Identifying Electric Vehicles to Best Serve University Fleet Needs and Support Sustainability Goals

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2 National Renewable Energy Laboratory

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
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Technical Report
NREL/TP-5400-81596
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- Arizona State University
- University of California, Los Angeles
- University of California, Riverside
- University of Colorado, Boulder
- University of Tennessee, Knoxville
- University of Virginia.

List of Acronyms

ASU	Arizona State University
CU Boulder	University of Colorado, Boulder
EPAct	Energy Policy Act of 1992
EV	electric vehicle
EVSA	electric vehicle suitability assessment
EVSE	electric vehicle supply equipment
GHG	greenhouse gas
ICE	internal combustion engine
kW	kilowatt
NREL	National Renewable Energy Laboratory
TCO	total cost of ownership
UC Riverside	University of California, Riverside
UCLA	University of California, Los Angeles
UT Knoxville	University of Tennessee, Knoxville
UVA	University of Virginia
VMT	vehicle miles traveled

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Introduction

The National Renewable Energy Laboratory (NREL) provides technical and analytical support to the U.S. Department of Energy's alternative fuel programs, including the State and Alternative Fuel Provider Fleet Program. Through the program, the U.S. Department of Energy implements regulations pursuant to the Energy Policy Act of 1992 (EPAct), as amended, which requires state and alternative fuel provider fleets to acquire alternative fuel vehicles and requires alternative fuel providers to use alternative fuels in those vehicles where the fuel is available. These fleets continue to be a subject of broad interest as a test bed for implementing and evaluating new vehicle and fuel technologies and are the subject of compliance options set forth in EPAct and associated regulations. The work in the alternative fuel arena that these fleets pursue inevitably generates case studies and lessons learned that other EPAct fleets—and indeed other fleets as well—can use to their advantage as they begin to deploy new and advanced vehicle technologies.

University fleets represent an enticing opportunity to explore the near-term feasibility of achieving net-zero-carbon emissions in transportation. In many instances, universities operate much like a small, self-contained ecosystem with all the same transportation needs as a larger municipality, but with a smaller geographic footprint. Their fleets often include a wide variety of vehicle types serving the campus, including low-speed vehicles (e.g., golf carts), light-duty sedans, SUVs, and pickups, as well as medium-duty trucks and delivery vehicles. The mix of vehicle and operational needs combined with broader activities related to net-zero campuses makes universities and colleges unique microcosms to determine the feasibility of and path to achieving net-zero fleets.

As the availability of electric drivetrains expands beyond light-duty sedans, fleets need to understand when it will be operationally and financially appropriate to start adding electric drivetrains to their fleets. To better understand these opportunities, NREL contracted Sawatch Labs to analyze the role electric vehicles (EVs) can have in helping universities meet net-zero emissions and fleet sustainability goals they have instituted. While many universities have established sustainability and net-zero goals, they have often not applied to fleet operations.[1] In fact, the U.S. Department of Energy does not include transportation in the definition of a zero-energy campus.[2] This may be due to the limited availability of alternative fuel vehicles within university fleets and access to alternative fuel to support a net-zero fleet goal, as well as limited means to capture relevant data. With the oncoming availability of more EV models and telematics analysis such as the results presented in this report, universities will be more readily able to incorporate transportation energy use of their vehicles into their broader zero-energy campus initiatives.

[1] Otto Van Geet, Ben Polly, Shanti Pless, Jenny Heeter, and Rachel Shepherd. 2018. "Zero Energy University Campuses: A 2018 Progress Update on Reaching Campus Energy Goals: Preprint." Golden, CO: National Renewable Energy Laboratory. NREL/CP-7A40-71822. https://www.nrel.gov/docs/fy18osti/71822.pdf.

[2] Ibid.

This analysis includes the assessment of fleet data from six universities across different regions of the United States to:

1. Identify university vehicles for which an EV replacement is a good operational and economic fit.
2. Identify EV opportunities, as well as the applications and reasoning, for where EVs are identified as a good fit.
3. Identify EV challenges, as well as the applications and reasoning, for where EVs were not identified as a good fit.

Garnering each of these pieces of information is expected to facilitate efforts by universities to achieve a net-zero fleet.

To accurately understand fleet electrification opportunities and challenges, fleet partners provided the research team with telematics data for their vehicles. Telematics data, such as vehicle speed and location, enable a detailed understanding of vehicle travel patterns to determine both energy needs based on driving behaviors and charging opportunities based on parking habits. The analytical methodology outlined in the next section provided fleets with vehicle electrification opportunities and charging demand analyses to support net-zero fleet planning efforts. Each participating fleet was provided with access, via Sawatch Labs' online dashboard, to the detailed analysis for its vehicles and parking facilities. This report provides an overview of the analysis across the six university fleets and identifies lessons learned that can help other EPAct-covered state fleets and other fleets as they increase their fleet electrification.

Methodology

The analysis assesses both the suitability of individual fleet vehicles for replacement with an EV and the aggregate charging demand across a fleet at increasing levels of fleet electrification. This analysis is based on Sawatch Labs' "ezEV" and "ezIO" tools. EV suitability assessments (EVSAs) such as these are a common way to determine which vehicles are the best candidates for replacement with an EV. The ezEV tool develops EVSAs that provide fleets with recommendations for EV acquisitions based on a scoring system that considers both financial and operational feasibility and establishes the foundation for the second component of this project: understanding the implications of increased fleet electrification on energy demands at each parking facility. The ezIO tool builds on the vehicle-specific ezEV results to help inform electric vehicle supply equipment (EVSE) infrastructure planning and consider potential electric utility bill impacts.

Understanding the details of these two concerns—vehicle electrification opportunities and charging demand impacts—is critical when planning for an electric fleet. Although both concerns are of great importance, some factors are more prominent in state fleets vs. university fleets. The results of this analysis on university fleets focus on electrification opportunities and why particular vehicles make good candidates for electrification, as this was more relevant at the university level. A similar study was performed concurrently on state fleets, in which the results focus more on the charging demand considerations due to the wide geographic regions in which those fleets operate.[3]

ezEV Suitability Assessment

The ezEV analysis assesses each vehicle for which telematics data were available to determine if there is an available EV model that meets both the operational needs and economic requirements based on the actual travel the vehicle covered. The ezEV tool analyzes the telematics data for each vehicle, determining the energy needed to move the vehicle every mile it traveled. Those energy needs are then modeled to determine the gasoline needs for the comparable internal combustion engine (ICE) vehicle and the electricity needs for all comparable EVs.[4] Employing high-fidelity telematics data affords a determination, with great precision, of a vehicle's energy needs based on both the speed and distance traveled in sub-minute increments.[5] This level of detail is important when considering operational feasibility and total energy costs because the energy requirements to move an EV or an ICE vehicle depend more on the speed at which the vehicle is moving than a simple consideration of vehicle miles traveled.

The ezEV analysis is characterized by three main aspects:

- Economics
- Energy
- Parking.

The economic portion of the ezEV analysis determines the total cost of ownership (TCO) for the comparable ICE vehicle and all comparable EV models and allows one to discern if the TCO would be higher or lower for an ICE vehicle compared with the likely EV replacement option. Many variables that impact the TCO can fluctuate over the lifetime of a vehicle, with a key parameter being price of gasoline, as compared to the use of fleet-owned EVSE.[6] To account for possible fluctuations in the price of gasoline, the analysis allows for an EV to be identified as a good fit to replace an ICE vehicle when the TCO for the EV is no greater than 5% more expensive than the TCO for the comparable ICE vehicle.

The energy portion of the ezEV analysis assesses the daily driving needs for each vehicle, identifying on which days the vehicle would have required midday EV charging. Any vehicle that would require midday charging more than 4 days per month is not considered a good candidate for replacement with an EV because it would require the driver to find the time for midday charging at least once a week on average. Midday charging events are important to

[3] Sarah Booth, Jesse Bennett, Matthew Helm, Devin Arnold, Bridget Baker, Remmy Clay, Mary Till, and Ted Sears. 2022. *Impacts of Increasing Electrification on State Fleet Operations and Charging Demand*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5400-81595. www.nrel.gov/docs/fy22osti/81595.pdf.

[4] The comparable ICE and EVs models were provided by the participating fleet, based on the procurement mechanism used for fleet purchases. This was typically from its state contract and/or Sourcewell.

[5] The granularity of the telematics data provided by the participating fleets varies based on the telematics provider. Each telematics provider has unique methods that determine the frequency with which data are pulled. The telematics data for all participants in this project covered increments of at least every 2 minutes, if not more frequently.

[6] The price of electricity is generally stable. The Alternative Fuels Data Center provides the average retail price for various liquid fuels and electricity: https://afdc.energy.gov/fuels/prices.html.

support long-distance travel, but for this study it was decided that midday charging more often than once per week could impact operations.

The parking portion of the ezEV analysis identifies locations where extended dwell periods occur after each day of travel, representing the best opportunities for charging.[7] The locations of these parking events, which typically occur overnight, help determine where charging infrastructure should be placed to support these vehicles. Vehicles with more than 25% of their extended dwell periods occurring at disparate locations are not considered good candidates for replacement with an EV because they may not have consistent access to dedicated EVSE. This parking analysis is meant to be an indicator of the ability for the vehicle to have access to charging infrastructure at a single location for at least 75% of extended dwell periods. It does not mean that a vehicle with disparate parking patterns cannot be replaced with an EV; instead, it simply means that it may be more difficult to ensure consistent access to EVSE for these vehicles. As charging infrastructure is installed across the fleet's facilities in the future, these vehicles may have ready access to EVSE at multiple locations.

These three components of the ezEV analysis—energy, economics, and parking—are intended to help identify which vehicles are most likely to be successful applications for an EV. Although the telematics data provide granular insight into each vehicle's driving, there are many other operational insights that fleet managers understand about unique vehicle requirements that could affect a determination as to whether an EV will meet the drivers' needs. For example, vehicles that are used for towing or plowing activities may not be good candidates for replacement with a currently available EV, even if they are a good candidate based on the ezEV analysis. Conversely, a vehicle that receives a low ezEV score may be a good candidate for replacement once other factors are considered. For example, a vehicle that does not meet the parking consistency threshold (at least 75% of extended dwell periods at the same location) may have access to EVSE at the other locations at which it dwells. In this case, this vehicle could have consistent access to EVSE for more than 75% of its extended dwell periods, and the fleet manager may determine that this vehicle is a good fit because access to EVSE will not be a barrier. Additionally, it may be possible for drivers to change their parking location to consistently park at a single parking facility if a dedicated charger were available. Similarly, the economic threshold (a TCO no greater than 5% higher than in a comparable ICE vehicle) may not be of much concern for fleets that have access to grant funding to purchase EVs or statewide policy mandates to purchase EVs, even if the vehicle's TCO exceeds a 5% threshold. The ezEV analysis and scores are intended to provide guidance to fleets about the vehicles that will likely be the easiest to replace with an EV with the least amount of impact on the fleet, drivers, and budget.

Until more options for EVs enter the market, it may be necessary to consider transitioning vehicles to EVs that are of similar model types. For example, until more electric pickup trucks and electric minivans become available, and in the context of fully considering transitioning fleet vehicles to electric versions, some fleet managers are considering replacing an ICE pickup truck with an electric SUV, in the event the electric SUV can be a good replacement for the ICE pickup truck. For this reason, the analysis includes the option to compare pickups and minivans with electric SUVs. If an electric SUV is identified as a good replacement, that vehicle model is

[7] Extended dwell periods are times during which the vehicle is parked at the same location for 9 or more hours.

listed. Understanding that an SUV may not meet the same mission requirements of a pickup or minivan, this approach is intended to best support fleets that are looking to electrify their fleet more aggressively, even in the absence of identical replacement EV models, and particularly for fleets looking to right-size their fleet vehicles by finding smaller, more efficient vehicle options. The online Sawatch dashboard provided participating fleets with the ability to filter to this different-class vehicle replacement option or only class-to-class comparisons.

ezIO Charging Demand Analysis

Deploying and managing an EV fleet can be complex and require planning across several areas, some of which are not traditionally within the fleet management realm. The effort requires attention to vehicle procurement, fueling infrastructure, and facilities planning. The ezIO tool leverages historical travel data for each vehicle to model vehicle charging requirements as if the current fleet of vehicles are EVs. The daily driving needs for each vehicle determine the energy that must be recovered from the next charging session, which occurs at the location of the vehicle's extended dwell period for that day. This charge session begins as soon as the vehicle has finished driving for the day, and the duration is determined by the time it would take a standard 6.9-kilowatt (kW) Level 2 EVSE to recharge the battery with the energy consumed the prior day.

The time and duration of each vehicle's daily charge session is aggregated to model the peak demand from vehicle charging at each location for every month during the period of analysis. The highest peak demands will result from the coincidence of multiple vehicles plugging into EVSE to charge at the same time. This highlights the minimum number of EVSE required, in order to reduce the deployment of charging infrastructure in locations where the number of EVSE required is less than the number of EVs. These data also detail the EV charging peak demand and can help fleet managers and facility staff identify when the potential charging peaks may coincide with facility peak demand, resulting in higher demand charges from the local utility. Under some circumstances, this new load could require policy or technical strategies to shift charging later in the evening to avoid increased demand charges from the local utility. At a minimum, it will require coordination among the fleet and facility managers.

Based on the telematics data, the primary extended dwell locations were identified for each vehicle to locate the likely charging location. The daily projected charging demand at varying levels of fleet electrification was determined based on (1) the time at which each vehicle arrived at the parking facility and did not take another trip for the rest of the day, and (2) the amount of energy needed to support the driving conducted that day. The projected charging demand for each vehicle at a location was layered together to build a charging demand curve for each day analyzed. The analysis assumes unmanaged charging where vehicles begin charging immediately upon being parked and charging occurs on Level 2 6.9-kW EVSE until the battery is fully charged. Fleets that have highlighted a peak demand concern, however, could shift this charging throughout the vehicle's dwell period, using managed charging to mitigate this concern.

Fleet Participants

Beginning in late 2019, the Sawatch and NREL teams reached out to multiple EPAct-covered university fleets to recruit participants for this study. Six fleets agreed to participate:

- Arizona State University (ASU)
- University of California, Los Angeles (UCLA)
- University of California, Riverside (UC Riverside)
- University of Colorado, Boulder (CU Boulder)
- University of Tennessee, Knoxville (UT Knoxville)
- University of Virginia (UVA).

The period of analysis varied for each fleet based on the telematics data available and is outlined in each of the fleet's respective appendices. The analysis was customized for each fleet to reflect their costs, vehicle procurement options, fleet management practices, and other inputs, including:

- Gas price
- Electricity rate
- Greenhouse gas (GHG) emissions factor for electricity generation
- Social cost of carbon
- ICE vehicle maintenance costs
- EV maintenance costs
- Vehicle life cycle
- ICE vehicle procurement options and pricing
- EV procurement options and pricing.

Detailed results for each fleet are summarized in their respective appendices, with the key takeaways outlined in the following section.

Fleet Electrification Analysis

The data for all six state universities in this study covered the travel requirements for a total of 1,231 vehicles. Throughout the total period of analysis—ranging from approximately 1 to 2 years per fleet—these vehicles traveled over 7 million miles over more than 1 million trips. A breakdown of vehicle count per fleet is summarized in Figure 1, representing the portion of each fleet where telematics data were made available for analysis. Throughout these fleets, UT Knoxville represented the largest data set, accounting for 483 vehicles. The data for these vehicles covered a wide range of trips taken and miles traveled, with UT Knoxville also representing the largest fleet with 4 million miles of travel data provided. A summary of approximate trips and miles traveled is provided in Table 1.

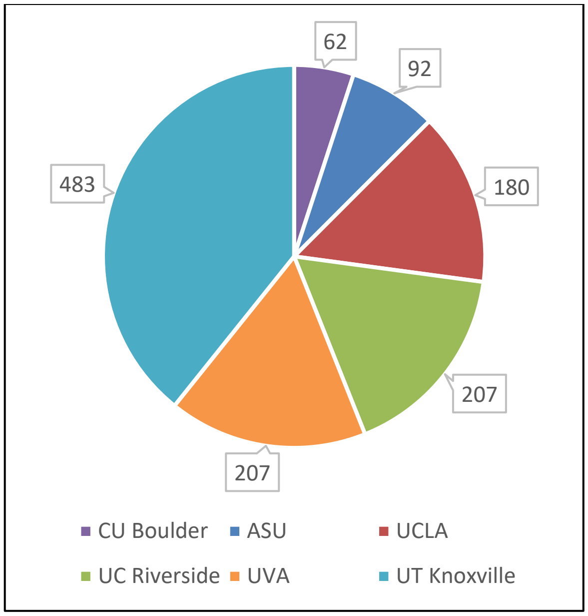

Figure 1. Analyzed vehicle count for participating universities

Table 1. Analyzed Trips and Vehicle Miles Traveled for Participating Universities

Fleet	Trips Recorded	Miles Traveled
CU Boulder	41,000	70,000
ASU	46,000	196,000
UCLA	145,000	1,700,000
UC Riverside	129,000	396,000
UVA	247,000	930,000
UT Knoxville	522,000	4,000,000
Total	1,130,000	7,292,000

Fleetwide Results

As fleet interest in electrification grows, the need for specific analysis of electrification candidates for EV replacement becomes increasingly important. The conclusions from the ezEV and ezIO assessments require detailed telematics analysis. While each participating fleet was able to share data on some of their vehicles, the following results account for only the vehicles for which telematics data were provided. Therefore, vehicles that do not have telematics devices and/or vehicles for which travel behaviors were considered sensitive information have been omitted from the following results.

EV Candidate Replacement Vehicles

On average, 29% of the vehicles in each fleet were identified as good candidates for electrification. The highest concentration of electrification candidates was found for the UVA fleet, with 47% of vehicles analyzed identified as having a suitable EV replacement option available in the market. Of the 207 vehicles analyzed in the UVA fleet, 98 were identified as a good candidate for electrification, primarily because of the large number of EV pickup trucks and vans within the fleet. The breakdown of fleet vehicles analyzed and electrification candidates identified for each fleet is outlined in Figure 2, and the results are summarized in Table 2.

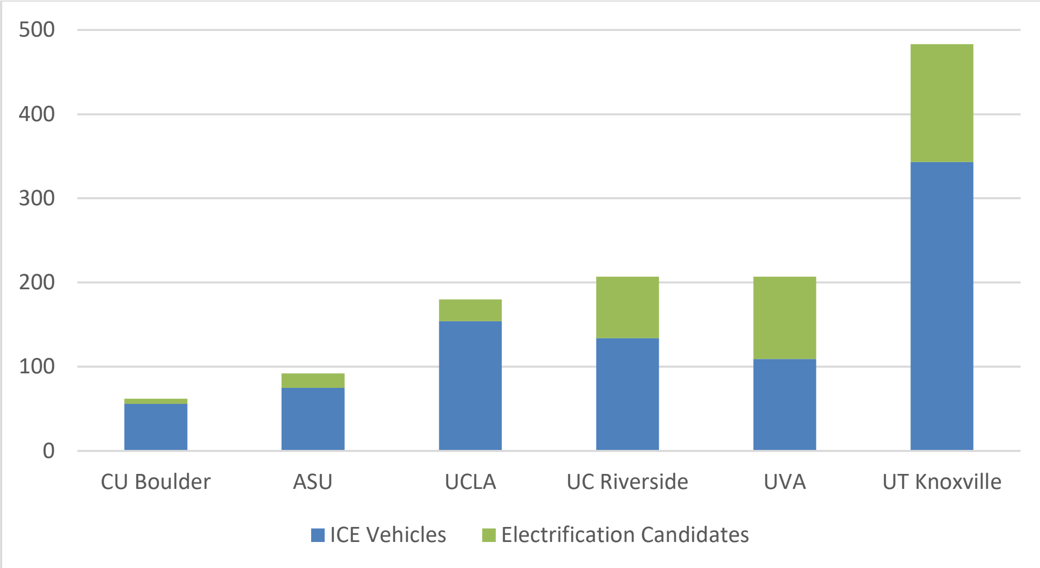

Figure 2. Electrification candidates per fleet

Table 2. Fleet Electrification Opportunities

Fleet	Total Vehicles	Electrification Candidates	Possible Fleet Electrification %
CU Boulder	62	6	10%
ASU	92	17	19%
UCLA	180	26	14%
UC Riverside	207	73	35%
UVA	207	98	47%
UT Knoxville	483	140	29%
Total	1,231	360	29%

Financial Benefits

Over the operating life of a typical EV, there are many operating cost reductions that can create favorable TCO savings. Across all six fleets, the 360 electrification candidates identified could create a total of nearly $1.6 million in TCO savings, with an average savings of over $4,400 per vehicle. This savings rate per vehicle does vary between each fleet, with UT Knoxville seeing the greatest potential at an average of over $6,000 of TCO savings per EV, as detailed in Table 3.

Table 3. Fleet Electrification Possible TCO Savings

Fleet	Electrification Candidates	Total Possible TCO Savings	Average Savings per EV
CU Boulder	6	$7,000	$1,167

Fleet	Electrification Candidates	Total Possible TCO Savings	Average Savings per EV
ASU	17	$35,000	$2,058
UCLA	26	$116,000	$4,462
UC Riverside	73	$265,000	$3,630
UVA	98	$282,000	$2,878
UT Knoxville	140	$882,000	$6,300
Total	360	$1,587,000	$4,408

Emissions Reductions

In addition to providing TCO savings, fleet electrification also reduces a fleet's GHG emissions. Driving an EV on electricity provided by the grid results in the complete elimination of all tailpipe emissions. Therefore, with plans to decarbonize the grid by as early as 2035,[8] EVs have the possibility to offer significant reductions in GHG emissions. Fleets with the largest number of electrification candidates also represent the greatest potential for GHG emissions reductions. This possibility is the greatest for UT Knoxville, with 140 vehicles identified as suitable for electrification, resulting in the possible reduction of almost 8,000 metric tonnes of CO_2 emissions. The possible emissions reductions for each fleet are presented in Table 4 where the possible GHG emissions reductions represent a transition from the use of ICE vehicles that run on gasoline to the use of EVs powered from a completely decarbonized grid.

Table 4. Fleet Electrification Possible GHG Emissions Reductions

Fleet	Electrification Candidates	Total Possible GHG Emissions Reductions (metric tonnes CO_2)
CU Boulder	6	300
ASU	17	500
UCLA	26	830
UC Riverside	73	2,400
UVA	98	4,200
UT Knoxville	140	7,800
Total	360	16,030

Electrification Opportunities

While the above results are a summary of the electrification candidates for each fleet, it is important to understand how individual metrics contribute to these results. There are many

[8] The White House. 2021. "Fact Sheet: President Biden Sets 2030 Greenhouse Gas Pollution Reduction Target Aimed at Creating Good-Paying Union Jobs and Securing U.S. Leadership on Clean Energy Technologies." Statements and Releases, April 22, 2021. https://www.whitehouse.gov/briefing-room/statements-releases/2021/04/22/fact-sheet-president-biden-sets-2030-greenhouse-gas-pollution-reduction-target-aimed-at-creating-good-paying-union-jobs-and-securing-u-s-leadership-on-clean-energy-technologies/.

reasons a vehicle could be a prime candidate for electrification. The following sections outline a few of the notable electrification opportunities for the fleets that participated in this study.

Battery Capacity

Of the 1,231 vehicles analyzed, only 93 vehicles (8%) would have EV battery capacity concerns (meaning a vehicle would require more than four midday charging events per month) with the current market of options. UT Knoxville had the highest concentration of battery capacity concerns, where 15% of their vehicles could require frequent midday charging. However, CU Boulder and UVA have a much lower need for midday charging and therefore had zero vehicles with battery capacity concerns. While this is not the only factor to consider when planning to electrify a fleet, it is often the most prominent. As Figure 3 outlines, because only 8% of the vehicles analyzed were identified to have frequent range concerns, other factors are likely to play a larger role when deciding whether to transition to an EV and selecting optimal candidates for replacement with EVs.

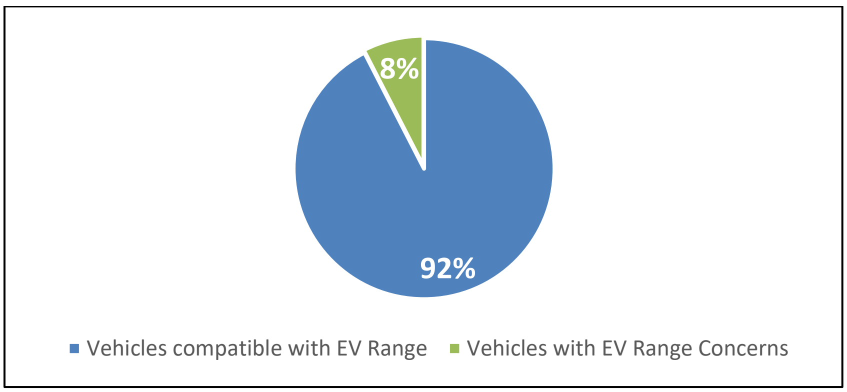

Figure 3. Vehicles compatible with EV range

Model Types

Historically, fleet electrification has focused on sedans and small SUVs due to the limited availability of larger vehicle model options. However, vehicle original equipment manufacturers have recently begun to offer larger models, such as vans and pickup trucks. These options present fleets with many electrification opportunities. Minivans in the UVA fleet presented the most promising vehicle class among all participating fleets, with 88% of UVA minivans representing a good fit for electrification. Pickup trucks and SUVs also represented promising opportunities. More than 40% of pickup trucks were identified as suitable for electrification in the UC Riverside, UT Knoxville, and UVA fleets, while more than 50% of SUVs could be electrified in the ASU, UCLA, UT Knoxville, and UVA fleets. The results in Figure 4 show that although sedans have historically represented the best electrification candidates, with manufacturers offering more EV model options, fleet electrification can be expanded to classes of larger vehicles. Additionally, the chart highlights that the use cases vary greatly by vehicle class across each of the participating fleets, even though they are all university fleets. For example, more than 80% of the minivans in UVA's fleet are good candidates for an EV while fewer than 10% of the minivans for UCLA, UC Riverside, CU Boulder, and UT Knoxville are good candidates.

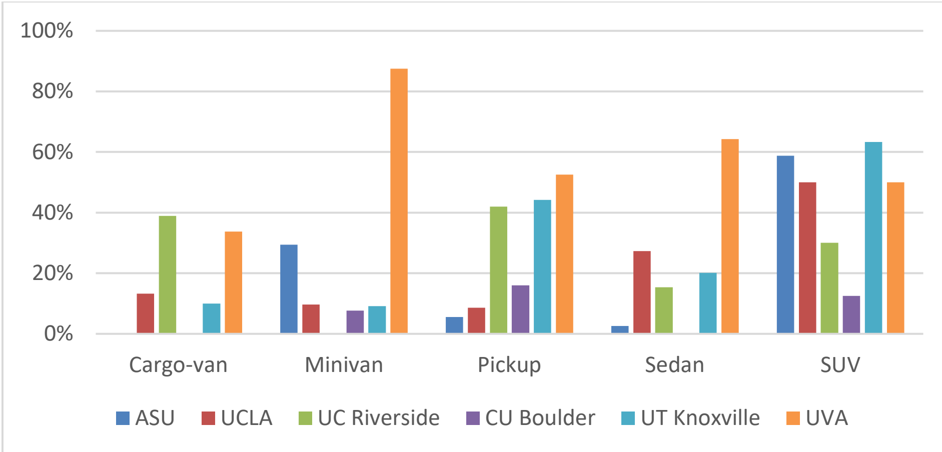

Figure 4. Electrification opportunities by vehicle class

Energy Pricing Impact

One of the most important operational costs of a vehicle is the energy needed to support daily driving needs. For ICE vehicles, this is the price of gas at the pump, whereas the cost for EVs is dependent on the price of electricity from the local utility. The price of electricity relative to the price of gas is one of the key factors contributing to favorable TCO numbers for EVs. According to the Alternative Fuels Data Center, electricity has a lower and more stable price of energy than gasoline, per gasoline gallon equivalent.[9] This trend suggests that stable electricity prices will result in reliable projections of energy costs for EVs throughout the life of the vehicle, assuming peak demand considerations and utility demand charges are mitigated. However, the volatility in gasoline prices suggests fleets should consider possible variations in gasoline prices and the possible impacts to EVSA results.

To understand if gasoline prices would have a significant impact on which vehicles could be replaced by an EV, the EVSA was run for each fleet with two different gasoline prices: $2.50 per gallon and $3.50 per gallon. In each of these two scenarios, all other parameters were as specified by each fleet and are listed in their respective appendices. The results in Figure 5 show the impact this difference in gasoline price has on the number of electrification candidates in each fleet. For each university, with the exception of UCLA, increasing gas prices from $2.50 to $3.50 per gallon resulted in more electrification candidates being identified. This is because the TCO analysis for an EV is generally more favorable than an ICE vehicle when the price of gasoline rises. However, this change in gasoline price had a minimal overall effect because other factors limited the suitability for replacement with an EV (i.e., variability in extended dwell locations or daily energy needs exceeding the range provided by existing battery capacities). As a result, these fleets can expect vehicle replacement decisions or electrification plans to be relatively consistent even with fluctuation in gas prices within this range.

[9] Over the past 10 years, electricity has fluctuated between $1.19 and $1.30 per gasoline gallon equivalent (accounting for an efficiency factor of 3.6, in comparison of ICE vehicles, when electricity is used for transportation), whereas gasoline has fluctuated between a low of $1.91 (in April 2020) and a high of $3.89 (in March 2012) per gallon during the same time period: https://afdc.energy.gov/fuels/prices.html.

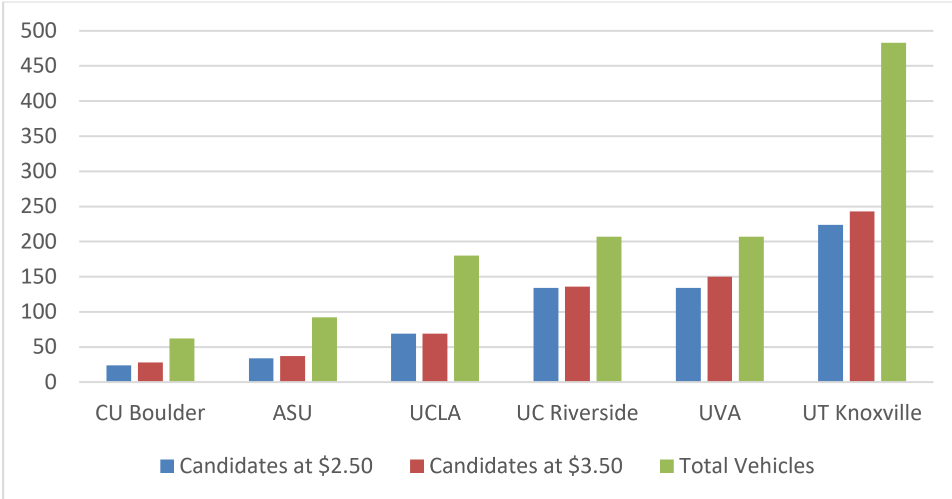

Figure 5. Electrification candidates based on varying gasoline prices compared to the overall fleet

Electrification Challenges

Although many of the vehicles in this study were identified as candidates for electrification, not every vehicle is currently fit to be replaced by an EV. It is important to understand the reason these vehicles were not identified for electrification and what advancements in the EV market must be made for that conclusion to change. The following sections outline several notable electrification challenges faced by the participating fleets.

Total Cost of Ownership

Although many vehicles are good candidates for electrification from an operational perspective, some may result in an unfavorable TCO (5% higher than a comparable ICE vehicle). This was most profound in the ASU fleet, where 57% of the vehicles analyzed were not a good fit for electrification because of an unfavorable TCO. This is in contrast with the UCLA fleet, where only 19% of the vehicles analyzed had an unfavorable TCO.

As noted, EVs have lower operation and maintenance costs than comparable ICE vehicles, which is one reason why fleets are interested in electrification. However, reduced operation and maintenance costs are not the only factor considered in an EV's TCO. The initial vehicle cost for many EVs is typically higher than that of a similar ICE. This additional cost is sometimes referred to as the incremental cost. Therefore, for an EV to have a favorable TCO, the cumulative operation and maintenance savings must be greater than the incremental cost, relative to a comparable ICE vehicle. As a result, the more a vehicle is driven, the more operation and maintenance savings are accrued, resulting in a more favorable TCO. This is outlined in Figure 6, where it is clear the largest TCO savings are generally in fleets with higher annual vehicle miles traveled (VMT) per vehicle.

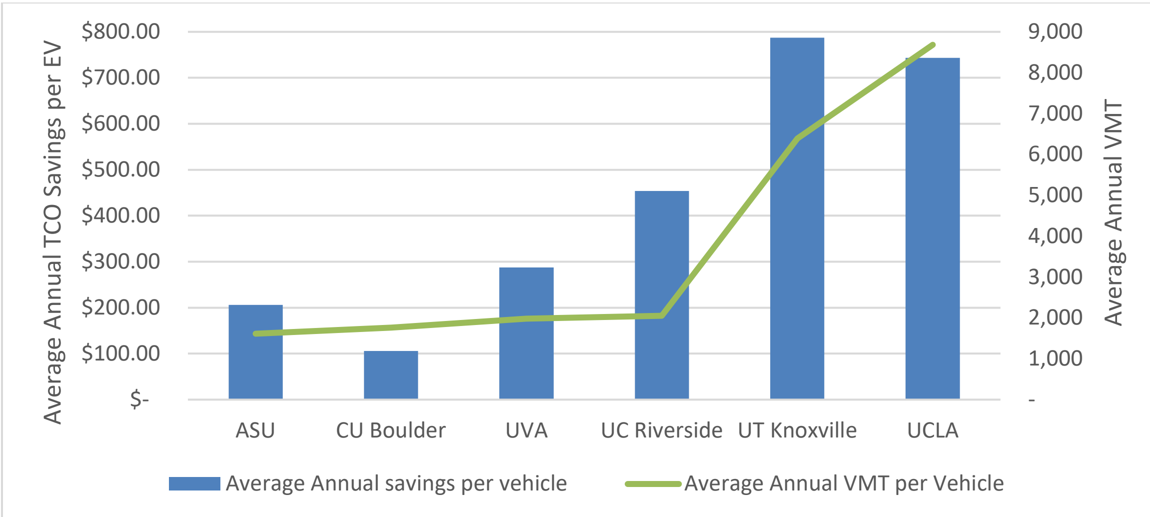

Figure 6. Average annual TCO savings per EV compared to annual VMT

The 43% of vehicles that were good candidates in the ASU fleet reflected an average of $206 per EV in annual TCO savings. This is less than the average annual TCO savings of $744 estimated for each of the 81% of the UCLA fleet vehicles identified with a suitable electrification candidate. Therefore, the UCLA fleet, with an average annual VMT of almost 9,000 miles per vehicle, resulted in a larger portion of the fleets identified as electrification candidates, with each electrification candidate resulting in the potential for greater TCO savings. This suggests that fleets encountering TCO concerns regarding electrification may increase their EV opportunities by right-sizing their fleets and working to deploy fewer vehicles that drive a larger number of miles per year.

Parking Consistency

Fleet electrification requires operational planning for both driving and charging potential EVs. Therefore, because the best fleet charging applications are typically AC Level 2 charging,[10] vehicle dwell periods are an important consideration. Long overnight dwell periods pose the best opportunities to fully recharge a vehicle with the standard 7-kW AC Level 2 EVSE. It is important for fleets to take advantage of these longer dwell periods, when possible, because higher-power DC fast chargers typically have higher EVSE unit and installation costs, as well as possible impacts to utility bill demand charges.

These longer dwell periods are important to ensure Level 2 charging will meet a fleet's energy needs, but the vehicle must also park in locations where the fleet has installed EVSE. Therefore, parking consistency—defined as parking in the same location at least 75% of the time—is an important consideration. Parking consistency was an important factor in determining optimal EV replacement opportunities and had the most profound impact on the UCLA fleet, where 58% of the vehicles analyzed were deemed to not be a candidate for electrification due at least in part to parking inconsistencies. An overview of these results is presented in Figure 7, in which electrification candidates for each fleet are identified, and all non-candidate vehicles are

[10] Jesse Bennett, Cabell Hodge, Chuck Kurnik, Kosol Kiatreungwattana, Lauren Lynch, and Jimmy Salasovich. 2019. *Electric Vehicle Supply Equipment Tiger Team Site Assessment Findings from Army Facilities*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5400-74538. https://www.nrel.gov/docs/fy20osti/74538.pdf.

separated between those with parking concerns and those without parking concerns (but with other challenges that prevent them from being a good candidate).

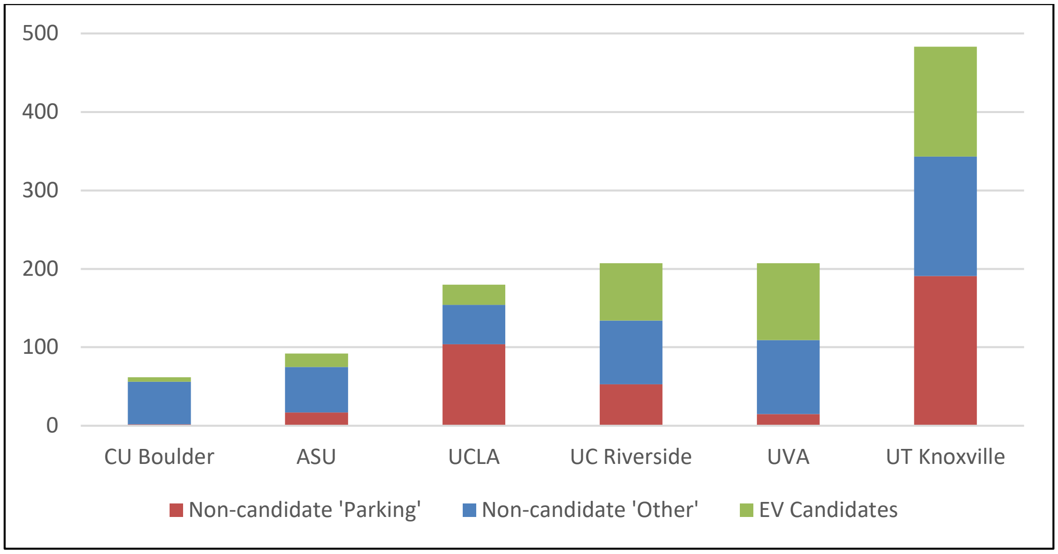

Figure 7. Electrification candidates and non-candidates with parking concerns identified

Parking inconsistencies have the potential to create concerns regarding fleet electrification. However, there are many different simple solutions that can be employed to mitigate the concerns captured in this study. The most obvious of these is to modify parking behaviors. Parking behaviors could be a result of the flexibility currently offered by the use of ICE vehicles. In these circumstances, many fleet applications could simply require drivers to park more consistently at a single location during the vehicle's longest dwell period of each day (the radius of parking locations in this analysis was 200 feet, suggesting this solution could have a small impact on some fleet operations).

In some circumstances, such as where vehicles must be parked in distant locations on a varying basis, other solutions might be required. The most straightforward solution would be to increase the deployment of EVSE to account for the varying parking locations of fleet vehicles. This could be done through additional EVSE deployments to ensure EVSE are always available, or a more dispersed deployment of EVSE where a fleet management system might be required to reserve EVSE for each vehicle to ensure charging infrastructure is always available.

Conclusions

As university fleets move beyond initial EV procurement to meeting fleet electrification goals and broader university-wide net-zero goals, it will be critical for fleet managers to determine where EVs will be a good operational and economic fit and why others may not be a good fit. Placing an EV in an application where it does not meet the drivers' needs will result in low utilization and lower-than-expected financial savings and GHG emissions reductions. Based on the assessment for these six university fleets, EVs are a good fit for 10%–50% of these fleets' light-duty vehicles. Each fleet has unique needs and will likely have different reasons for why a vehicle may or may not be a good candidate for electrification.

Fleet electrification planning and implementation efforts expand beyond the typical fleet staff and often require coordination across departments such as facilities, sustainability, and procurement. Fleet electrification may require modifications to fleet operations to accommodate parking inconsistencies and TCO considerations. Analyzing the daily driving for each vehicle allows fleets to confidently determine when an EV will meet their drivers' needs and also supports data-driven EVSE infrastructure planning with all stakeholders. This analysis has helped the participating fleets identify which vehicles are the best candidates for electrification, but also has resulted in a list of the following high-level conclusions on how to identify electrification candidates:

- Given the current market of EV battery capacity options, the rated range of these vehicles will meet the needs of 92% of vehicles analyzed. This suggests range anxiety is not a significant factor for university fleets considering an EV.
- The use case for many vehicles in a university fleet requires the utility of pickup trucks and vans. With the EV market expanding scope beyond sedans, pickup trucks and vans present fleets with some of the largest opportunities for electrification.
- The price of energy is a key contributor in any fleet's TCO analysis, and these costs, specifically for ICE vehicles, have the tendency to fluctuate over time. However, the cost of electricity is relatively stable, and gas price fluctuations between $2.50 and $3.50 per gallon presented little impact on the EVSA results. This suggests that energy cost fluctuations will not significantly change a fleet's electrification opportunities.
- Although energy pricing fluctuations proved to have little impact on TCO calculations, unfavorable TCO results—specifically for fleets with lower vehicle miles traveled—was one of the main reasons a vehicle was not a good candidate for electrification. This suggests fleets should consider right-sizing their fleet to increase annual VMT per vehicle to increase their opportunities for electrification.
- In addition to TCO challenges, many vehicles parked at multiple locations, suggesting either a lack of access to EVSE or the need to deploy EVSE at multiple locations. This could be solved by managing the parking locations of EVs or deploying EVSE at many different locations to ensure a vehicle is always able to receive the energy it needs.

Future Research

Based on this analysis, EVs can meet the needs of many fleet operations, but are unlikely to be sufficient to replace all light-duty university vehicles under the current technology and market conditions. These gaps are typically a result of TCO concerns, often resulting from vehicles with low VMT, or parking inconsistencies, best mitigated through additional EVSE deployment. For those pursuing aggressive fleet sustainability goals, it may be appropriate to consider how these factors would affect fleet operations or if other alternative fuel vehicle technologies could better meet their sustainability goals.

This analysis focused on light-duty EVs because those vehicles are widely available to fleets. Growth in medium- and heavy-duty EVs is expected over the next few years, and there is much interest from university fleets in understanding how those vehicles could meet their needs and how to best manage charging. As more medium- and heavy-duty EVs become available, fleets may find it useful to conduct a similar analysis with their medium- and heavy-duty vehicles.

Appendix A. Arizona State University

ASU provided telematics data for 92 fleet vehicles. The data covered operation of these vehicles from November 27, 2019, through March 22, 2021. Notably, this period includes months in which university operations and associated vehicle operations were impacted by the COVID-19 pandemic, and driving patterns were identified by ASU personnel as less than normal during this period.

Table A-1. ASU Fleet Summary

Category	Stats
Vehicles	92
Telematics provider	Geotab
Period of analysis	11/27/2019–3/22/2021
Miles analyzed	196,000
Total trips analyzed	46,000

A.1 EV Suitability Assessment

Of the 92 ASU fleet vehicles analyzed, 17 are good candidates for replacement with an EV within the same vehicle class, and 34 are good candidates if pickups and minivans can be replaced with an SUV. If all the vehicles with a good in-class replacement are replaced, the estimated lifetime savings for the entire set of vehicles analyzed would be about $35,000, and the GHG emissions reductions would be about 500 metric tonnes.

Table A-2. ASU EVSA Results

Vehicle Class	# of Vehicles Analyzed	Electrification Candidates (in class)
Cargo-van	1	0
Minivan	17	5
Pickup	18	1
Sedan	39	1
SUV	17	10
TCO savings	-	*$35,000*
GHG emissions reductions	-	*500 metric tonnes*

- The driving range of EVs available on the market today can meet the needs of 99% of the ASU vehicles analyzed.
- The primary reason that many ASU vehicles were identified as not having a suitable EV replacement is that the EV TCO exceeded the 5% threshold, rendering them more expensive than the comparable ICE vehicle. Of the 92 vehicles analyzed, 57% would be more than 5% more expensive as an EV than as an ICE vehicle. The higher upfront purchase price of an EV continues to be difficult for these vehicles to offset with

operational savings. However, there may be policy reasons that are driving fleet electrification, and vehicles that came close but did not meet the economic threshold may be worth additional consideration if the university is willing to purchase vehicles with a higher projected TCO.

- Although most of the ASU vehicles analyzed were found to park at the same location for at least 75% of their extended dwell periods, 18% parked at multiple locations more than 25% of the time.
- The ezEV scores for ASU's SUVs and minivans indicate that they are most suitable for conversion to EVs.
- Although available EVs could meet the daily energy needs of every sedan analyzed, the operational savings would not be sufficient to offset the higher upfront cost of an EV, and the savings alone would not justify replacement of the ICE vehicle with an EV. The savings, however, may have been limited due to the fact that this analysis included months in which vehicle operations were limited due to COVID-19 restrictions. If the annual VMT on sedans increases as operations normalize post-pandemic, some of these sedans may experience additional savings relevant to further consideration for EV replacement.
- The pickups were compared against the Rivian R1T, the Ford F150 Lightning, and two theoretical pickups intended to reflect the likely vehicle models available in the next few years from major original equipment manufacturers. One pickup was identified to be a good fit for an electric pickup. Economics make it such that none of the other pickups analyzed were a good fit for replacement with an EV. However, many were a good fit for replacement with an electric SUV if an SUV could meet the drivers' operational needs.

A.2 ezEV Scenario Analysis

Multiple scenario analyses were conducted to assess the impact of varying inputs, with a particular focus on the price of gasoline and the willingness to pay a premium for an EV. For the ASU fleet, the scenario analyses revealed the following:

- Increasing the TCO threshold to allow for the EV TCO to exceed the ICE vehicle TCO by up to 10% increases the number of vehicles for which converting to an EV is appropriate by 24%.
- Increasing gasoline prices from $2.50 to $3.50 per gallon increases the number of vehicles for which converting to an EV is appropriate by 9%.
- Adjusting the social cost of carbon does not have an impact on the number of vehicles that are a good candidate for an EV until the value is around $90/ton.

A.3 EV Charging Impact at Varying Electrification Levels

The projected maximum charging demand for each month was addressed at each of the ASU parking facilities. The results for a single ASU parking facility are provided in Figure A-1 to demonstrate the change in charging demand at increasing levels of fleet electrification. This location has the highest projected charging demand at 100% fleet electrification. However, at 5% fleet electrification, no vehicles are projected to charge at this location. At 20% fleet electrification, of the 18 vehicles identified for replacement with an EV, 2 are projected to charge concurrently at this location. At 50% fleet electrification, 4 of the 46 candidates for replacement with an EV are projected to charge concurrently at this location. At 100% fleet electrification, 6 of the 92 vehicles that are candidates for replacement with an EV are projected to charge concurrently at this location.

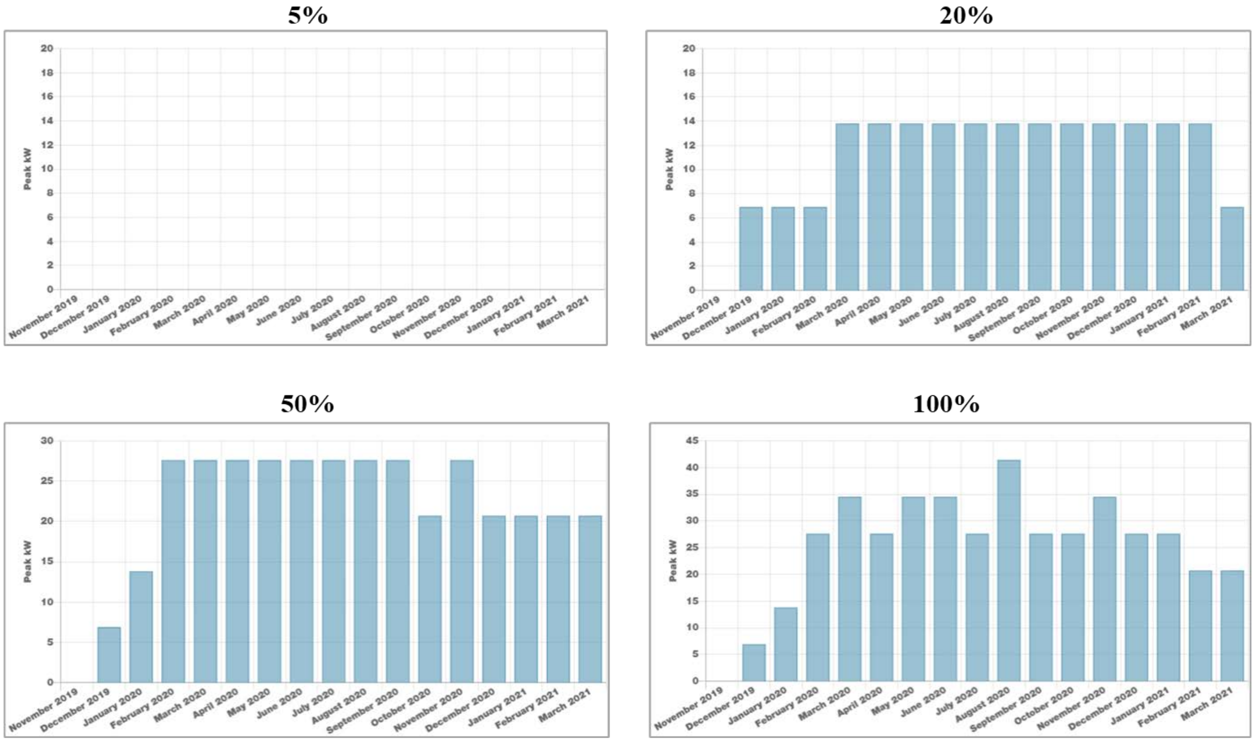

Figure A-1. Projected monthly peak charging demand at increasing levels of fleet electrification for a single parking facility: ASU

Appendix B. University of California, Los Angeles

UCLA provided telematics data for 180 fleet vehicles. The data covered operation of these vehicles from March 31, 2019, through April 30, 2020. Notably, this period includes months in which the COVID-19 pandemic affected university operations and associated vehicle operations such that driving patterns were less than normal, according to UCLA personnel.

Table B-1. UCLA Fleet Summary

Category	Stats
Vehicles	180
Telematics provider	CalAmp
Period of analysis	3/31/2019–4/30/2020
Miles analyzed	1,700,000
Total trips analyzed	145,000

B.1 EV Suitability Assessment

Of the 180 UCLA fleet vehicles analyzed, 26 are good candidates for replacement with an EV within the same vehicle class, and 68 are good candidates if pickups and minivans can be replaced with an SUV. If all the vehicles with a good in-class replacement are replaced, the estimated lifetime savings for the entire set of vehicles analyzed would be about $116,000, and the GHG emissions reductions would be about 830 metric tonnes.

Table B-2. UCLA EVSA Results

Vehicle Class	# of Vehicles Analyzed	Electrification Candidates (in class)
Cargo-van	83	11
Minivan	31	3
Pickup	35	3
Sedan	22	6
SUV	6	3
TCO savings	-	*$116,000*
GHG emissions reductions	-	*830 metric tonnes*

- The driving range of EVs available on the market as of June 2021 can meet the needs of 96% of the UCLA vehicles analyzed.
- The primary reason that many UCLA vehicles were identified as not having a suitable EV replacement is that their extended dwell periods occur at multiple locations, with less than 75% of their extended dwell periods occurring at a single location, indicating that it may be difficult for these vehicles to have regular access to charging infrastructure. However, if dwell locations can be consolidated or there is substantial charging

infrastructure across campus and at other locations where the vehicle may dwell, this may not be a barrier for EV adoption.

- For the 83 cargo vans analyzed, the Ford eTransit is projected to meet the daily driving needs of all but 2 vehicles, and 69 of the cargo vans would save money if replaced with an eTransit. However, the cargo vans had sporadic extended dwell periods, with 81% of the vehicles parking less than 75% of the time at the same location.
- Of the 180 vehicles analyzed, 81% would have a TCO no more than 5% higher as an EV than as an ICE vehicle.
- The pickups were compared against the Rivian R1T, the Ford F150 Lightning, and two theoretical pickups intended to reflect the likely vehicle models available in the next few years from major original equipment manufacturers. Three UCLA pickups were identified as good fits for an electric pickup. Economics make it such that none of the other pickups analyzed were a good fit for replacement with an EV. However, many were a good fit for replacement with an electric SUV if an SUV could meet the drivers' operational needs.

B.2 ezEV Scenario Analysis

Multiple scenario analyses were conducted to assess the impact of varying inputs, with a particular focus on the price of gasoline and the willingness to pay a premium for an EV. For the UCLA fleet, the scenario analyses revealed the following:

- Increasing the TCO threshold to allow for the EV TCO to exceed the ICE vehicle TCO by as much as 10% increases the number of vehicles for which an EV would be a good operational and economical fit by 6%.
- Increasing gasoline prices from $3.17 to $4.50 per gallon increases the number of vehicles for which converting to an EV is appropriate by only 3%.

B.3 EV Charging Impact at Varying Electrification Levels

The projected maximum charging demand for each month was addressed at each of the UCLA parking facilities. The results for a single UCLA parking facility are provided in Figure B-1 to demonstrate the change in charging demand at increasing levels of fleet electrification. This location has the highest projected charging demand at 100% fleet electrification. However, at 5% fleet electrification, no vehicles are projected to charge at this location. At 20% fleet electrification, 2 of the 36 vehicles identified for replacement with an EV are projected to charge concurrently at this location. At 50% fleet electrification, 4 of the 90 candidates for replacement with an EV are projected to charge concurrently at this location. At 100% fleet electrification, 6 of the 180 electrification candidates are projected to charge concurrently at this location.

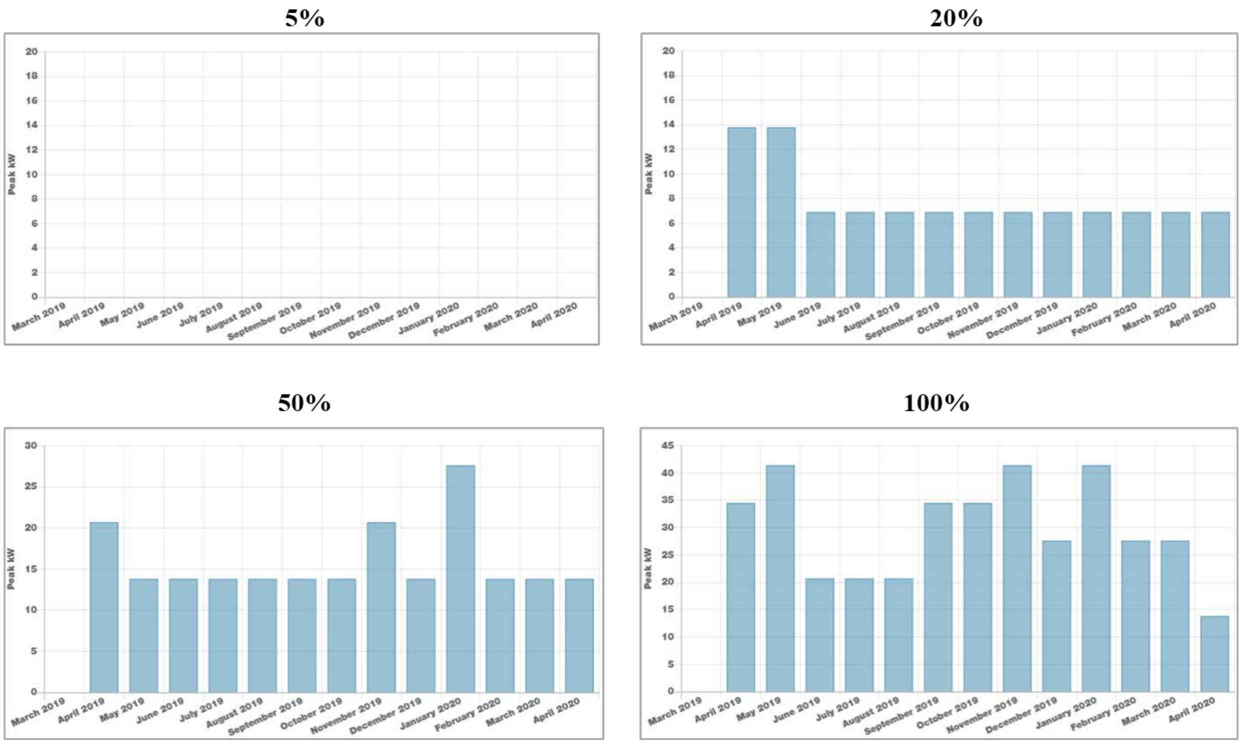

Figure B-1. Projected monthly peak charging demand at increasing levels of fleet electrification for a single parking facility: UCLA

Appendix C. University of California, Riverside

UC Riverside provided telematics data for 207 fleet vehicles. The data covered operation of these vehicles from April 17, 2020, through March 22, 2021. Notably, this period includes months in which the COVID-19 pandemic affected university operations and associated vehicle operations such that driving patterns were less than normal, according to UC Riverside personnel.

Table C-1. UC Riverside Fleet Summary

Category	Stats
Vehicles	207
Telematics provider	Verizon Networkfleet
Period of analysis	4/17/2020–3/22/2021
Miles analyzed	396,000
Total trips analyzed	129,000

C.1 EV Suitability Assessment

Of the 207 UC Riverside fleet vehicles analyzed, 73 are good candidates for replacement with an EV within the same vehicle class, and 136 are good candidates if pickups and minivans can be replaced with an SUV. If all the vehicles with a good in-class replacement are replaced, the estimated lifetime savings for the entire set of vehicles analyzed would be about $265,000, and the GHG emissions reductions would be about 2,400 metric tonnes.

Table C-2. UC Riverside EVSA Results

Vehicle Class	# of Vehicles Analyzed	Electrification Candidates (in class)	Electrification Candidates (allowing SUVs[11])
Cargo-van	18	7	7
Minivan	18	0	3
Pickup	138	58	118
Sedan	13	2	2
SUV	20	6	6
TCO savings	-	*$265,000*	*$462,000*
GHG emissions reductions	-	*2,400 metric tonnes*	*2,900 metric tonnes*

- The driving range of EVs available on the market as of June 2021 can meet the needs of 94% of the UC Riverside vehicles analyzed.

[11] Due to the limited availability of electric pickup and minivan options in the market as of June 2021, vehicles in these two classes were also compared to electric SUVs to identify options where an SUV would be a good fit to meet the daily energy and TCO thresholds. The Ford F150 Lightning specifications were released in mid-May 2021, and the results were updated to include the Lightning as a pickup option.

- Economics and parking location variability are the primary reasons that many UC Riverside vehicles were identified as not having a suitable EV replacement. The EV TCO exceeded the 5% threshold for 23% of the vehicles, rendering them more expensive than the comparable ICE vehicle. The higher upfront purchase price of an EV continues to be difficult for these vehicles to offset with operational savings. However, there may be policy reasons that are driving fleet electrification, and vehicles that came close but did not meet the economic threshold may be worth additional consideration if the university is willing to purchase vehicles with a higher projected TCO. About one-quarter of the vehicles parked at multiple locations more than 25% of the time, and it may therefore be difficult for them to have regular access to charging infrastructure because their extended dwell periods were at multiple locations.
- Only 2 of the 13 sedans analyzed were identified as a good fit for EV replacement. The remaining 11 sedans were determined to have an EV TCO 5% higher than the comparable ICE sedan model.
- About 40% of the cargo vans analyzed were identified as a good fit for replacement with an electric cargo van.
- The pickups were compared against the Rivian R1T, the Ford F150 Lightning Pro, and two theoretical pickups intended to reflect the likely vehicle models available in the next few years from major original equipment manufacturers. Forty-two percent of the pickups analyzed were identified as a good fit for replacement with an electric pickup.
- None of the minivans were identified as a good fit for replacement with an electric minivan; however, an electric SUV was identified as a good fit for three of the minivans and could be considered as a replacement option if an SUV would meet the operational needs of these minivans.

C.2 ezEV Scenario Analysis

Multiple scenario analyses were conducted to assess the impact of varying inputs, with a particular focus on the price of gasoline and the willingness to pay a premium for an EV. For the UC Riverside fleet, the scenario analyses revealed the following:

- Increasing the TCO threshold to allow for the EV TCO to exceed the ICE vehicle TCO by as much as 10% increases the number of vehicles for which an EV would be a good operational and economic fit by 8%.
- Increasing gasoline prices from $3.56 to $4.50 per gallon increases the number of vehicles for which converting to an EV is appropriate by only 1%.

C.3 EV Charging Impact at Varying Electrification Levels

The projected maximum charging demand for each month was addressed at each of the UC Riverside parking facilities. The results for a single UC Riverside parking facility are provided in Figure C-1 to demonstrate the change in charging demand at increasing levels of fleet electrification. This location has the highest projected charging demand at 100% fleet electrification. At 5% fleet electrification, 3 of the 10 candidate vehicles are projected to charge concurrently at this location. At 20% fleet electrification, 5 of the 41 vehicles identified for replacement with an EV are projected to charge concurrently at this location. At 50% fleet electrification, 10 of the 103 candidates for replacement with an EV are projected to charge concurrently at this location. At 100% fleet electrification, 11 of the 207 electrification candidates are projected to charge concurrently at this location.

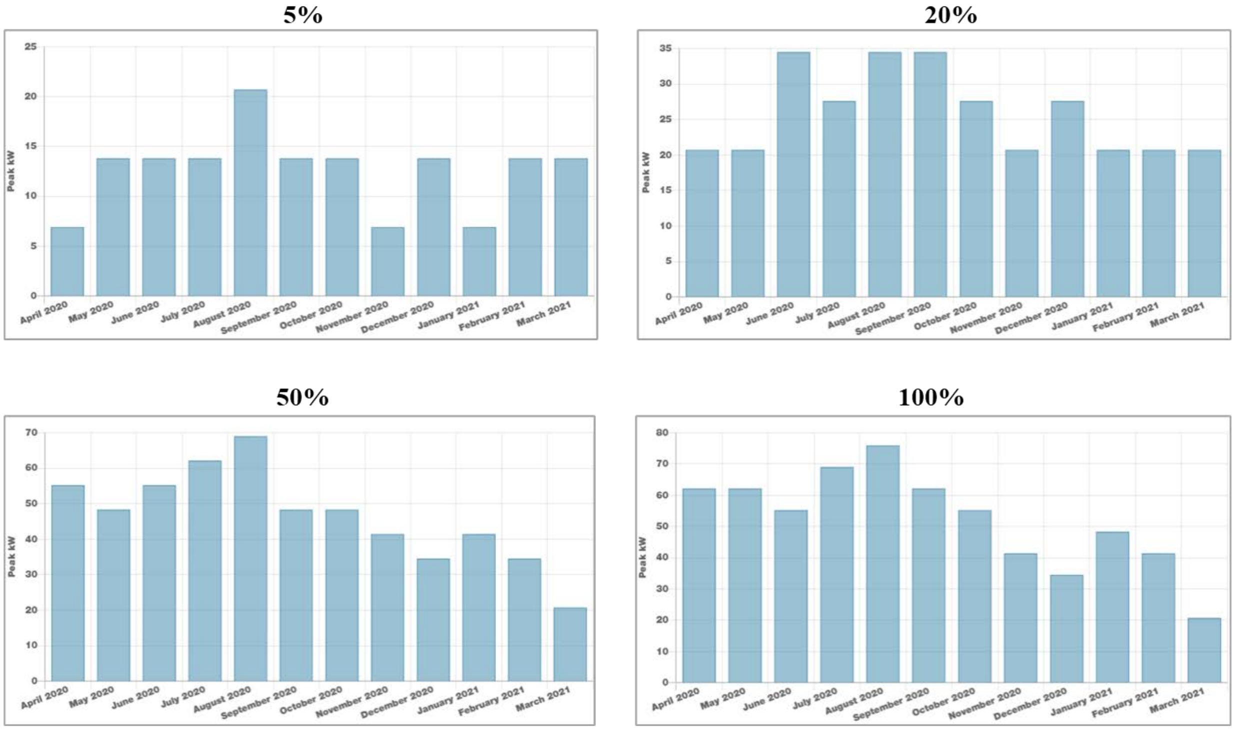

Figure C-1. Projected monthly peak charging demand at increasing levels of fleet electrification for a single parking facility: UC Riverside

Appendix D. University of Colorado, Boulder

CU Boulder provided telematics data for 62 fleet vehicles. The data covered operation of these vehicles from August 1, 2020, through March 22, 2021. Notably, this period includes months in which the COVID-19 pandemic affected university operations and associated vehicle operations such that driving patterns were less than normal, according to CU Boulder personnel.

Table D-1. CU Boulder Fleet Summary

Category	Stats
Vehicles	62
Telematics provider	Geotab
Period of analysis	8/1/2020–3/22/2021
Miles analyzed	70,000
Total trips analyzed	41,000

D.1 EV Suitability Assessment

Of the 62 CU Boulder fleet vehicles analyzed, 6 are good candidates for replacement with an EV within the same vehicle class, and 29 are good candidates if pickups and minivans can be replaced with an SUV. If all the vehicles with a good in-class replacement are replaced, the estimated lifetime savings for the entire set of vehicles analyzed would be about $7,000, and the GHG emissions reductions would be about 300 metric tonnes.

Table D-2. CU Boulder EVSA Results

Vehicle Class	# of Vehicles Analyzed	Electrification Candidates (in class)
Cargo-van	13	0
Minivan	13	1
Pickup	25	4
Sedan	3	0
SUV	8	1
TCO savings	-	*$7,000*
GHG emissions reductions	-	*300 metric tonnes*

- The driving range of EVs available on the market as of June 2021 can meet the needs of 100% of the CU Boulder vehicles analyzed.
- The primary reason that many CU Boulder vehicles were identified as not having a suitable EV replacement is that the EV TCO exceeded the 5% threshold, rendering them more expensive than the comparable ICE vehicle. Of the 62 vehicles analyzed, 47% would be more than 5% more expensive as an EV than as an ICE vehicle. The higher upfront purchase price of an EV continues to be difficult for these vehicles to offset with operational savings. However, there may be policy reasons that are driving fleet

electrification, and vehicles that came close but did not meet the economic threshold may be worth additional consideration if CU Boulder is willing to purchase vehicles with a higher projected TCO.

- All but six of the vehicles were found to park at the same location for at least 75% of their extended dwell periods, indicating that regular access to charging infrastructure would be feasible.
- Although available EVs could meet the daily energy needs of every sedan analyzed, the operational savings alone would not be sufficient to offset the higher upfront cost of an EV. The savings, however, may have been limited due to the fact that this analysis included months in which vehicle operations were limited due to COVID-19 restrictions. If the annual VMT on sedans increases as operations normalize post-pandemic, these sedans would generate additional savings, rendering them relevant for further consideration for EV replacement.
- The pickups were compared against the Rivian R1T, the Ford F150 Lightning, and two theoretical pickups intended to reflect the likely vehicle models available in the next few years from major original equipment manufacturers. Four CU Boulder pickups were identified as good fits for an electric pickup. Economics make it such that none of the other pickups analyzed were a good fit for replacement with an EV. However, many were a good fit for replacement with an electric SUV if an SUV could meet the drivers' operational needs.

D.2 ezEV Scenario Analysis

Multiple scenario analyses were conducted to assess the impact of varying inputs, with a particular focus on the price of gasoline and the willingness to pay a premium for an EV. For the CU Boulder fleet, the scenario analyses revealed the following:

- Increasing the TCO threshold to allow for the EV TCO to exceed the ICE vehicle TCO by as much as 10% increases the number of vehicles for which converting to an EV is appropriate by 6%.
- Increasing gasoline prices from $2.90 to $4.00 per gallon does not affect the number of vehicles for which converting to an EV is appropriate.

D.3 EV Charging Impact at Varying Electrification Levels

The projected maximum charging demand for each month was addressed at each of the CU Boulder parking facilities. The results for a single CU Boulder parking facility are provided in Figure D-1 to demonstrate the change in charging demand at increasing levels of fleet electrification. This location has the highest projected charging demand at 100% fleet electrification. However, at 5% fleet electrification, no vehicles are projected to charge at this location. At 20% fleet electrification, 3 of the 12 vehicles identified for replacement with an EV are projected to charge concurrently at this location. At 50% fleet electrification, 3 of the 31 candidates for replacement with an EV are projected to charge concurrently at this location. At 100% fleet electrification, 6 of the 62 candidate vehicles are projected to charge concurrently at this location.

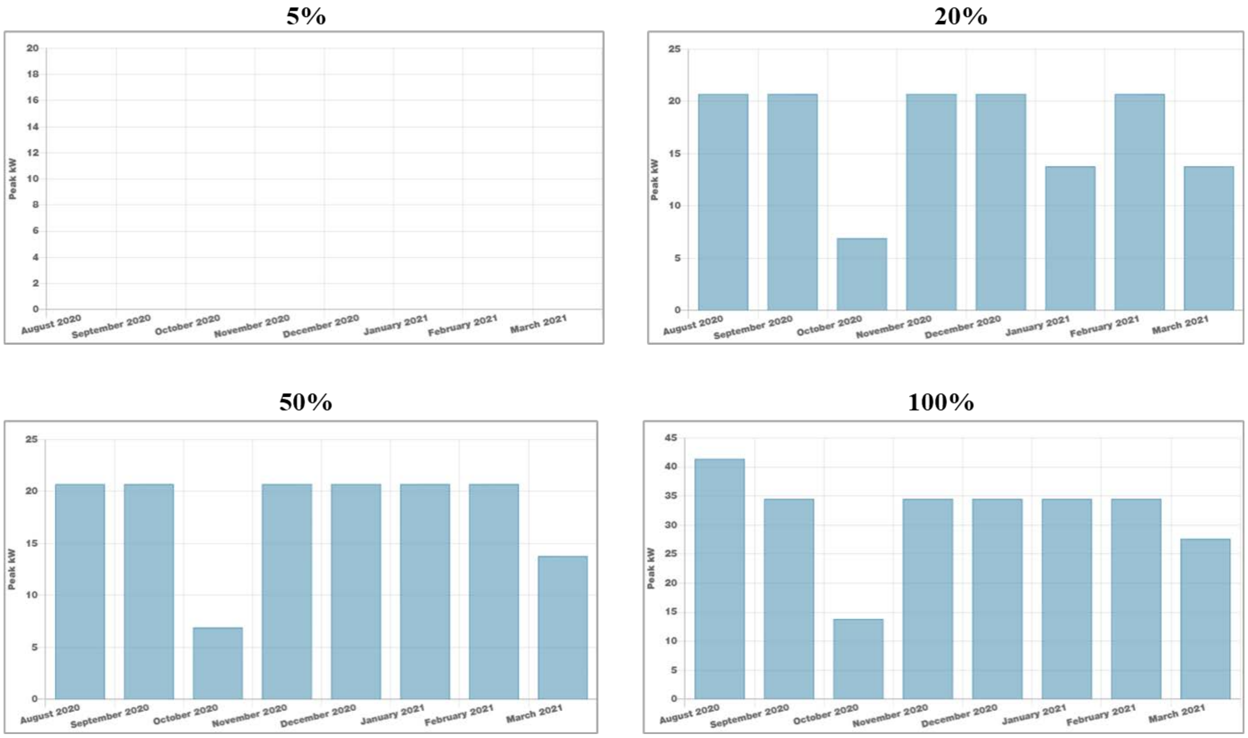

Figure D-1. Projected monthly peak charging demand at increasing levels of fleet electrification for a single parking facility: CU Boulder

Appendix E. University of Tennessee, Knoxville

UT Knoxville provided telematics data for 483 fleet vehicles. The data covered operation of these vehicles from November 27, 2018, through March 13, 2020.

Table E-1. UT Knoxville Fleet Summary

Category	Stats
Vehicles	483
Telematics provider	Geotab
Period of analysis	11/27/2018–3/13/2020
Miles analyzed	4,000,000
Total trips analyzed	522,000

E.1 EV Suitability Assessment

Of the 483 UT Knoxville fleet vehicles analyzed, 140 are good candidates for replacement with an EV within the same vehicle class, and 216 are good candidates if pickups and minivans can be replaced with an SUV. If all the vehicles with a good in-class replacement are replaced, the estimated lifetime savings for the entire set of vehicles analyzed would be about $882,000, and the GHG emissions reductions would be about 7,800 metric tonnes.

Table E-2. UT Knoxville EVSA Results

Vehicle Class	# of Vehicles Analyzed	Electrification Candidates (in class)
Cargo-van	90	9
Minivan	66	6
Pickup	138	61
Sedan	129	26
SUV	60	38
TCO savings	-	*$882,000*
GHG emissions reductions	-	*7,800 metric tonnes*

- The driving range of EVs available on the market as of June 2021 can meet the needs of 85% of the UT Knoxville vehicles analyzed.
- Economics and parking location variability are the primary reasons that many UT Knoxville vehicles were identified as not having a suitable EV replacement. The EV TCO exceeded the 5% threshold for 29% of the vehicles, and about 40% of the vehicles parked at multiple locations more than 25% of the time.
- EV options with a TCO that would exceed the 5% threshold would likely be more expensive than a comparable ICE vehicle option over the lifetime of the vehicle. The higher upfront purchase price of an EV continues to be difficult for these vehicles to offset with operational savings. However, there may be policy reasons that are driving

fleet electrification, and vehicles that came close but did not meet the economic threshold may be worth additional consideration if the university is willing to purchase vehicles with a higher projected TCO.
- Vehicles that park at multiple locations more than 25% of the time might make it difficult for an EV to have regular access to charging infrastructure. Consistent parking locations for EVs simplify the fleet management of EV charging by ensuring regular access to EVSE. However, a vehicle that parks at multiple locations could still make a good candidate for replacement with an EV but may require additional deployment of EVSE or the sharing of EVSE between multiple vehicles with compatible parking schedules.
- Only 20% of the 129 sedans analyzed were identified as a good fit for replacement with an EV. For the remaining sedans, range limitations were an issue for only seven vehicles. Fifty-five sedans were determined to have an EV TCO 5% higher than the comparable ICE sedan model, and 70 sedans parked at multiple locations more than 25% of the time.
- Ten percent of the cargo vans analyzed were identified as a good fit for replacement with an electric cargo van. A combination of range limitations, economics, and varied parking locations were identified as limiting factors for EVs to meet the needs of these cargo vans.
- The pickups were compared against the Rivian R1T, the Ford F150 Lightning Pro, and two theoretical pickups intended to reflect the likely vehicle models available in the next few years from major original equipment manufacturers. Forty-four percent of the pickups analyzed were identified as a good fit for replacement with an electric pickup. The driving range of the electric pickups met the driving needs of every ICE pickup analyzed for the UT Knoxville fleet.
- Nine percent of the minivans were identified as a good fit for replacement with an electric minivan.

E.2 ezEV Scenario Analysis

Multiple scenario analyses were conducted to assess the impact of varying inputs, with a particular focus on the price of gasoline and the willingness to pay a premium for an EV. For the UT Knoxville fleet, the scenario analyses revealed the following:

- Increasing the TCO threshold to allow the EV TCO to exceed the ICE vehicle TCO by as much as 10% increases the number of vehicles for which an EV would be a good operational and economic fit by 13%.
- Increasing gasoline prices from $1.95 to $3.00 per gallon increases the number of vehicles for which converting to an EV is appropriate by only 7%.

E.3 EV Charging Impact at Varying Electrification Levels

The projected maximum charging demand for each month was addressed at each of the UT Knoxville parking facilities. The results for a single UT Knoxville parking facility are provided in Figure E-1 to demonstrate the change in charging demand at increasing levels of fleet electrification. This location has the highest projected charging demand at 100% fleet electrification. However, at 5% fleet electrification, no vehicles are projected to charge at this location. At 20% fleet electrification, of the 86 vehicles identified for replacement with an EV, no more than one is projected to charge at the same time at this location. At 50% fleet electrification, 2 of the 217 candidates for replacement with an EV are projected to charge concurrently at this location. At 100% fleet electrification, 16 of the vehicles are projected to charge concurrently at this location.

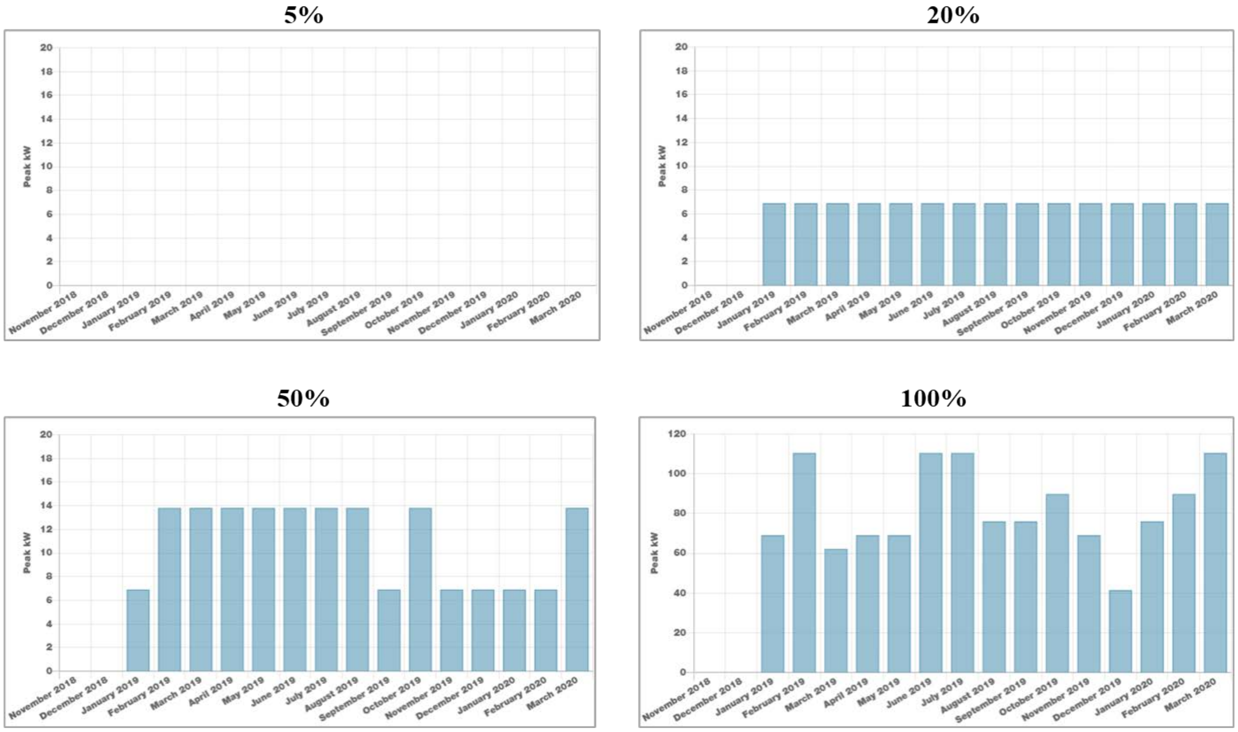

Figure E-1. Projected monthly peak charging demand at increasing levels of fleet electrification for a single parking facility: UT Knoxville

Appendix F. University of Virginia

UVA provided telematics data for 207 fleet vehicles. The data covered operation of these vehicles from December 17, 2018, through March 22, 2021. Notably, this period includes months in which the COVID-19 pandemic affected university operations and associated vehicle operations such that driving patterns were less than normal, according to UVA personnel.

Table F-1. University of Virginia Fleet Summary

Category	Stats
Vehicles	207
Telematics provider	Geotab
Period of analysis	12/17/2018–3/22/2021
Miles analyzed	930,000
Total trips analyzed	247,000

F.1 EV Suitability Assessment

Of the 207 UVA fleet vehicles analyzed, 98 are good candidates for replacement with an EV within the same vehicle class, and 136 are good candidates if pickups and minivans can be replaced with an SUV. If all the vehicles with a good in-class replacement are replaced, the estimated lifetime savings for the entire set of vehicles analyzed would be about $282,000, and the GHG emissions reductions would be about 4,200 metric tonnes.

Table F-2. University of Virginia EVSA Results

Vehicle Class	# of Vehicles Analyzed	Electrification Candidates (in class)
Cargo-van	80	27
Minivan	8	7
Pickup	97	51
Sedan	14	9
SUV	8	4
TCO savings	-	*$282,000*
GHG emissions reductions	-	*4,200 metric tonnes*

- The driving range of EVs available on the market as of June 2021 can meet the needs of 100% of the UVA vehicles analyzed.
- The primary reason that many UVA vehicles were identified as not having a suitable EV replacement is that the EV TCO exceeded the 5% threshold, rendering them more expensive than the comparable ICE vehicle. Of the 207 vehicles analyzed, 32% would be more than 5% more expensive as an EV than as an ICE vehicle. The higher upfront purchase price of an EV continues to be difficult for these vehicles to offset with operational savings. However, there may be policy reasons that are driving fleet

electrification, and vehicles that came close but did not meet the economic threshold may be worth additional consideration if the university is willing to purchase vehicles with a higher projected TCO.

- One-third of the cargo vans analyzed were identified as a good fit for replacement with an electric cargo van.
- The pickups were compared against the Rivian R1T, the Ford F150 Lightning Pro, and two theoretical pickups intended to reflect the likely vehicle models available in the next few years from major original equipment manufacturers. More than half of the pickups were identified as a good fit for an electric pickup. Additionally, many others were a good fit for replacement with an electric SUV if an SUV could meet the drivers' operational needs.
- A plug-in hybrid EV was identified as a better fit than a battery electric vehicle for eight of the nine sedans identified as a good fit for replacement with an EV.

F.2 ezEV Scenario Analysis

Multiple scenario analyses were conducted to assess the impact of varying inputs, with a particular focus on the price of gasoline and the willingness to pay a premium for an EV. For the UVA fleet, the scenario analyses revealed the following:

- Increasing the TCO threshold to allow for the EV TCO to exceed the ICE vehicle TCO by as much as 10% increases the number of vehicles for which an EV would be a good operational and economical fit by 14%.
- Increasing gasoline prices from $1.95 to $3.00 per gallon increases the number of vehicles for which converting to an EV is appropriate by only 5%.

F.3 EV Charging Impact at Varying Electrification Levels

The projected maximum charging demand for each month was addressed at each of the UVA parking facilities. The results for a single UVA parking facility are provided in Figure F-1 to demonstrate the change in charging demand at increasing levels of fleet electrification. This location has the highest projected charging demand at 100% fleet electrification. At 5% fleet electrification, no vehicles are projected to charge at this location. At 20% fleet electrification, 3 of the 37 vehicles identified for replacement with an EV are projected to charge at the same time at this location. At 50% fleet electrification, 17 of the 94 candidate vehicles are projected to charge concurrently at this location. At 100% fleet electrification, 28 of the vehicles are projected to charge concurrently at this location.

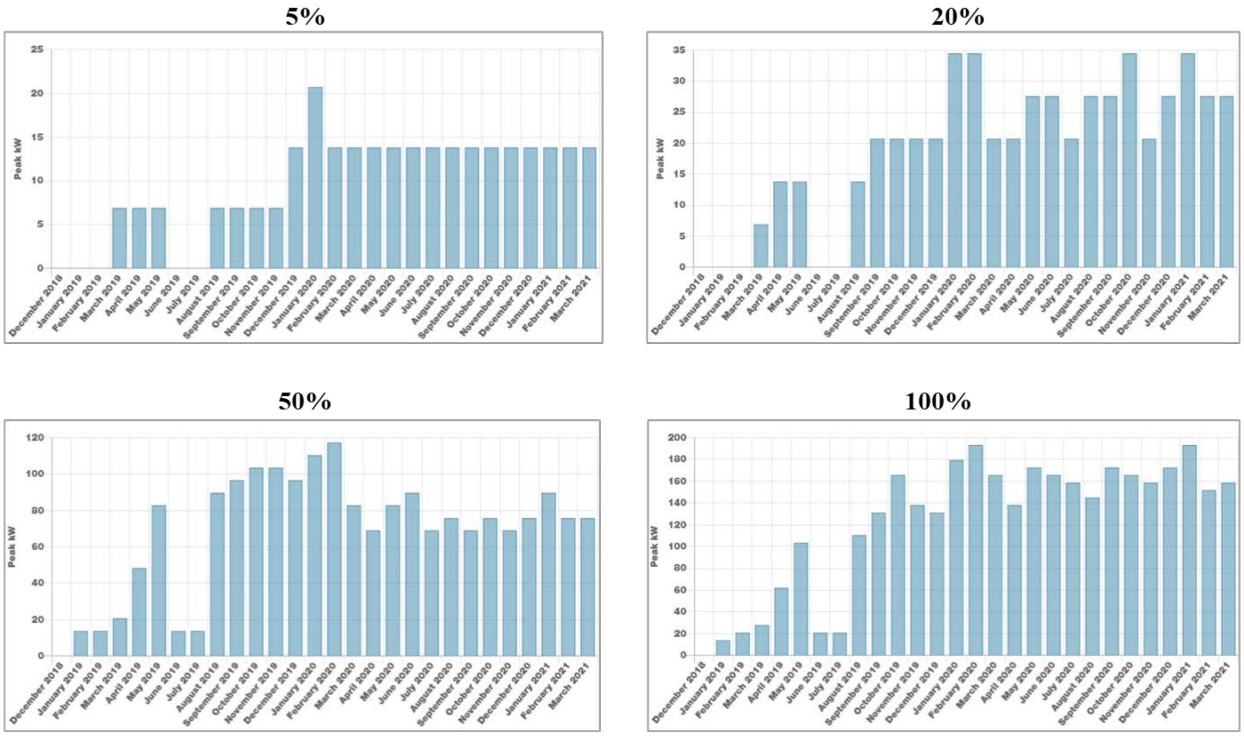

Figure F-1. Projected monthly peak charging demand at increasing levels of fleet electrification for a single parking facility: UVA