Electrify Heartland Plan

Appendix Q: EVSE Corridor Analysis

Project title: Kansas – Missouri
Community Readiness for EV and EVSE

Funded by: US DOE DE-EE0005551

By: Metropolitan Energy Center

and Kansas City Regional Clean Cities Coalition

With: Black & Veatch

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Electrify Heartland Plan

Electrify Heartland Project Abstract

Electrify Heartland is an electric vehicle planning project managed by Metropolitan Energy Center. It is a product of the Greater Kansas City Plug-In Readiness Initiative, co-chaired by Kansas City Regional Clean Cities Coalition. Our goal is to produce a regional plan to prepare public resources and secure the economic and environmental benefits of plug-in vehicles within targeted metro areas with estimated 2.7M population. The targeted metro areas include Kansas City, MO & KS; Jefferson City, MO, Wichita, KS; Salina, KS; Lawrence, KS; and Topeka, KS. (14 Counties: Cass, Clay, Cole, Douglas, Jackson, Johnson, Leavenworth, Miami, Platte, Ray, Saline, Sedgwick, Shawnee, Wyandotte).

Electrify Heartland Steering Committee

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Vehicle & Fleet	University of Missouri at Kansas City	Henry Marsh

Exhibit i-i. Electrify Heartland Steering Committee Members

Table of Appendices

The following appendices are in separate files on www.ElectrifyHeartland.org

Appendix Q: EVSE Corridor Analysis

Synopsis:

This appendix to the Electrify Heartland Plan presents a technical analysis of a corridor that would support electric vehicle travel in the triangle of highways between the cities of Kansas City, Missouri; Topeka, Kansas; and Wichita, Kansas. The main focus of the report is on the analysis of vehicle energy consumption along this corridor and the identification of areas where charging infrastructure could be deployed to effectively support electric vehicle travel.

The report also contains qualitative discussions on a variety of issues related to EV corridor design and implementation, based on our experience with similar projects.

The comprehensive design, planning, and implementation of an EV corridor involve activities that are not contemplated in the scope of this report. Important examples of such activities include a stakeholder participatory process, a techno-economic analysis, and market and travel demand analyses. This report provides a solid platform to facilitate these other activities.

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Regional Electric Vehicle Corridors

An Analysis for Missouri-Kansas

Prepared for the Kansas City Metropolitan Energy Center

Prepared by Logios

December 2012

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The Metropolitan Energy Center is a non-profit organization whose mission is to help create resource efficiency, environmental health, and economic vitality in the Kansas City region.

This document was commissioned by the Metropolitan Energy Center as part of Kansas-Missouri Community Readiness for Electric Vehicles (EV) and Electric Vehicle Supply Equipment (EVSE) to Logios, LLC. Research, interviews, data collection, analysis, and documentation under this project were conducted by Logios, LLC (project manager, Gustavo Collantes). Logios, LLC is a company dedicated to clean energy innovation, integration and implementation (www.logios3i.com).

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Acknowledgments

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Michael Wegner, Kansas Corporation Commission

The contents of this report do not necessarily reflect the views and opinions of these stakeholders or their organizations.

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Introduction

The Metropolitan Energy Center received US DOE Award No. DE-EE0005551, to support the implementation of the project titled "Kansas–Missouri Community Readiness for Electric Vehicles (EV) and Electric Vehicle Supply Equipment (EVSE)". The scope of work for this award included a task titled Analysis of an Electric Vehicle Corridor for Missouri. This report was prepared toward fulfillment of the requirements under that task.

Corridor is defined in the Merriam-Webster dictionary as a: "a densely populated strip of land including two or more major cities"; and b: "an area or stretch of land identified by a specific common characteristic or purpose." For the purpose of this report, we define EV corridor as a strip of land that hosts the infrastructure needed to support seamless regional travel of electric vehicles. We consider infrastructure in its broadest sense, including roads, charging equipment, and any other types. A key word in our definition of EV corridor is seamless, embeds the concepts of network and practical. An infrastructure network enables any point in the corridor to be reached from any other point. This connectivity differentiates a network from a disaggregated set of pieces of infrastructure. While an infrastructure network may theoretically enable regional travel between two points in the corridor, it may not necessarily be practical. A network that does not provide the type of amenities that users seek would be an example of an impractical network.

This reports presents the results of the first empirical quantitative analysis of a regional EV corridor. It incorporates some of the lessons learned by the author during the planning of EV corridors in the Northwest of the United States. The geographical scope of the analysis, covering over 200 miles in the states of Kansas and Missouri, was decided upon by the Metropolitan Energy Center. This choice of scope does not necessarily reflect assumptions about the geography of future EV markets in this region. It is rather a first attempt to understand some of the challenges and opportunities for regional EV travel and will hopefully be expanded, as efforts continue in the region to create an EV-friendly environment.

Objectives

This report presents a technical analysis of a corridor that would support electric vehicle travel on highways between the cities of Kansas City, MO, Topeka, KS, and Wichita, KS. The main focus of the report is on the analysis of vehicle energy consumption along this corridor and the identification of areas where charging infrastructure could be deployed to effectively support electric vehicle travel. The report also contains qualitative discussions on a variety of issues related to EV corridor design and implementation, based on our experience with similar projects.

The comprehensive design, planning, and implementation of an EV corridor involve activities that are not contemplated in the scope of this report. Important examples of such activities include a stakeholder participatory process, a techno-economic analysis, and market and travel demand analyses. This report provides a solid platform to facilitate the undertaking of these other activities. A discussion of the interrelation between the present analysis and supplementary activities will be included in the Discussion and Recommendations section of the report.

More broadly, this report provides quantitative and qualitative information to support a discussion about the opportunities for electric vehicle travel at the regional level. In general, electric vehicles are thought of as predominantly city creatures. While most current models of electric vehicles find a more natural habitat in urban environments, it is important also to understand the extent to which they are a viable option for travel on a regional scale. It was found, during earlier efforts to commercialize electric vehicles (Collantes, 2006), that the limited ability of these vehicles to meet the regional travel needs of many consumers had an impact on the extent of their market adoption. Peer-reviewed literature confirms the negative impact of range limits on consumer preference (for example, Bunch et al., 1993, Bronwstone et al., 2000, and Collantes, 2010. The same literature also confirms that range is only one of many factors affecting consumer choice. Electric vehicles have a number of attractive attributes, some still unknown to most consumers, ranging from instant torque to the ability to refuel at home. The rigorous analysis and planning of electric vehicle corridors is one strategy that can help expand the attractiveness of these vehicles in the eyes of greater consumer segments.

Methodology

We focus on the analysis of travel along corridors by battery electric vehicles. These vehicles differ from plug-in hybrid electric vehicles (PHEV) in that the motive power comes strictly from an electric motor, which in turn only uses energy stored in a rechargeable battery.[1] PHEV support various configurations, the commonality of which is that the powertrain uses energy both from a rechargeable battery and a conventional fuel, typically gasoline. Corridor planning is essential to EV because of their full reliance on electricity fuel.

The characteristics of an electric vehicle's energy consumption are affected by variables falling into three broad categories, namely: vehicle design, driving behavior, and external factors. Vehicle design affects energy dynamics through variables such as battery pack configuration, onboard charger specifications, and braking regeneration performance. Driving behavior impacts energy dynamics through variables such as speed and acceleration. External variables include ambient temperature, wind speed and direction, topography, and road conditions.

To estimate energy requirements, we use Logios' proprietary vehicle dynamics model. The model accounts for the full set of forces acting on the vehicle on the vertical plane of vehicle motion. The main advantage of our model is that it uses actual geographical positioning system data to measure position in time and space, speed, and acceleration. It will be seen in the presentation of our results that empirical data result in speed profiles more complex than those typically assumed for in studies of vehicle energy consumption. Empirical data also enables the estimation not only of the effect of gravity forces, but also of the interplay of gradients of altitude and speed in actual driving behavior.

As with every model, assumptions are needed for the values of a number of variables to run our model. For this report, we try to recreate rather demanding conditions. For example, we choose to model scenarios with low temperatures that would induce drivers to have the vehicle heating system on at all times.[2] We also assume that the vehicle carries a load of 500 pounds. Table 1 includes a list of the values assigned to some of the central variables in our model.

[1] This assumption is consistent with the configurations currently commercialized, although other technological configurations, such as including ultracapacitors, may also be possible.

[2] The choice between assuming the heating system on versus the air conditioning system on was relatively arbitrary. A rigorous comparison of energy consumption under each scenario would involve additional runs of the model, which fell beyond the scope of this particular study. Our model used values of heating power comparable to the maximum power used by air conditioning systems as modeled in Farrington and Rugh (2000).

Table 1 Values adopted for key variables in the vehicle dynamics model

Variable	Assumed value
Sea-level ambient temperature	40 degrees Fahrenheit
Vehicle curb weight	3350 pounds
Load weight	500 pounds
Vehicle frontal area	25 square feet
Aerodynamic drag coefficient	0.29

We scaled our estimated driving speeds to a maximum ceiling, the value of which is consistent with speeds we observed in the particular corridor leg. While lower speeds would significantly increase the range of electric vehicles (and of any vehicle, for that matter), higher speeds are, according to our experience, more representative of typical average speeds observed in highways in the region.

Our results are presented as point estimates of energy consumption along a given corridor leg. Ideally, this type of analysis would be done using stochastic analysis (e.g. Monte Carlo simulations), so as to provide probabilistic estimates of energy consumption (ranges of estimates, instead of point estimates). A stochastic approach is beyond the scope of this report.

It is not the purpose of this analysis to make definitive recommendations regarding the type of charging infrastructure that would more effectively support travel along a corridor. The reader will find a few references to estimated charging times; in such instances we generally assume the use of DC fast-charging equipment.

Important to interpret and draw conclusions from the results presented in this report is to understand the key differences between level 2 and DC fast charging infrastructure. Essentially, level 2 charging is characterized by the use of 240 volts. An onboard charger, the power of which varies across vehicle models, controls the charging.[3] DC fast charging is characterized by the use of 480 volts. In this case, the charger is part of the charging infrastructure and is typically rated at 50 kW. For a detailed discussion of these and other questions related to the installation of charging infrastructure, the reader is referred to other sources (see, for example, Washington State Department of Commerce, 2010).

[3] The Nissan Leaf, for example, offers models with 3.3 kW and 6.6 kW chargers. The standard allows for up to 19.2 kW.

Kansas City, MO-Topeka, KS Leg

Kansas City, MO and Topeka, KS are connected by Interstate 70 and separated by about 65 miles.

To anchor our GPS data collection, we used a number reference points in each of the end-point cities. We looked for landmarks that could be considered regional trip destinations. We avoided excessive speculation about the socio-demographic characteristics of typical EV owners to identify suitable landmarks. In Kansas City, MO, we chose the Kauffman Center for the Performing Arts, the City Market, the Kansas City Star, and the Plaza. The Kauffman Center (Figure 1) opened its doors in 2011 and by the end of its first year it has attracted half a million people for events. The garage under the main building hosts two level-2 charging stations (Figure 2). The Kansas City Metropolitan area hosts over 30 public-access charging sites.

The Kauffman Center is located in downtown Kansas City, MO, and close to many other travel attractors, such as the Kansas City Convention Center, the Kansas City Star (Figure 3), centers for worship, Kansas City Power & Light, banking institutions, the City Hall, the Kansas City Amtrak Station, and others.

Figure 1 Kansas City Kauffman Center for the Performing Arts

Figure 2 Charging stations at the Kauffman Center

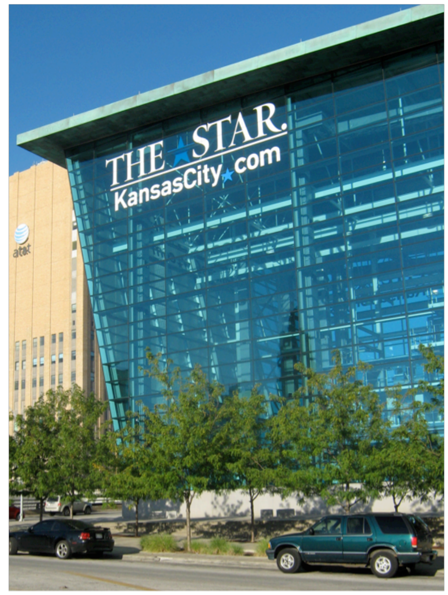

Figure 3 The Kansas City Star

As reference landmarks in Topeka, we chose the Kansas State Capitol (Figure 4), the Kansas Department of Transportation, the Topeka City Hall, and the Kansas Corporation Commission. With the exception of the Corporation Commission, these buildings are located around Old Town Topeka, where many other state government buildings, such as the State Department of Commerce (Figure 5), Westar's headquarters, the Topeka Performing Arts Center, and other trip attractors are located.

The Kansas Turnpike Authority counted over 14,000 daily trips either direction between Kansas City and Topeka on I-70 in the year 2011. Many more trips that enter Topeka or Kansas City start at locations in between, such as Lawrence and the Kansas City suburbs. As an indicator, about 5.1 million vehicles entered and exited the Eastern Terminal interchange, which connects the Turnpike to the Kansas City Metropolitan area, in 2011 (Kansas Turnpike Authority, 2011). About 4.6 million vehicles entered and exited the Topeka interchange on I-70 in the same year. In the next section we focus on trips to and from Lawrence.

Figure 4 Kansas State Capitol

Figure 5 Government buildings in Topeka (view from the State Capitol campus)

For all our simulations of this leg, we scale driving speeds to a maximum speed of 70 miles per hour. Figure 6 and Figure 7 show driving speeds, topographical elevations, and vehicle energy consumption on a trip from the Kauffman Center in Kansas City to the Kansas State Capitol in Topeka, using I-70.[4] Data collection followed a route along Broadway St to enter I-70 right south of the Missouri River, then taking exit 362B to SW 10th St, to arrive at the State Capitol.

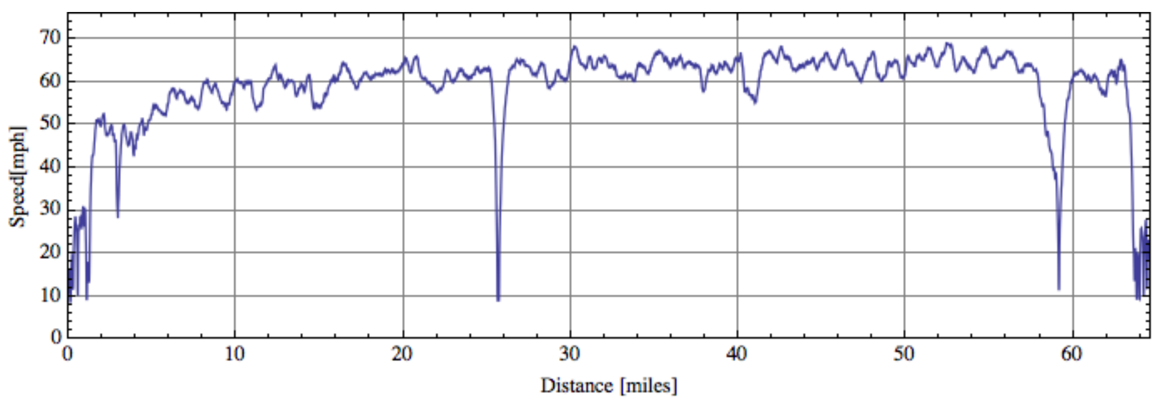

Figure 6 Driving speed profile from the Kauffman Center to the Kansas State Capitol

[4] The legal speed limit on parts of this segment is 75 mph. We model a 70 mph ceiling to reflect traffic conditions other than free flow. We note that lower ceilings do not need to necessarily result on lower energy consumption, particularly when heating or air conditioning is operated. .

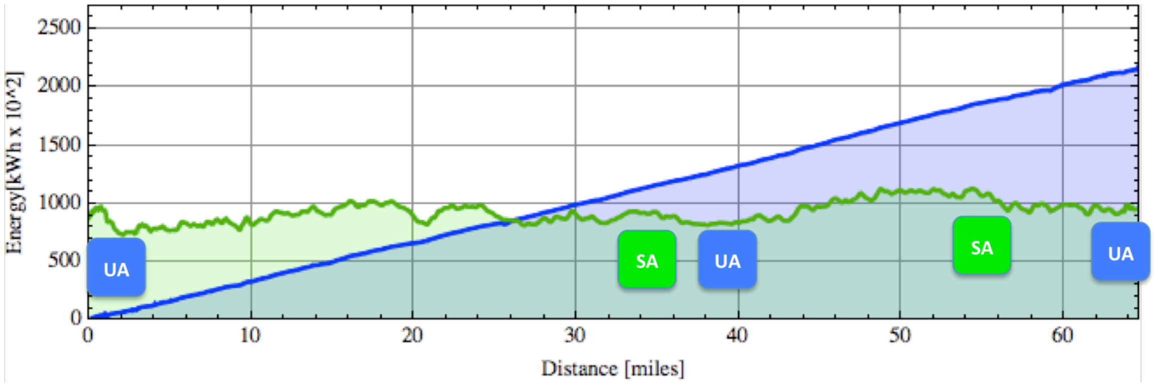

Figure 7 Elevation profile and energy use from the Kauffman Center to the Kansas State Capitol (elevations shown in feet)

To improve the readability of the speed charts, we apply a filter to the actual speed profile. The results are smoothed-out, clearer speed profiles that will not show the maximum and minimum speeds attained during cruising data collection. The driving speeds profile shows two deep decelerations at around 26 and 59 miles, corresponding to the Turnpike's toll stations. Two relatively short urban-cycle segments are observed toward the beginning and end of the trip. The blue marks in Figure 7 indicate the locations of major urban areas (UA) along the route (Kansas City, Lawrence, and Topeka), while green marks show the location of Turnpike service areas (SA). These represent natural locations that could host electric vehicle support infrastructure (EVSE), should it be deployed, to support this corridor. Other urban areas between Kansas City and Topeka, such as Tonganoxie, are in our judgment too detached from I-70 to be suitable hosts. Conversations with stakeholders also pointed to the Turnpike toll collection areas as potential hosts. While we would not completely discard this possibility, these areas were not designed to support 15-25 minute stops like service areas were.

The blue line in Figure 7 shows cumulative energy consumption. In other words, it shows the estimated amount of energy that the vehicles has used by a particular distance driven. We represent both energy and elevations on the left vertical axis. Elevations should be read as feet; in Figure 7, the axis shows elevations between 0 and 2,500 feet. Energy should be read as 100 times the value of energy; in Figure 7 the axis shows values of energy between 0 and 25 kilowatt-hours.

Figure 8 and Figure 9 show, respectively, the scaled profile of driving speeds and the topographical elevation profile along with the estimated progression of energy consumption along a trip from the Kansas Corporation Commission and the Kauffman Center. The total distance on the trip east was 62.72 miles; slightly shorter than the 64.01 miles recorded for the trip west, due to the different routes taken to depart from and arrive at the Kauffman Center.

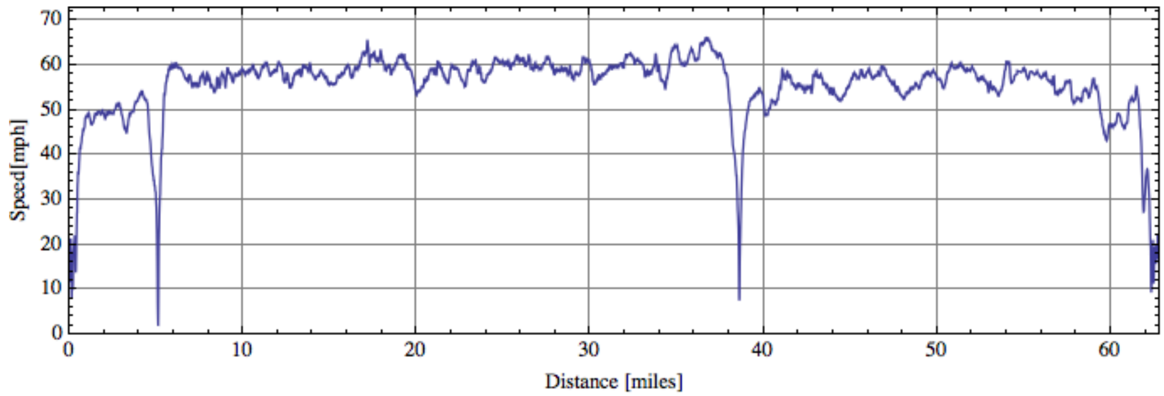

Figure 8 Driving speed profile from the Kansas Corporation Commission to the Kauffman Center

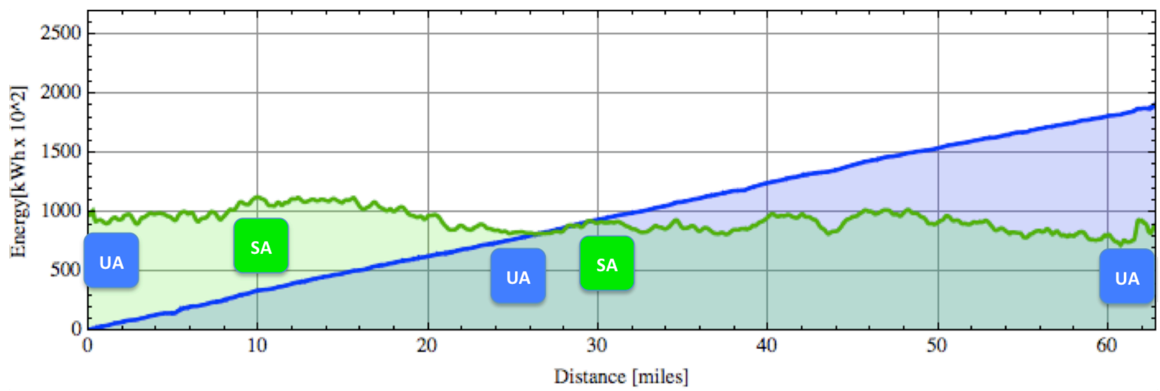

Figure 9 Elevation profile and energy use from the Kansas Corporation Commission to the Kauffman Center

All topographical elevation profiles are shown as projections on the envelope of the distance. In reality, these distances are measured in three dimensions. Figure 10 shows the three-dimensional topography along the trip between Kansas City and Topeka.

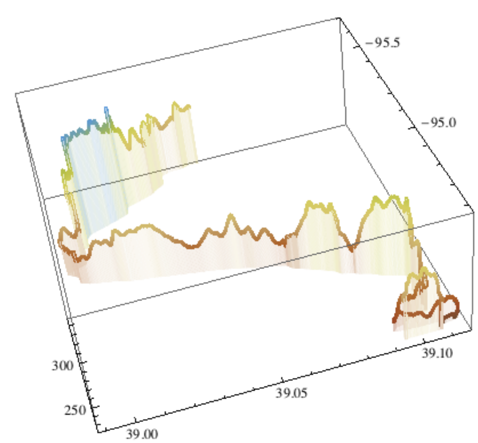

Figure 10 Three-dimensional representation of topographical elevations between Kansas City and Topeka

Our simulations suggest that EVs traveling from Kansas City to Topeka under the assumed conditions would use about 21 kilowatt-hours. Partly as a consequence of the difference in trip lengths, our simulations show that energy consumption on the trip back east is lower than on the trip west. The difference of approximately 2 kilowatt-hours can also be partially attributed to somewhat lower average speeds on the trip east back to Kansas City.

Although the starting and ending points are at comparable altitudes, the profile of topographic elevations reveal continuous variations in elevation along the route. The histogram in Figure 11 reveals a significant variation in altitude between 800 and 1,100 feet (shown on the horizontal axis). Variations in altitude, though relative minor taken individually, can have a significant cumulative effect on energy requirements on longer trips.

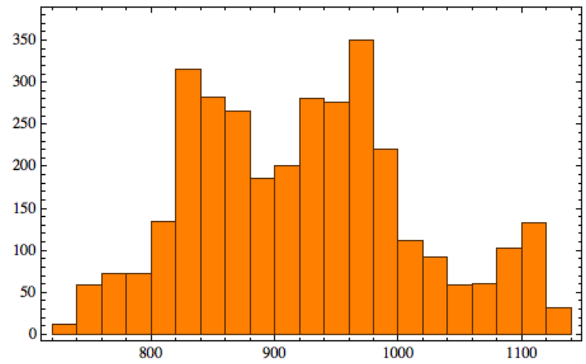

Figure 11 Histogram of elevations between Kansas City and Topeka

To shed additional light into the characteristics of elevation variation and its effect on energy use, we perform a wavelet analysis of the elevation profile (or "signal", using jargon typical to wavelet analysis) in Figure 7. The results are illustrated in Figure 12. We avoid the technical details and focus on the conceptual meaning of these results. Conceptually, wavelet analysis simply enables us to decompose the shape of the elevation profile into a smooth component (representing the overall trend of the elevations) and a high-frequency component (representing the details of the elevation at a finer scale of resolution). The latter component gives us an indication of the amplitude and frequency of the topography ups and downs along a route. The chart on the right shows the overall trend of the elevations for our sampling points. The chart in the middle shows the finer details, and provides clear indication of the non-trivial magnitude and frequency of changes in elevation along the selected route, both of which directly impact energy requirements.

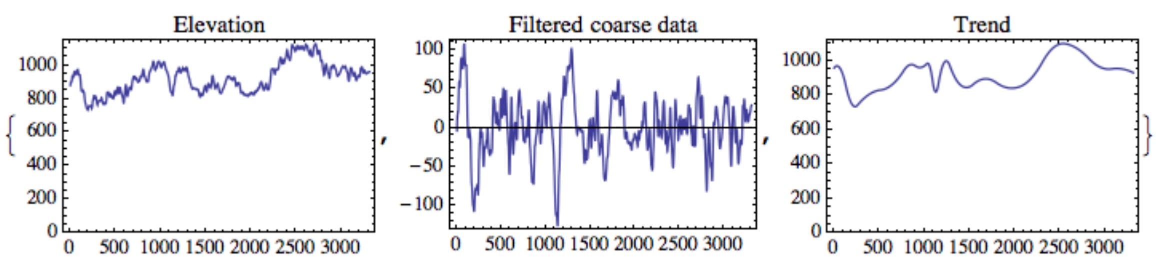

Figure 12 Wavelet decomposition of the elevation signal

We will not perform wavelet analyses for the rest of the legs included in this report, but the results just presented should prove helpful to interpret the rest of the simulations.

A note on the interpretation of the simulation results

The simulations are, of necessity, based on a number of assumptions about the variables that determine vehicle energy consumption between two given points. Certainly, simulations could be generated for a large number of combinations of values of these variables (for example, different assumptions about ambient temperatures, driving behavior, driver tolerance to temperatures, prevalent wind speed and directions, number of vehicle occupants, regenerative braking efficiency, and so forth.) However, such approach would not be very practical for the purposes of this report.

The simulations included in this report do not represent optimistic scenarios. Neither do they represent ceilings of energy requirements for an electric vehicle to drive between two given points. The results should instead be interpreted as representative of a compact electric vehicle traveling under rather energy intensive conditions.

Preliminary Assessment

The analysis presented in this section indicates that a typical electric vehicle should be able to travel from end to end of the Kansas City-Topeka corridor leg without recharging, assuming a full battery at the beginning of the trip, without compromising on comfort (e.g. heating use) and travel time (i.e. driving at prevalent speeds). The ability to travel between two points of course is only part of the analysis and planning of a corridor. Understanding the infrastructure requirements on a particular leg to support electric vehicle travel is also dependent on two broader questions, namely:

A- The type of travel that the leg is intended to support;
B- Related to point A, the role of the particular leg in the context of the larger corridor or corridors.

The levels of energy demand to travel from end to end of this corridor leg (see Figure 7 and Figure 9) would require a few hours of recharging time at the destination, using level 2 infrastructure. A reasonable estimate of the time needed to charge approximately 20 kilowatt-hours requires information about the charger onboard of the vehicle. For the sake of our discussion, it suffices to say that charging time may be as long as in excess of six hours for certain vehicle models.

In view of this information, it is safe to consider the Kansas City-Topeka leg as suitable to support commute or similar trips, where vehicles have extended dwell times during the day, assuming that the necessary level-2 infrastructure is installed. To support shorter trips, fast-charging infrastructure in at least one strategic point along this leg should be considered.

The results in this section illustrate the importance of careful analysis for the planning of integrated charging infrastructure networks, and speak to the risk of making infrastructure investment decisions based on back-of-the-envelope calculations. In this context, it should be noted that the analysis presented pertains to downtown areas in the end-point cities, with fairly comfortable access to I-70. No speculation is attempted regarding the extrapolation of these results to include more distant localities in greater Kansas City, such as Liberty, Independence, or Lees Summit.

Kansas City-Lawrence Sub-Leg

The city of Lawrence is a major university town along the corridor between Kansas City and Topeka. Because of its significance and the volumes of travel to/from this city from/to Kansas City and Topeka, we dedicate a section to analyze this sub-leg in more detail.

Kansas City, MO/Kansas City, KS are connected with Lawrence, KS by Interstate 70, Kansas State Highway 10 (K-10), and Kansas State Highway 24 (K-24). The distance between these metropolitan areas, measured along I-70, is about 41 miles. K-10 carries significant commuter traffic—about 24,000 trip counts a day—particularly to and from southern sections of Kansas City and surrounding towns, such as Overland Park. These sections are rich in office buildings, education institutions, health centers (Figure 13), and other commute trips attractors. There is also significant recreational travel between these two cities. For this reason, we chose the KU Memorial Stadium as one of the reference landmarks in Lawrence (Figure 14), representing a number of sports centers on campus, including for example the Allen Fieldhouse. We also used the city's administration offices, located in the heart of downtown, as another landmark in Lawrence.

Figure 13 St. Joseph Medical Center in Kansas City, MO.

Figure 14 Kansas University Memorial Stadium

Interstate 70

On the data collection trip west to Lawrence, we departed from the Kauffman Center. Conservatively, we took an indirect route to exit Kansas City, using Interstate 35 South, connecting with K-69 North/S 18th St Expressway, and eventually entering I-70 near the City Park. Using longer routes we simulate contingency situations when more efficient routes are not available. This route choice is reflected in Figure 15, which shows a different deceleration behavior in the Kansas City part of the trip and a traveled distance approximately four miles longer compared to the return trip (Figure 17).

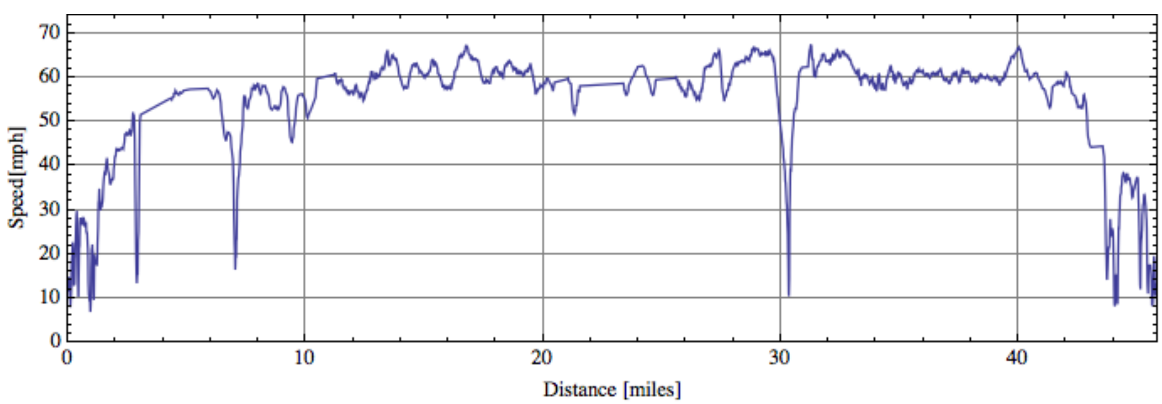

Figure 15 Driving speed profile along I-70 from the Kauffman Center to the Lawrence city offices

We took exit 204 toward downtown Lawrence at about mile 43, entering the city on N 2nd St. toward the City's offices on W 6th St and Massachusetts St, where we stopped data collection.

Figure 16 reveals that the topographical elevations of Lawrence and Kansas City are very similar, although the elevation variance along the route was found to be about 200 feet. Per our discussion in the previous section, these variations in altitude may have a significant impact on vehicle energy use. Our simulations show an energy consumption of about 14 kilowatt-hours. As expected, a typical EV, as modeled in our simulations, would easily cover the distance between these cities, but it would need to spend some time recharging before starting the return trip. At this point it may be useful to remember that our analysis focuses on battery electric vehicles. This is important to interpret the last statement, since a plug-in hybrid electric vehicle would not require charging to be able to complete the return trip.

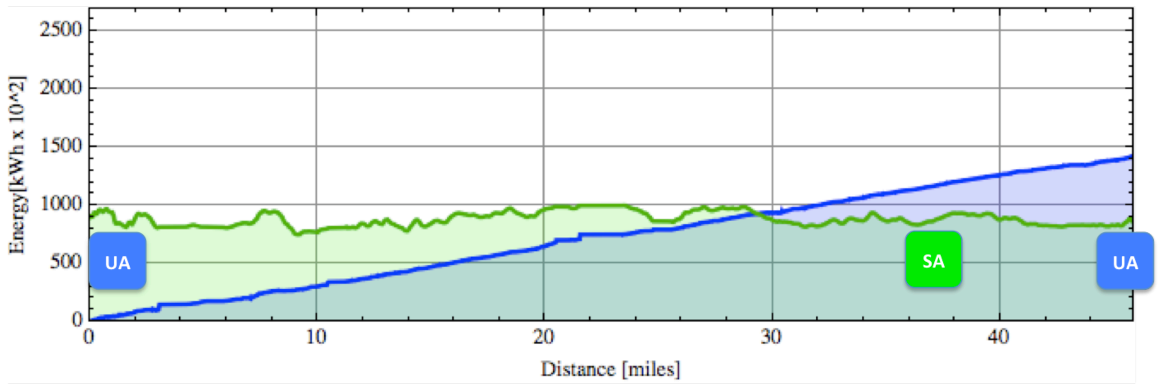

Figure 16 Elevation profile and energy use along I-70, from the Kauffman Center to the Lawrence city offices

The duration of the recharge event can more appropriately be estimated looking at Figure 18, from which it can be inferred that a minimum battery state of charge of 13-14 kilowatt-hours (as shown in the vehicle information system) would be needed to travel from the KU Memorial Stadium in downtown Lawrence and the Kauffman Center in downtown Kansas City.

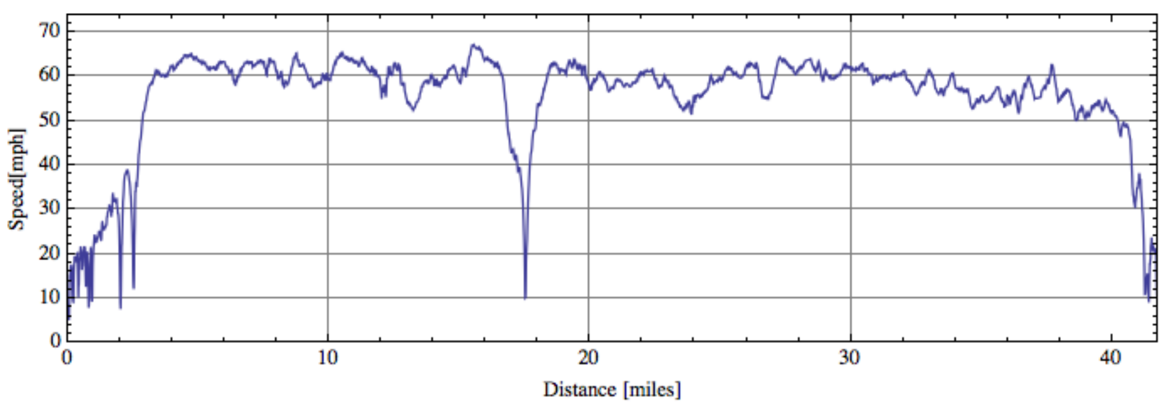

Figure 17 Driving speed profile along I-70 from the KU Memorial Stadium to the Kansas City Kauffman Center

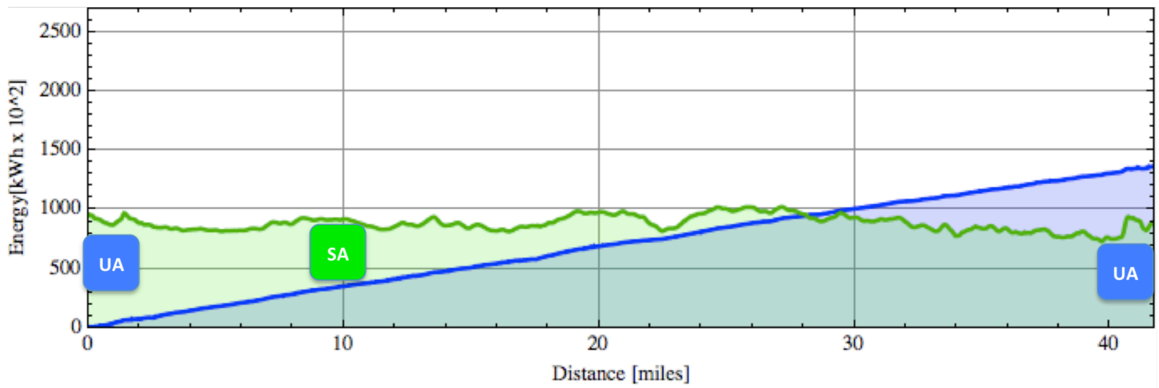

Figure 18 Elevation profile and energy use along I-70, from the KU Memorial Stadium to the Kansas City Kauffman Center

Kansas State Highway 10

K-10 is not part of the Kansas Turnpike and as such it provides a toll-free alternative route between Lawrence and Kansas City. It runs along a pleasant prairie and through Eudora, a small city less than 10 miles from Lawrence. For our departure point from the Kansas City metropolitan area we chose an arbitrary office building in Overland Park. For the arrival and departure landmark in Lawrence we chose the Kansas University Memorial Stadium (Figure 14). For the arrival landmark on the return trip we chose the St. Joseph Medical Center, in south Kansas City (Figure 13).

Our simulations for this connector assume a maximum speed of 65 miles per hour. Figure 19 and Figure 20 are showing travel speed and energy consumption profiles, respectively, on the trip west to Lawrence. Figure 21 and Figure 22 show the results for the trip east to south Kansas City.

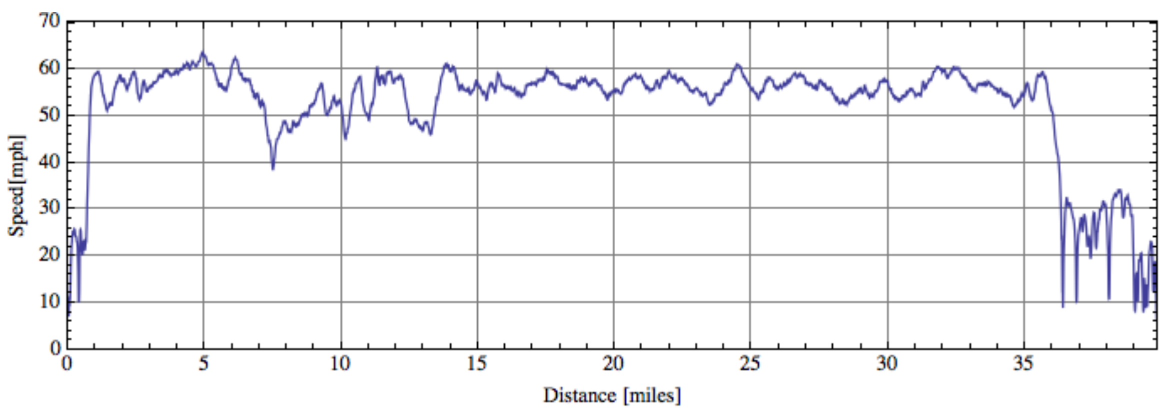

Figure 19 Driving speed profile along K-10 from Overland Park to the KU Memorial Stadium

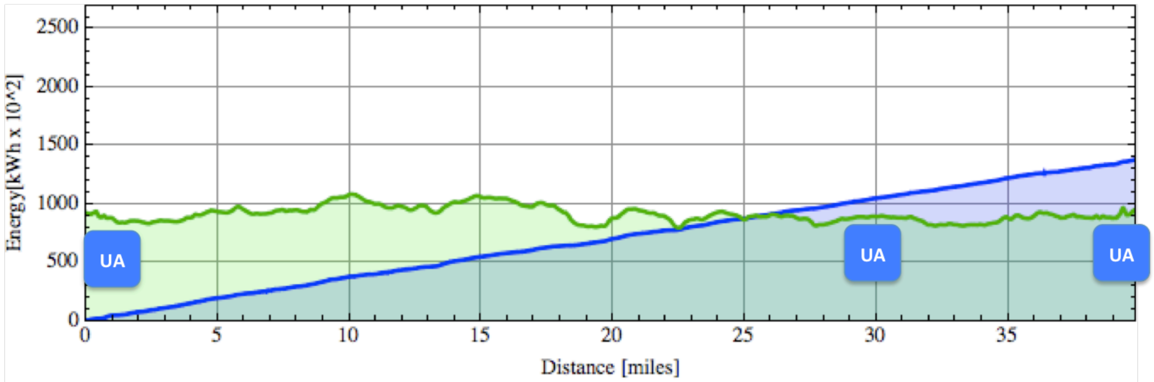

Figure 20 Elevation profile and energy use along K-10, from Overland Park to the KU Memorial Stadium

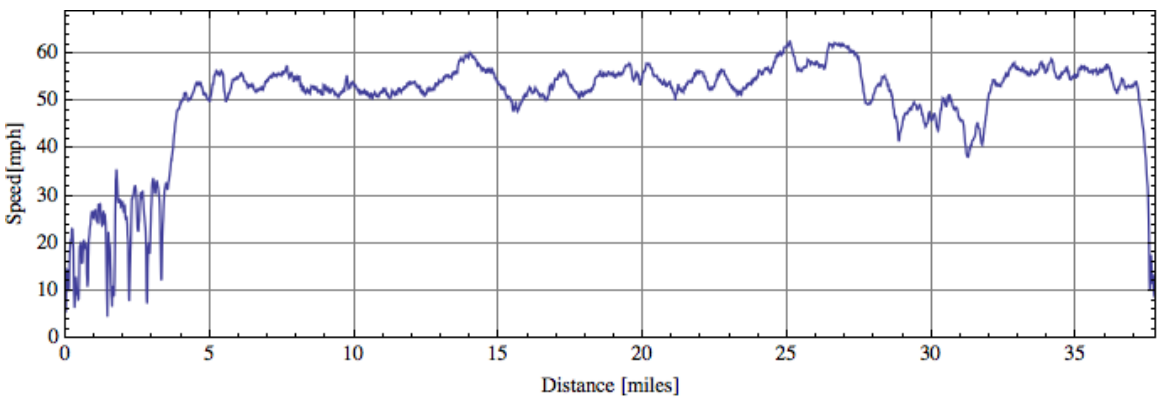

Figure 21 Driving speed profile along K-10 from the KU Memorial Stadium to South Kansas City

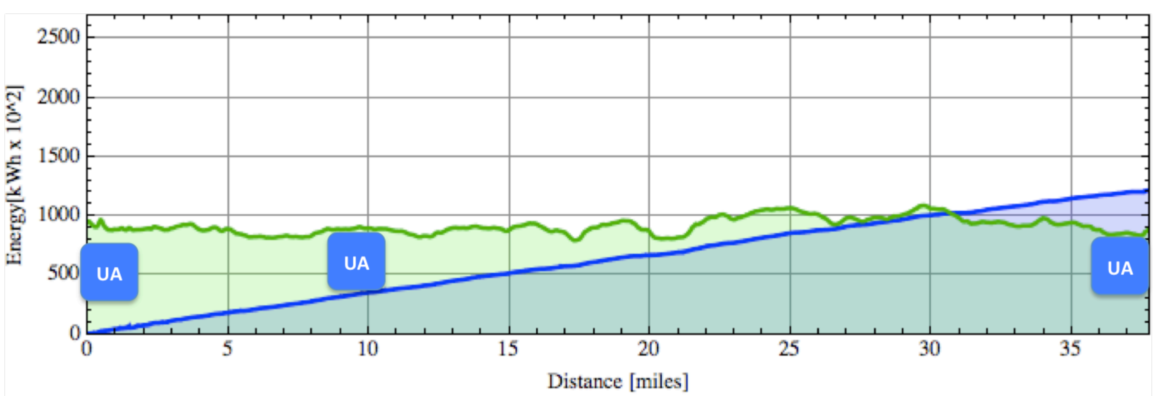

Figure 22 Elevation profile and energy use along K-10, from the KU Memorial Stadium to South Kansas City

Energy consumptions along the K-10 route are similar to that estimated for the trips on I-70. We do observe a lower level of energy use on the trip east, which can be explained by the slightly shorter distance and the lower average speed, which becomes apparent when comparing Figure 19 and Figure 21.

Preliminary assessment

The Kansas City-Lawrence leg presents no major challenges to electric vehicle travel from an energy standpoint. Indeed, this leg constitutes an opportunity to promote EV adoption and use. Many of the most important attractors of trips between these cities, such as downtown Lawrence and KU's campus offer adequate conditions for the deployment of supporting charging infrastructure. Collaboration between city governments and partnerships with private institutions in both cities could be pursued for the planning of an electric vehicle friendly environment along this short corridor.

Our modeling suggests that public-access infrastructure strategy to support travel between these cities could also include level-1 charging equipment. Thus, with adequate planning, capital costs of installation could be kept at relatively modest levels. Risks of any impacts on the grid related to EVSE clustering are also expected to be nominal with level-1 infrastructure.

As of the end of 2012, the Kansas City Metropolitan area hosts over 30 public-access charging sites. Two of them are located at the Kauffman Center for the Performing Arts.

Topeka-Wichita Leg

Topeka and Wichita are connected by Interstate 335 and separated by about 140 miles. A vast, beautiful prairie frames the route between these two cities. Urban centers along this path are few, with Emporia and El Dorado being the largest. Recreational destinations include the Tallgrass Prairie National Preserve, state parks, and historical sites. The city of Wichita, at the southern end of this leg, is the largest touristic attraction, with about six million visits per year, according to Go Wichita Convention and Visitors Bureau.

We will show results using data collected along a route anchored by the Kansas State Capitol at the north end and the Wichita State University's Cessna Stadium at the south end. We also collected data using alternative travel demand centers in Wichita, including the city hall and the Intrust Bank Arena.

We covered this leg in four stages, or sub-legs, stopping at each of the three service areas along the Turnpike between Topeka and Wichita. A map of this leg with the locations of the service areas can be found at http://www.ksturnpike.com/travel_information/kta_map_weather#service_areas. For a leg of this length, a multi-step approach yields at least two benefits: a) It will make the analysis easier, and b) It reduces the risk of problems with GPS data collection.

Sub-leg 1 southbound:

The first sub-leg stretches from the Kansas State Capitol to the Emporia service area (milepost 132) on I-335, a few miles before the exit to the city of Emporia.

We show in Figure 23 the driving speed profile scaled to have a maximum value of 70 miles per hour. To improve the readability of the chart, we continue to apply a filter to the actual speed profile.

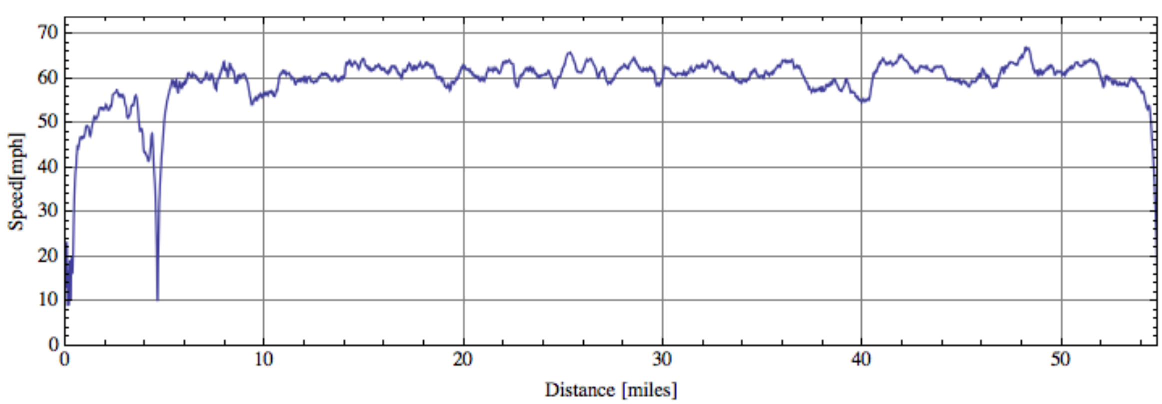

Figure 23 Driving speed profile from Topeka to Emporia service area, with ceiling of 70 mph

For this speed profile, we estimate vehicle energy consumed at the end of the sub-leg to be about 17 kWh, as shown in Figure 24. To provide a sense of the influence of driving speeds on energy requirements, we show in Figure 25 the same speed profile, scaled to a higher ceiling of 75 miles per hour.

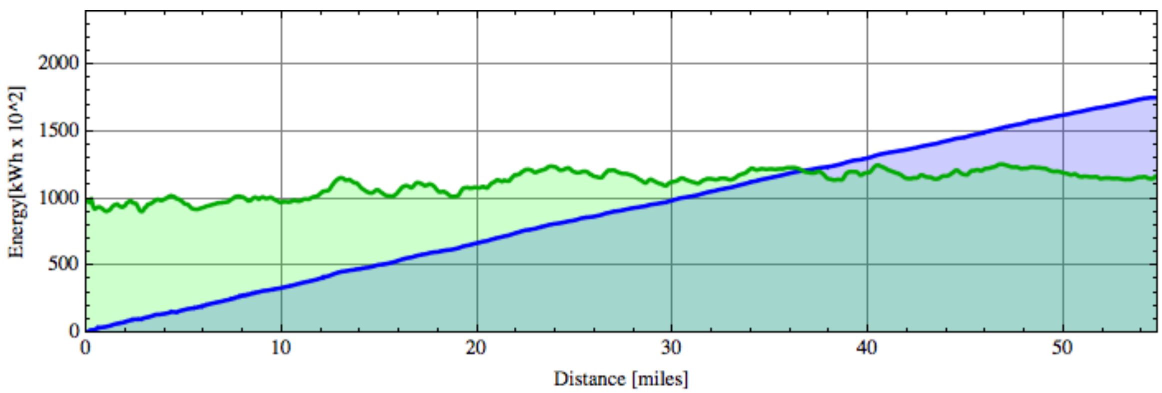

Figure 24 Elevation profile and energy use with speed ceiling of 70 mph

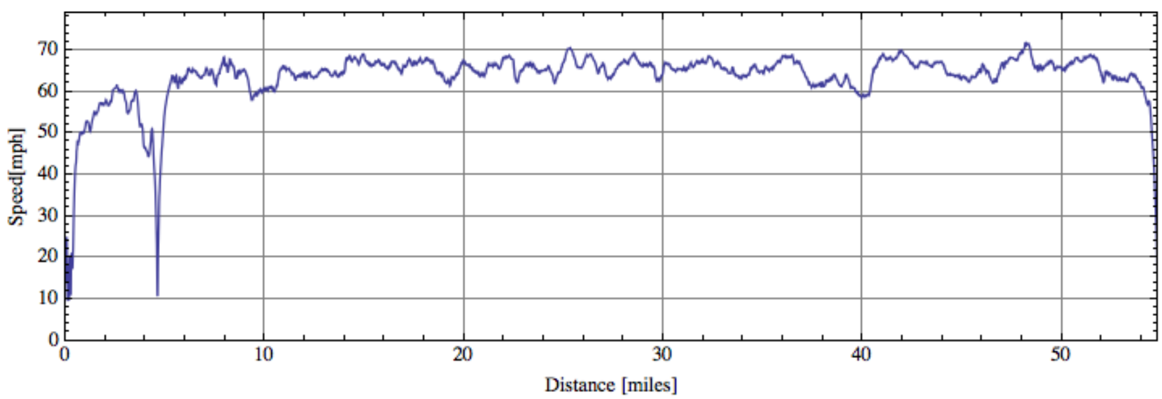

Figure 25 Driving speed profile from Topeka to Emporia service area, with ceiling of 75 mph

As Figure 26 demonstrates, a relatively small increase in maximum (with its consequent increase in average) speed results in rather significant increases in energy consumption. Energy increases with the square of speed, and marginal increases are higher at larger speeds. In other words, speed increases will have larger impacts on energy use during highway travel than during urban typical driving cycles.

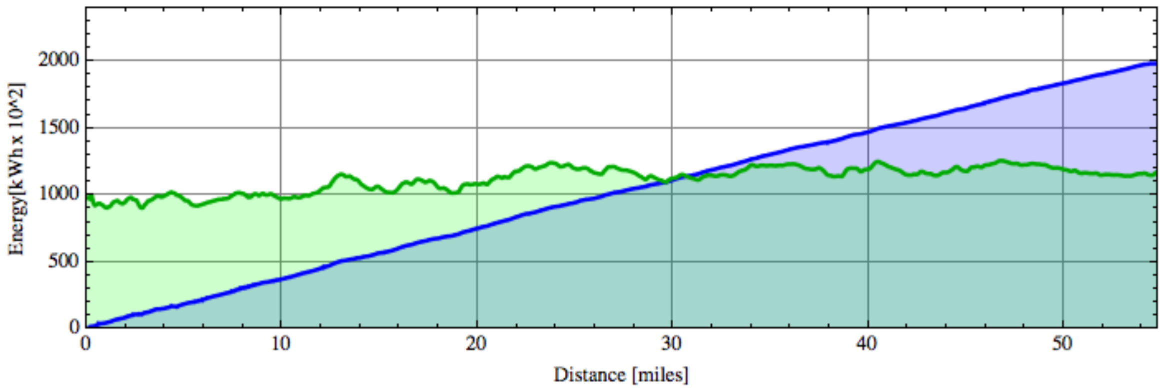

Figure 26 Elevation profile and energy use with speed ceiling of 75 mph

Assuming the vehicle leaves Topeka fully charged, the time to recharge the battery completely using DC-fast infrastructure at the Emporia service area could be estimated at 20 to 24 minutes. From an electrical infrastructure standpoint, Turnpike service areas on the Topeka-Wichita corridor offer the basic necessary infrastructure environments for the installation of fast-charging equipment. It would be the purview of a separate study to determine whether they provide the type of amenities sought by typical EV adopters in the region.

Sub-leg 2 southbound

The second sub-leg stretches from the Emporia service area (mile post 132) to the Matfield Green service area (milepost 97). For this and the remaining sub-legs we continue to assume a speed ceiling of 75 mph, consistent with prevailing speeds on this corridor.

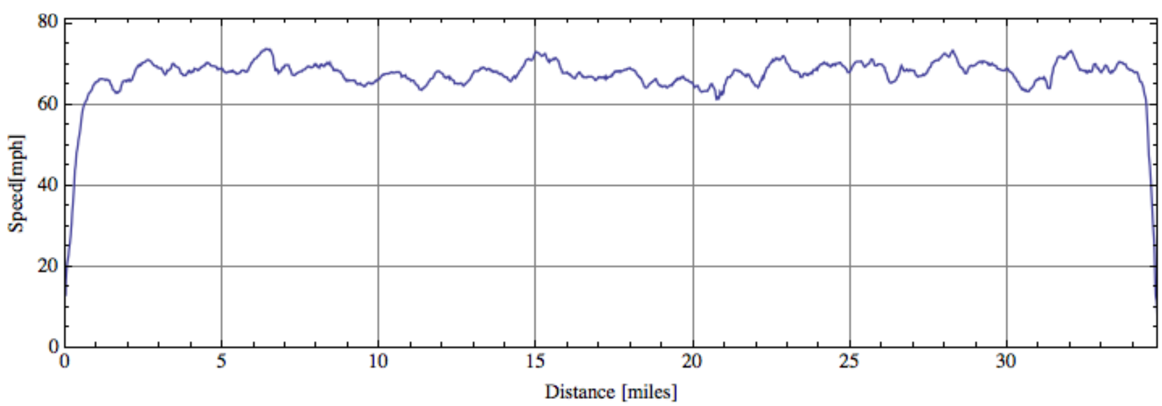

Figure 27 Driving speed profile from Emporia service area to Matfield Green service area

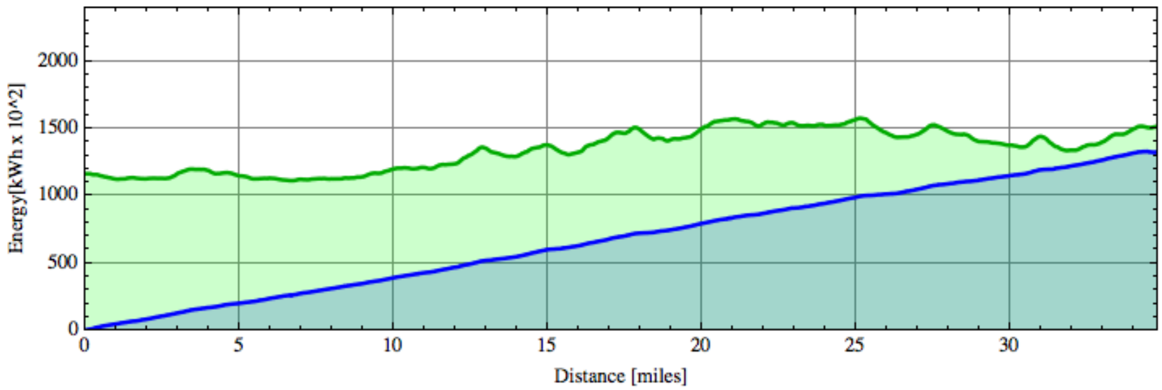

Figure 28 Elevation profile and energy use from Emporia service area to Matfield Green service area

Assuming the vehicle leaves Emporia fully charged, the time to recharge the battery completely using DC-fast infrastructure at Matfield Green could be estimated at 13 to 17 minutes.

Sub-leg 3 southbound

The third sub-leg stretches from the Matfield Green service area (milepost 97) to the Towanda service area (milepost 65).

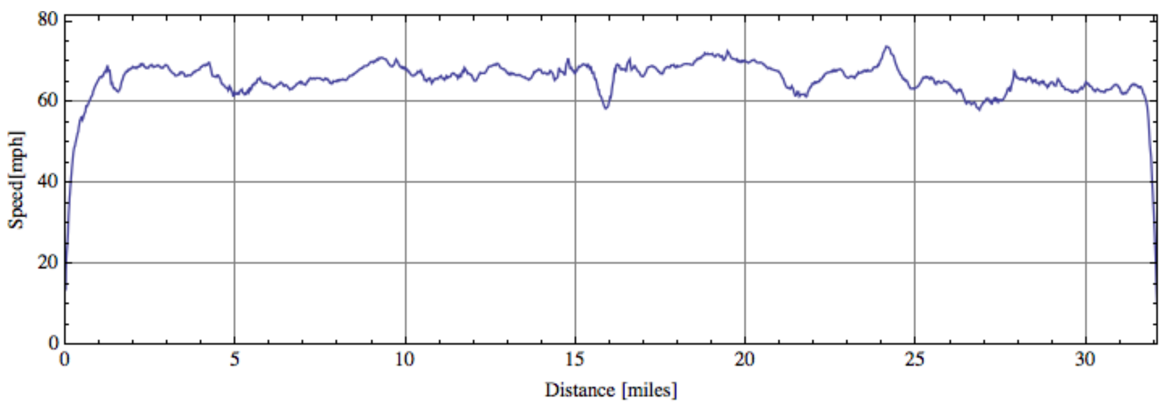

Figure 29 Driving speed profile from Matfield Green service area to Towanda service area

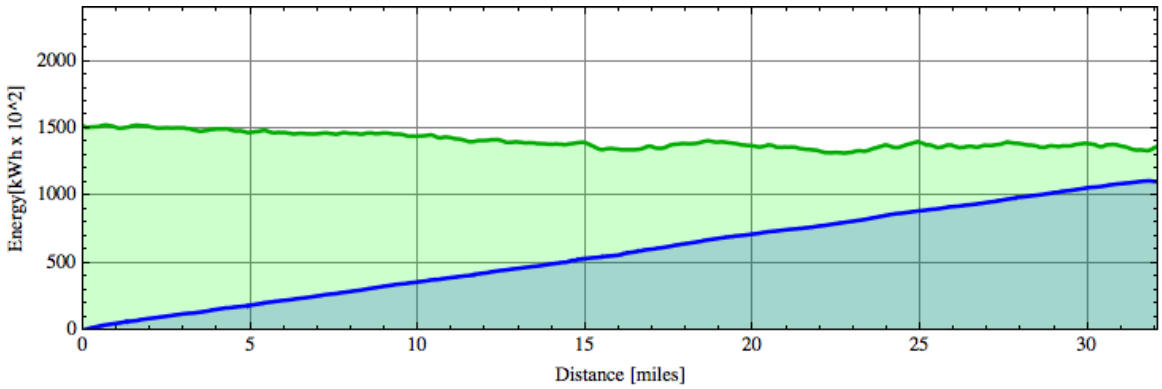

Figure 30 Elevation profile and energy use from Matfield Green service area to Towanda service area

Assuming the vehicle leaves Matfield Green fully charged, the time to recharge the battery completely using DC-fast infrastructure Towanda could be estimated at 11 to 15 minutes.

Sub-leg 4 southbound

The fourth and last sub-leg stretches from the Towanda service area (milepost 65) to the Cessna Stadium in Wichita State's campus in Wichita. Figure 31 shows the driving speed profile, including a stop at the Turnpike tollbooth between miles 12 and 13, and an urban driving segment after mile 21.

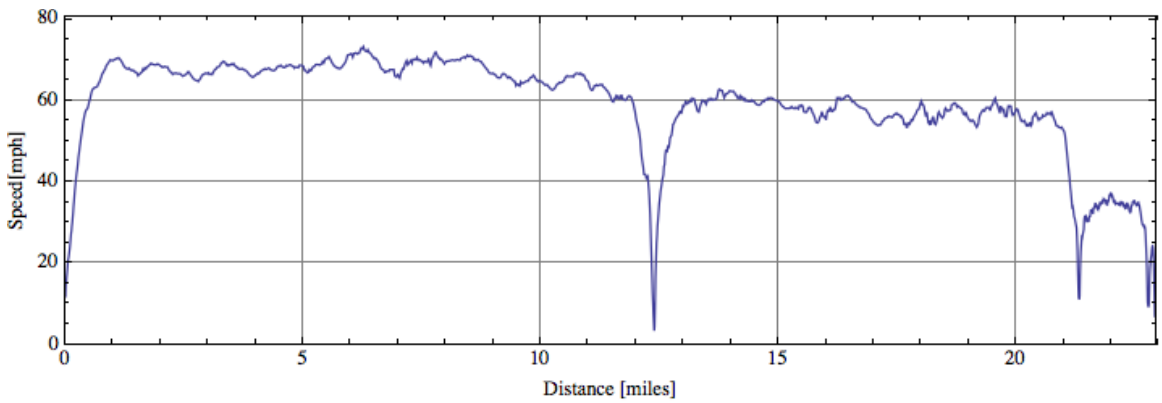

Figure 31 Driving speed profile from Towanda service area to Wichita

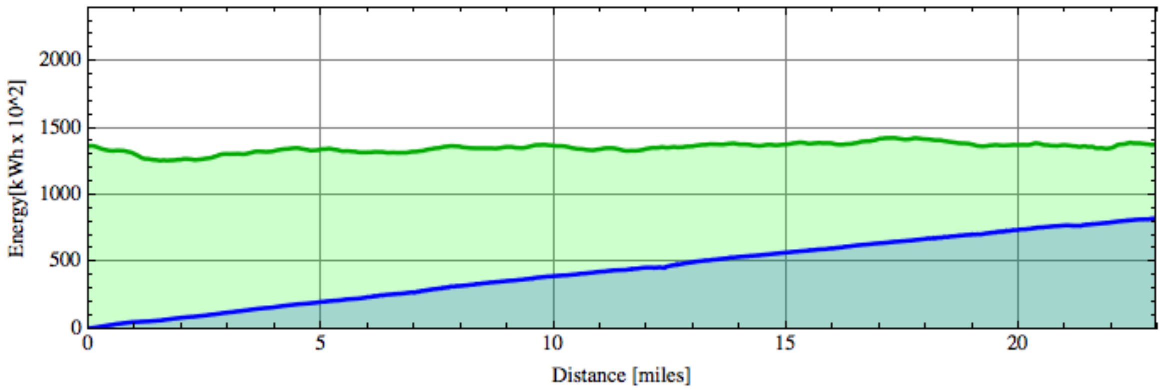

Figure 32 Elevation profile and energy use from Towanda service area to Wichita

Assuming the vehicle leaves Towanda fully charged, the time to fully recharge in Wichita could be estimated at 8 to 12 minutes using DC-fast infrastructure and between 1.5 and 2.5 hours using level-2 infrastructure.

The overall energy use under the assumed conditions is estimated at over 50 kilowatt-hours. The topographic elevation trends upwards along the southbound route, so we expect, all else equal, that the northbound trip would take less energy.

In Table 2 we describe a set of four possible charging scenarios for a trip from Topeka to Wichita, assuming that DC fast charging infrastructure[5] is available at each of the stops. For each scenario, we show one column with the estimated charging time range and one column indicating the final state of charge assumed at the end of the charging event for the particular scenario. Scenario 1 shows the estimative times it would take to fully charge the battery (the capacity of which was assumed at 24 kilowatt-hour) at each of the stops.

From a network efficiency standpoint, scenarios with shorter maximum charging events are preferable because they increase the flow capacity of the network. So for example, even though Scenario 2 shows that it would be possible to skip one stop, Scenario 3 would be preferred because the maximum length of a charging event is shorter (15 minutes vs. 20 minutes), thus allowing more vehicles to charge per hour. We note that using a driver's preference perspective might lead to a different relative assessment of the different charging scenarios. For example, would a particular driver prefer one longer stop to two shorter stops? While arguments could be made in both directions, these are behavioral questions that the present study is not prepared to assess fairly. Such assessment would also be intertwined with the planning of infrastructure deployment, as choices made in this realm can affect drivers' choices. For example, distance between charging sites, location of the charging site relative to the highway, amenities at each of the sites, and other variables can be influenced by the planning process and will likely influence drivers' choices.

[5] DC fast charge infrastructure is typically characterized by 50 kW of maximum output power and 200 Amps maximum output current.

Scenario 4 describes a sequence of charging events that would, in theory, minimize the total charging time. This scenario is presented only for illustration purposes with the understanding that it represents an unrealistically optimistic case.

The last row in Table 2 shows the estimated minimum total on-route charging time (excluding time charging in Wichita).

Table 2 Charging scenarios on a trip from Topeka to Wichita

Stop	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	Time [1] (min)	SOC [2] (kWh)	Time (min)	SOC (kWh)	Time (min)	SOC (kWh)	Time (min)	SOC (kWh)
Emporia	20-24	24	20-24	24	15-19	19	9-13	13
Matfield Green	13-17	24	13-17	24	15-19	21	11-15	11
Towanda	11-15	24			5-9	15	8-12	8
Wichita	8-12	24	19-23	24	17-21	24	30-34	24
Minimum on-route charging time [3]	44		33		35		28	

[1]: Charge time using DC fast charge infrastructure

[2]: Energy stored in the battery after the charging event is completed

[3]: Total minimum time spent charging during stops, excluding time charging in Wichita

Sub-leg 4 northbound

We now show our results for energy use on each of the sub-legs in reverse order, driving northward from Wichita to Topeka. Figure 33 shows the driving speed profile, still with a 75 mph ceiling, between the Cessna Stadium and Towanda service area, including a stop at the Turnpike tollbooth.

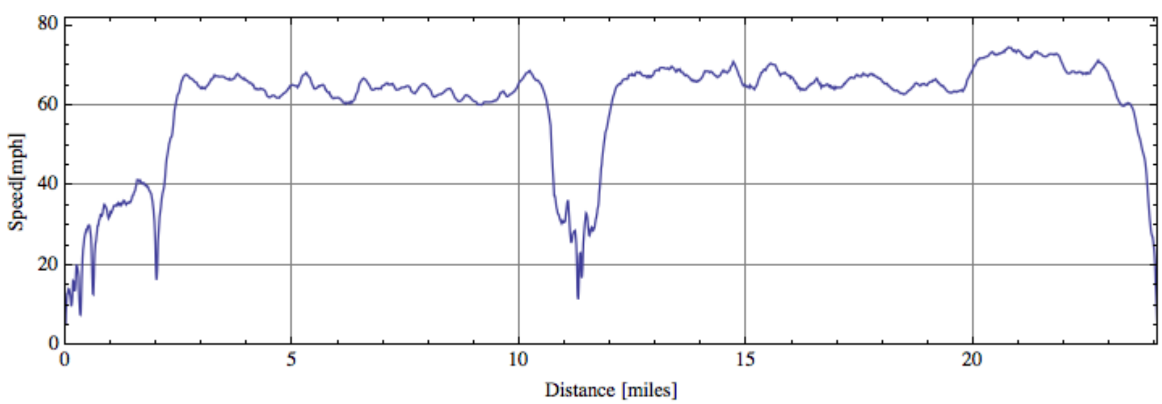

Figure 33 Driving speed profile from Wichita to Towanda service area

Figure 34 shows the topographic elevation profile between Wichita and Towanda, along with the energy use. Energy use on the northbound drive is slightly higher than for the southbound drive, which can be mostly attributed to the comparatively higher average driving speed (compare Figure 33 to Figure 31). It is worthwhile to remember, in order to properly interpret these results, that these simulations assume low-temperature weather conditions and that the onboard heating system is turned on at all times.

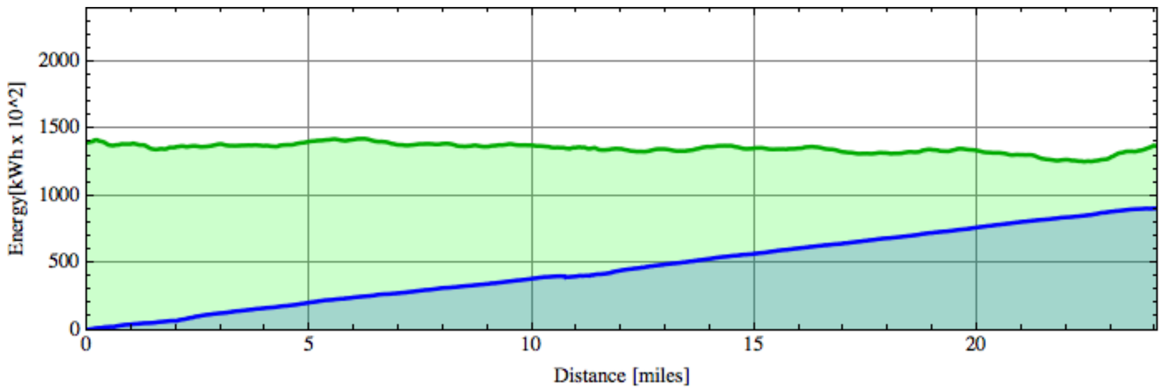

Figure 34 Elevation profile and energy use from Wichita to Towanda service area

Sub-leg 3 northbound

Figure 35 and Figure 36 show the speed profile and energy use on a drive from Towanda service area to Matfield Green service area, respectively.

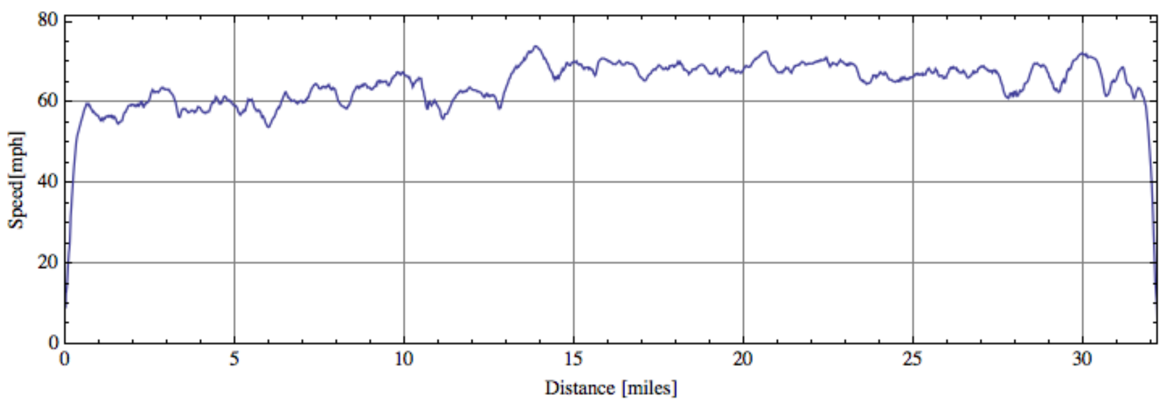

Figure 35 Driving speed profile from Towanda service area to Matfield Green service area

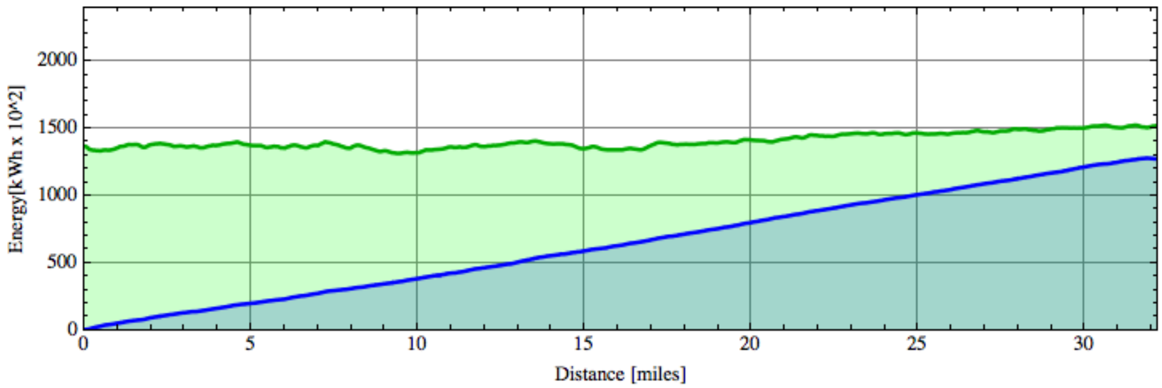

Figure 36 Elevation profile and energy use from Towanda service area to Matfield Green service area

Sub-leg 2 northbound

Figure 37 shows the profile of driving speed along the northbound trip from Matfield Green and Emporia service areas. Figure 38 shows the topographical elevation profile and energy consumption along the same drive. This segment is where the effect of topography starts to become more important on differentiating energy use on the southbound and northbound drives.

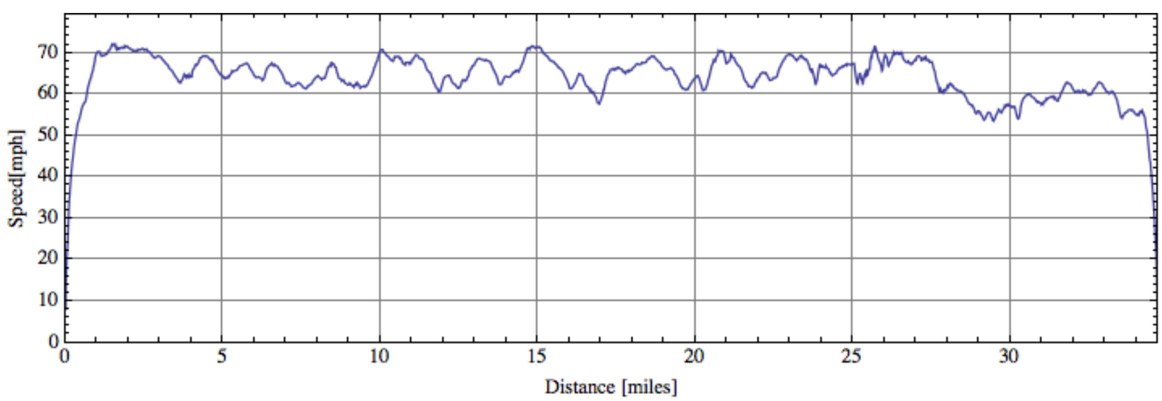

Figure 37 Driving speed profile from Matfield Green service area to Emporia service area

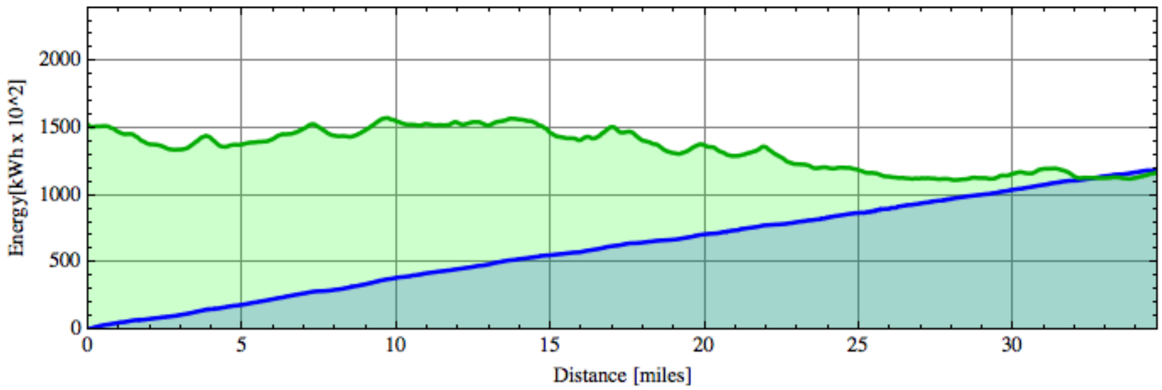

Figure 38 Elevation profile and energy use Matfield Green service area to Emporia service area

Sub-leg 1 northbound

Figure 39 shows the driving speed profile from the Emporia service area to the Kansas State Capitol building in Topeka. The speed profile in the last segment differs significantly from the first part in the southbound trip for this sub-leg (Figure 23), which is due to our choice of an urban route for that segment. Lower speeds over this roughly five-mile stretch and the difference in elevation trends contribute to the lower energy use in the northbound trip relative to the southbound trip.

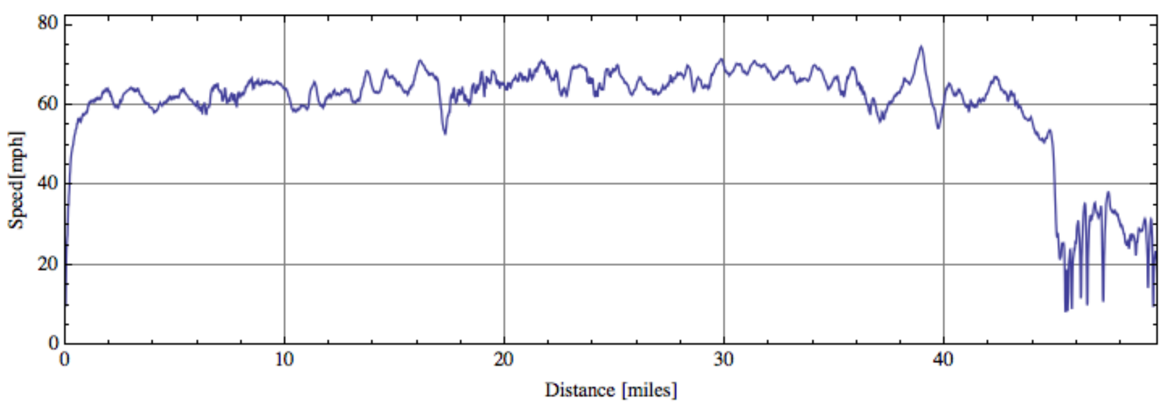

Figure 39 Driving speed profile from Emporia service area to Topeka

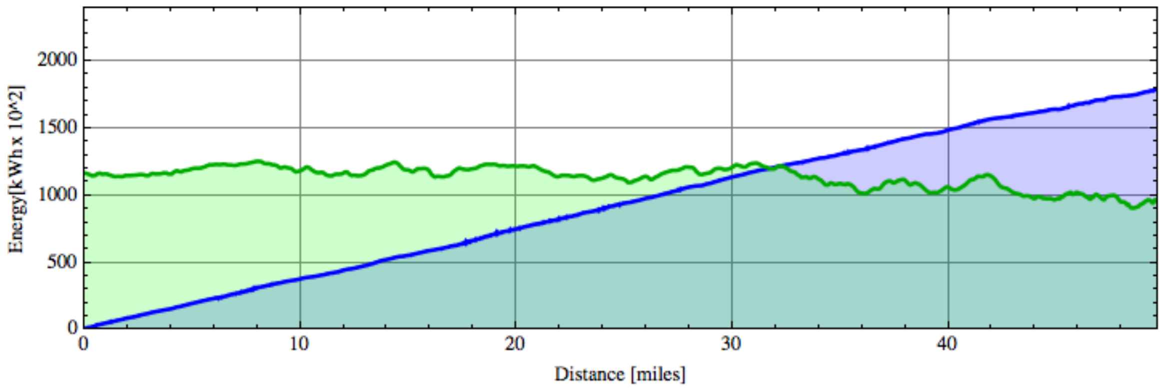

Figure 40 Elevation profile and energy use Emporia service area to Topeka

Under the assumed conditions, the estimated energy use on the trip between Wichita and Topeka is just over 50 kilowatt-hours, which is lower but very similar to the estimated energy used on the southbound trip.

Table 3 describes four possible charging scenarios for a trip between Wichita and Topeka, assuming that DC fast charging infrastructure is available at each of the stops. As with the southbound direction, we find a scenario (Scenario 2) where charging infrastructure in the Towanda service area is not needed, thus offering the possibility of reducing upfront capital costs. Charging behaviors such as those in Scenario 3 however render the network more efficient, increasing its flow rate.

Table 3 Charging scenarios on a trip from Wichita to Topeka

Stop	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	Time [1] (min)	SOC [2] (kWh)	Time (min)	SOC (kWh)	Time (min)	SOC (kWh)	Time (min)	SOC (kWh)
Towanda	9-13	24			5-9	20		15
Matfield Green	13-17	24	20-24	22	13-17	20	10-14	12
Emporia	12-16	24	12-16	22	13-17	21	18-22	18
Topeka	18-22	24	20-24	24	25-29	24	30-34	24
Minimum on-route charging time [3]	34		32		31		28	

[1]: Charge time using DC fast charge infrastructure

[2]: Energy stored in the battery after the charging event is completed

[3]: Total minimum time spent charging during stops, excluding time charging in Topeka

Alternative infrastructure host areas

Our data collection and analysis was predominantly focused on the case where charging infrastructure would be hosted at Turnpike service areas. We have shown that purely from a technological (vehicle and infrastructure) standpoint, the services areas could host an adequate charging station network that supports EV travel from Topeka to Wichita.

However important, technological factors are one of several factors relevant to determine optimal host sites. The choice of host sites, in addition, need to take into consideration factors related to consumer satisfaction, local regulations, economic constraints, the need for electrical infrastructure upgrades, and so forth.

To complement our analysis, we briefly discuss the case where charging infrastructure is located in urban centers along the Topeka-Wichita corridor. The two main urban areas on this corridor are Emporia and El Dorado.

With about 25,000 residents, Emporia ranks 16th among Kansas' cities in terms of population. The city is located at the intersection of I-335 (connecting with Topeka and Wichita) and I-35 (connecting with Kansas City), making it an important road transportation hub.

Exit 127 to Emporia is only a few minutes south of the Emporia service area. The city hall offers public parking and has direct access from the street to the City Code Services and Fire Marshall offices, which could offer opportunities for public education through the installation of level 2 charging stations (Figure 41). The city hall area is, in our opinion, too far from the Turnpike to be a suitable host for fast-charge infrastructure supporting the corridor.

Figure 41 Emporia Code Services and Fire Marshall offices.

Emporia does offer suitable locations for corridor-supporting infrastructure in the commercial areas directly accessible from the Turnpike. The example in Figures 42 and 43 illustrates this point: A cafe, hotels, and a fuel station located next to each other offer the amenities and infrastructure that could host fast-charging stations.

Figure 42 Food and lodging amenities in Emporia near I-355

Figure 43 Potential suitable host site in Emporia near I-355

Discussion and Recommendations

We have presented an analysis of the electric vehicle energy consumption along a corridor connecting the cities of Kansas City, Topeka, and Wichita. This analysis is a necessary first step toward a robust assessment of the locations where charging infrastructure could be deployed to more effectively support EV travel.

Consistent with the discussion included in the Methodology section, we will not be presenting here final recommendations regarding the type of infrastructure to be installed at any one potential location. Our opinion, based on previous experience, is that supporting EV travel along corridors exceeding the range of typical EV will generally need of DC fast-charging equipment. We acknowledge that level 2 charging is standardized for up to 19.2 kW and that at least one car manufacturer offers models that can be charged at powers levels in this neighborhood. Charging at the maximum power within the level 2 standard would, however, approximately double the charging time relative to DC fast charge, for the same energy draw. Data collected informally for this and other projects suggest that visits to freeway service areas (not rest areas) lasting 15 minutes or more are common. As shown in Table 2 and Table 3, DC fast charge infrastructure can deliver the needed charge within such time scales and it thus supports more realistically the notion of seamless travel that we described in the Introduction. Higher power level 2 charging can certainly offer a range-extending strategy, but, in our opinion, to a more modest degree. In general, we view the role of level 1 and level 2 infrastructure, within the context of corridor planning, as supporting charging at destination points such as commute trip attractors and recreation areas.

We believe that the following point is important for planning purposes: *If and only if* charging infrastructure is to be deployed at a short-dwell site (for example a service area), DC fast infrastructure is more likely the better solution. This does not imply that short-dwell sites are necessarily the ideal place to install DC fast charging. The overall approach taken during our participation of the planning of the Washington State EV corridor was to identify, to the extent possible, sites in the vicinity of highway intersections in urban areas (West Coast Green Highway, 2012). These factors need to be considered on a case-by-case basis. For example, Washington freeways are served by rest areas, which offer fewer amenities than service areas.

The process of selecting charging sites involves a number of variables and it needs to be approached simultaneously at the system and individual levels. As the general guiding principle we continue to recommend respecting the notion of seamless travel. The following set of questions provides a simple framework to guide the planning process:

a- Does the selected system of charging sites constitute a robust network?

The obvious primary goal of a corridor planning is to ensure that EVs can effectively travel between any two points in the corridor. An analysis of the type presented in this report is an essential step toward meeting this goal. A casual selection of sites could result in overspending on one extreme or on network dysfunction on the other extreme. Concepts typically found in the study of other types of networks, such as connectivity, centrality, and capacity, are also very relevant for the study of EV corridors.

b- Are the selected host sites consistent with travel and consumer preferences?

To the extent that typical early EV adopters are not representative of other market segments, EV planning efforts specifically geared toward meeting the needs of this particular segment are not recommended. Since ultimately the goal of EV planning is to create the conditions for large-scale commercialization of plug-in electric vehicles, we recommend that such planning give attention to meeting the needs of the second and third waves of adopters.

In the context of corridor planning, we recommend that the combination of characteristics of each charging site — predominantly, location relative to other charging sites, accessibility, type of charging infrastructure, and accessible amenities — meets the needs of later EV adopters. Our analysis has taken this approach by, for instance, assuming mainstream driving behavior.

c- Do the selected host sites support cost-efficient installations?

Financial considerations are an important aspect of EV corridor planning. The cost of DC fast charging equipment is a large fraction of the total expected costs but by no means the only important factor. The investment approach and stakeholder engagement can also be significant factors in the short and longer terms. Without attempting a comprehensive listing of the economic variables that affect the implementation of an EV corridor, the point we wish to focus on here is infrastructure readiness. Access to three-phase and 480V service, and demand charge structures are factors that can significantly impact the overall economics of the installation and operation.

For selection of charging sites in previous similar projects, we adopted a three-step process including the identification of recharge zones, followed by the identification of host areas, and finally the identification of the host site. In general terms, the first step is guided by technical considerations related to vehicle energy consumption, while the last step is guided predominantly by economic and infrastructure conditions on the ground.

Applying a similar approach to the Topeka-Wichita leg, we can identify three recharge zones, namely:

i- The segment between the Towanda service area and El Dorado;
ii- The Matfield service area; and
iii- The area around Emporia.

To the extent that the service areas on this leg provide the amenities required by EV users (this particular study is not concerned with addressing this question), they would all be natural candidates for host areas. For the case of the Emporia recharge zone, more consideration could be given to potential sites within the city of Emporia, which could simultaneously serve EV traffic on I-35 (connecting Emporia with Kansas City) and on I-335. All else being equal, this option would enable better returns on investment.

As discussed above, electric vehicle travel on the leg between Topeka and Kansas City can be adequately served with a well-planned mix of level 2 and level 1 infrastructure deployed at destination areas. The challenge that we see ahead on the planning of an EV corridor along I-70 is defining the right geographical scale. While our analysis focused on a relatively short segment, there are relevant urban centers west of Topeka (for example, Manhattan) and east of Kansas City (for example, Columbia) that could be included in the planning of a regional EV corridor. The integration of a larger corridor along I-70 may require the deployment of DC fast charging infrastructure between Topeka and Kansas City. The analysis done for this report could be expanded in a relatively straightforward manner to increase the geographical scale of the corridor.

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