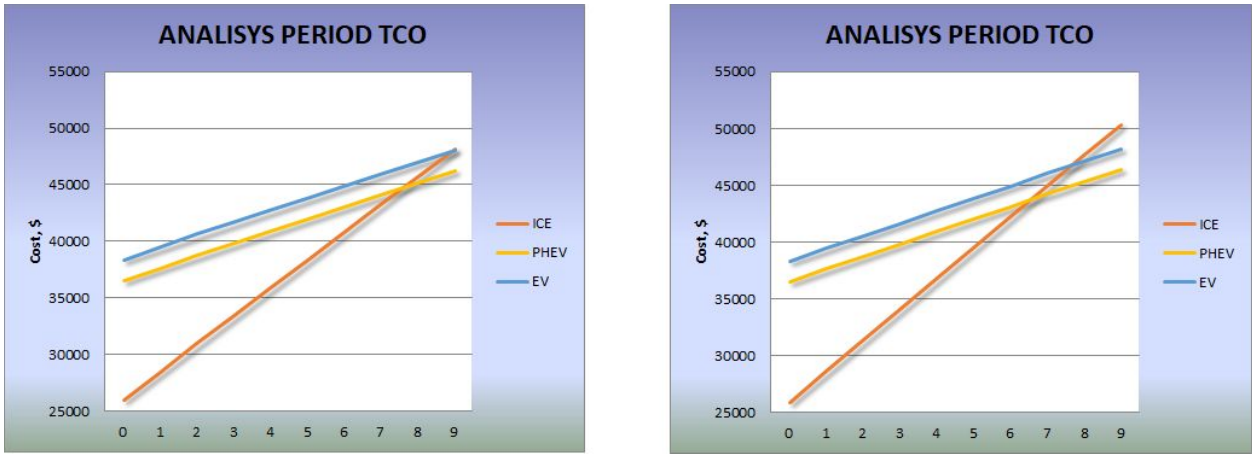

Figure 1: Total cost of ownership with and without 2 hours of idling per day

4. Constraints

There are certain constraints that had to be acknowledged during our analysis: limited vehicle trip information, one month of detailed real-world data was acquired for processing. In terms of vehicle constraints, since some vehicles were utilized for long-distance travel, battery electric vehicles (BEV) could not meet the trip requirements considering reasonable time-allowing ability to recharge along the way.

An additional cost to account for when swapping conventional vehicles for EVs is necessary infrastructure cost. Capital cost for additional charging infrastructure required with fleet vehicle swaps can vary widely. From about $750 single port Level 2 charger that may be able to support one or two EVs, to a $6000 Level 2 multiport charger that can service the needs of several EVs and up to $35,000 of a DC Fast Charger which may be justified if the deployed fleet size is large enough [2]. Additionally, federal tax credit of up to 30 percent of the cost of installing EV infrastructure for businesses is available, however there is a cap at $30,000 (Department of Energy, 2020). Further, due to temporary inability to access current charging infrastructure at UC Davis, additional charging infrastructure requirements should be evaluated upon the quality inventorization of existing one. Availability of spare electrical capacity at perspective EV charger installation locations is a detrimental factor in total cost of adding a charger at that location. Without spare capacity availability, it may be cost-prohibitive to add charging infrastructure at certain locations.

There are key assumptions undertaken as part of our study to keep modeling manageable within an allocated time frame. Due to significant gas price volatility we proceed with assuming constant gas price at $2.87 a gallon [3] and $0.0687 a kWh for electricity price per UC Davis Facilities Management. GHG intensity of all energy sources energy were considered constant at data values available at the time of modeling. Vehicle fuel consumption was considered constant at discrete vehicle-specific values for city miles per gallon and highway miles per gallon. Due to limited data available, we assumed 45% share of highway driving for short trips (<50 mi) and

80% highway share for long trips (>50 mi). In case with EVs, in order to achieve sufficient range to cover longer-distance trips (over 200 miles), we assumed 1.5 battery charges per trip (assumed 1 stop along the way to recharge vehicle battery). Dollar values were held constant due to equivalent analysis period for all the vehicles.

5. Fleet Electrification Tool Inputs & Outputs

The first set of inputs for the tool are vehicle specific inputs which will change with each vehicle that is selected to compare. These inputs fall into two categories: car price and car performance metrics. The car price is a straight forward input and should be the MSRP for the car of interest. If the fleet manager has a better price for the car of interest because he or she has already shopped around then that value can be used but MSRP is a good starting point and is readily available with a quick google search. The car performance metric is a little more complex because all electric drive and conventional drive need to be taken into consideration. Conventional driving fuel consumption is entered using city miles per gallon and highway miles per gallon. Electric drive energy consumption is entered using city kiloWatt-hour per 100 miles and highway kiloWatt-hour per 100 miles. These values can sometimes be difficult to find but eMPG can be readily converted to kiloWatt-hour per 100 miles. There is one additional input for cars with pure electric drive and that is all-electric range. For PHEVs, this dictates how much grid energy is used before switching to gasoline and for EVs this dictates the max trip the car can take before refueling. The final performance metric is engine displacement in liters. The value is used to calculate idle fuel consumption. The idle calculator doesn't take into account idle reduction technology such as automatic engine off-on or active fuel management systems which deactivate cylinders under light load. This may lead to overestimates for fuel consumption for vehicles equipped with this technology.

The second set of inputs for the tool are application specific inputs and should be the same for every vehicle compared for a specific application. These inputs include vehicle service life and vehicle trip data. Vehicle service life is simply how long a fleet plans to own and operate the vehicle. This will have impacts on total service life emissions and total cost of ownership. It also will impact the salvage value of the vehicle which is assumed to depreciate at about 10% per year until the tenth year. Then the salvage value is assumed to be one thousand dollar for the rest of the service life. Trip data is broken down into daily driving and additional trips. For our analysis we assumed any trip under 50 miles was a daily driving and any trip over 50 miles was considered in the additional trip section. This was done to ensure a large number of short trips didn't skew the average trip distance and make it seem like more miles were driven on all electric range than makes sense. One other key note is daily driving doesn't need to occur every day. The input categories days per week and weeks per year can be adjusted to match any frequency of trips. Also idling energy consumption is only accounted for in the daily driving portion. This means even if the idling occurred during additional trips, daily idle time should be adjusted to account for this additional idling.

The final set of inputs are for cost of operation and pounds of greenhouse gases (GHG) generated. The cost of operation uses the price of fuel, price of electricity and maintenance cost. Price of fuel and price of electricity should be updated with the current price at time of the calculation. Particularly, the price of fuel can be quite volatile and needs to be updated. The current values in the calculator are the average price of gasoline in California and current price of electricity provided by UC Davis facilities. Maintenance cost is calculated by the mile and there is a value for any car with an internal combustion engine and a value for pure electric vehicles. These values came from AAA and represent the national average. It would be best practice to update these values with empirical maintenance cost to provide more accurate results. The inputs for GHG generation are broken into a value for electricity in lb GHG per kWh and lb GHG per gallon for fuel. The fuel value is entered directly and represents the value for gasoline. This value needs to be updated if a diesel vehicle is evaluated. The value for electricity is calculated by inputting the GHG intensity for each form of power generation and how much of the electricity is generated using the form of power generation. Current values in the tool represent the makeup of UC Davis grid power from fiscal year 2018 to 2019.

The fleet electrification tool has a number of outputs but the vast majority are simply intermediate calculations that can be used to debug if the final values don't seem correct. The critical outputs are total service life vehicle cost and service life emissions. These are the values that can compare how expensive a vehicle will be for the fleet to operate and how green the purpose vehicle will be for the fleet. It is important to keep in mind that total service life vehicle cost doesn't include incentives. This was done intentionally because incentives can vary broadly for type of vehicle and even manufacture of the vehicle.

6. Case Studies

6.1. 2019 Chevrolet Volt and 2020 Chevrolet Bolt

To evaluate the outputs of our tool and produce examples of potential vehicle comparisons the fleet manager may be considering, we performed three case studies. First, we chose to compare the 2019 Chevrolet Volt, a PHEV that fleet owns and the 2020 Chevrolet Bolt, a new electric vehicle alternative. Trip data from campus fleet revealed that the average daily driving distance for this type of vehicle was 35 miles per day with a daily idle time of 0.85 hours in October 2019. Idling has a large impact on energy consumption for this vehicle type and use, contributing 20% of the energy use. Additionally, nearly ⅕ of the vehicle's trips are greater than 50 miles and average at 160.4 miles per day. As the all-electric range of the Bolt is 259 miles, this is well within range. The Volt's all-electric range is much lower, at 53 miles, noting that for these longer trips, the engine would run, consuming gas.

The vehicles have a number of other differences. The Bolt begins at a higher Manufacturer Suggested Retail Price (MSRP) of $37,495 compared to the Volt's MSRP of $34,095. Each vehicle requires different costs throughout its analysis period at UC Davis. The Volt costs $0.10 per mile and the Bolt costs a lower, $0.06 per mile. This contributes to the final Total Cost of Ownership (TCO) quantities at the end of the nine year ownership period in which the Volt is projected to sell for $3,069 and the Bolt for $3,375. The TCO of the Volt is $42,737, while the TCO of the Bolt is slightly lower at $41,051. Further calculations determined that over the 9 years the Volt would produce 43,747 lbs of GHG emissions and the Bolt would result in 12,097 lbs of GHG emissions, a difference of 27.65%. As illustrated by the TCO tool, the Bolt is both the cheapest option and substantially reduces GHG emissions that are a direct effect of driving.

6.2. 2020 RAV4 Conventional, 2021 RAV4 Prime, and 2020 Hyundai Kona EV

In the next case study we chose to compare a current campus fleet vehicle, the conventional 2020 RAV4, against a not yet on the market PHEV vehicle, the 2021 RAV4 Prime, and an electric competitor to those models, the 2020 Hyundai Kona EV. This case study further tests that our tool can evaluate vehicles based on not just current options, but also future potential campus vehicles, and can be used to compare a number of vehicles at once. One key difference is the all-electric range (AER) of the three vehicles. The 2020 RAV4, as a conventional gasoline vehicle has an AER of 0 miles. The 2021 RAV4 Prime has an AER of 39 miles and the Kona, an all electric vehicle has an AER of 258 miles. Including range in the comparison is essential to demonstrating if a vehicle is a good replacement option. Gasoline vehicles are able to refuel faster and are then less restricted by distance. The average daily travel for this vehicle group is manageable for each alternative, however the car may be used for longer distanced trips. Fleet data collected on the 2020 RAV4 revealed that 4 of the 9 trips taken in the evaluated period, October 2019, exceeded the range of the all electric Kona on a single charge. While this is important to consider, it can be addressed through more research on charging accessibility and the availability of DC fast chargers. Ultimately the TCO of the 2020 RAV4, the Prime, and the Kona revealed that the Kona becomes the cheapest option at $45,790, $51,512, and $44,599 respectively. As we had anticipated, the 2020 RAV4 contributed the greatest amount of GHG emissions and the Kona produced the least. The results came down to 112,209 lbs of GHG emissions from the 2020 RAV4, 77,362 lbs of GHG emissions from the Prime, and 16,771 lbs of GHG emissions from the Kona. This case study demonstrated that a fleet manager could save $1,191 and reduce emissions by 95,438 lbs by purchasing the electric Kona rather than the conventional RAV4. When using the tool, a fleet manager can consider their unique needs to determine which vehicle suits their needs best.

6.3. 2020 Chrysler Pacifica and 2020 Chrysler Pacifica PHEV

Lastly, we chose to compare a conventional and PHEV minivan option using the two Chrysler Pacficias. Campus fleet trip data revealed that the minivans are under utilized, driving an average of 20 miles a day, 50% of the week. This low average daily mileage impacts the TCO of each vehicle, as the lower cost per mile of $0.12 for the PHEV compared to $0.17 per mile for the regular Pacifica is not able to make up for it. Furthermore, the PHEV begins with an MSRP that is $8,500 greater than the regular vehicle, a larger difference than in our previous comparisons. Despite the low daily mileage, the PHEV results in less than 50% of the GHG emissions compared to the regular vehicle. If the PHEV were to be selected by the fleet manager, TCO and GHG emissions in comparison to the regular Pacifica alternative could be reduced further by keeping the vehicle longer than the expected 9 year life span, thus increasing the total mileage on the car. If the $7,500 federal tax credit and the $1000 state tax credit were applied, the TCO of the PHEV would drop below the regular Pacifica [8 and 10].

7. Sources of uncertainty

As with any modeling, there are several sources of uncertainty in proposed analysis. One source of uncertainty is vehicle analysis period and corresponding mileage accrued over that period which will vary depending on the actual usage of the vehicle and chosen vehicle utilization time frame. Another source of financial uncertainty is vehicle salvage value determination at the end of the analysis period, which will depend on the number of factors such as condition of the vehicle and mileage at the time of sale. Electrical vehicle operation and maintenance expenses represent another source of uncertainty due to relative newness of the technology and number of factors that can influence such estimation. For example, depending on whether some fleet EVs will require battery replacement over analysis period or not O&M expenses may lead to a significant difference in TCO.

8. Follow-on research direction

In order to properly evaluate the TCO of a particular fleet vehicle it is imperative to correctly determine the release value of the vehicle at the end of the intended service period. This type of determination presents a certain challenge. The resale value of a used vehicle is determined by three factors: the vehicle's age, total mileage, and overall condition. Additionally, depending on if it is a conventional, EV or PHEV technology different depreciation methods and potential consumer base needs to be accounted for. A used fleet vehicle, because of possible driver abuse or neglect, may result in lost resale value or incur unnecessary reconditioning expenses at auction [7]. Further, the very way a vehicle is being disposed of - whether it is on an action or resale to a private party, present another variable that is hard to predict. Future research is needed to develop a solid framework to determine resale value in order to model TCO with acceptable level of precision.

References

[1] Anon. 2018. University of California Strategies for Decarbonization: Replacing Natural Gas TomKat Natural Gas Exit Strategies Working Group Report to the TomKat Foundation. http://doi.org/10.17605/OSF.IO/HNPUJ.

[2] Kettles, D. 2016. Electric Vehicle Fleet Implications and Analysis.

[3] Anon. AAA Gas Prices. https://gasprices.aaa.com/state-gas-price-averages/. Accessed May

25, 2020.

[4] Anon. Current Clean Air Vehicle Decal | California Air Resources Board. https://ww2.arb.ca.gov/resources/fact-sheets/current-clean-air-vehicle-decal. Accessed June 8, 2020.

[5] Anon. High-Occupancy Vehicle (HOV) Lane Access | Clean Vehicle Rebate Project. https://cleanvehiclerebate.org/eng/ev/incentives/hov-lane-access. Accessed June 8, 2020.

[6] Anon. Eligible Carpool Sticker List | California Air Resources Board. https://ww2.arb.ca.gov/eligible-carpool-sticker-list. Accessed June 8, 2020.

[7] Anon. Vehicle Abuse: An Overlooked Remarketing Cost - Market Trends - Automotive Fleet. https://www.automotive-fleet.com/159511/vehicle-abuse-an-overlooked-remarketing-cost. Accessed May 25, 2020.

[8] Anon. Federal Tax Credits for New All-Electric and Plug-in Hybrid Vehicles | U.S. Department of Energy Office of Energy Efficiency and Renewable Energy. https://www.fueleconomy.gov/feg/taxevb.shtml. Accessed June 8, 2020.

[9] Brauer, C. 2012. How Public Sector Fleets Can Take Advantage of EV Tax Credits | Greenfleet Magazine. https://www.greenfleetmagazine.com/155527/how-public-sector-fleets-can-take-advantage-of-ev-tax-credits.

[10] Anon. CVRP Eligible Vehicles | Clean Vehicle Rebate Project. https://cleanvehiclerebate.org/eng/eligible-vehicles. Accessed June 8, 2020.