Assessment of Willingness to Accept and Return on Investment of Bidirectional Charging Programs in Colorado

Prepared for the Colorado Smart Cities Alliance

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Executive Summary

This study was conducted for the Colorado Smart Cities Alliance to assess whether Colorado electric vehicle (EV) drivers would be willing to accept (W2A) bidirectional charging programs in support of vehicle to building (V2B)/vehicle to grid integration (V2G). In addition to assessing whether EV drivers would participate in bidirectional charging programs, factors associated with where, when, and for how long EV drivers would charge at various compensation levels were also studied. A survey was administered to members of EV clubs in Colorado to gather information to conduct the study. The information gathered from this survey was then utilized to conduct an analysis of the potential return on investment of V2G integration in Colorado in comparison to energy forecasting scenarios prepared for the Xcel Energy 2021 Electric Resource and Clean Energy Plan. The results from the survey indicate that bidirectional charging programs may require an hourly bidirectional charging compensation rate closer to existing residential electricity rates within the Xcel Energy service territory to be cost-effective compared to other energy infrastructure investments through 2030. Acceptance of additional bidirectional charging times and locations was positively correlated with availability of another car but negatively correlated with EV miles driven per year and the number of days EV drivers worked from home. The maximum distance from home that EV drivers would be willing to bidirectional charge was positively correlated with EV miles driven per year and the number of days EV drivers worked from home and negatively correlated with availability of another car. However, these factors were not statistically significant. Policy tools to achieve cost-effective bidirectional charging compensation rates through behavior change and EV policy collaboration synergies are also discussed.

Assessment of Willingness to Accept and Return on Investment of Bidirectional Charging Programs in Colorado

According to recent estimates from the Colorado Department of Public Health & Environment (CDPHE), greenhouse gas (GHG) emissions from the transportation and electric power sectors were projected to represent over 41% of total Colorado GHG emissions in 2020 (Taylor, 2021). To address these GHG emissions and GHG emissions in other sectors, the Colorado Energy Office (CEO) developed a GHG Pollution Reduction Roadmap to reach a GHG emission target of 90% below 2005 levels by 2050 as well as other interim targets over the next several decades (CEO, 2021a). The GHG Pollution Reduction Roadmap identifies increased adoption of electric vehicles (EVs) as a major contributor to addressing statewide GHG emissions (CEO, 2021a).

The CEO EVs in Colorado Dashboard reports that over 44,000 EVs currently operate in Colorado (CEO, 2021b). To meet the state target of 340,000 EVs by 2030, CEO indicates that additional investments and policies will be necessary (CEO, 2020). The Colorado EV Plan 2020 outlines measures that will contribute to achieving this goal, including identifying charging infrastructure needs to support EV adoption (CEO, 2020). Colorado has also implemented a variety of measures to encourage the uptake of EVs, including tax incentives, funding for public fleets, grants, exemptions from vehicle emissions inspections, and other incentives and rebates at the local and utility level (CEO, 2020; Hartman and Shields, 2021).

In addition to initiatives to increase the number of Colorado EV drivers, the Colorado Smart Cities Alliance (The Alliance) partnered with Fermata Energy, Xcel Energy, and Colorado CarShare in 2021 to deploy a pilot project to demonstrate the use of bidirectional EV charging infrastructure that enabled vehicle to building (V2B) integration at The Alliance Center, a co-working space in Downtown Denver (The Alliance Center, 2021b). As one of the first V2B applications in the United States, the project “demonstrates a business model that benefits buildings, grids, carsharing, transit electrification and the environment alike” (The Alliance Center, 2021a, p. 16). Xcel Energy has also recently launched a “Charging Peaks” pilot program with BMW, Ford, General Motors, and Honda to encourage six hundred pilot program participants to charge their EVs when renewable energy is most abundant and electricity is least costly (Xcel Energy, 2021e). While the pilot program does not yet address bidirectional power flows through bidirectional charging (between the vehicle and the building and/or grid), it does address managed charging as a potential means for deriving grid and renewable energy benefits from EVs (Xcel Energy, 2021e).

This study regarding the potential return on investment (ROI) of vehicle to grid (V2G) integration based on Colorado EV driver behaviors and attitudes towards bidirectional charging technology is of interest to the project client, The Alliance, in that it supports the organization’s efforts to advance “A statewide digital and collaborative ecosystem that improves quality of life for all Coloradans” (The Alliance, 2021, par. 2). This study also contributes data-driven policy recommendations that could help advance V2G technology in Colorado in support of the statewide climate targets discussed above if adopted more widely. The Alliance is a 501(c)(3) non-profit organization that officially formed in 2018 to create partnerships between the public and private sectors to support the development of smart communities in Colorado and beyond (The Alliance, 2021).

The following sections of this paper include an explanation of the research purpose; a literature review of V2G policies, barriers to V2G charging adoption, attitudes and behaviors that impact V2G charging program participation, and potential ROI for V2G charging technology; a method section that describes the quantitative, cross-sectional analysis carried out to address main areas of interest raised by the literature review and project client; results of the analysis; and a discussion regarding policy strategies for future V2G charging programs in Colorado.

Research Purpose

This study aims to evaluate the potential ROI of V2G technology compared to other energy storage infrastructure that will otherwise be required to support an increasingly renewable energy grid in alignment with statewide climate targets. The study assesses Colorado EV driver behaviors, motivations, and concerns with respect to V2G charging integration to inform policy recommendations that could support more widespread adoption of this technology throughout the state.

Literature Review

V2G Charging Policy Landscape

Despite the proliferation of EV policies and incentives and demonstration of V2B technology in Colorado, the policy landscape for V2G integration remains relatively limited both within the state and nationally. To date, many of the policy activities surrounding vehicle-grid integration (VGI) have occurred in California (National Conference of State Legislature, 2021). The California Independent System Operator (CAISO) identified the need for updates to current policies and introduction of new policies to enable adoption of V2G technology in California as part of its Vehicle-Grid Integration Roadmap (2014). At the time, this Roadmap identified only two policies at the federal level and eight within the state of California that related to the potential for VGI (CAISO, 2014). Of note, CAISO highlighted the importance of coordinating V2G policy with related policies at various levels of government (2014). Similarly, the development of a comprehensive set of policies to support V2G integration could help to avoid "policy coordination failure" as a type of failure that can preclude "transformative change" based on a framework proposed by Weber & Rohracher (2012, as cited in Sovacool et al., 2017, p. 395).

Since publication of the CAISO report, lawmakers in California passed Senate Bill (SB) 676, Transportation Electrification: Electric vehicles, which included a requirement for the California Public Utilities Commission "to establish strategies and quantifiable metrics to maximize the use of feasible and cost-effective electric vehicle grid integration by January 1, 2030" (California Senate, 2020, par. 2). This requirement resulted in Decision Concerning Implementation of SB 676 and Vehicle-Grid Integration Strategies D-20-12-029 in Order Instituting Rulemaking 18-12-006 that formed the VGI Working Group between the CAISO, California Energy Commission, California Air Resources Board, and California Public Utilities Commission (California Public Utilities Commission, 2021). This working group was tasked with providing recommendations with respect to capturing the current value of VGI, developing and revising policies to address VGI, and assessing how the business case for VGI compared to other investments in energy infrastructure and storage (California Public Utilities Commission, 2021). The VGI Working Group proposed 320 use cases that could be implemented by 2022 and 92 policy recommendations across sectors and agencies (Gridworks, 2020). However, this report also notes that the VGI Working Group was unable to address two key areas, including a full cost-benefit analysis due to a lack of data and a determination of willingness to participate in V2G programs, especially in the context of the investment required to encourage this participation (Gridworks, 2020).

In Colorado, similar cross-agency and cross-sector coordination could support V2G policies, especially through building off the current EV policies and programs and VGI pilot projects discussed above. Currently, although the 2020 Colorado EV Plan addresses the potential for research into smart charging as part of its measures to develop new EV technologies, it does not specifically contemplate the potential role of V2G technology in meeting the state's EV goals (CEO, 2020). Furthermore, comprehensive V2G policies that address policy gaps identified in the CAISO Vehicle-Grid Integration Roadmap and VGI Working Group related to considerations such as V2G business models and participant incentive mechanisms have not yet been adopted in Colorado (National Conference of State Legislatures, 2021; U.S. Department of Energy, 2021). While the 2021-2023 Transportation Electrification Plan for Colorado's largest electric utility, Xcel Energy, considers unidirectional managed charging, the plan currently focuses on V2G in the context of demonstration efforts for heavy-duty vehicles through school bus electrification pilot projects (Xcel Energy, 2020). As a result, effective implementation of a comprehensive suite of policies regarding V2G integration in Colorado should be coordinated across agencies and sectors already involved with vehicle electrification and informed by the current challenges faced by V2G integration.

Barriers to V2G Adoption

V2G remains a nascent technology that has been evaluated through case studies but has not yet been implemented at scale (National Governors Association, 2020; Noel et al., 2019a; Sovacool et al., 2018). However, a European energy supplier recently accepted applications for a bidirectional charging 24-month trial program for Nissan Leaf owners at grid scale (OVO Energy, 2021). A reason for the lack of widespread implementation of V2G might be due to a "disconnect" between the benefits of V2G discussed in the literature and the understanding of these benefits in the industries that would advance the technology (Noel et al., 2019a, p. 75).

Despite the potential benefits of V2G, there are a variety of challenges that currently exist with respect to the potential for V2G integration. Noel et al. (2019a) studied the barriers to V2G adoption through interviews with experts in fields related to V2G technology (i.e., transportation and energy) across Nordic European countries. The most referenced issues (10% or more of interview participants) associated with V2G integration included, in order, "preference (for other energy storage) technologies, consumer resistance, poor business case/model, unnecessary here, uncertainty and skepticism, increased cost and complexity, and battery degradation" (Noel et al., 2019a, p. 69). Several of the major barriers to achieving V2G integration, including a preference for other technologies, a lack of necessity for V2G technology, and uncertainty and skepticism, were likely influenced by the availability of other energy storage options in the study area (Noel et al., 2019a). Overall, the main challenges primarily related to consumer behaviors and concerns and the business case for the technology (Noel et al., 2019a). Sovacool et al. also identified three areas in addition to "technical" considerations critical to advancing V2G integration, including "socio-environmental, financial, and behavioral" factors (2017). Sovacool et al. found that V2G studies focused primarily on technical aspects of the technology while failing to address other considerations critical to V2G adoption, such as EV driver attitudes (2.1% of all studies) and the business case for V2G integration (4.6% of all studies)(2018).

CAISO also summarized 2014 stakeholder workshop comments on the topic of V2G into three principal areas that mirror the findings from Sovacool et al.(2018) and Noel et al. (2019a) from the business case perspective. These comments expressed V2G concerns related to solidifying the costs and benefits of V2G, determining communications and implementation policies and programs, and advancing technical capabilities through uniform standards (CAISO, 2014). Recent testimony from Jack Ihle, Director of Regulatory and Strategic Analysis at Xcel Energy, cited uncertainty with respect to the availability of light-duty vehicles to participate in V2G programs, immature status of V2G communications and control platforms, and availability of V2G-capable vehicles as the main barriers to V2G integration (Hearing Exhibit 118, Supplemental Direct Testimony of Jack Ihle, Proceeding No. 21A-0141E, 2021, pp. 16-17). Thus, the present study will consider what EV driver behaviors, motivations, and concerns currently support V2G technology or could be modified to do so, especially in the context of supporting a V2G business case that maximizes potential ROI in Colorado.

Factors Affecting Participation in V2G Programs

V2G Stated Preference Studies

Despite there being less focus on the behavioral aspects of V2G in the literature as discussed above, willingness to accept (W2A) V2G technology has been assessed through stated preference studies that utilized contingent valuation and choice experiment methods across several geographical areas. Through utilization of contingent valuation survey questions in a study across South Korea, Lee et al. (2020) found that requirements for EV drivers to discharge to the grid and concerns associated with battery degradation played a substantial role in dissuading potential V2G program participants while increased compensation for participation in a V2G program did not increase interest in V2G integration. Similarly, Parsons et al. (2014) utilized a choice experiment administered via a survey conducted throughout the United States to assess how minimum remaining battery charge, battery discharge requirements, compensation for participation, and price of EVs influenced willingness to participate in V2G programs. They found that prospective program participants were primarily concerned with maintaining their ability to utilize their EV with as few restrictions as possible. However, unlike the findings in Lee et al.'s study, compensation was still a relatively key factor for V2G program participants that helped to offset a perceived lack of flexibility from required charging times or lower battery range minimums (Parsons et al., 2014).

Huang et al. also utilized a choice experiment in their study of drivers in the Netherlands to assess the impact of V2G program participant compensation, battery discharge requirements, guaranteed battery level, battery charging/discharging cycles, and V2G contract commitment time periods on participation in V2G programs (2021). The results of their study align with Lee et al. (2020) and Parsons et al. (2014) in that faster EV battery charging, which could provide V2G program participants with additional flexibility and address concerns about minimum battery levels, positively influences V2G program participation (Huang et al., 2021). Huang et al. also found that prospective V2G program participants were significantly motivated to participate in V2G by higher compensation amounts (2021). Geske and Schumann similarly utilized a discrete choice experiment to analyze the most important determinants of willingness to participate in V2G programs in Germany and found that the top two considerations were a lack of adequate available battery charge when needed and constrained EV travel range (2018). Similarly, this study found that higher compensation for V2G program participation was less important to survey respondents (Geske and Schumann, 2018). Finally, utilizing semi-structured interviews with EV drivers in the Netherlands, van Heuveln et al. (2021) found that payment for participation in a V2G program followed by battery degradation and concerns about the availability of EV range contributed most to willingness to participate in a V2G program, with the majority of the interview participants expressing that they would take part in a V2G program.

In summary, these studies suggest that prospective V2G program participants place a high importance on retaining autonomy with respect to utilizing their EVs, especially in the context of ensuring adequate battery charge availability. However, the findings regarding the overall importance of compensation as part of V2G program participation incentivization remains relatively mixed. Therefore, with uncertainties about the importance of V2G program participant compensation, solidifying the financial benefits of V2G integration is also important to developing V2G policies.

V2G Use Cases, Electricity Markets, and ROI

Use Cases

At a micro level, V2G could provide EV drivers with a revenue generation opportunity through compensation for their participation in a V2G program. In addition, as demonstrated by comments from the recent VGI Working Group, V2G is anticipated to offset initial costs of purchasing an electric vehicle rather than an internal combustion vehicle that is less expensive (Gridworks, 2020). Parsons et al. corroborate this finding with some skepticism depending on whether V2G program participants receive payment for participating in V2G upfront or on a voluntary basis rather than through an ongoing contract (2014).

At a macro-level, CAISO developed a framework for defining various VGI use cases that depend on three factors, including the number of EVs involved, whether the VGI program participants act together or separately, and whether EVs discharge (bidirectional charging) in addition to charging (unidirectional) from the grid (CAISO, 2014). The VGI Working Group also identified parameters for defining the use cases for VGI, including, “sector, application, type, approach, resource alignment, and technology” (Gridworks, 2020, p. 16). The Alliance Project V2B use case is technically less challenging to implement than coordinating multiple

EVs with different goals to facilitate bidirectional grid-integrated charging (Sovacool et al., 2017). As discussed above, V2G technology has not yet been commercialized, especially in the United States. Therefore, pilot projects like The Alliance project support demonstration of the value proposition for eventual adoption of more wide-spread V2G applications across the advanced use cases identified by CAISO. The majority of VGI Working Group members also voiced agreement on five policy proposals related to pilot projects, especially with respect to demonstrating resilience, competing with other distributed energy resources, and understanding the value proposition for VGI that could help advance VGI in the short-term (Gridworks, 2020).

Electricity Markets

According to the VGI Working Group, the “application” use case factor influences how V2G will be integrated with the grid, which further relates to its potential business case (Gridworks, 2020). Kempton and Tomić (2005) suggested that the market with the greatest potential ROI for V2G would be for providing capacity to the electrical grid through the ancillary service market, including spinning reserves and regulation, rather than solely as an ongoing power supply. However, a more recent analysis presented by Energy+Environmental Economics at the April 2019 VGI Working Group meeting suggests that in California, the regulation market would quickly reach the point where additional participants would not derive economic benefits, and as a result, load shifting would present the greatest potential return on investment ($1,009 million for load shifting v. $40 million for frequency regulation) (2019).

ROI

V2G could also reduce costs for supporting an increasingly renewable energy grid by decreasing the need for investments in other energy generation and storage infrastructure (Gridworks, 2020; Kempton and Tomić, 2005). Noel et al. compiled findings from studies on the costs of various energy storage technologies and compared them to the costs of V2G and found that the cost of storage for V2G ranged from \$0-\$40 kilowatt-hour (kWh) (with the high-end of the estimate including potential battery degradation costs) while the costs of other technologies such as compressed air energy storage and purpose-built batteries ranged from \$40/kWh to \$4,800/kWh, respectively (2019b, p. 35). This analysis also demonstrated that equivalent investment in energy storage to match the potential for V2G "would cost *trillions* of dollars" at the low end of the alternative technology cost spectrum (Noel et al., 2019b, p. 36). However, achieving storage at this scale through V2G would require increased uptake of EVs compared to current levels coupled with measures to ensure participation in V2G programs (Noel et al., 2019b).

This challenge can be seen for Colorado specifically in that Xcel Energy reported similar findings in their High EV/V2G Scenario as part of the Xcel Energy 2021 Electric Resource and Clean Energy Plan. Although this scenario added 130 megawatts (MW) of peak demand in 2030 due to increased electricity demand from EVs, the model also added 230 MW of storage capacity in 2030 that allowed for a greater focus on investment in additional renewable energy rather than energy storage (Hearing Exhibit 119, Supplemental Direct Testimony of Jon Landrum, Proceeding No. 21A-0141E, 2021, p. 19). The barriers that contributed to the lack of feasibility in adopting this model, as discussed above, were cited as the availability of V2G-enabled EVs, participation in V2G programs, and existence of technology and communication platforms to implement V2G (Hearing Exhibit 118, Supplemental Direct Testimony of Jack Ihle, Proceeding No. 21A-0141E, 2021). These first two barriers reiterate the importance of this research with respect to understanding Colorado EV driver behaviors, motivations, and concerns regarding V2G in order to estimate the potential feasibility and ROI of this technology.

Method

Research Question

This study seeks to understand what V2G use cases and markets would support the economic feasibility and ROI of V2G integration in Colorado. To address this question, this study assessed what Colorado EV driver characteristics and behaviors explain W2A bidirectional charging program participation at various compensation levels, durations, locations, and times of day.

Hypotheses

This study will assess the following hypotheses:

- H1: There is a relationship between EV ownership and W2A bidirectional charging programs.
    - In a study of EV drivers in the Netherlands, EV drivers that leased rather than owned EVs had less overall concern about battery degradation from bidirectional charging (van Heuveln et al., 2021). As a result, it is hypothesized that EV drivers that lease rather than own EVs may demonstrate a greater W2A bidirectional charging programs.
- H2: There is a relationship between EV miles driven per year and W2A bidirectional charging programs.
    - Parsons et al. (2014) and Huang et al. (2021) found that EV drivers place a high premium on retaining their ability to utilize their EV at their convenience, including with respect to the mileage they would be guaranteed when participating in a bidirectional charging program. If EV drivers drive fewer EV

miles annually, it is hypothesized that this low EV utilization rate may explain greater W2A bidirectional charging programs.

- H3: There is a relationship between number of days worked from home and W2A bidirectional charging programs.
    - Similar to H2 above, it is hypothesized that working from home may result in greater EV driver flexibility for bidirectional charging as a result of fewer EV miles driven per year if EV drivers do not commute. As such, based on findings from Parsons et al. (2014) and Huang et al. (2021) with respect to the importance of flexibility for EV drivers that participate in bidirectional charging programs, it is hypothesized that working more days from home will explain greater W2A bidirectional charging programs.
- H4: There is a relationship between availability of another household vehicle and W2A bidirectional charging programs.
    - This hypothesis also relates to H2 above in that the availability of another household vehicle could explain decreased reliance on an EV that would require additional flexibility from an EV driver based on the findings from Parsons et al. (2014) and Huang et al. (2021). As such, if an EV driver has another vehicle available, this characteristic may explain greater W2A bidirectional charging programs.
- H5: There is a relationship between home solar generation and W2A bidirectional charging programs.
    - Interviews with Dutch EV drivers suggested that making a positive impact on the environment, including through improving the energy grid and reducing GHG

    emissions, was one of the top ten reasons EV drivers cited as motivation for participating in bidirectional charging programs (van Heuveln et al., 2021). As such, it is hypothesized that individuals that have installed solar panels may hold similar views regarding electricity and the environment and would be more W2A bidirectional charging programs.

- H6: There is a relationship between living in a single-family home and W2A bidirectional charging programs.
    - The California VGI Working Group ranked V2G use cases by benefits, costs, and ease/risk of implementation and found that the highest ranked use cases were for residential single-family homes (Gridworks, 2020). As a result, it is hypothesized that living in a single-family home may explain W2A bidirectional charging programs.
- H7: There is a relationship between living in an urban or rural location and W2A bidirectional charging programs.
    - Bidirectional charging has been cited as an opportunity to increase energy resilience, especially with increasingly severe wildfires and other natural disasters threatening the availability of electricity from the grid when these events occur (Gridworks, 2020). As a result, rural EV drivers that may experience power shutoffs in heavily vegetated, remote areas during wildfire threats or lack access to other energy resources in the event of a natural disaster are hypothesized to demonstrate a greater W2A bidirectional charging programs.

Data Collection

This project utilized a cross-sectional quantitative analysis involving an online survey questionnaire (Kelly et al., 2003). The Alliance reviewed the survey prior to its administration and provided feedback on the questions and survey structure. Potential survey respondents were identified by contacting EV clubs and groups listed on the Drive Electric Colorado EV Club website (Meintsma, n.d.). Outreach was conducted via email to the following EV Clubs on October 25, 2021: Colorado Springs EV Club, Denver EV Council, and EV Four Corners.

The administrators and moderators of EV clubs that had Facebook groups listed on the Drive Electric Colorado EV Club website with the most members were also contacted via Facebook to request posting of the survey in their groups. However, there were restrictions for joining groups based on EV ownership for the first two groups listed. These EV clubs are listed below:

- Denver Tesla Club
- Model 3/Y Club of Denver
- Nissan Leaf Owners Colorado
- Western Colorado EV Club

The 25-question survey was administered via Qualtrics between October 27, 2021, and November 12, 2021, and 55 responses were received. The IRB approval for this project is COMIRB No: # 21-4596 Electric Vehicle Charging Behaviors. Two of these responses were from survey respondents that were located outside of Colorado (New Mexico and California), and as a result, these observations were not included in the analysis.

Sampling Plan

The sample frame includes EV drivers that provided their email contact information to the Colorado Springs EV Club (member list of 239 members). The EV Four Corners Club also posted the survey on its blog and the post received 59 views. Finally, the survey was posted in the Colorado Nissan Leaf Club Facebook group with 283 members. As a result, approximately 581 individuals received the survey and a response rate of approximately nine percent was achieved. The unit of analysis for this study is individual EV drivers. The survey utilized a convenience sample of voluntary responses from members of the EV clubs and groups listed above. This sample is not representative of the entire population of EV drivers in Colorado, and therefore, is non-probabilistic.

Survey Instrument

Survey questions were drafted based on the structure and question content included in similar surveys regarding V2G integration that were included in recent studies on the topic (Bohnsack et al., 2015; Geske and Schumann, 2018; Huang et al., 2021; Lee et al., 2020; Parsons et al., 2014; and van Heuveln et al., 2021). In addition to the survey questions, a brief video providing an explanation of V2G technology was included in the survey followed by a question regarding the participants’ understanding of the technology, which reflects the usage of a similar survey component utilized in other studies to maximize understanding of the V2G concept (Bailey and Axsen, 2015; Huang et al., 2021). A copy of the survey instrument and a link to the video can be found in Appendix A.

To address the potential for common factor bias, survey structure recommendations from Podsakoff et al. (2012) were incorporated, including separating the questions regarding the independent and dependent variables in the order of the survey and mixing the types of question responses (i.e., Likert scale and selection of the top three concerns). Due to the current lack of widescale adoption of V2G integration, instead of utilizing revealed preference to assess EV drivers' W2A V2G technology, this study relied on stated preferences similar to the method utilized by Huang et al. (2021), Lee et al (2020)., and Parsons et al. (2014) in their studies on this topic. Stated preferences were analyzed based on the responses to survey questions (Appendix A) that asked respondents to assess whether they would participate in a V2G program depending on compensation level, charging location, and times of day while holding battery degradation potential constant through a 10-year battery warranty and guaranteeing 70-90% minimum charge.

It is important to recognize the limitations to this approach; Sovacool et al. cite warnings from Hoeffler (2003) that stated preferences for V2G may be unrealistic and overly enthusiastic as a technology that has not yet been commercialized (2018). Sovacool et al. also found that most studies on V2G consumer attitudes and behaviors rely on sample frames constituted of existing EV drivers (2017). Similarly, this study relies on a sample of current EV drivers. This is a limitation of the study in that it will also be important to understand attitudes and behavior amongst non-EV drivers that would eventually need to become EV drivers for widespread V2G integration to occur (Sovacool et al., 2017).

Variables

The independent and dependent variables for this study have been identified in Tables 1 and 2, Independent and Dependent Variable Measurement Tables, below. The independent variables for this study were selected based on surveys conducted by Geske and Schumann, 2018; Huang et al., 2021; Lee et al., 2020; and Parsons et al., 2014 to address similar research questions with respect to understanding EV drivers' W2A bidirectional charging programs.

These independent variables were also developed to provide data-driven, actionable insights to the client that could be utilized to help shape policy and program recommendations with respect to required charging times, locations, durations, and other EV driver behaviors and characteristics. The dependent variable of W2A bidirectional charging programs was selected based on similar studies conducted by Geske and Schumann (2018), Huang et al. (2021), and Lee et al. (2020) that also assessed this measure as a dependent variable. The remaining dependent variables regarding W2A charging times and locations and W2A maximum bidirectional charger distance from home were selected to assess how incremental changes in compensation could influence bidirectional charging program behaviors for EV drivers and impact overall ROI of a bidirectional charging program.

Dichotomous and ordinal string variables were re-coded for use in the statistical analysis. Table 1 describes the study variables, measurement, level of measurement, and hypothesized relationships between the independent and dependent variables. Data for all variables in the table below have been collected from the survey described above that was conducted for this study.

Table 1

Independent Variable Measurement Table

Variable Name	Variable Measurement	Hypothesized Relationship with W2A Bidirectional Charging Programs
EV Ownership	Lease or own (dichotomous variable, 1-own, 0-lease)	Negative relationship
EV Miles per Year	Less than 5,000 to over 20,000 miles in 5,000 mile increments, recoded as low-less than 5,000 miles, medium-5,000-15,000 miles, and high-15,000-over 20,000 miles based on average annual highway vehicle miles traveled per capita for Colorado in 2017 (US Department of Energy, 2019) (ordinal variable, 1-3)	Negative relationship
Days Worked from Home	0, 1-2, 3-4, 5 or more (ordinal variable, 0-3)	Positive relationship

Another Car Available	Yes or no (dichotomous variable, 1-true, 0-false)	Positive relationship
Home Solar Panels	Yes or no (dichotomous variable, 1-yes, 0-no)	Positive relationship
Housing Type	Single family home; condominium, townhome, or duplex; apartment; or other (dichotomous variable, 1-single family home, 0 condominium, townhome, or duplex or apartment)	Positive relationship
Urban/Rural	Urban or rural (urban was characterized based on the US Census proposed 2021 definition of an urban area having a population of 2,500 or more based on Census data)(US Census, 2021) (dichotomous variable, 1-urban, 0-rural)	Positive relationship
EV Driver Age Range	18-65+ in 5 year increments (ordinal control variable, 1-5)	Positive relationship

Table 2

Dependent Variable Measurement Table

Variable Name	Variable Measurement
W2A Bidirectional Charging	Selection of “yes” in question 7 regarding willingness to utilize a bidirectional charger (dichotomous variable, 1-yes, 0-no)
Maximum Bidirectional Charging Times/Locations	The maximum number of total charging times and locations selected for participation in a bidirectional charging program at home or work in the morning, afternoon, or overnight (continuous variable)
Maximum Bidirectional Charger Distance (Home)	0-2 miles away from a home charger (continuous variable)

Analysis

Descriptive and Inferential Statistics

The analysis was run in STATA BE V.17 and a copy of the Do File for the analysis can be found in Appendix B. Descriptive statistics were utilized to summarize the independent and dependent variables in Tables 1 and 2 above and to identify the current prevalence of charging behaviors based on their location, time of charging, and duration of charging. In addition to descriptive statistics, the survey data was visualized via bar, column, scatter, and pie graphs. Although not included as independent or dependent variables, data visualizations were also used to report on the most frequently cited benefits and concerns associated with bidirectional charging programs and are provided in Appendix C.

Fisher's Exact Test and Ordinary Least Squares (OLS) regressions were utilized to test the hypotheses listed above and analyze the relationships between the independent and dependent variables. For the OLS regression analysis, predictor variables were divided into two models. The first model was based on whether the independent variables related to the characteristics of EV drivers' home, including whether it is located in an urban or rural location, whether it is a single-family home, and whether solar panels have been installed. The second model included predictor variables for how convenient a bidirectional charging program might be based on availability of another car, the number of EV miles driven per year, and days worked from home.

ROI Calculation

The potential micro- and macro-level ROI of bidirectional charging programs was also assessed based on the dependent variables in Table 2 above and the maximum number of hours and associated bidirectional charging compensation required by EV drivers. The average values of these dependent variables were utilized to determine the potential fixed and variable costs associated with bidirectional charging programs based on EV driver compensation requirements and maximum charging durations and times/locations. These calculations were compared to the High EV/V2G Scenario (Hearing Exhibit 118, Supplemental Direct Testimony of Jack Ihle and Hearing Exhibit 119, Supplemental Direct Testimony of Jon Landrum, Proceeding No. 21A-0141E, 2021) developed in support of the Xcel Energy 2021 Electric Resource and Clean Energy Plan based on the energy generation and storage cost assumptions prepared for various electric energy resource scenarios included in Volume 2, Technical Appendix, of this Plan.

Results

Descriptive Statistics

Table 3 below provides a summary of the descriptive statistics for the independent and dependent variables discussed in the Method section above. Please refer to Tables 1 and 2 for the measurement of each of the variables as shown in Table 3.

Table 3

Descriptive Statistics

Independent Variables	Observations	Mean	SD	Min	Max
EV Ownership	46	0.91	0.28	0	1
Home Charging	43	4.78	0.57	2	5
Work/School Charging	36	1.58	1.15	1	5
Public Charging	38	2.24	0.97	1	5
Other Charging	18	1.50	0.98	1	5
Morning Charging	31	1.74	0.89	1	4
Afternoon Charging	33	2.03	1.10	1	4
Evening Charging	39	3.46	0.88	1	4
EV Miles per Year	43	2.02	0.46	1	3
Days Worked from Home	38	1.78	1.16	0	3
Home Solar Panels	39	0.41	0.50	0	1
Another Car Available	39	0.71	0.46	0	1
Urban/Rural	39	0.87	0.33	0	1
Housing Type	38	0.89	0.31	0	1
EV Driver Age Range	39	4.28	1.24	1	6
Dependent Variables	Observations	Mean	SD	Min	Max
W2A Bidirectional Charging	42	0.93	0.26	0	1
Maximum Bidirectional Charging Times/Locations	40	3.60	1.17	2	6
Maximum Bidirectional Charger Distance (Home)	38	0.45	0.56	0	2

Survey Response Data Visualizations

The following figures show responses to the survey questions that were utilized in the inferential statistical analysis discussed in more detail below.

Survey Respondent EV Charging and Driving Behaviors

As shown in Figure 1, 42 survey respondents indicated that they owned an EV. Figures 2-8 provide information on the current EV charging habits of survey respondents based on the time and location of charging. These figures demonstrate that home charging is the most frequent charging location, and that evening charging is the most common charging time. As shown in Figure 9, 33 survey respondents indicated that they drive their EVs between 5,000-15,000 miles each year.

Figure 1

EV Ownership

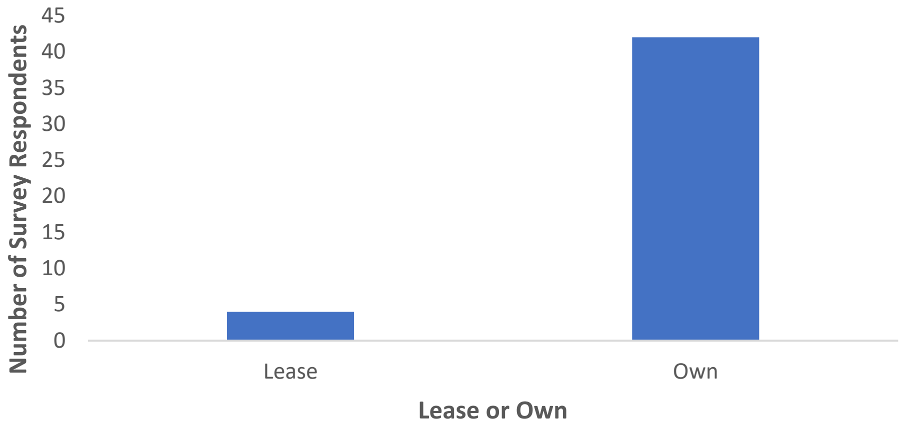


Figure 2

Home Charging Frequency

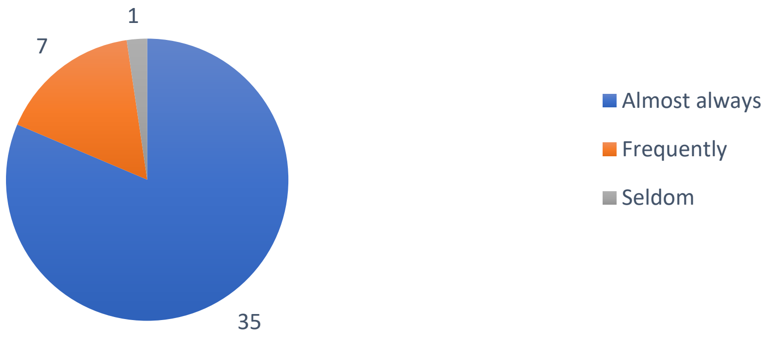


Figure 3

Work Charging Frequency

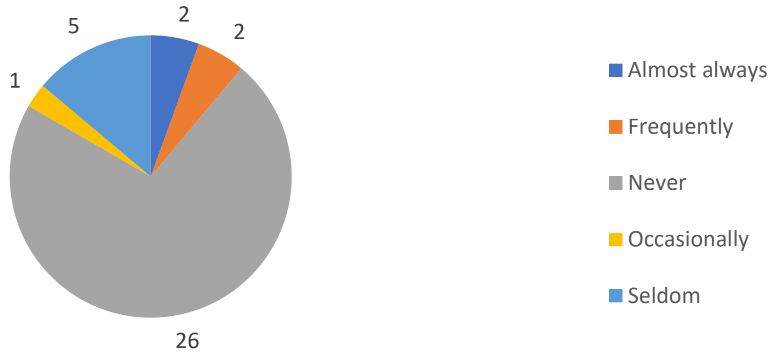


Figure 4

Public Charging Frequency

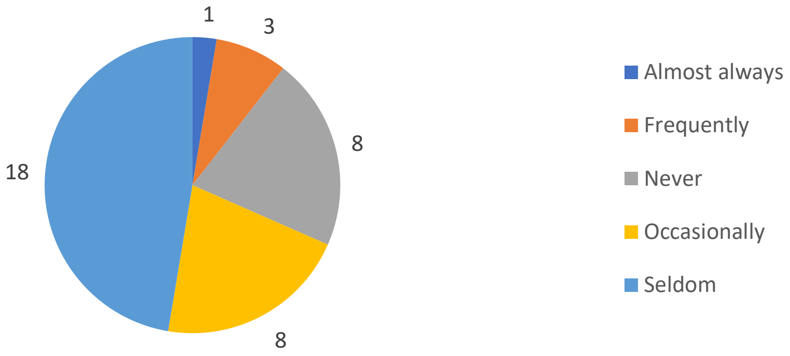


Figure 5

Other Charging Frequency

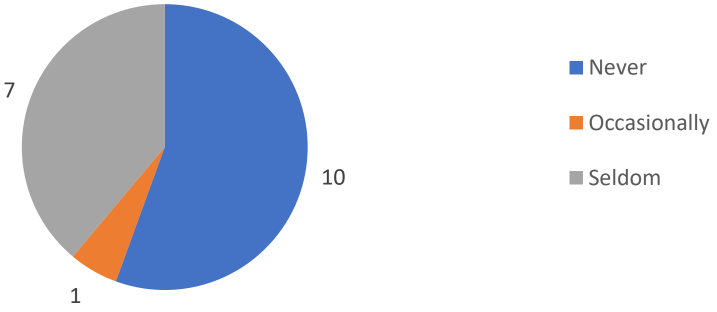


Figure 6

Morning Charging Frequency

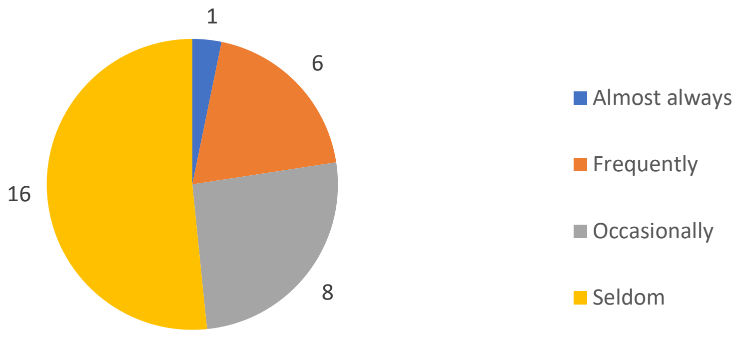


Figure 7

Afternoon Charging Frequency

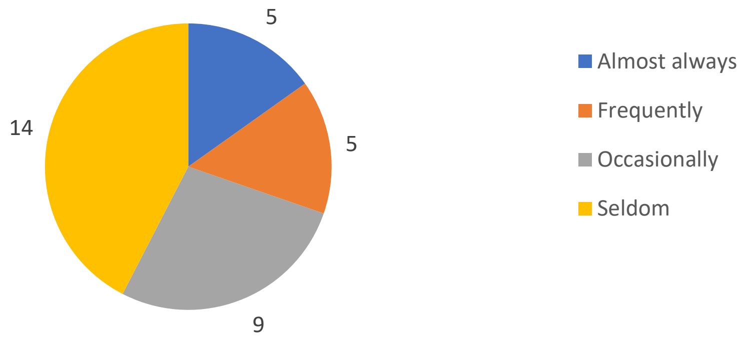


Figure 8

Evening Charging Frequency

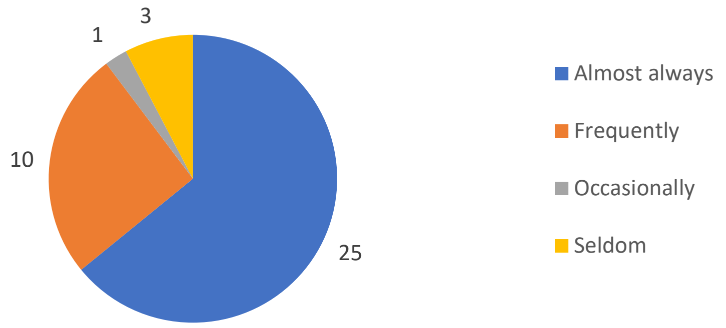
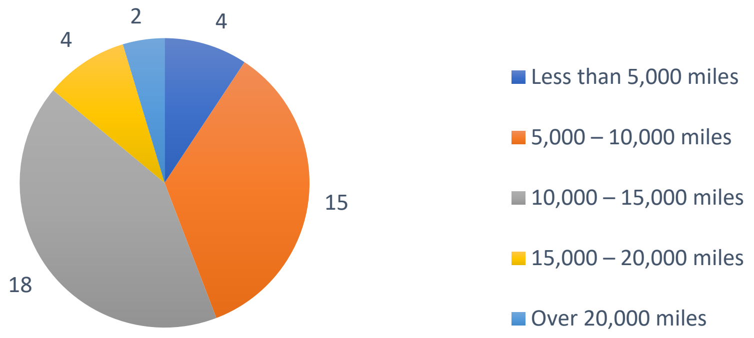


Figure 9

EV Annual Miles



Survey Respondent Living Arrangements

All but four survey respondents indicated that they lived in a single-family house, as shown in Figure 10 below, and most survey respondents (34) live in urban areas as shown in Figure 11. Sixteen survey respondents indicated that they had installed solar panels on their home, as shown in Figure 12.

Figure 10

Housing Type

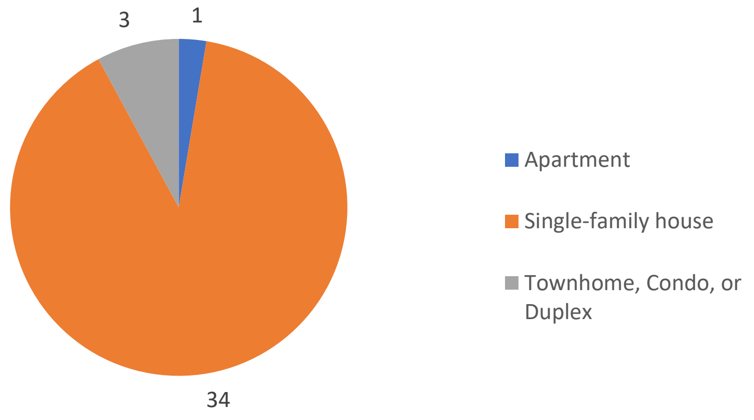


Figure 11

Housing Location

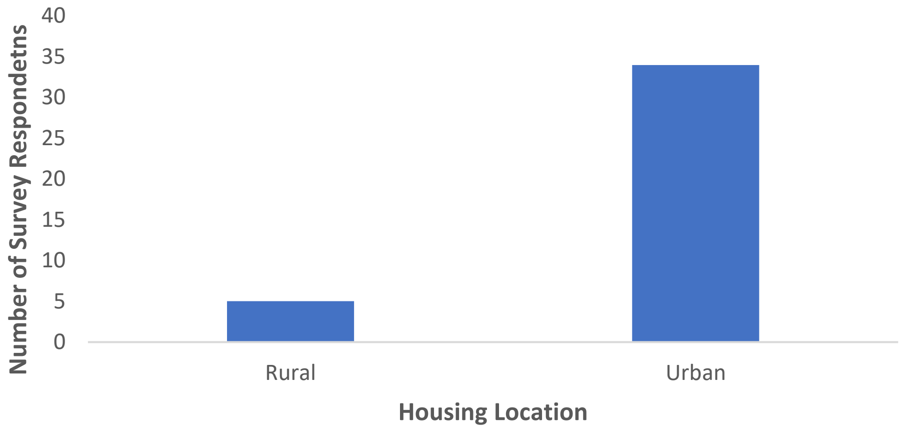
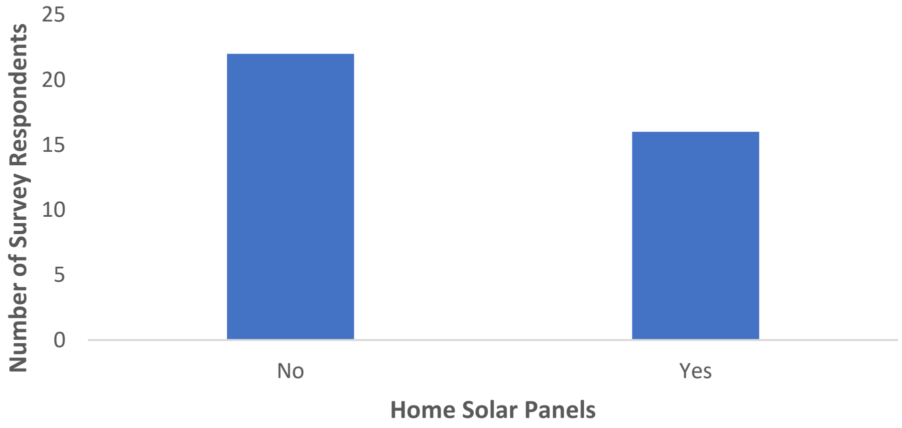


Figure 12

Home Solar Panels



Current EV Charging Flexibility

Figures 13 and 14 below demonstrate factors that relate to how much flexibility survey respondents have with respect to EV charging. The most survey respondents indicated that they worked form home five or more days per week (14) and 28 survey respondents indicated that they had another car available.

Figure 13

Days Worked from Home

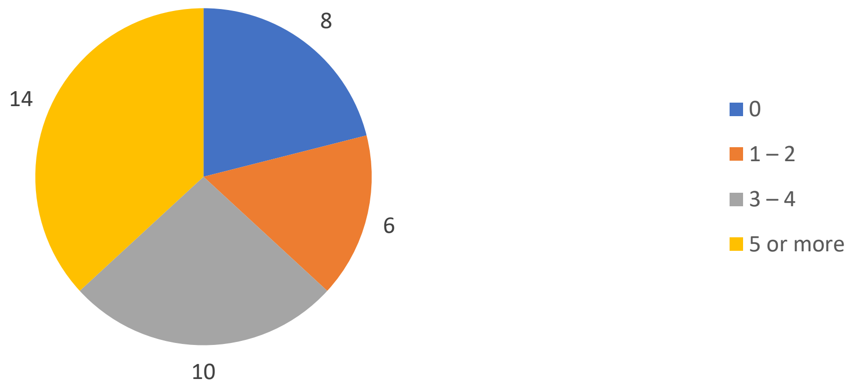
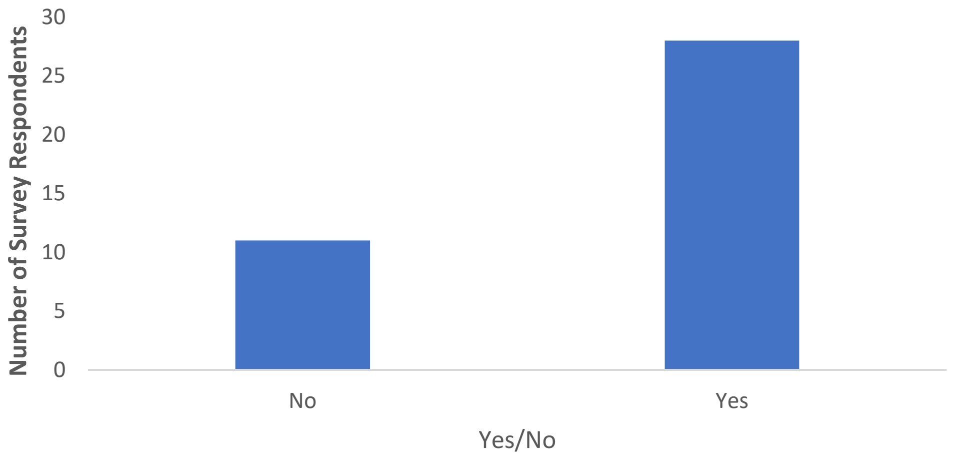


Figure 14

Availability of Another Car



Survey Respondent Bidirectional Charging Program Perceptions

As shown in Figure 15, 39 survey respondents indicated that they would accept bidirectional charging programs, while only three survey respondents indicated they would not be willing to do so based on the conditions set forth by the survey (please refer to question #7 in the survey instrument in Appendix A). The most survey respondents indicated that they were “very concerned” about preservation of EV battery warranties (15), which was followed closely by the accessibility of bidirectional chargers (14). Survey respondents chose “not concerned” most frequently for privacy as a potential bidirectional charging program concern (30), which was also followed closely by concerns associated with the complexity of utilizing a bidirectional charger (26). The most frequently cited benefits associated with bidirectional charging programs included availability of back-up power source in case of a power outage (18), ease of access to a bidirectional charging station (15), and higher compensation rates for discharging EVs (14). Please refer to Figures C1-C8 in Appendix C for figures that demonstrate these results.

Figure 15

W2A Bidirectional Charging Programs

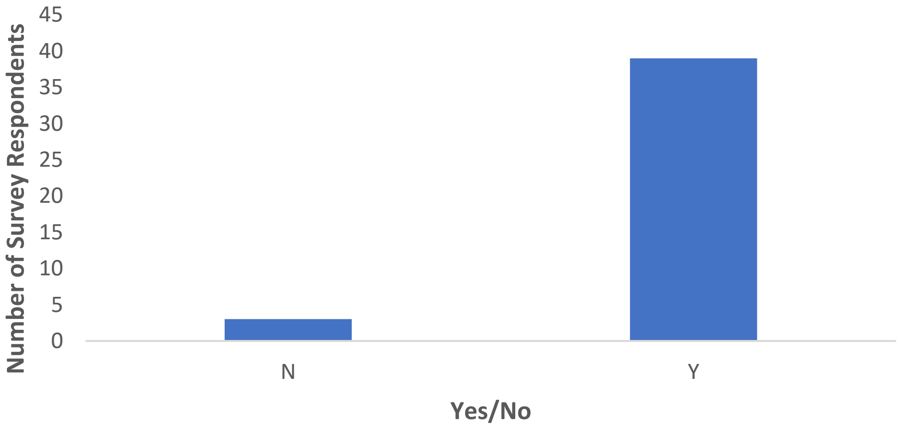


Table 2 above provides a summary of the bidirectional charging program characteristics selected by survey respondents. The average maximum compensation required was $0.39 per hour for an average of 3.6 times/locations. The average acceptable maximum distance of charging locations from home was 0.45 mile. The average number of maximum charging hours selected was 6.33, which corresponds to an approximate range of 40-50 hours of bidirectional charging per week at an average maximum compensation rate of $0.86 per hour.

Figures 16-18 show the bidirectional charging times and locations selected by survey participants at various levels of compensation, ranging from $0 per hour to $1 per hour. For no compensation, survey participants were most likely to select bidirectional charging at home overnight, which aligns with the most common charging times/locations described in Figures 2-8 above. Fifty cents of compensation per hour induced the most survey respondents to be willing to charge at home in the morning while $1 of compensation per hour led survey respondents to select morning charging at work and afternoon charging at home. In total, $0.50 compensation per hour resulted in selection of an additional 27 bidirectional charging times and locations and $1 compensation per hour resulted in the selection of 15 more bidirectional charging times and locations.

Figure 16

W2A Bidirectional Charging Times/Locations-No Compensation

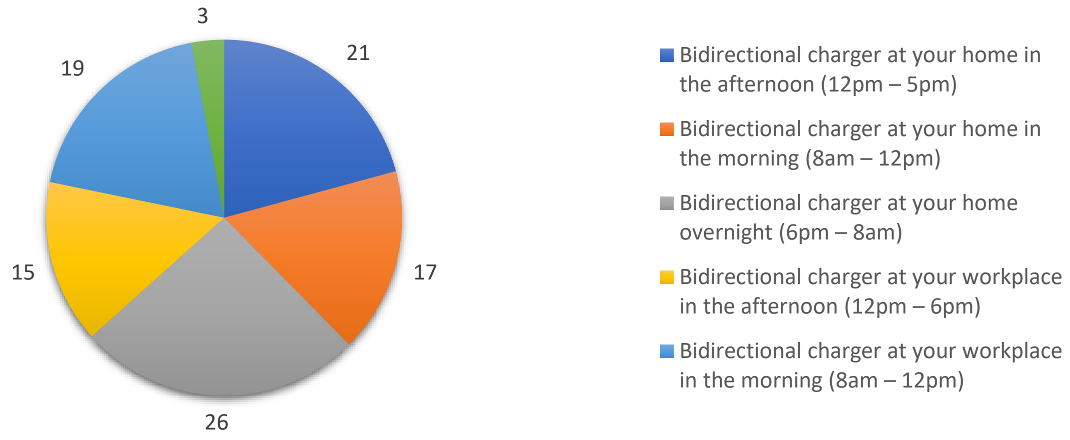


Figure 17

Additional W2A Bidirectional Charging Times/Locations-$0.5 Compensation per Hour

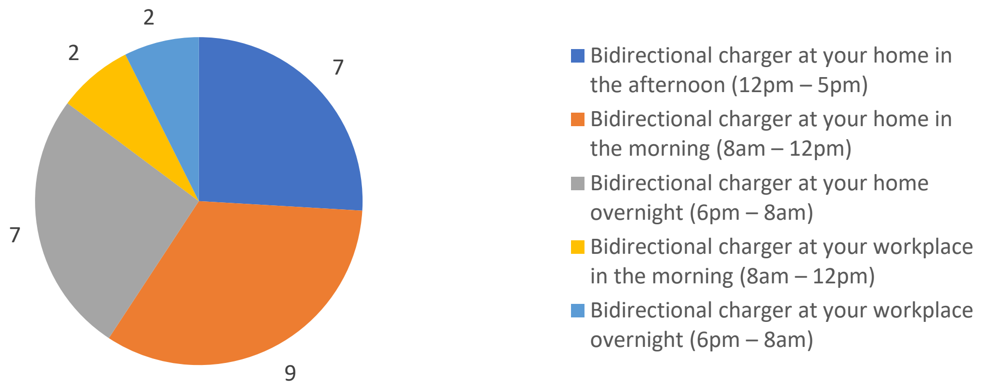
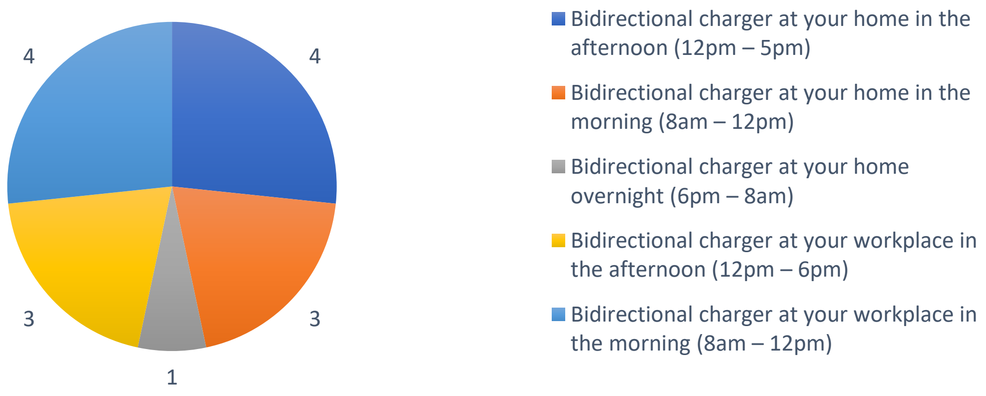


Figure 18

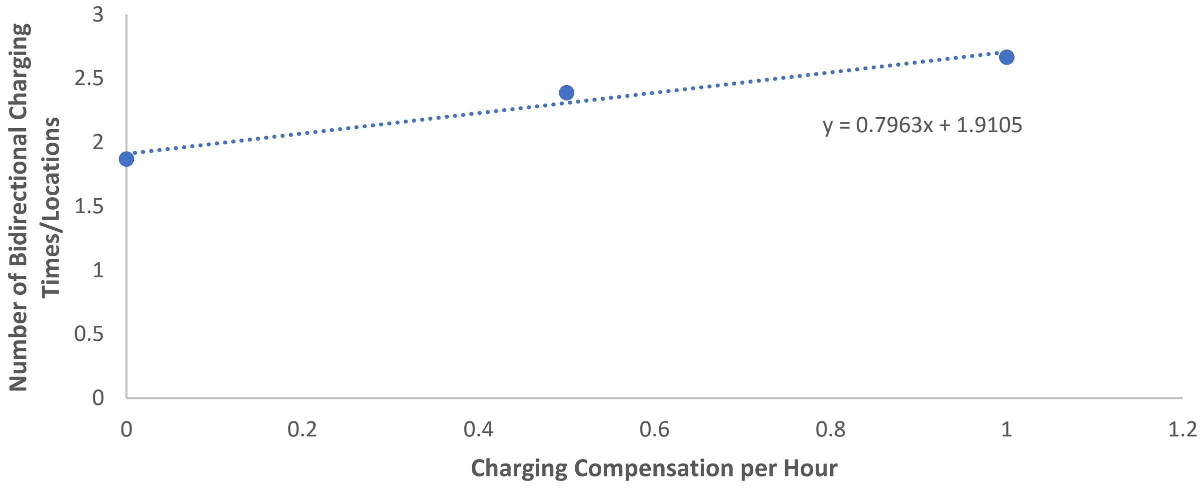
Additional W2A Bidirectional Charging Times/Locations $1 Compensation per Hour



A supply curve was developed for the number of bidirectional charging times/locations per survey respondent at various rates of compensation in Figure 19 below. Based on this analysis, for each $1 in compensation, 0.80 additional charging times/locations would be selected per survey respondent.

Figure 19

Hourly Bidirectional Charging Compensation and Number of Bidirectional Charging Times/Locations per Survey Respondent



Over 60 hours of charging was the most selected response for no compensation; however, providing $0.50 compensation per hour encouraged an additional 11 survey respondents to choose over 60 hours of charging per week and providing $1 compensation per hour resulted in 9 more survey respondents choosing over 60 hours of charging per week. Compensation had a greater impact on increasing the number of survey respondents that would charge at home and compensation had the greatest influence on morning charging. Please refer to Figures C9-C12 in Appendix C for a visual representation of these results.

Inferential Statistics

To assess whether to reject the null hypotheses listed in the Hypotheses section above, a series of inferential statistical tests were run to analyze the survey responses, including Fisher’s Exact Test and OLS regression models.

Tests of Independence

Fisher’s Exact Test was utilized due to the small sample size of the data because the expected frequencies were n<5 for 80% of the cells in 2x2 tests of association (Kim, 2017). Based on the results in Table 4 below, none of the tests of independence between the independent variables and dependent variable, W2A bidirectional charging programs, is statistically significant.

Table 4

Tests of Independence Results

	W2A Bidirectional Charging Programs			
	Yes	No	Fisher’s Exact p-value	Cramer’s V
EV Ownership				
Lease	4 (3.7)	0 (0.3)	1.00	-0.09
Own	33 (33.3)	3 (2.7)		
EV Miles per Year				
Less than 5,000 (Low)	3(3.7)	1(0.3)	0.31	0.24
5,000-15,000 (Medium)	29 (28.7)	2(2.3)		
15,000-Over 20,000 (High)	5 (4.6)	0 (0.4)		
Days Worked From Home Omitted due to lack of “no” responses for EV drivers that work from home 5 days a week or less.				
Home Solar Generation				
Yes	16 (15.2)	0 (0.8)	0.50	0.19
No	21 (21.8)	2 (1.2)		
Another Car Available				
Yes	27 (26.6)	1 (1.4)	0.49	0.11
No	10 (10.4)	1 (0.6)		
Home Location				
Urban	32 (32.3)	2 (1.7)	1.00	-0.09
Rural	5 (4.7)	0 (0.3)		
Housing Type				
Single-family house	4 (3.8)	0 (0.2)	1.00	-.08
Other	32 (32.2)	2 (1.8)		

Note: Expected frequencies are shown in parenthesis.

OLS Regression Analysis

OLS regression analysis was utilized to understand whether the independent variables explained the dependent variables for this study. Two models were assessed for each dependent variable. One model included the variables related to survey respondents’ home characteristics and the other utilized variables associated with how convenient a bidirectional charging program would be based on current survey respondent characteristics. Both models also included survey respondents’ age range as a control variable. Assumptions for utilizing OLS regression were evaluated for each model, including testing for multicollinearity, normal distribution of the residuals, linearity, and homoscedasticity. Based on these tests, only the convenience models for regressions on maximum bidirectional charging times/locations and maximum bi-directional charging distance from home met the OLS assumptions. Table 6 shows that the only significant coefficient out of the two models is the control variable, EV driver age range, which has a negative relationship with maximum bi-directional charging distance from home. The model in Table 6 has an R^2 value of 0.24, which indicates that the predictors in this model explain 24% of the variance in the dependent variable. However, the probability that the model in Table 6 explains the variation in the maximum bi-directional charging distance from home better than no predictor variables is not statistically significant.

Table 5

Regression Coefficients for Predicting Maximum Bidirectional Charging Times/Locations

Predictor Variables	Coefficients (p-value)
EV Miles per Year	-0.23 (0.61)
Availability of Another Car	0.33 (0.50)
Days Worked from Home	-0.21 (0.23)
EV Driver Age Range (Control Variable)	-0.33(0.07)
N	35
R^2	0.15
Probability F	0.29

Table 6

Regression Coefficients for Predicting Maximum Bidirectional Charger Distance (Home)

Predictor Variables	Coefficients (p-value)
EV Miles Per Year	0.25 (0.23)

Availability of Another Car	-0.10 (0.75)
Days Worked from Home	0.01 (0.92)
EV Driver Age Range (Control Variable)	-0.23 (0.03)*
N	29
R^2	0.24
Probability F	0.24
*$p<0.05$	

Discussion and Recommendations

Predictors of Bidirectional Charging Program Acceptance

As discussed in the Results section above, the inferential statistical analysis did not yield significant relationships between the independent and dependent variables as hypothesized. Therefore, further studies with additional survey responses are needed to assess whether statistically significant relationships exist between the independent and dependent variables. In addition, similar to the semi-structured interview study conducted by van Heuveln et al. in the Netherlands regarding the factors that impacted willingness to participate in bidirectional charging for EV drivers (2021), qualitative studies of Colorado EV drivers' characteristics and attitudes towards bidirectional charging programs may also be helpful in inductively identifying patterns of potential variables that may influence willingness to participate in bidirectional charging programs.

ROI of Bidirectional Charging Programs

Based on survey responses regarding current EV charging behaviors and EV driver characteristics as well as attitudes towards bidirectional charging programs, this study aimed to understand the economic feasibility of V2G integration in Colorado to determine whether V2G integration could provide a positive ROI compared to other electric resource planning scenarios. The following analysis utilizes the survey data and references from Xcel Energy to assess the potential ROI of V2G at both the micro and macro scale.

Bidirectional Charging Rates

Survey respondents demanded a higher compensation rate to achieve the maximum number of bidirectional charging hours, with an average maximum of $0.86 per hour. In contrast, survey respondents indicated that the maximum bidirectional charging compensation they required to maximize the number of charging locations and times was less than half of this rate at $0.39 per hour. This result is also interesting considering findings from Huang et al. (2021) and Parsons et al. (2014) in that EV drivers typically value flexibility and convenience as a component of bidirectional charging programs. For Colorado EV drivers, committing to a set number of hours rather than timeframes and locations may appear to set more restrictions on EV utilization, which was found to increase compensation requirements (Parsons et al., 2014).

Service Territory and Bidirectional Charging Location

Twenty-nine out of 34 survey respondents that indicated that they charged at home “almost always” were willing to participate in bidirectional charging programs, and as a result, the following assessment of potential ROI focuses on residential charging. The analysis also addresses the ROI for the Xcel Energy service territory specifically given that Xcel Energy is the largest electricity provider in Colorado, serving 1.5 million electric customers (Xcel Energy, 2021b) and is the only utility in the state to have published a Transportation Electrification Plan that could be most readily adapted to incorporate bidirectional charging programs. As discussed further in the sections below, this analysis also utilizes assumptions regarding Xcel Energy’s High EV/V2G Scenario described in recent testimony from Jon Landrum, Manager, Resource Planning Analytics at Xcel Energy, and Jack Ihle, Director, Regulatory and Strategic Analysis (Hearing Exhibit 118, Supplemental Direct Testimony of Jon Landrum, and Hearing Exhibit 119, Supplemental Direct Testimony of Jack Ihle, Proceeding No. 21A-0141E, 2021) and assumptions from the Xcel Energy 2021 Electric Resource Plan and Clean Energy Plan Volume 2 Technical Appendix (Xcel Energy, 2021d).

Initial Investment (Fixed Costs) for Residential Bidirectional Charging Programs

The fixed costs of residential bidirectional chargers would be approximately $4,000 for home chargers based on the first commercially available residential chargers in Spain that will be soon adapted for use in the United States, the Wallbox Quasar DC Charger (Cross, 2021; Markus, 2020). Similarly, Fermata Energy aims to launch its vehicle to home (V2H) bidirectional chargers in 2022 (Fermata Energy, 2021). Additional fixed costs associated with installation of bidirectional chargers would depend upon whether a Level 2 charging station has already been installed, in which case if a Level 2 charging station has not been installed, an additional cost of approximately $200-$1,500 would be incurred (including updates to the home electric panel if necessary) (City of Fort Collins, n.d.; Drive Electric Northern Colorado, n.d.). Therefore, the total initial investment for bidirectional charging programs would conservatively be $5,500 per EV drive. On average, survey respondents indicated that they would use a bidirectional charger up to 0.45-mile away from their home, and as a result, some opportunities may also exist for community bidirectional chargers in residential areas.

Variable Costs of Residential Bidirectional Charging Programs

As shown in the Table 7 below, based on the survey responses, the range for the total variable costs associated with compensation for EV drivers that participate in bidirectional charging ranges from approximately $332 million to $916 million over a five-year period leading up to full incorporation of V2G technology in 2030 consistent with the assumptions of the High EV/V2G scenario. These estimates maximize the average amount of time EV drivers would be willing to participate in bidirectional charging at 40-50 hours per week on average and include compensation estimates for both the high compensation requirement based on the average maximum duration of charging ($0.86/hour) or the average maximum times/locations of charging ($0.39/hour). According to Parsons et al., requiring contracts to maximize charging time may be less effective in encouraging bidirectional charging and utilizing “pay-as-you-go” programs may yield better results (2014, p. 323). Similarly, Huang et al. suggest either utilizing average daily charging requirements to increase EV driver flexibility or creating location-specific contracts (2021). If bidirectional charging program compensation structures do not set required times and hours, there is less certainty with respect to guaranteed energy storage capacity (Huang et al., 2021); however, this issue could be addressed if there is a surplus of EV drivers that may be interested in participating in V2G programs.

Table 7

Variable Costs of Residential Bidirectional Charging Programs

Assumptions	2026	2027	2028	2029	2030	Total Cost
Projected EVs (Colorado EV Plan 2020 ZEV+ Scenario)*	325,000	490,000	525,000	725,000	838,997	
Available Bidirectional Charging Program Participants	234,000	352,800	378,000.00	522,000	604,078	
Roadmap Scenario Light Duty Vehicles**	510,156	632,237	759,435	889,507	1,039,542	
Projected Statewide Bidirectional Charging Program Participants***	19,500	39,000	78,000	117,000	156,000	
Variable Costs (Low Scenario Bidirectional Charging Annual Compensation, $0.39/Hour, 40 Hours/Week) ($811/year)	$15,814,500	$31,629,000	$63,258,000	$94,887,000	$126,516,000	$332,104,500
Variable Costs (Low Scenario Bidirectional Charging Compensation, $0.39/Hour, 50 Hours/Week)($1,014/year)	$19,773,000	$39,546,000	$79,092,000	$118,638,000	$158,184,000	$415,233,000
Variable Costs (High Scenario Bidirectional Charging Compensation, $0.86/Hour, 40 Hours/Week)($1,788/year)	$34,866,000	$69,732,000	$139,464,000	$209,196,000	$278,928,000	$732,186,000
Variable Costs (High Scenario Bidirectional Charging Compensation, $0.86/Hour, 50 Hours/Week)($2,236/year)	$43,602,000	$87,204,000	$174,408,000	$261,612,000	$348,816,000	$ 915,642,000
Approximate Break Even Variable Costs Low V2G Savings (Bidirectional Charging 40 Hours/Week)($0.03/hour, $62.40/year)	$1,216,800	$2,433,600	$4,867,200	$7,300,800	$9,734,400	$25,552,800
Approximate Break Even Variable Costs Low V2G Savings (Bidirectional Charging 50 Hours/Week)($0.024/hour, $62.40/year)	$1,216,800	$2,433,600	$4,867,200	$7,300,800	$9,734,400	$25,552,800

*The 2026-2028 values are approximate based on the 2020 Colorado EV Plan (CEO, 2020, p. 14).

**The Roadmap Scenario Light-Duty Vehicles represent the number of light-duty vehicles assumed for the High EV Scenario and are based on EV projections from the CEO GHG Pollution Reduction Roadmap (Xcel Energy, 2021d, p. 41).

**Number of bidirectional charging program participants is based on requirements for the High EV/V2G Scenario (Hearing Exhibit 118 Supplemental Direct Testimony of Jack Ihle, Proceeding No. 21A-0141E,2021, pp. 18-19), with additional bidirectional charging program participants available assuming an estimated 72% participation rate based on the survey findings.

Micro Scale ROI of V2G

If EV drivers do not receive a rebate, tax credit, discount, or other incentive for installation of a bidirectional charger, the simple payback period would be between approximately 2– 7 years based on the assumptions above for average compensation per hour and average maximum hours of charging developed from the survey responses. The net present value (NPV) of the bidirectional EV charger would be between -$4,152.32 and -$1,784.33 if a discount rate of 0.53 is utilized (Parsons et al., 2014, p. 320) over the five-year period analyzed in the Xcel Energy High EV/V2G Scenario. Parsons et al. developed this high discount rate for bidirectional charging program rebates because of high discount rates for energy conservation, high upfront investment, and lack of familiarity with V2G technology for potential bidirectional program participants (2014). Please refer to Appendix D for the NPV calculations.

The bidirectional charger could have a longer lifetime than the five-year period from the Xcel Energy High EV/V2G Scenario and would therefore result in a higher NPV; however, the High EV/V2G scenario timeframe is utilized here for consistency with the remainder of the analysis. Based on the range of NPVs, the results suggest that some type of financial incentive may be necessary to encourage EV drivers to participate in bidirectional charging to increase the perception of the bidirectional charger NPV and potentially offset required bidirectional charging compensation. This analysis assumes no costs associated with battery degradation, which was at least somewhat of a concern for 35 survey respondents based on Figure C4 in Appendix C. However, bidirectional charging does not necessarily negatively impact EV battery if managed appropriately (Guo et al., 2019), which survey respondents were informed of in the informational background video provided as part of the survey.

Macro Sale ROI of V2G

Thirty-nine out of 53 total survey respondents (72%) indicated that they would participate in bidirectional charging programs (three responded “no,” and 11 responses were blank). As a result, the survey responses indicate a slightly higher W2A bidirectional charging programs than the estimates included in the Xcel Energy High EV/V2G Scenario, which assumed 70% participation from V2G-capable vehicles (Hearing Exhibit 118, Supplemental Direct Testimony of Jack Ihle, Proceeding No. 21A-014E, 2021, p. 14). Currently, there are approximately 44,000 EV drivers in Colorado (CEO, 2021b), and EV ownership in Colorado is expected to increase exponentially in the years leading up to 2030 consistent with targets set forth in the 2020 Colorado EV Plan (CEO, 2020). As such, if EV drivers adopted bidirectional charging at the rate projected by the survey responses, 604,000 EV drivers throughout Colorado could be W2A V2G technology in 2030. Approximately 156,00 EV drivers would need to participate in V2G integration by 2030 for the High EV/V2G scenario to become a viable technology that would supply 1,500 MW of technical potential and 456 MW achievable potential to the electric grid (Hearing Exhibit 118, Supplemental Direct Testimony of Jack Ihle, Proceeding No. 21A-014E, 2021, pp.12-13).

As shown in Appendix E, based on the current EV makes and models reported by survey respondents, the average battery capacity at full charge of these EVs is 68.83 kWh (EV Adoption, 2020). In 2030, if all 604,000 EV drivers deployed bidirectional charging simultaneously with V2G-enabled vehicles, V2G integration could theoretically supply an estimated 41,573.32 megawatt-hours (MWhs) to the grid (or 4,157.3 MW for 10 hours). In comparison to the assumptions in the Xcel Energy High EV/V2G scenario, which assumed 156,00 EVs with 100 kWh of energy stored for 1,500 MW of technical capacity (Hearing Exhibit

118, Supplemental Direct Testimony of Jack Ihle, Proceeding No. 21A-014E, 2021, pp. 13-14), the survey findings suggest that more EV drivers (approximately 227,273) may be needed to meet these High EV/V2G Scenario technical potential assumptions based on an average battery capacity of 68.83 kWh at full charge supplying 6.6 kW for 10.4 hours.

The survey results suggests that interest in bidirectional charging may slightly outpace the assumptions in the High EV/V2G scenario (Hearing Exhibit 118, Supplemental Direct Testimony of Jack Ihle, Proceeding No. 21A-0141E, pp. 13-14). As discussed in the Literature Review above, one of the main barriers to advancing V2G integration technology in Colorado would be the achieving an adequate number of bidirectional charging program participants, and this analysis suggests sufficient numbers of EV drivers would potentially be willing to participate in bidirectional charging programs. However, it will be critical to also encourage adoption of EVs that have V2G compatibility such that EV drivers interested in participating in bidirectional charging programs have vehicles capable of doing so (Hearing Exhibit 118, Supplemental Direct Testimony of Jack Ihle, Proceeding No. 21A-0141E, p. 14).

High EV/V2G Scenario Energy Generation and Storage Infrastructure Investment

The High EV/V2G Scenario “selected 200 MW less generic storage, 450 MW more wind, and 200 MW less CTs and 100 MW less reciprocating engine capacity by 2030 compared to the Social Cost of Carbon (SCC) 7 Scenario,” (Hearing Exhibit 119, Supplemental Direct Testimony of Jon Landrum, Proceeding No. 21A-0141E, pp. 18-19) with the SCC 7 Scenario being the Company’s Preferred Plan that was submitted to the Colorado Public Utilities Commission for consideration in March 2021 and is currently under review (Xcel Energy, 2021a). The costs associated with a V2G program were considered “unknown” and the High EV/V2G Scenario did not include a cost comparison with the SCC 7 Scenario (Hearing Exhibit

119, Supplemental Direct Testimony of Jon Landrum, Proceeding No. 21A-0141E, p. 20). However, the increased electricity demand and resulting investment in additional renewable energy generation infrastructure for the High EV/V2G Scenario was a consequence of the high number of EVs included in the Roadmap Load Forecast (Hearing Exhibit 119, Supplemental Direct Testimony of Jon Landrum, Proceeding No. 21A-0141E, p. 20), which assumes a substantially higher electrification rate for light-duty vehicles than the Base/Low EV Scenario modeled in the SCC 7 Scenario (e.g., 1,039,542 for the Roadmap EV Scenario v. 451,342 for the Base/Low EV Scenario in 2030)(Xcel Energy, 2021d, p. 41). The Roadmap Load Forecast is based on the Colorado GHG Pollution Reduction Roadmap that incorporates higher EV adoption estimates than the estimates included in the Base/Low EV Scenario based on the adopted Transportation Electrification Plan (Xcel Energy, 2021c, pp. 31-32). As a result, given that the number of EVs assumed (156,000) for full implementation of a V2G program in 2030 would be lower than the number of EVs assumed in 2030 for the Base/Low EV Scenario (451,342) included in the SCC 7 Plan Scenario, the incremental change in investment costs associated with a V2G program would need to be modeled separately because it would likely require less investment in renewable energy generation infrastructure for the purpose of enabling V2G technology specifically.

Table 8 below shows the cost differentials between the SCC 7 Preferred Plan Scenario and the High EV/V2G Scenario. The cost estimates are based on the assumptions in Volume 2-Technical Appendix of the 2021 Electric Resource Plan & Clean Energy Plan that utilized the EnCompass model (Xcel Energy, 2021d). As shown in Table 8, the High EV/V2G Scenario would require an estimated additional $837 million investment in energy generation infrastructure than the SCC 7 Preferred Plan Scenario. However, as noted above, the investments for this High EV/V2G Scenario reflect the assumptions from the Roadmap EV Scenario, which would result in 1,039,542 EVs by 2030 (Xcel Energy, 2021d, p. 41). This EV adoption rate is substantially higher than the 156,000 EVs required in 2030 for V2G integration or the Base/Low EV Scenario adoption assumption of 451,342 EVs used in the SCC 7 Preferred Plan Scenario (Hearing Exhibit 118, Supplemental Direct Testimony of Jack Ihle, and Hearing Exhibit 119, Supplemental Direct Testimony of Jon Landrum, Proceeding No. 21A-0141E, 2021).

Therefore, estimation of the potential ROI of V2G integration should be considered separately from investment costs for the High EV Scenario. Even if additional EVs were necessary to meet the assumptions discussed above for the required kWhs of battery capacity, the number of EVs (227,273) would still be lower than the 451,342 assumed for the Base/Low EV Scenario that was incorporated in the SCC 7 Preferred Plan Scenario. Therefore, incremental V2G investment cost estimates would not necessarily need to incorporate the additional generation infrastructure required for the Roadmap EV Scenario, as the demand from the 156,000 V2G EVs would already be accounted for in the Base/Low EV adoption assumptions of the SCC 7 Preferred Plan Scenario. Based on this analysis, by providing the technical potential for 1,500 MW of storage capacity by 2030, V2G could at minimum eliminate the need for 200 MW of investment in standalone storage capacity in 2030, which would displace $25 million in required energy storage investments included in the High EV/V2G Scenario as shown in bold in Table 8 below (Hearing Exhibit 119, Supplemental Direct Testimony of Jon Landrum, Proceeding No. 21A-0141E, 2021, p. 19).

Analysis of the potential ROI of V2G integration that assumes adoption of EVs at the rate included in the Base/Low EV Scenario specifically rather than the Roadmap EV Scenario would further isolate the ROI of V2G by subtracting out the incremental investment associated with 130

MW of energy generation infrastructure to accommodate the Roadmap EV Scenario peak demand as well as the investment in standalone energy storage infrastructure discussed above (Hearing Exhibit 119, Supplemental Direct Testimony of Jon Landrum, Proceeding No. 21A-0141E, 2021, p.20; Xcel Energy, 2021d, p. 51). Depending on whether solar or wind generation infrastructure is subtracted for the Roadmap EV Scenario peak load, the investment reduction associated with excluding the Roadmap EV Scenario would be between approximately $181 million-$253 million. Subtracting out these incremental investments in wind and solar generation infrastructure from the High EV/V2G scenario to assess the impact of V2G specifically would still yield an overall investment cost increase for the High EV/V2G Scenario compared to the SCC 7 Preferred Plan Scenario, which results from "the increased load in the model from the High EV forecast [that] increases total system costs simply due to serving higher capacity and energy needs than the base assumptions" (Hearing Exhibit 119, Supplemental Direct Testimony of Jon Landrum, Proceeding No. 21A-0141E, 2021, p. 20). As a result, the above analysis suggests that modeling of a V2G-only 2030 scenario with the Base/Low EV Scenario assumptions included in the SCC 7 Preferred Plan Scenario could demonstrate additional ROI of V2G integration beyond subtracting out the $25 million in standalone storage infrastructure investments that bidirectional charging programs would offset. Given the technical capacity of 1,500 MW from V2G integration, V2G may also yield additional investment cost savings in years following 2030 when projections indicate that only 200 MW of energy storage infrastructure would be offset by V2G technology.

Table 8

SCC 7 Preferred Plan Scenario and High EV/V2G Scenario Cost Comparison

Generation /Storage Type	2026	2027	2028	2029	2030	Total Cost Delta
Standalone Storage	-	-	-	-	**($24,936,00)**	**($24,936,00)**
Wind	$456,000,0000	($76,000,000	$228,000	$228,000,000	($152,000,000)	$684,000,000
Solar	$420,000,000	($290,000,000)	($112,000,000)	-	$156,000,000	$174,000,000
Combustion Turbine	($35,044,800.00)	$35,609,280.00	-	$18,416,160		$18,980,640
Aeroderivative	-	-	-	-	-	-
Reciprocating Generating Capacity				$14,868,000		$14,868,000
Combined Cycle	-	-	-	-	-	-
			High EV/V2G Scenario Cost Comparison with Preferred Plan			$837,176,640

V2G ROI

Comparing the variable bidirectional charging compensation costs through 2030 to the displacement of investment costs for other energy infrastructure in Tables 7 and 8 above suggests that bidirectional EV charging would not yet be economically feasible unless the average compensation required for maximizing bidirectional charging program participation decreased to the break-even points described in Table 7 above based on the potential V2G investment cost savings of $25 million. These total annual bidirectional charging compensation costs would correspond with a substantially lower average compensation rate between $0.024 -$0.03 per hour. However, these costs do not account for the fixed costs of installing bidirectional chargers, which would further increase bidirectional charging program investment costs for electric utilities. This lower compensation range would align more closely with Xcel Energy residential electric rates that range from approximately $0.03-$0.13/ kWh (Xcel Energy, 2018). Therefore, future analyses of W2A bidirectional charging programs may consider setting the compensation rate to match the kWh rate the customer would be charged for using electricity at a certain time of day to determine the associated impact on W2A bidirectional charging at these compensation levels. Several of the free responses to the survey suggested taking this approach to bidirectional charging compensation as well.

Bidirectional Charging Program Use Case

Aligning bidirectional charging program compensation with kWh rates could also be impacted by when most EV drivers would participate in bidirectional charging, which based on the survey responses, could address a portion of the on-peak period during evening hours between 6 p.m. to 9 p.m. for the Time of Use Pricing Residential Rate structure (Xcel Energy, n.d.b). In addition, it appears that there are opportunities to persuade prospective bidirectional charging program participants to also charge during afternoon hours when solar generation is most abundant and peak demand pricing is available between 2 p.m. -6 p.m. (Xcel Energy, n.d.a). Doing so could be achieved through utilization of the techniques described in the behavior change policy section below.

Policy Strategies

The following policy strategies could be utilized to increase the ROI and economic feasibility of V2B/V2G integration in Colorado by creating policy coordination efficiencies and changing EV driver behaviors that may result in barriers to V2B/V2G integration. These policy strategies are described in greater detail below, including achieving behavior change through social norms and V2B/V2G collaboration efforts.

Leveraging Social Norms for Behavior Change

This study aimed to understand the behaviors and attitudes of Colorado EV drivers with respect to bidirectional charging programs. While this study presents a snapshot of these attitudes and behaviors currently, leveraging social norms can provide a powerful, non-financial means of changing electricity usage behaviors in the future (Allcott, 2011). These behavior changes could help to enhance the economic feasibility of bidirectional charging programs through encouraging behaviors such as individual investment in residential bidirectional EV chargers or decreasing potential bidirectional charging compensation requirements for various durations, times, and locations.

With respect to energy efficiency, an injunctive social norm indicates how one should behave to receive approval from others (i.e., a smiling face on a home energy report) while a descriptive social norm focuses on how others behave (i.e., neighboring households' energy usage)(Allcott, 2011). Social norm tools have been found to increase the effectiveness of energy and water conservation campaigns for residential utility customers (Allcott, 2011; Lede et al., 2014; Lohan 2019). Electric utilities have similar opportunities to implement social norm tools for bi-directional charging programs because social norm efficiency campaigns have relied on communications with utility customers (i.e., via a customer portal or monthly bill). V2B/V2G integration would be enabled through a smartphone application interface. Similar to home energy reports provided to electric utility customers that include both descriptive and injunctive norms about energy usage, a V2B/V2G smartphone application interface could provide real-time information to bidirectional charging program participants regarding how their charging behaviors (i.e., time, location, and duration) compare to other EV drivers.

Lede et al. found that water conservation campaigns that utilized social norms were more effective than campaigns that only provided information as a tool to reduce residential water consumption (2014). Similarly, Allcott found that utilizing social norms through home energy reports resulted in substantial energy savings equivalent to an 11-20% increase in electricity rates (2011), which could be especially important with respect to establishing optimal compensation rates for bidirectional charging. Furthermore, leveraging social norms with respect to groups of similar individuals (i.e., bidirectional program participants that are part of the same EV Club) could strengthen the impact of social norm tools (Lede et al., 2014). Phrases that emphasize in-group norms and social identity could increase social norms surrounding V2B/V2G charging (Lede et al., 2014). For example, a bidirectional charging campaign could be entitled “Colorado: We V2B/V2G” to associate V2B/V2G behaviors with social norms for Colorado residents.

Communications regarding bidirectional charging programs could be tailored to EV drivers depending on group characteristics, such as whether an EV driver lives in an urban or rural area of Colorado. For example, 80% of survey respondents in rural areas indicated that they perceived availability of a back-up power source as an important benefit of bidirectional charging programs, thus demonstrating that this benefit should be highlighted in communications to EV drivers that live in rural areas.

V2B/V2G Collaboration Efforts

In addition to promoting behavior change at the micro scale, promoting change at the macro scale with respect to the future of vehicle electrification will also be crucial for V2B/V2G integration. As discussed above in the analysis of the potential ROI of V2G technology, the SCC 7 Preferred Plan Scenario currently utilizes a Base/Low Scenario for EV adoption in alignment with the Xcel Energy Transportation Electrification Plan that does not forecast EV adoption at the higher rate indicated in the Roadmap EV Scenario that aligns with the CEO GHG Pollution Reduction Roadmap (Xcel Energy, 2021c, pp. 31-32). In addition, policy coordination will be critical to ensuring that adoption of EVs that would support bidirectional charging are encouraged or incentivized, especially given that availability of V2G-enabled EVs was cited as one of the main barriers to V2G integration in Colorado (Hearing Exhibit 118, Supplemental Direct Testimony of Jack Ihle, Proceeding No. 21A-0141E 2021, pp.16-17). Achieving EV adoption targets, and consequently the availability of bidirectional charging program participants to support the required electric grid demand, will require synergies between efforts to advance the number of EV drivers and implement V2G technology. As such, facilitation of collaboration efforts in these spaces should be prioritized.

Collaboration via networks can provide a means of addressing complex, multi-stakeholder issues that a firm or hierarchical organization (i.e., a government entity) would not be well-suited to address alone (Powell, 1990). Networks facilitate information-sharing, respond rapidly to changes in circumstances that arise from uncertainty, and reduce risks for individual network participants (Powell, 1990). In addition, networks can unlock progress towards goals that organizations acting alone would struggle to achieve individually (Huxham and Vangen, 2005; Popp et al., 2014). By working together, network participants can share limited resources (i.e., funding and grants for EV pilot projects (Gridworks, 2020)) to advance V2B/V2G integration goals more effectively than they would by acting alone without access to additional resources or ability to leverage economies of scale (Popp et al., 2014). This policy strategy is especially relevant for bidirectional charging programs due to the potential synergies between bidirectional charging and opportunities to simultaneously accelerate EV adoption (Gridworks, 2020).

Currently, the following public and private stakeholders play a key role in the implementation of EV policies and programs in Colorado (CEO, 2020; Hartman & Shields, 2021; US Department of Energy, 2021):

- Colorado Air Quality Control Commission
- Colorado Department of Public Health & Environment (including the Clean Fleet Enterprise)
- Colorado Department of Transportation (including the Clean Transit Enterprise)
- Colorado Energy Office (including the Colorado Electric Vehicle Coalition [CEVC], Community Access Enterprise, and Recharge Colorado)
- Colorado Public Utilities Commission
- Colorado Regional Air Quality Council (including Clean Air Fleets)
- Drive Electric Colorado
- Drive Electric Northern Colorado

- Electric utilities (including Black Hills Energy, Gunnison County Electric Association, Holy Cross Energy, San Isabel Electric Vehicle Association, and Xcel Energy)

Like the model developed in California for the VGI Working Group, a collaborative effort dedicated specifically to addressing V2B/V2G integration should be developed to help enable transformative change and prevent policy coordination failure as described by Sovacool et al. in the Literature Review section above (2017). Based on the findings from the survey and ROI analysis, coordination across industries and sectors will be crucial to incentivizing adoption of V2G-enabled EVs and setting compensation rates that would support the economic feasibility of bidirectional charging programs.

To facilitate network development between these organization, the Alliance could serve as a “network weaver” to make deliberate connections between the stakeholders listed above involved in bidirectional charging programs that may not occur otherwise (Krebs and Holley, 2006). Eventually, as the V2B/V2G network matures within Colorado, the Alliance could then transition to the role of a network facilitator with other V2B/V2G networks in additional geographies, such as other states (Krebs and Holley, 2006). In terms of network structures, V2B/V2G programs in Colorado are currently at a hub-and spoke stage between several clusters (i.e., the Alliance, Fermata Energy, and Xcel Energy), but the goal would be to eventually transition to the core/periphery structure that could help support connections at the periphery of the network, such as the VGI Working Group in California (Krebs and Holley, 2006).

The California VGI Working Group, although initiated by several California government agencies, utilized a network administrative organization (NAO)(Gridworks, 2020) to facilitate the network. If a similar V2B/V2G collaboration effort formed in Colorado, the CEVC or its governmental agency administrator, the CEO, may similarly consider utilizing a NAO such as the Alliance to lead the collaboration effort. NAOs are best-suited for collaboration environments where there is a high need for network administrative capabilities with a moderate number of participants that have fairly aligned goals (Provan and Kenis, 2008), which is appropriate for this type of collaboration effort in that there would be significant administrative, technological, and regulatory coordination; participants from a variety of sectors throughout Colorado; and general goal alignment with respect to advancing viable use cases for the implementation of V2G/V2G integration.

A V2B/V2G effort may exist as part of the existing CEVC subgroups, which include Policy, Beneficial Electrification, EV Equity, Transit, Marketing and Outreach, and Retail Charging (CEO, 2020). In California, the VGI Working Group was developed the by the CAISO, California Energy Commission, California Air Resources Board, and the California Public Utilities Commission (California Public Utilities Commission, 2021). Based on the current stakeholders primarily involved in advancing EVs in Colorado listed above in comparison to stakeholders that participated in VGI Working Group, a CEVC subgroup may also consider requesting participation from other groups such as electric car, charging infrastructure, and battery companies; interest groups that represent ratepayers; academia; and industry associations (Gridworks, 2020).

Limitations

This study had a small sample size compared to all EV drivers in Colorado that relied on a convenience sample of Colorado EV Clubs via their blogs, newsletters, and Facebook groups where voluntary responses were received. The age range of the survey respondents was also positively skewed, and anecdotally, four survey respondents provided input in the final free response question that they were retired and no longer had a workplace that would impact their current or prospective EV charging behaviors. As such, while home charging was a popular response overall and 14 survey respondents also indicated that they worked from home at least five days per week, a more representative sample of the overall Colorado population may yield different results.

Future Research

As discussed in the Method section above, future research should also assess the W2A bidirectional charging programs for non-EV drivers to evaluate whether Colorado residents that do not yet have an EV may be interested in participating in bidirectional charging programs in the future. In their study, van Heuveln et al. similarly acknowledged that the behaviors and attitudes towards V2G of current EV drivers are representative of early adopters of EVs, and as EVs become increasingly common, future EV drivers may have differing perspectives towards bidirectional charging programs and/or different motivations or concerns associated with participation in these programs (2021). Incorporating the perspectives of these future EV drivers will be critical to supporting the potential economic feasibility of V2G technology long-term. Subsequent studies may also consider setting bidirectional charging compensation rates within lower ranges similar to those discussed above that would align more closely with current Xcel Energy residential electricity rates to determine how these lower compensation rates would impact overall W2A bidirectional charging programs.

Conclusion

In summary, despite the lack of statistical significance of predictors of W2A bidirectional charging programs and associated bidirectional charging behaviors, the preceding analysis supports continued assessment of the potential for V2B/V2G integration in Colorado based on the willingness of survey respondents to participate in bidirectional charging programs.

Bidirectional charging compensation at rates similar to those currently charged by Xcel Energy for residential electricity usage would potentially result in cost-effective bidirectional charging programs at approximately the same costs as the generation and storage infrastructure investments offset by a High EV/V2G Scenario. Supporting behaviors that will enable cost-effective bidirectional charging and ensuring coordination between key policy actors will be critical to ensuring the economic viability of potential residential bidirectional charging programs in the future.

References

Allcott, H. (2011). Social norms and energy conservation. *Journal of Public Economics, 95*(9), 1082-1095. https://doi.org/10.1016/j.jpubeco.2011.03.003

Application of Public Service Company of Colorado for approval of its 2021 Electric Resource Plan and Clean Energy Plan, Hearing Exhibit 118, Supplemental Direct Testimony of Jon Landrum Proceeding No. 21A-0141E (2021). http://www.dora.state.co.us/pls/efi/EFI_Search_UI.search

Application of Public Service Company of Colorado for approval of its 2021 Electric Resource Plan and Clean Energy Plan, Hearing Exhibit 119, Supplemental Direct Testimony of Jack Ihle Proceeding No. 21A-0141E (2021). http://www.dora.state.co.us/pls/efi/EFI_Search_UI.search

Bailey, J., & Axsen, J. (2015). Anticipating PEV buyers' acceptance of utility controlled charging. *Transportation Research Part A: Policy and Practice, 82*, 29–46. https://doi.org/10.1016/j.tra.2015.09.004

Bohnsack, R., Van den Hoed, R., & Oude Reimer, H. (2015). Deriving vehicle-to-grid business models from consumer preferences. *World Electric Vehicle Journal, 7*(4). https://doi.org/10.3390/wevj7040621

California Independent System Operator. (February 2014). *California vehicle-grid integration (VGI) roadmap: Enabling vehicle-based grid services. https://www.caiso.com/Documents/Vehicle-GridIntegrationRoadmap.pdf*

California Public Utilities Commission. (2021). *Vehicle-grid integration activities*. Transportation Electrification. https://www.cpuc.ca.gov/vgi/

California Senate, S.B. 676, 2019-2020 Reg. Sess. (CA. 2020). https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201920200SB676

City of Fort Collins. (n.d.). *Powering EVs*. Utilities. https://www.fcgov.com/utilities/residential/conserve/EVs

Colorado Energy Office. (April 2020). *Colorado electric vehicle plan 2020.* https://drive.google.com/file/d/1-z-lNQMU0pymcTQEH8OvnemgTbwQnFhq/view

Colorado Energy Office. (2021a, January 14). *Colorado greenhouse gas reduction roadmap final report.* https://drive.google.com/file/d/1jzLvFcrDryhhs9ZkT_UXkQM_0LiiYZfq/view

Colorado Energy Office. (2021b, November 28). *EVs in Colorado dashboard | Colorado Energy Office*. Zero Emission Vehicles. https://energyoffice.colorado.gov/zero-emission-vehicles/evs-in-colorado-dashboard

Cross, R. (2021, October 21). *Charging stations*. NUVVE Corp. https://nuvve.com/chargers/

Drive Electric Northern Colorado. (n.d.). *Charging*. http://driveelectricnoco.org/charging/

Energy+Environmental Economics. (2019, April 12). *California framework for grid value of vehicle grid integration (VGI).* VGI Working Group April Meeting, California, United States. https://Gridworks.org/wp-content/uploads/2019/05/VGI_4.12-Slides.pdf

EV Adoption. (2020, December 3). *EV models currently available in the US*. Retrieved November 28, 2021, from https://evadoption.com/ev-models/#home/?view_2_search=model%203&view_2_page=1

Fermata Energy. (2021). *Homeowners*. https://www.fermataenergy.com/homeowner

Geske, J., & Schumann, D. (2018). Willing to participate in vehicle-to-grid (V2G)? Why not! *Energy Policy*, *120*, 392–401. https://doi.org/10.1016/j.enpol.2018.05.004

Gridworks. (2020, June 30). *Final report of the California joint agencies vehicle-grid integration working group. https://Gridworks.org/wp-content/uploads/2020/09/GW_VehicleGrid-Integration-Working-Group.pdf*

Guo, J., Yang, J., Lin, Z., Serrano, C., & Cortes, A. M. (2019). Impact analysis of V2G services on EV battery degradation -A review. *2019 IEEE Milan PowerTech*. Published. https://doi.org/10.1109/ptc.2019.8810982

Hartman, K., & Shields, L. (2021, August 20). *State policies promoting hybrid and electric vehicles*. National Conference of State Legislatures. https://www.ncsl.org/research/energy/state-electric-vehicle-incentives-state-chart.aspx

Huxham, C., & Vangen, S. (2005). *Managing to collaborate: The theory and practice of collaborative advantage.* New York: Routledge.

Huang, B., Meijssen, A. G., Annema, J. A., & Lukszo, Z. (2021). Are electric vehicle drivers willing to participate in vehicle-to-grid contracts? A context-dependent stated choice experiment. *Energy Policy*, *156*, 112410. https://doi.org/10.1016/j.enpol.2021.112410

Kelley, K., Clark, B., Brown, V., & Sitzia, J. (2003). Good practice in the conduct and reporting of survey research. *International Journal for Quality in health care*, *15*(3), 261-266. https://academic.oup.com/intqhc/article/15/3/261/1856193

Kim, H. Y. (2017). Statistical notes for clinical researchers: Chi-squared test and Fisher's exact test. *Restorative Dentistry & Endodontics*, *42*(2), 152. https://doi.org/10.5395/rde.2017.42.2.152

Krebs, V., & Holley, J. (2006). Building smart communities through network weaving. *Appalachian Center for Economic Networks*.

Lede, E., Meleady, R., & Seger, C. R. (2019b). Optimizing the influence of social norms interventions: Applying social identity insights to motivate residential water conservation. *Journal of Environmental Psychology*, *62*, 105–114. https://doi.org/10.1016/j.jenvp.2019.02.011

Lee, C.-Y., Jang, J.-W., & Lee, M.-K. (2020). Willingness to accept values for vehicle-to-grid service in South Korea. *Transportation Research Part D: Transport and Environment*, *87*, 102487. https://doi.org/10.1016/j.trd.2020.102487

Lohan, T. (2016a, November 3). *Social norms messaging: How water agencies can change our habits*. Water Deeply. https://deeply.thenewhumanitarian.org/water/articles/2016/11/03/social-norms-messaging-how-water-agencies-can-change-our-habits

Kempton, W., & Tomić, J. (2005b). Vehicle-to-grid power fundamentals: Calculating capacity and net revenue. *Journal of Power Sources*, *144*(1), 268–279. https://doi.org/10.1016/j.jpowsour.2004.12.025

Markus, F. (2020, January 7). *Wallbox's affordable bidirectional EV charger is coming to America*. MotorTrend. https://www.motortrend.com/news/wallbox-quasar-bidirectional-ev-charger-price-america/

Meintsma, S. (n.d.). *Colorado EV clubs*. Drive Electric Colorado. https://driveelectriccolorado.org/discovering-evs/ev-clubs

National Conference State Legislature. (2021, October 9). *Energy state bill tracking database*. Energy State Bill Tracking Database. https://www.ncsl.org/research/energy/energy-legislation-tracking-database.aspx

National Governor's Association. (2020). The road ahead: Planning for electric vehicles by managing grid interactions. https://www.nga.org/wp-content/uploads/2020/12/EV-Grid-Interaction.pdf

Noel, L., Zarazua De Rubens, G., Kester, J., & Sovacool, B. K. (2019a). Navigating expert skepticism and consumer distrust: Rethinking the barriers to vehicle-to-grid (V2G) in the Nordic region. *Transport Policy*, *76*, 67–77. https://doi.org/10.1016/j.tranpol.2019.02.002

Noel, L., de Rubens, Z. G., Kester, J., & Sovacool, B. K. (2019b). *Vehicle-to-grid: A sociotechnical transition beyond electric mobility (energy, climate and the environment)* (1st ed. 2019 ed.). Palgrave Macmillan.

OVO Energy. (2021). *OVO vehicle-to-grid trial: Building a better grid for everyone | OVO Energy*. OVO Smart Home. https://www.ovoenergy.com/electric-cars/vehicle-to-grid-charger

Parsons, G. R., Hidrue, M. K., Kempton, W., & Gardner, M. P. (2014). Willingness to pay for vehicle-to-grid (V2G) electric vehicles and their contract terms. *Energy Economics*, *42*, 313–324. https://doi.org/10.1016/j.eneco.2013.12.018

Podsakoff, P. M., MacKenzie, S. B., & Podsakoff, N. P. (2012). Sources of method bias in social science research and recommendations on how to control it. *Annual Review of Psychology*, *63*(1), 539–569. https://doi.org/10.1146/annurev-psych-120710-100452

Popp, J., Milward, H., MacKeen, G., Casebeer, A., & Lindstrom R. (2014). Inter-organizational networks: A review of the literature to inform practice. https://www.businessofgovernment.org/report/inter-organizational-networks-review-literature-inform-practice

Powell, W. (1990). Neither market nor hierarchy: Network forms of organization. *Research in Organizational Behavior, 12(1)*, 295-336. https://pdodds.w3.uvm.edu/files/papers/others/1990/powell1990a.pdf

Provan, K. G., & Kenis, P. N. (2007). Modes of network governance: Structure, management, and effectiveness. *Journal of Public Administration Research and Theory, 18*(2), 229-252. https://doi.org/10.1093/jopart/mum015

Sovacool, B. K., Axsen, J., & Kempton, W. (2017). The future promise of vehicle-to-grid (V2G) integration: A sociotechnical review and research agenda. *Annual Review of Environment and Resources*, *42*(1), 377–406. https://doi.org/10.1146/annurev-environ-030117-020220

Sovacool, B. K., Noel, L., Axsen, J., & Kempton, W. (2018). The neglected social dimensions to a vehicle-to-grid (V2G) transition: a critical and systematic review. *Environmental Research Letters*, *13*(1), 013001. https://doi.org/10.1088/1748-9326/aa9c6d

Taylor, T. (September 2021). *Colorado 2021 greenhouse gas inventory update with historical emissions from 2005 to 2019 and projections to 2050*. Colorado Air Pollution Control Division, Colorado Department of Public Health & Environment. https://drive.google.com/file/d/1SFtUongwCdZvZEEKC_VEorHky267x_np/view

The Alliance. (2021). *The team.* https://coloradosmart.city/the-team/

The Alliance Center. (2021a). 2020 *impact report.* https://www.thealliancecenter.org/wp-content/uploads/2021/04/2020-Impact-Report.pdf

The Alliance Center. (2021b). *Our mission*. https://www.thealliancecenter.org/ourmission/

US Census. (2020). *Bayfield town, Colorado*. Explore Data. https://data.census.gov/cedsci/profile?g=1600000US0805265

US Census. (2020). *Cascade-Chipita Park CDP, Colorado*. Explore Data. https://data.census.gov/cedsci/profile?g=1600000US0812325

US Census. (2019). *U.S. Census Bureau quick facts: Colorado*. Census Bureau QuickFacts. https://www.census.gov/quickfacts/fact/table/US/PST045219

US Census. (2021, February 19). *Urban areas for the 2020 Census-proposed criteria*. Federal Register. https://www.federalregister.gov/documents/2021/02/19/2021-03412/urban-areas-for-the-2020-census-proposed-criteria

US Department of Energy. (2019, December 23). *FOTW #1113, December 23, 2019: Average annual highway vehicle miles traveled per capita varies by state*. Energy.Gov. https://www.energy.gov/eere/vehicles/articles/fotw-1113-december-23-2019-average-annual-highway-vehicle-miles-traveled

US Department of Energy. (2021, June). *Alternative fuels data center: State laws and incentives*. Colorado Laws and Incentives. https://afdc.energy.gov/laws/state

van Heuveln, K., Ghotge, R., Annema, J. A., van Bergen, E., van Wee, B., & Pesch, U. (2021). Factors influencing consumer acceptance of vehicle-to-grid by electric vehicle drivers in the Netherlands. *Travel Behaviour and Society*, *24*, 34–45. https://doi.org/10.1016/j.tbs.2020.12.008

Xcel Energy. (2018, May 1). *CO rate books electric summation sheet.* *https://www.xcelenergy.com/staticfiles/xe-*

responsive/Company/Rates%20&%20Regulations/CO-rate-books-Electric-Summation-Sheet.pdf

Xcel Energy. (2020). *Transportation electrification plan 2021-2023.* https://www.xcelenergy.com/staticfiles/xe-responsive/Company/Rates%20&%20Regulations/Regulatory%20Filings/20A-0204E-_2021-2023_TEP_Updated.pdf

Xcel Energy. (2021a). *Colorado 2021 clean energy plan*. Environment. https://co.my.xcelenergy.com/s/environment/clean-energy-plan

Xcel Energy. (2021b, Feb 17). *Form 10-K.* *https://s25.q4cdn.com/680186029/files/doc_downloads/irw/SEC_10-K_Filings/updated/Xcel-2020-10-K-As-Filed.pdf*

Xcel Energy. (2021c, March 31). *Xcel Energy 2021 electric resource plan and clean energy plan* https://www.xcelenergy.com/staticfiles/xe-responsive/Company/Rates%20&%20Regulations/Resource%20Plans/Clean%20Energy%20Plan/Vol_1-Plan_Overview.pdf

Xcel Energy. (2021d, March 31). *Xcel Energy 2021 electric resource plan and clean energy plan volume 2 technical appendix.* https://www.xcelenergy.com/staticfiles/xe-responsive/Company/Rates%20&%20Regulations/Resource%20Plans/Clean%20Energy%20Plan/Vol_2-Technical_Appendix.pdf

Xcel Energy. (2021e, September 30). *Xcel Energy announces new electric vehicle smart charging pilot with automakers* [Press release]. https://co.my.xcelenergy.com/s/about/newsroom/press-release/xcel-energy-announces-new-electric-vehicle-smart-charging-pilot-with-automakers-MCAMWGE6254FFLNEAWSFYXMYBQA4

Xcel Energy. (n.d.a). *Peak demand pricing*. *https://co.my.xcelenergy.com/s/billing-payment/residential-rates/peak-demand-pricing*

Xcel Energy. (n.d.b). *Time of use*. https://co.my.xcelenergy.com/s/billing-payment/residential-rates/time-of-day

Appendix A

Survey Instrument

1. Do you currently own or lease an EV/Hybrid?

Own

Lease

I do not own or lease an EV

2. What are the make and the model of your EV? (If you have more than one EV, please select the one that you use the most frequently.)

Make:

Model:

3. On a typical week, where do you usually charge your EV most frequently?

	Never	Seldom	Occasionally	Frequently	Almost always
Home garage or parking space					
Work or school parking space					

	Never	Seldom	Occasionally	Frequently	Almost always
Public charging station (e.g., mall, park, grocery store)					
Others					

4. On a typical week, during what time(s) do you charge your EV the most frequently?

	Seldom	Occasionally	Frequently	Almost always
8:00 am – 12:00 pm				
12:00 pm – 6:00 pm				
6:00 pm – 8:00 am				

5. How many miles do you (or your household) drive your EV per year?

Less than 5,000 miles

5,000 – 10,000 miles

10,000 – 15,000 miles

15,000 – 20,000 miles

Over 20,000 miles

This 4-minute video explains how Vehicle-to-Grid (V2G) and bidirectional charging work.

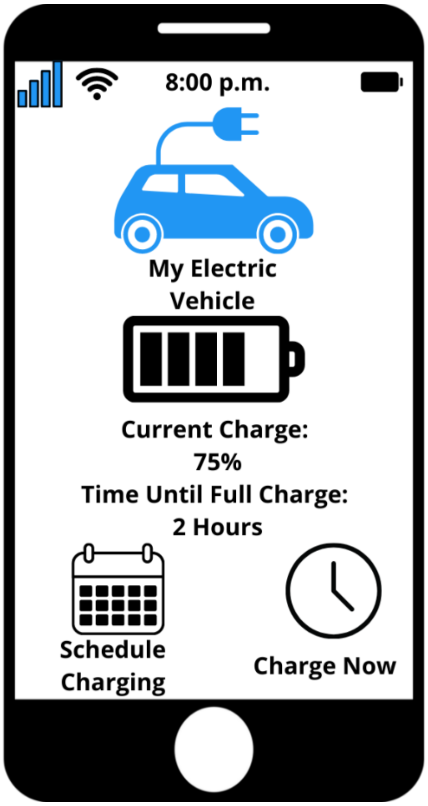
The following 5 questions will ask your willingness to use a bidirectional charging station.

6. According to the video, which statement about bidirectional charging is correct?

Bidirectional charging always causes faster degradation of EV batteries

Bidirectional charging can enhance EV battery health by preventing overcharging of the battery and managing the rate (speed) of charging

7. If you opt for a V2G charging solution, your car battery will always be charged to 50 – 80 % when you need to drive. You can set up the battery level and the time for your EV to complete charging using a cell-phone application shown below.



If your car supports bidirectional charging with 10-year battery warranty, would you consider using a bidirectional charger?

Yes

No

8. What time of the day and what locations would you consider to plug in your EV to a bidirectional charger? Assume there is no financial compensation.

Bidirectional charger at your workplace in the morning (8am – 12pm)

Bidirectional charger at your workplace in the afternoon (12pm – 6pm)

Bidirectional charger at your workplace overnight (6pm – 8am)

Bidirectional charger at your home in the morning (8am – 12pm)

Bidirectional charger at your home in the afternoon (12pm – 5pm)

Bidirectional charger at your home overnight (6pm – 8am)

9. If you are compensated $ 0.5 / hour, are there any additional times of the day and locations would you consider plug in your EV to a bidirectional charger?

Bidirectional charger at your workplace in the morning (8am – 12pm)

Bidirectional charger at your workplace in the afternoon (12pm – 6pm)

Bidirectional charger at your workplace overnight (6pm – 8am)

Bidirectional charger at your home in the morning (8am – 12pm)

Bidirectional charger at your home in the afternoon (12pm – 5pm)

Bidirectional charger at your home overnight (6pm – 8am)

10. If you are compensated $ 1 / hour, are there any additional times of the day and locations would you consider plug in your EV to a bidirectional charger?

Bidirectional charger at your workplace in the morning (8am – 12pm)

Bidirectional charger at your workplace in the afternoon (12pm – 6pm)

Bidirectional charger at your workplace overnight (6pm – 8am)

Bidirectional charger at your home in the morning (8am – 12pm)

Bidirectional charger at your home in the afternoon (12pm – 5pm)

Bidirectional charger at your home overnight (6pm – 8am)

11. If the bidirectional charger is not located at your home or workplace, what would be the maximum distance you may consider using a bidirectional charger?

12. On a typical week, how many hours are you willing to plug in your EV to a bidirectional charger?

	Less than 5 hours	5 – 10 hours	10 – 20 hours	20 – 30 hours	30 – 40 hours	40 – 50 hours	50 – 60 hours	Over 60 hours
No compensation								

13. If you are compensated $0.5/hour for using a bidirectional charger, how many hours are you willing to plug in your EV to a bidirectional charger?

	Less than 5 hours	5 – 10 hours	10 – 20 hours	20 – 30 hours	30 – 40 hours	40 – 50 hours	50 – 60 hours	Over 60 hours
Compensated $ 0.5 per hour								

14. If you are compensated $1/hour for using a bidirectional charger, how many hours are you willing to plug in your EV to a bidirectional charger?

	Less than 5 hours	5 – 10 hours	10 – 20 hours	20 – 30 hours	30 – 40 hours	40 – 50 hours	50 – 60 hours	Over 60 hours
Compensated $ 1 per hour								

15. What are the three most important considerations in using bidirectional charging? Please select three.

Ease of access to bidirectional charging stations

Diversity of charging options (e.g., fast charging)

Ease of using cell phone app for bidirectional charging

Lower electricity rates for charging your EV

Higher compensation rates for discharging your EV

EV battery health optimization by using the bidirectional charging management

Your contribution to electric grid optimization

Your contribution to energy conservation

Your contribution to the reduction of greenhouse gas emissions

Availability of a back-up power source in case of a power outage

16. Please indicate how much you are concerned about the following factors in bidirectional EV charging.

	Not concerned	Somewhat concerned	Very concerned
Impact on battery longevity			
Privacy concerns			

	Not concerned	Somewhat concerned	Very concerned
Access to bidirectional charging stations			
Complexity of using bidirectional charging			
EV battery warranty			
Guaranteed mileage range			
Ability to plan EV charging schedules in advance			

18. On a typical week, how many days a week do you work from home?

0

1 – 2

3 – 4

5 or more

19. Do you have solar panels on your home?

Yes

No

20. Do you have another car that you can share with someone else in your household?

Yes

No

21. Which city do you live in?

City
State

22. Which category below includes your age?

18 –24

24 –34

35 –44

45 –54

55 –64

65+

23. In which type of housing do you currently live?

Single-family house

Townhome, Condo, or Duplex

Apartment

Other

24. Anything else you would like to let us know about EV charging options?

25. If you would like to be entered to win one of ten (10) $50 Amazon.com virtual gift cards, please enter your email address below.

Appendix B

STATA Do File

```
***Data Cleaning***
label define EVOwnrshp 1 "Own" 0 "Lease"
encode OwnLease, gen(EVOwnr) label(EVOwnrshp)
label define CrntChrgngPrf 1 "Never" 2 "Seldom" 3 "Occasionally" 4 "Frequently" 5 "Almost always"
label define YN 1 "Y" 0 "N"
encode ChargingLocation_Home, gen(HmChrgng) label(CrntChrgngPrf)
encode ChargingLocation_WorkSchool, gen(WrkSchlChrgng) label(CrntChrgngPrf)
encode ChargingLocation_Public, gen(PblcChrgng) label(CrntChrgngPrf)
encode ChargingLocation_Other, gen(OthrChrgng) label(CrntChrgngPrf)
label define CrntChrgngTm 1 "Seldom" 2 "Occasionally" 3 "Frequently" 4 "Almost always"
encode ChargingTime_Morning, gen(MrngChrgng) label(CrntChrgngTm)
encode ChargingTime_Afternoon, gen(AftrnChrgng) label(CrntChrgngTm)
encode ChargingTime_Evening, gen(EvnngChrgng) label(CrntChrgngTm)
tabulate MainChargingLocation, generate (MnChrgngLctn)
tabulate MainChargingTime, generate(MnChrgngTm)
encode W2A_BiDirectionalCharging, gen(W2ABDrctnlChrgng) label (YN)
label define EVMls 1 "Low" 2 "Medium" 3 "High"encode EVMilesPerYearLevel, gen (EVAnnlMls) label (EVMls)
label define TF 1 "T" 0 "F"
destring MaximumDistance_Home, generate(MxDstncHm)
destring MaximumDistance_Work, generate(MxDstncWrk)
label define ChrgngHrs 1 "Less than 5 hours" 2 "5 – 10 hours" 3 "10 – 20 hours" 4 "20 – 30 hours" 5 "30 – 40 hours" 6 "40 – 50 hours" 7 "50 – 60 hours" 8 "Over 60 hours"
encode PlugInHours_NoComp, gen(PlgInHrsNCmp) label (ChrgngHrs)
encode PlugInHours_05, gen(PlgInHrs05Cmp) label (ChrgngHrs)
destring AdditionalCharging_05, generate(AdtlChrgng_05)
```

```
encode PlugInHours_MaxHours, gen(MxChrgngHrs) label (ChrgngHrs)
label define WFH 0 "0" 1 "1 – 2" 2 "3 – 4" 3 "5 or more"
encode DaysChargedFromHome, gen(WFH) label(WFH)
encode SolarPanels, gen(HmGnSlr) label(YN)
encode AnotherCarAvailable, gen(OthrCr) label(YN)
label define AgRng 1 "18-24" 2 "24-34" 3 "35-44" 4 "45-54" 5 "55-64" 6 "65+"
encode Age, gen(EVDrvrYrs) label (AgeRange)
label define HmLctn 1 "Urban" 0 "Rural"
encode Geography, gen(UrbnRrl) label (HmLctn)
label define HsngTyp 1 "Single-family house" 0 "Townhome, Condo, or Duplex"
encode HousingType, gen(SFH) label(HsngTyp)
replace SFH=0 if SFH==2
***Descriptive Statistics Independent Variables***
sum EVOwnr
sum EVAnnlMls
sum MrngChrgng
sum AftrnChrgng
sum EvnngChrgng
sum HmChrgng
sum WrkSchlChrgng
sum PblcChrgng
sum OthrChrgng
sum WFH
sum HmGnSlr
sum OthrCr
sum UrbnRrl
sum SFH
sum EVDrvrYrs
***Descriptive Statistics Dependent Variables***
sum W2ABDrctnlChrgng
```

```
sum W2A_MaxTimeLocations
sum W2A_MaximumComp
sum MaximumDistance_Home
sum MaximumDistance_Work
sum PlugInHours_MaxComp
sum MxChrgngHrs
***Fisher Exact Tests***
*Owning an EV explains W2A BiDirectional Charging Programs
tabulate EVOwnr W2A_BiDirectionalCharging, chi2 exact expected V
*EV Miles per Year explains W2A BiDirectional Charging Programs
tabulate EVAnnlMls W2A_BiDirectionalCharging, chi2 exact expected V
*Days worked from home explains W2A BiDirectional Charging Programs
tabulate WFH W2A_BiDirectionalCharging, chi2 exact expected V
*Home solar panels explains W2A BiDirectional Charging Programs
tabulate HmGnSlr W2A_BiDirectionalCharging, chi2 exact expected V
*Another car available explains W2A BiDirectional Charging Programs
tabulate OthrCr W2A_BiDirectionalCharging, chi2 exact expected V
*Urban/rural home location explains W2A V2G programs
tabulate UrbnRrl W2A_BiDirectionalCharging, chi2 exact expected V
*Housing type explains W2A BiDirectional Charging Programs
tabulate SFH W2A_BiDirectionalCharging, chi2 exact expected V
***Tests for Normal Distribution of Outcome Variable (Shapiro-Wilk test)***
swilk W2A_MaxTimeLocations
swilk MaximumDistance_Home
***OLS Regression Analysis***
*W2A Bidirectional Charging Programs Maximum Times/Locations
*Home Characteristics Model
twoway (scatter W2A_MaxTimeLocations SFH)(lfit W2A_MaxTimeLocations SFH)
twoway (scatter W2A_MaxTimeLocations UrbnRrl)(lfit W2A_MaxTimeLocations UrbnRrl)
twoway (scatter W2A_MaxTimeLocations HmGnSlr)(lfit W2A_MaxTimeLocations HmGnSlr)
```

```
twoway (scatter W2A_MaxTimeLocations EVDrvrYrs)(lfit W2A_MaxTimeLocations EVDrvrYrs)
reg W2A_MaxTimeLocations HmGnSlr SFH UrbnRrl EVDrvrYrs
estat hettest
vif
predict r, resid
swilk r
drop r
*Non-normal residuals, does not meet all OLS assumptions
*Convenience Model
twoway (scatter W2A_MaxTimeLocations EVAnnlMls)(lfit W2A_MaxTimeLocations EVAnnlMls)
twoway (scatter W2A_MaxTimeLocations WFH)(lfit W2A_MaxTimeLocations WFH)
twoway (scatter W2A_MaxTimeLocations OthrCr)(lfit W2A_MaxTimeLocations OthrCr)
twoway (scatter W2A_MaxTimeLocations EVDrvrYrs)(lfit W2A_MaxTimeLocations EVDrvrYrs)
reg W2A_MaxTimeLocations EVAnnlMls WFH OthrCr EVDrvrYrs
estat hettest
vif
predict r, resid
swilk r
drop r
*Meets all OLS assumptions
*Maximum Distance Home for Bidirectional Charging
*Home Characteristics Model
twoway (scatter MaximumDistance_Home SFH)(lfit MaximumDistance_Home SFH)
twoway (scatter MaximumDistance_Home UrbnRrl)(lfit MaximumDistance_Home UrbnRrl)
twoway (scatter MaximumDistance_Home HmGnSlr)(lfit MaximumDistance_Home HmGnSlr)
twoway (scatter MaximumDistance_Home EVDrvrYrs)(lfit MaximumDistance_HomeEVDrvrYrs)
reg MaximumDistance_Home HmGnSlr SFH UrbnRrl EVDrvrYrs
```

```
estat hettest
vif
predict r, resid
swilk r
drop r
*Non-normal residuals, does not meet all OLS assumptions
*Convenience Model
twoway (scatter MaximumDistance_Home EVAnnlMls)(lfit MaximumDistance_Home EVAnnlMls)
twoway (scatter MaximumDistance_Home WFH)(lfit MaximumDistance_Home WFH)
twoway (scatter MaximumDistance_Home OthrCr)(lfit MaximumDistance_Home OthrCr)
twoway (scatter MaximumDistance_Home EVDrvrYrs)(lfit MaximumDistance_Home EVDrvrYrs)
reg MaximumDistance_Home EVAnnlMls WFH OthrCr EVDrvrYrs, robust
vif
predict r, resid
swilk r
drop r
*Meets all OLS assumptions
```

Appendix C

Survey Figures

Figure C1

Bidirectional Charging Concerns - Privacy

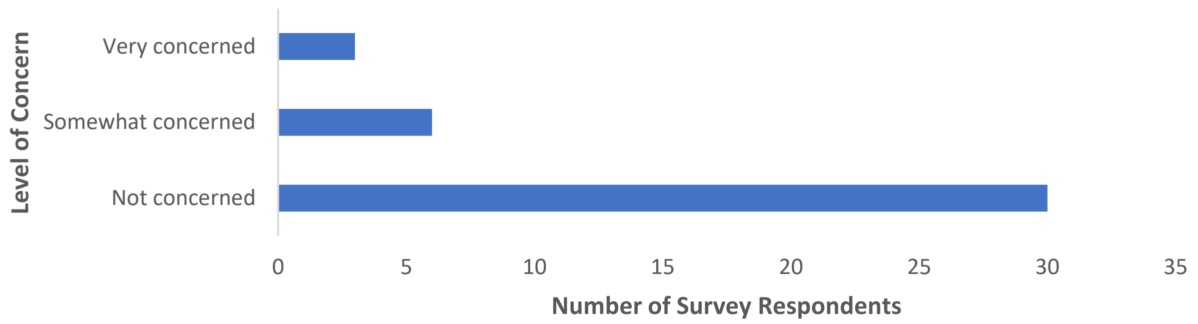


Figure C2

Bidirectional Charging Concerns-Access to Chargers

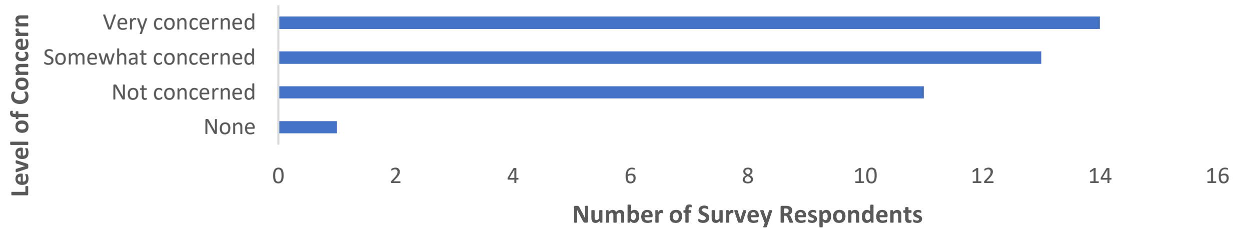


Figure C3

Bidirectional Charging Concerns- Complexity of Using Bidirectional Charger

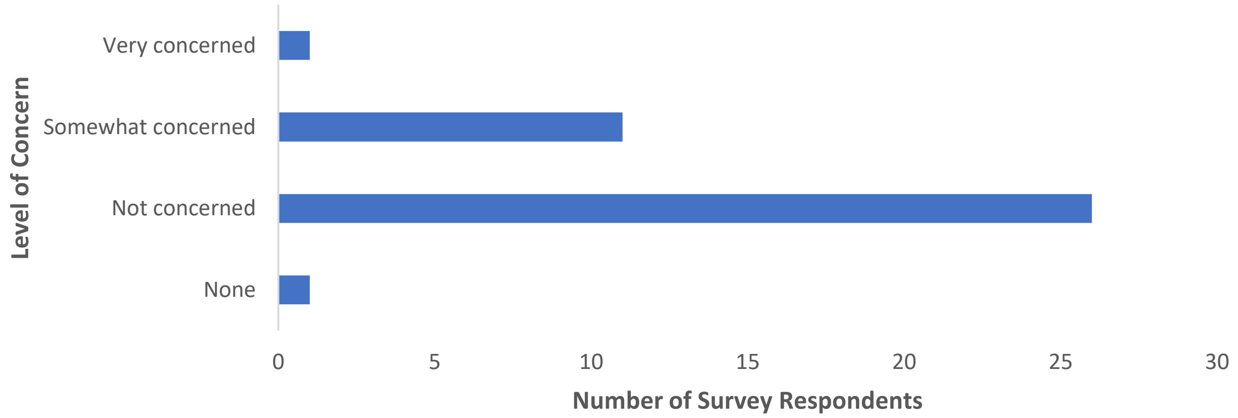


Figure C4

Bidirectional Charging Concerns-EV Battery Warranty

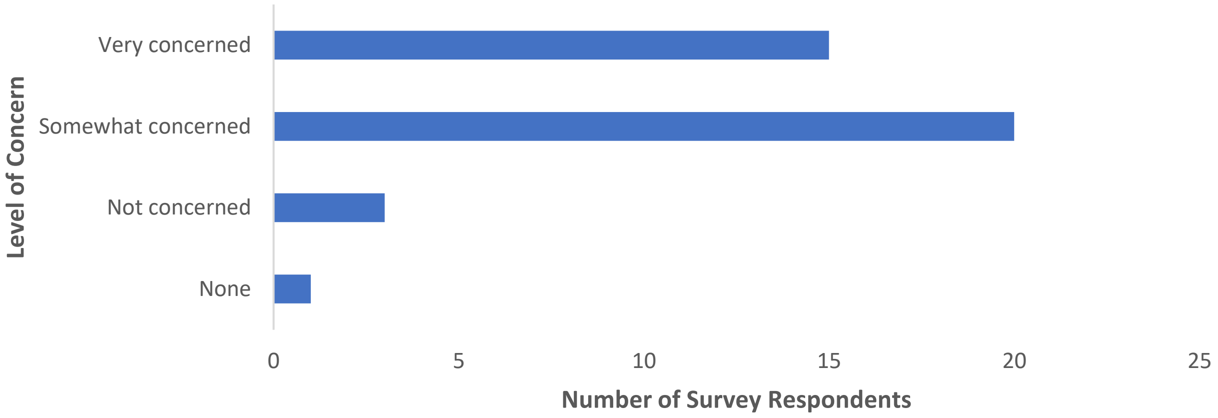


Figure C5

Bidirectional Charging Concerns-Guaranteed Mielage Range

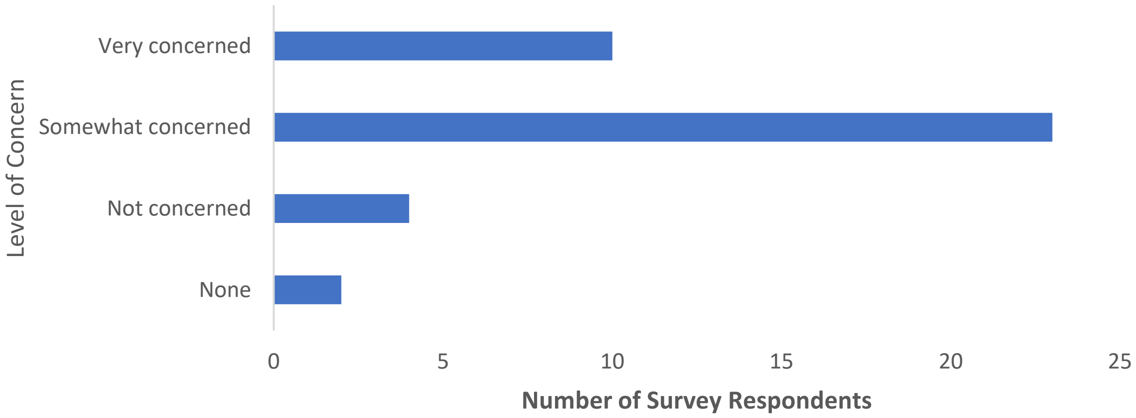


Figure C6

Bidirectional Charging Concerns-Ability to Plan EV Charging Schedules in Advance

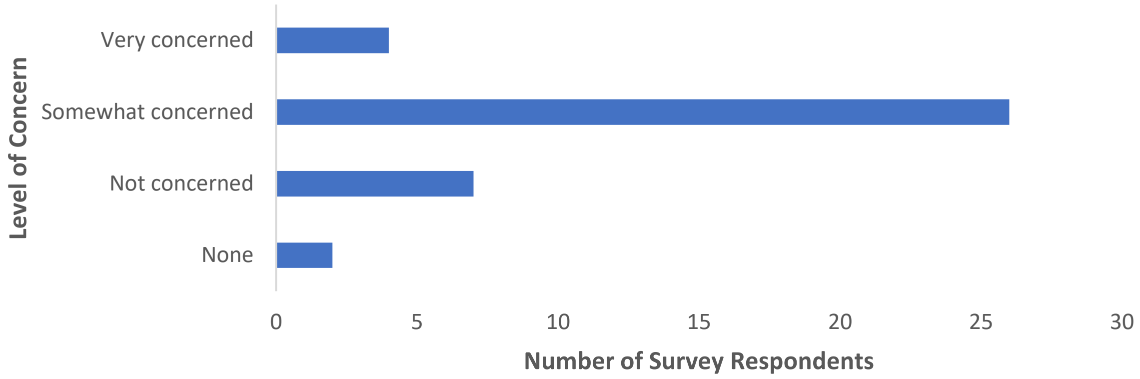


Figure C7

Bidirectional Charging Benefits

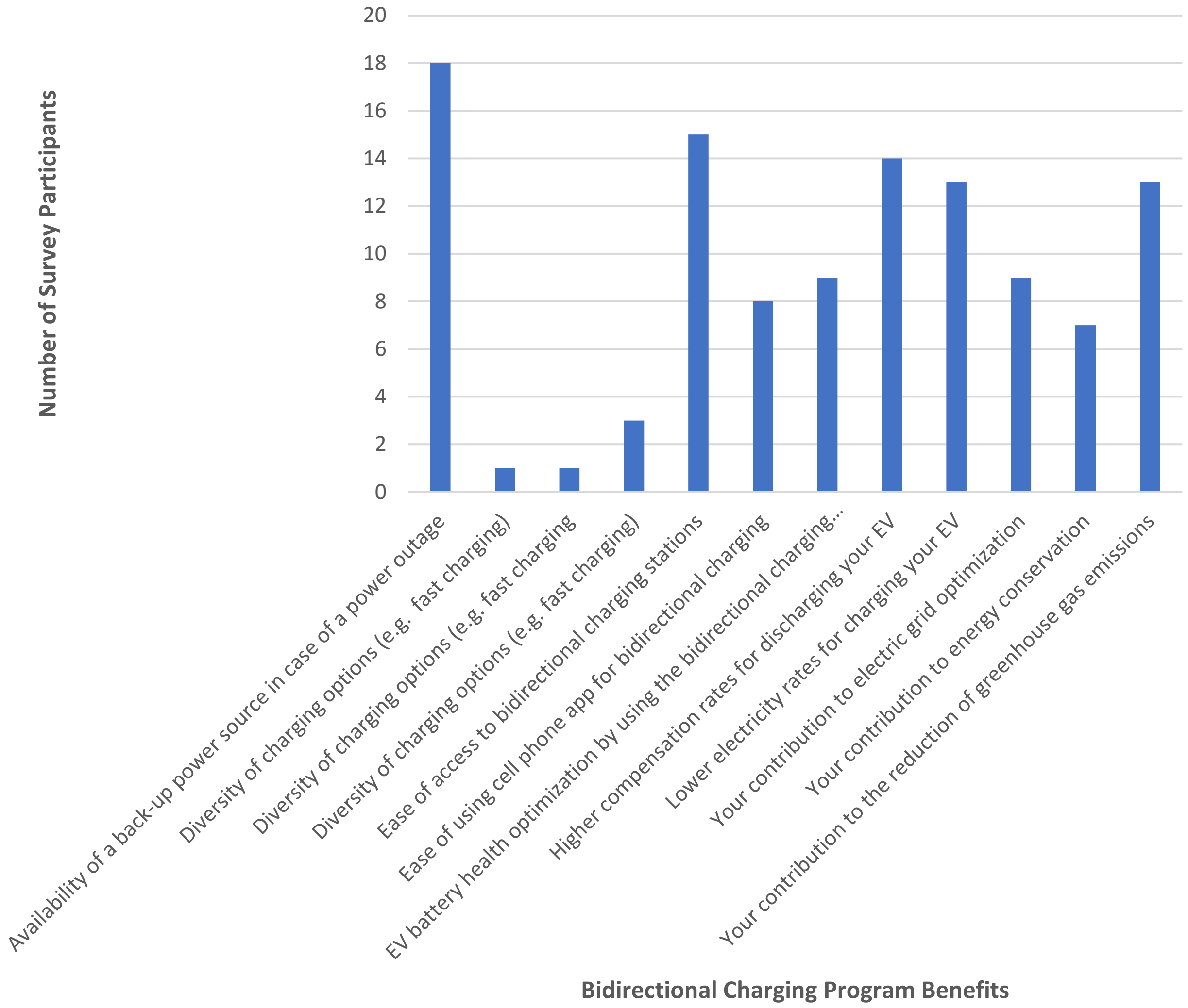


Figure C8

Plug-In Hours with No Compensation

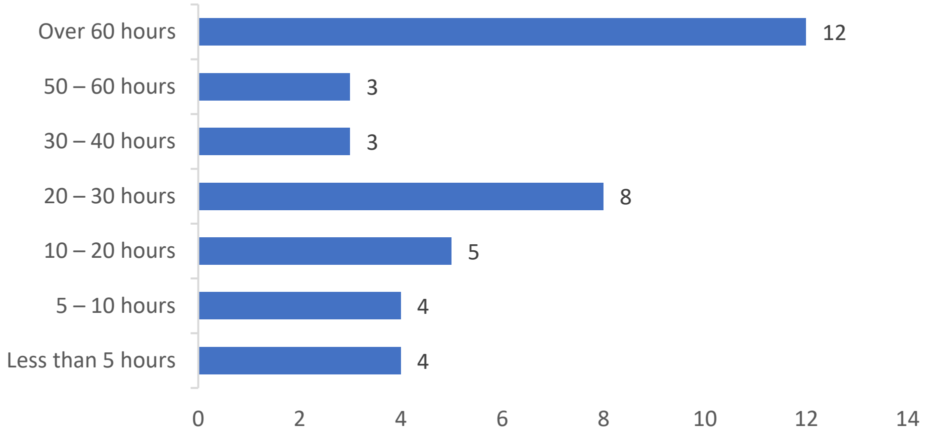


Figure C9

Additional Plug-In Hours with $0.5 Compensation

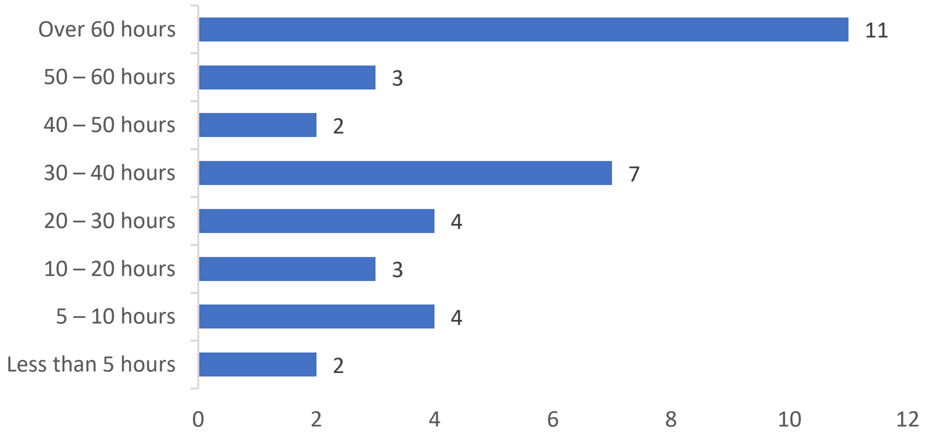


Figure C10

Additional Plug-In Hours per Week with $1 Compensation per Hour

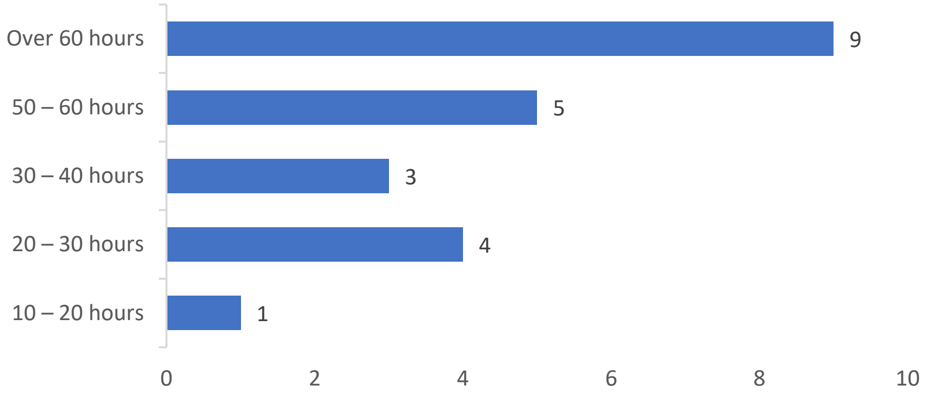


Figure C11

Cummulative Willingness to Bidirectional Charge -Locations

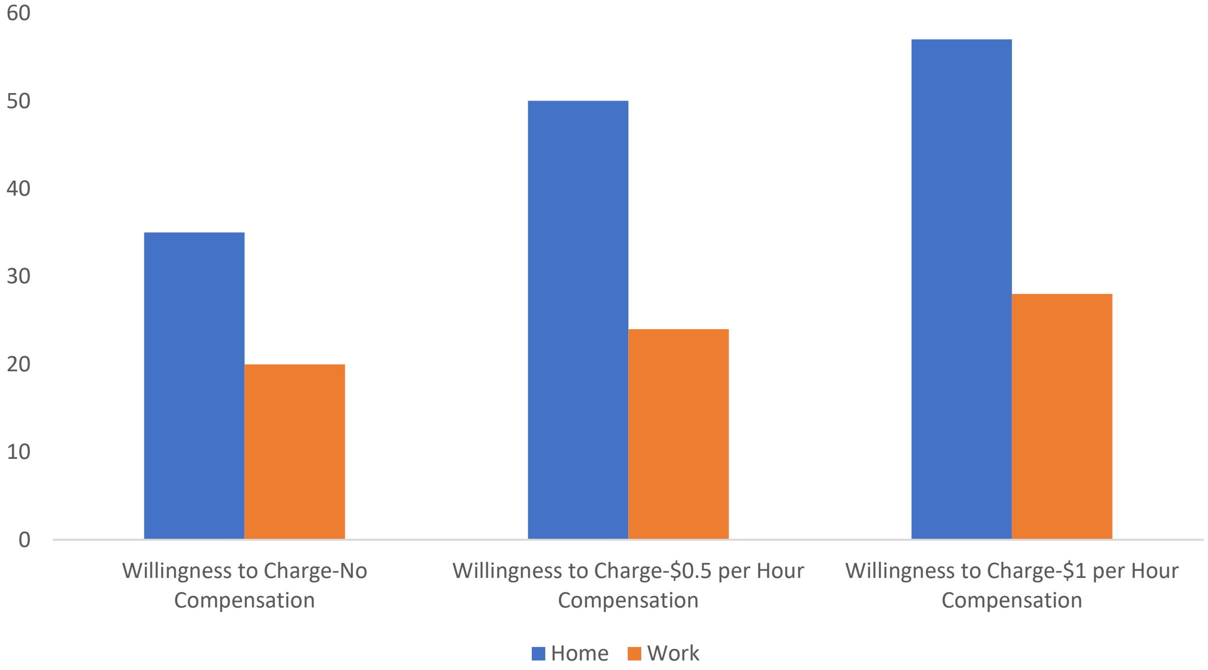
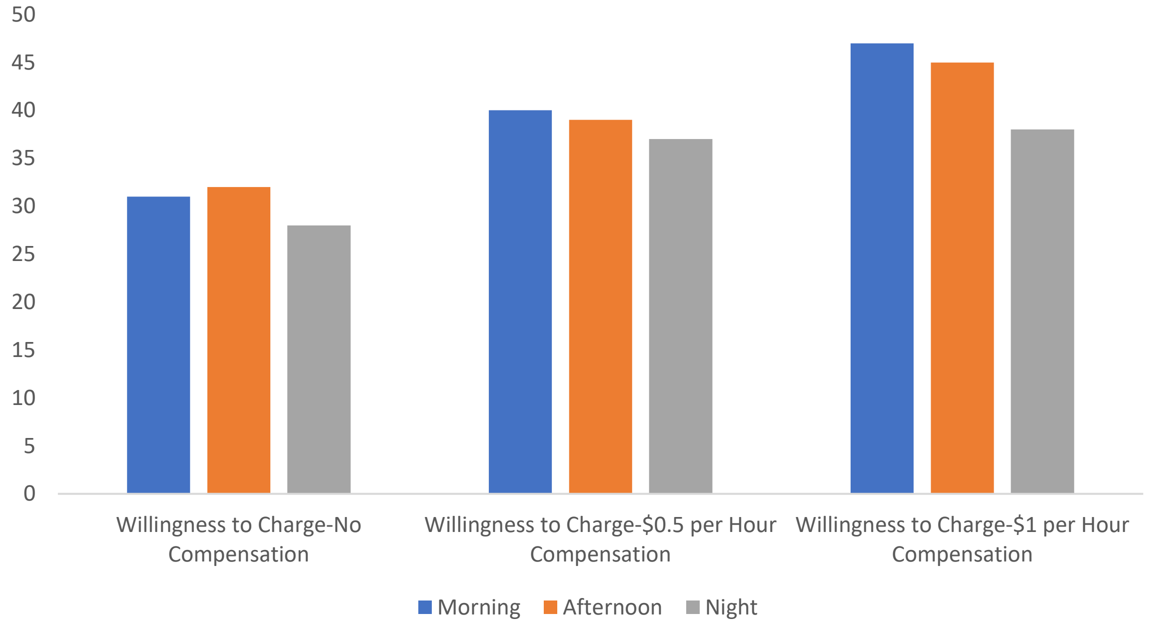


Figure C12

Cummulative

Willingness to Bi-Direcitonal Times



Appendix D

Net Present Value Calculations

Table D1

Net Present Value Calculations

Discount Rate	0.53		
Year	Initial Investment	Bidirectional Charging Compensation (40 Hours/Week, Low Compensation Scenario)	Present Value Formula
0	($5,500)	$ -	($5,500)
1	-	$811	$530
2	-	$811	$346
3	-	$811	$226
4	-	$811	$148
5	-	$811	$97
		Net Present Value of Bidirectional Charger	($4,152.32)
Year	Initial Investment	Bidirectional Charging Compensation (50 Hours/Week, Low Compensation Scenario)	Present Value Formula
0	($5,500)	$ -	($5500)
1	-	$1,014	$663
2	-	$1,014	$433
3	-	$1,014	$283
4	-	$1,014	$185
5	-	$1,014	$121
		Net Present Value of Bidirectional Charger	($3,814.99)
Year	Initial Investment	Bidirectional Charging Compensation (40 Hours/Week, High Compensation Scenario)	Present Value Formula
0	($5,500)	$ -	($5,500)
1	-	$1,788	$1,169
2	-	$1,788	$764
3	-	$1,788	$499
4	-	$1,788	$326
5	-	$1,788	$213
		Net Present Value of Bidirectional Charger	($2,528.79)
Year	Initial Investment	Bidirectional Charging Compensation (50 Hours/Week, High Compensation Scenario)	Present Value Formula
0	($5,500)	$-	($5,500)
1	-	$2,236	$1,461
2	-	$2,236	$955
3	-	$2,236	$624
4	-	$2,236	$408
5	-	$ 2,236	$267
		Net Present Value of Bidirectional Charger	($1,784.33)

Appendix E

EV Battery Capacity

Table E1

EV Driver Battery Capacity

Model	Number	Battery (kWh)	Total Battery Capacity (kWh)
i3	1	42	42
Bolt EV	4	60	240
Mustang Mach E California Route 1	1	88	88
Mustang Mach E Premium	1	68	68
Mustang Mach-E Select	1	68	68
Clarity PHEV	1	17	17
Leaf S	6	40	240
Leaf S Plus	5	62	310
Model 3 Long Range	8	78	624
Model 3 Performance	3	78	234
Model 3 Standard Range Plus	1	55	55
Model S Long Range	2	100	200
Model S Plaid	1	100	100
Model X Performance	1	100	100
Model Y Long Range	6	75	450
Average Battery Capacity (kWh)			68.73
Source: (EV Adoption, 2020)			

Appendix F

Master of Public Administration Competencies

2. Participate in and contribute to the public policy process: This capstone project included a literature review that assessed the current policy landscape for bidirectional charging programs in Colorado and beyond. The barriers to bidirectional charging programs were also investigated, including from a policy perspective. Recommendations were made specifically for bidirectional charging programs in Colorado to help address these barriers with respect to the development of collaboration efforts via networks that could help advance bidirectional charging program policies within the existing regulatory landscape. Furthermore, the capstone project recognized connections between public policy and the private sector through analyzing the role of Xcel Energy, Colorado's largest electric utility provider, in bidirectional charging program adoption.

Coursework supporting this competency includes: PUAD 5004-Economics and Public Finance, PUAD 5005-Public Policy and Democracy, PUAD 5130 Collaboration Across Sectors PUAD 5631-Seminar in Environmental Policy and Politics, and PUAD 5644 Environmental and Hazards Law.

3. Analyze, synthesize, think critically, solve problems, and make decisions: This capstone project required developing appropriate research methods based on a review of the current literature regarding bidirectional charging programs. The literature review resulted in development of a survey and subsequent analysis of the survey data via appropriate descriptive and inferential statistics, data visualizations, and micro-and macro-scale estimations of return on investment (ROI) based on the survey responses and other data sources from reputable references, including regulatory filings from Xcel Energy and state agencies such as the

Colorado Energy Office. The survey data and ROI calculations were then utilized to make data-driven policy recommendations with respect to policy strategies that may be employed to increase the cost-effectiveness of bidirectional charging programs in Colorado based on the current policy landscape as well as the existing behaviors and characteristics of Colorado EV drivers.

Coursework supporting this competency includes: PUAD 5003-Research and Analytical Methods, PUAD 5004-Economics and Public Finance, and PUAD 5008-Evidence-Based Decision-Making

5. Communicate and interact productively with a diverse and changing workforce and citizenry: This project required partnering with a Colorado 501(c)(3) non-profit, the Colorado Smart Cities Alliance, to develop the research question, project proposal, and survey. Communications with the project client included a kick-off meeting, survey review, and final presentation of the project results. In addition, this capstone project required outreach to the Colorado EV driver community throughout various regions of Colorado via Colorado EV Clubs listed on the Drive Electric Colorado EV website through survey invitations, email, and social media.

Coursework supporting this competency includes: PUAD 5002 Organizational Management and Behavior, PUAD 5006 Public Service Leadership and Ethics, and PUAD 5631 Seminar in Environmental Management