Introducing smart grid communication through telematics-based applications

Abigail Braun, Chris Johnson
ADM Associates Inc

ABSTRACT

Smart device applications that allow communication between supply and consumer electricity demand are an integral step in transitioning to Smart Grid (SG) technology. SG technology includes overlaying a hierarchical communication system on the power grid (Abrahamsen, Ai, Cheffena 2021). Because apps are easily attainable and low cost, an app could initially serve as that communication system while familiarizing consumers with SG technology, encouraging future buy in.

A pilot program was designed and evaluated where participants were asked to download an EV charging management app. The app offered a telematics-based EV charging management service to participants who were rewarded with electricity bill credits for charging during low carbon events. It also automatically pushed charging times to periods when the grid was supplied with cleaner energy. The evaluation found statistically significant kW reductions, annual kWh savings (potentially due to behavioral changes), and carbon reductions per-participant (Thomas, Offenstein, and Johnson 2023).

Participants perceived automated cost savings and automated carbon reduction as large benefits of the app (67% and 61% respectively) (Thomas, Offenstein, and Johnson 2023). Previous studies have found consumers are more likely to accept new technology if the perceived value outweighs the perceived risk and cost of adoption (Ellabban and AbuRub 2016). The evaluation found the telematics-based approach had a 37% lower cost over ten years than the installation of smart charging hardware (Thomas, Offenstein, and Johnson 2023). The lower cost and accessibility of an app along with perceived large benefits could sway consumers towards adopting SG technology.

Introduction

Globally, EVs are projected to reach 28% of all new car sales by 2030. Additionally, according to the DOE, 80% of EV car owners charge their car overnight at their residence. This has several implications and possibilities regarding the evolution of the Smart Grid: namely, charging management opportunities, battery storage potential, and changes in grid load distribution management. A study from NREL (2021) indicates that charging management-based benefits of vehicle electrification include reduced emissions, lower utility operating costs, and less dependence on fossil fuel resources (Blonsky, Munankarmi, and Balamurugan 2021).

Increased demand due to charging needs has been a concern in the design and operation of residential distribution networks. Increased demand would work against carbon neutral initiatives if the energy were not coming mainly from renewable energy resources. Therefore, it is necessary to have an infrastructure upgrade to a more advanced energy distribution network that can guide energy use towards times where energy supply is cleaner. According to Kabalci

(2016), the bidirectional flow of energy and communication signals is the main contribution of SG technology to the existing power grid.

A Smart Grid can be primarily defined as an existing electricity grid enhanced with load-controlling demand-side management technology (Perri et al 2020). To begin this demand side management, an overlying hierarchical communication system must be established between the utility and the consumer (Abrahamsen, Ai, Cheffena 2021). This communication makes it possible for energy consumption patterns to be controlled by the utility when necessary, such as during peak hours or low carbon events (Perri et al 2020). In this system, the idea is that demand follows supply instead of supply following demand as it has been for the past century (Ellabban and AbuRub 2016). This creates a more efficient, environmentally sustainable, and economic energy production and distribution system (Abrahamsen, Ai, Cheffena 2021). Customers currently have a more passive relationship with energy consumption, but a Smart Grid transformation may require a more active role from consumers. (Ellabban and AbuRub 2016).

The electric power system faces several challenges including an aging infrastructure, integrating renewable energy resources into the existing power supply, improving security of supply, and reducing carbon emissions (Ellabban and AbuRub 2016). Additionally, the intermittency and high variability of renewable energy systems (RES) is a challenge because it is not adaptable to demand cycles. This unreliable nature of RES is not accounted for in the current power grid but could be countered by a Smart Grid system (Perri et al 2020). Pedro, Polasko, and Molina (2016) specify that smart grid technology increases the implementation of renewable energy in electricity markets, can help alleviate the issues of global climate change, and will help improve environmental and financial conditions for end users. Barman et al (2023) adds that smart charging brings several benefits and provides cost-effective opportunities to use various RES (Barman et al 2023).

Because the residential sector uses 30% of global electricity, integrating smart grid technologies into existing residential areas could make a significant difference in carbon reduction and electricity savings (Ellabban and AbuRub 2016). However, this is highly dependent on customer acceptance and engagement of smart grid technology. Marketing the SG by establishing a familiar channel of system management in the form of apps could help familiarize consumers with the idea of managing demand based on supply. The initial familiarity with smart grid technology through the app will create a more subjective norm - the perceived social pressure to perform the behavior - among EV owners, encouraging a higher rate of future public buy in (Perri et al 2020).

Chadoulos, Koutsopoulos, and Polyzos (2020) further support the idea that apps have a positive impact on electricity consumer engagement and overall smart grid efficiency. Their 2020 study observes how mobile apps can facilitate smart grid technology and found that apps contribute to smart grid efficiency through consumption reduction and demonstration of improved flexibility or load shifting (Chadoulos, Koutsopoulos, and Polyzos 2020).

The top two factors that influence customers’ willingness to accept and adopt new technology includes showcasing the ease and simplicity of the user interface through clear visuals, intuitive settings, and simple steps for setting preferences, and pre-programmed default settings. The second factor includes highlighting the benefits of a SG, including long-term financial benefits, which is vital to its social marketing and political success (Ellabban and AbuRub 2016). It is also important to give customers various options that suit their needs and meet them where they are (Paqueo 2024).

Ecobee (2024) performed a study on smart thermostat demand response (DR) with the aim of reducing peak demand during summer in California. The study utilized an opt-in design for the DR program, with participants being able to opt out after being notified of a DR event, and the study found opt out rates were low at 5%. This was found to be much more successful than attempting behavioral change with the opportunity to opt in (Paqueo 2024). Highlighting the benefits of participation - such as the quantity of emissions saved and economic savings - encourages environmentally friendly preference settings and maintenance of preset defaults. This incentivizes and creates an intrinsic motivation for customers to save more energy (Ellabban and AbuRub 2016).

One drawback is the lack of inclusivity when integrating these new technologies into society. According to the National Telecommunications and Information Administration (2022), 58% of the 24 million households without broadband internet in the United States express no interest in being online, while 18% would like broadband internet, but cannot afford it (NTIA 2022). Creating a more equitable system is a complex obstacle which is beyond the reach of this Pilot study but is important to consider in the greater body of research surrounding smart grid creation.

For Smart Grids to effectively change the energy landscape, the public must accept and engage with the new technology. Acceptance and engagement will depend on consumer perceived costs and benefits, subjective norms, outreach and communication from stakeholders, and customer education with the technology to grow familiarity. It will also depend heavily on public attitude towards SG technology. People assess costs and benefits when determining whether to perform a behavior. Individuals tend to hold a favorable attitude when the outcomes are positively evaluated and thus the benefits from the behavior are worth the costs (Perri et al 2020). This is why it is important to highlight benefits of the system so that consumers' normative beliefs are that it helps save money, is good for energy stability, and cuts carbon emissions.

Bugden et al (2021) as well as others support the claims that outreach and communication should focus on increasing familiarity with smart grid technology (Bugden et al 2021; Chadoulos, Koutsopoulos, and Polyzos 2020). They also support the idea that outreach and communication should highlight the climate benefits of smart meter enabled products and services. Further, they rightfully communicate that not all segments of the population will adopt the technology regardless of outreach and communication. Trust in the utility is a central factor in the technological transition to smart grid technologies (Bugden et al 2021).

Methods

The EV Charging Application was developed as part of a grant funded telematics-based program. The telematics-based application was designed to sway electric vehicle (EV) charging times towards low carbon events and help customers save money on electricity bills. The app notified participants of when there was a substantial amount of clean energy available on the grid and rewarded them for charging during those events with points that could be redeemed for electricity bill credits. The app was fully automated to reduce retail costs to the customer and minimize emissions (Thomas, Offenstein, and Johnson 2023).

Two treatments were utilized in the study. The first was directed towards long-term charging management (steady state) while the second focused on low carbon events and pushing EV charging to times where the grid was supplied with cleaner energy. Long-term (steady state) refers to treatment that occurs every day of the year through the app's automatic optimization algorithm.

A load shape analysis was conducted to evaluate the treatment group of 50 single-family participants with complete hourly AMI interval data for the period of February 2021 to October 2021. Thirty-minute telemetry data containing EV charging was obtained and used to confirm participant charging patterns. However, the telemetry data was not utilized to estimate impacts because it did not cover the period prior to treatment. A non-participant control group of 50 customers was chosen by matching hourly AMI interval data prior to the pilot program for comparison (Thomas, Offenstein, and Johnson 2023).

The following approaches were employed to estimate impacts from the Pilot program:

- *Propensity Score Matched (PSM) Comparison Group.* This approach estimated demand impacts by comparing hourly usage for participants with a matched control group. The modeling effort included hourly AMI meter consumption data from participants and control customers. This method was utilized for both treatments.
- *Prior Day Customer Baseline (CBL).* This approach estimated demand impacts for participants by comparing their hourly usage during low carbon events with average prior non-event and non-holiday weekday hourly usage. This modeling effort included hourly AMI meter consumption data from participant customers. This method was utilized for treatment 2 (low carbon emissions events).

Further details on each treatment group and the respective evaluation methodology are provided below.

Treatment 1

Program impacts for Treatment 1 were estimated using a matched control group. Treatment 1 was applied to all customers who signed up to participate in the Pilot. For Treatment 1, charging was primarily optimized to reduce retail costs to the customer by selecting customers on EV-2A, EV-A, EV-B, TOU, and standard rates. The app moved Treatment 1 charging to off-peak times) with a secondary optimization applied to minimize emissions.

Treatment 1 Methodology

A matched comparison group was created using a Propensity Score Matching (PSM) approach. With the PSM approach, a propensity score was estimated for treatment customers (i.e., those who received Treatment 1 and Treatment 2) and a group of customers who did not receive the treatment using a logit model. Customers in the treatment and control groups were matched based on average weekly pre-period usage and exactly matched based on their quartile of average hourly load during hour 1:00 (charging peak) and hour 16:00 (mid-day peak). It was found that this combination of matching variables produced the closest match for average pre-period annual, monthly, weekly, and hourly usage.

Hourly AMI data was provided for non-participant customers with electric vehicles from which control customers were selected.

Treatment 2

Treatment 2 impacts were estimated using prior day matching and a matched control group. Treatment 2 consisted of low carbon emissions events where customer vehicles would charge during the event if their vehicle was connected to the charging unit. For Treatment 2, customers were notified via the app a day in advance of an event time where the grid was especially clean. Participants were informed that the platform would automatically charge their vehicle if it was plugged in during the event time.

Treatment 2 Methodology

Program impacts for carbon shift were estimated using prior day CBLs and a matched control group. Prior day CBLs involved taking average hourly usage on 5 (or 10) non-event, non-holiday weekdays, prior to the carbon shift event day. The CBLs do not utilize hours within the carbon shift event window, which was defined as 12 hours before and after the carbon event midpoint time. The matched control group method was the same one used for Treatment 1.

Cost Benefit Analysis

Smart chargers are EV chargers able to connect to the cloud, allowing the charging station owner to manage, monitor, and restrict energy usage to optimize energy distribution (Barman et al 2023). The telematics-based approach to smart charging establishes communication between the app and the vehicle while the charger only serves to deliver power to the vehicle. Smart chargers have the same type of management function as the app.

For this study, the net present value (NPV) was determined by gathering pricing data for nine models of consumer-ready smart chargers with the ability to control charging similarly to the app. The average purchase price for smart chargers was $984 with a median value of $899. To analyze the cost of the app, the monthly subscription fee for High Mobility was utilized. This developer provides telematics access for BMW, Ford, Mercedes-Benz, and MINI. Pricing ranged from $2.93 - $9.32 USD per month for continued access. The midpoint value of $73.50 per year was utilized for this analysis (Thomas, Offenstein, and Johnson 2023).

The NPV was projected over a ten-year period with a 2% annual increase in the app subscription price based on the long-term consumer price index (Thomas, Offenstein, and Johnson 2023).

Participant Survey

A survey was distributed to all participants with 38 out of 69 (55%) Pilot participants responding. Participants were asked a range of questions regarding charging equipment, charging practices, motivation for participation in the Pilot, and feedback on the overall app experience (Thomas, Offenstein, and Johnson 2023).

Results and Discussion

Participants showed statistically significant kW reductions and CO_2 emission reductions. The steady state treatment using the app showed annualized per participant impacts of 0.05 peak kW reduction, 255 kWh normalized annual savings, $76 in energy cost savings, and 248 lbs. of

CO_2 saved. The carbon shift treatment showed impacts of 0.078 peak kW reduction and 3.78 lbs. of CO_2 saved per participant for all carbon events (Thomas, Offenstein, and Johnson 2023).

The primary function of the app was to redirect charging needs to periods that are price- and carbon-optimized. The annual kWh savings found in the model indicate that beyond this, there is an impact from the app that is resulting in lower charging need. This could only happen through reduced vehicle miles traveled, as the app does not have a means to produce energy use reductions. It is possible that engagement with the app increased awareness of energy use and costs, which could result in fewer miles traveled for some users (perhaps through reduced discretionary trips, increased carpooling, etc.). Given that a Randomized Control Trial was not utilized, further research is necessary to confirm the presence of kWh savings, because even slight differences in participant and control group usage patterns that remain after matching could account for this finding (Thomas, Offenstein, and Johnson 2023).

NREL created a residential energy model using OCHRE that accounted for EVs being charged by a specific time for resident convenience. The model simulated a community with high EV penetration. The study supports the app Pilot research findings that smart charging technology can reduce peak demand on the energy grid. Smart charging also can smooth or more evenly distribute nighttime energy distribution by spacing out charging times for more level load demand. The simulation revealed that the proposed control framework nearly eliminates peak period EV charging and reduces the daily peak demand from EVs by 23% which was also supported by the Pilot study (Blonsky, Munankarmi, and Balamurugan 2021; Thomas, Offenstein, Johnson 2023).

Consumers are more likely to accept this technology if the perceived value of the technology outweighs the perceived risk and cost of adopting it. This is the basis of the Value-based Adoption Model (VAM) (Ellabban and AbuRub 2016). Adoption intention is determined when individuals compare the perceived value and sacrifices involved in decision making (Ellabban and AbuRub 2016). Individuals tend to hold a favorable attitude when the outcomes are positively evaluated and thus the benefit from the behavior is worth the cost (Perri et al 2020). This supports the hypothesis that because participants perceived cost savings and automated carbon reduction as large benefits (67% and 61% respectively), they may be more inclined to adopt app-based technologies outside of the pilot program. Respondents provided the following feedback on perceived benefits of the program as shown in Figure 1. When marketing an app or smart system, it is important to highlight the potential benefits of technology adoption, because perceived benefits are what drive acceptance.

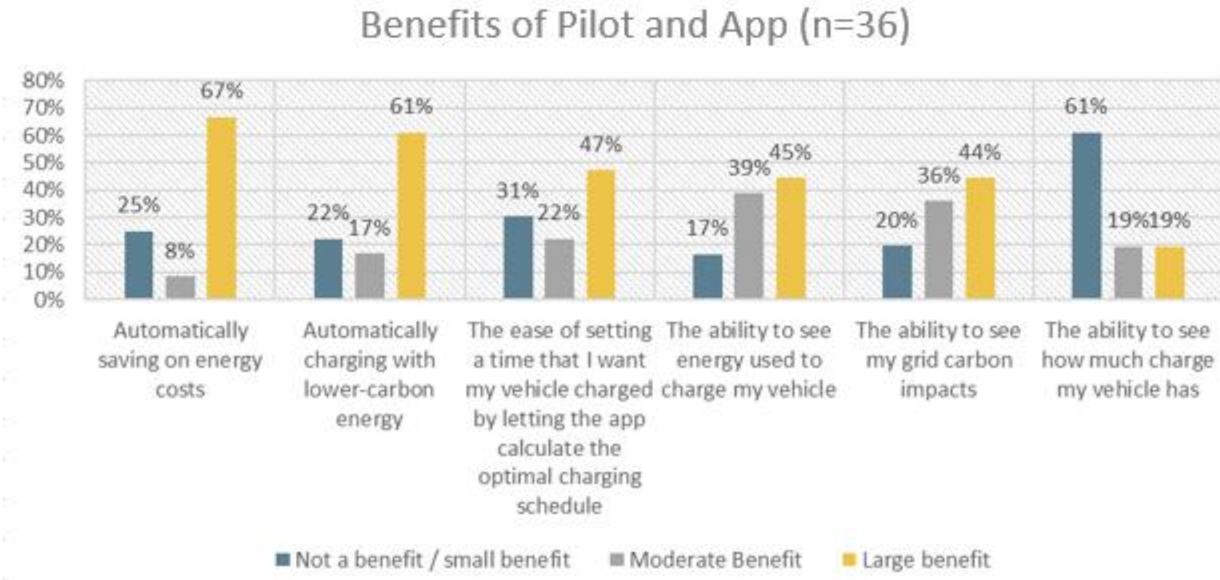

Figure 1 Perceived Benefits of Pilot and App

As mentioned in the Introduction, normative beliefs play a large role in persuading customer attitude towards technology adoption. Figure 2 shows respondent results when asked if they would recommend the app to others. The results were mixed in terms of technology acceptance. The 33% who said they would not recommend the app indicated that it was because the app provided little benefit over the car software. However, 33% said that they would recommend the app to some and the remaining 33% said they would recommend the app to anyone (Figure 2). Having 66% of respondents willing to at least recommend the app to some would theoretically influence the subjective norm and normative beliefs systems of customers who may not have considered smart charging apps otherwise. Highlighting to customers that this technology helps establish a Smart Grid and painting that in a beneficial light can help shape public belief favorably towards SG technology.

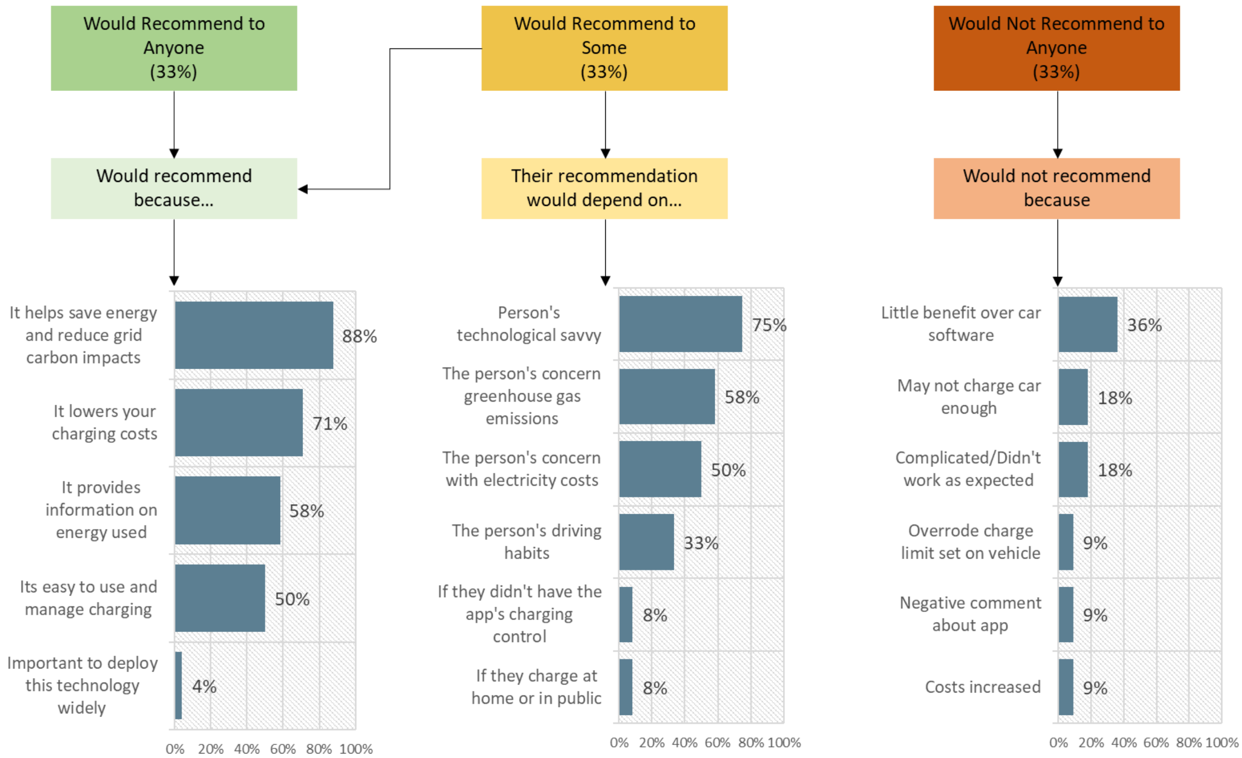

Figure 2 Participant Perspectives on Recommending EV Charging Management App to Others (n=36)

Perri et al. (2020) articulates that several studies have demonstrated that one's intention is positively influenced by their self-confidence in their ability to perform a behavior. Because apps are already so widely used and familiar to consumers, individuals are likely to feel more confident about their ability to navigate an app as an introduction to smart grid technology. This idea is supported in the EV charging management pilot app results with 69% of survey respondents indicating that they were not at all concerned that the app would be difficult to use as shown in Figure 3 along with other attitudes of interest.

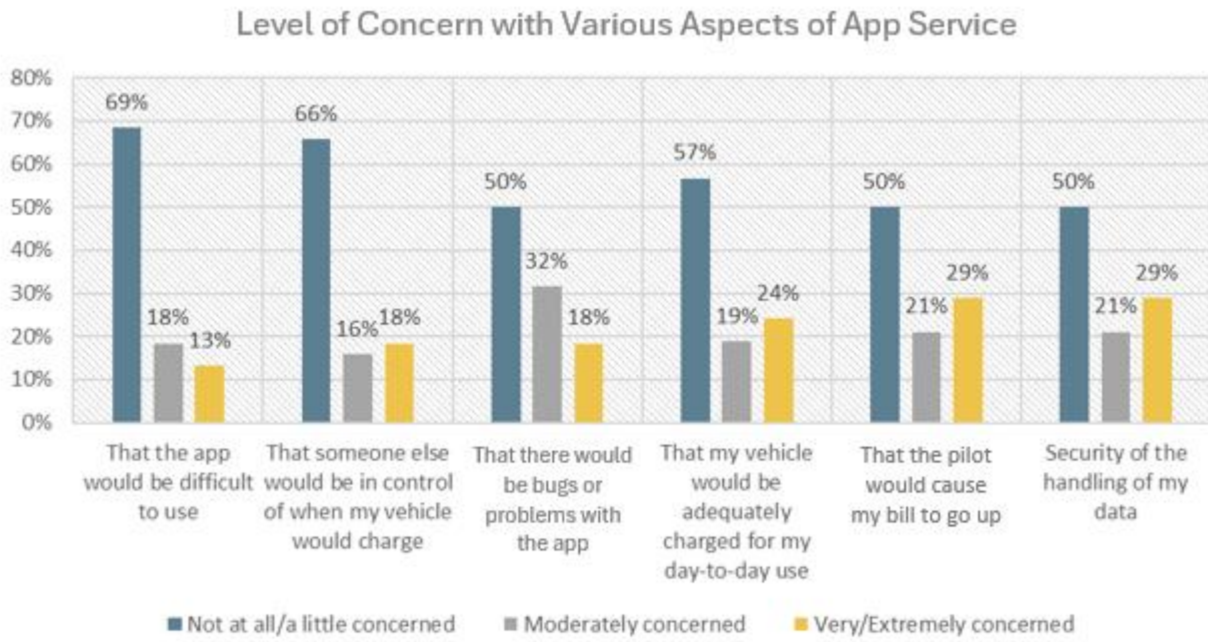

Figure 3 Initial Concern with EV Charging App Service

Perhaps unsurprisingly, respondents were generally "early adopters" of technology with 60% indicating they like to have the newest technology and 32% indicating that they like to adopt new technology once it has been available for some time. Ninety percent (90%) of participants had level 2 charging and 18% had a smart charger. Additionally, all respondents had the capacity to schedule charging using their vehicle's app or software. Forty-three percent (43%) indicated that they have a charger that delayed or scheduled charging.

The case could be made that it does not matter exactly which app consumers use to manage their charging if it cuts carbon, operates in off peak hours, and charges their vehicle to the desired level at the predetermined time. The Tesla app recently introduced technology that allows people to charge their EVs using surplus solar energy (Tesla 2024). Unfortunately, it is only available to customers who own solar panels. For more active communication between utilities and customers, apps specific to EV brand could partner with utilities to facilitate more targeted carbon neutral charging. On the other hand, marketing apps that are constructed around the concept of telematic communication with the utility could potentially be a more effective on ramp towards utility facilitated home energy management. If utility focused apps offer a more robust number of benefits than the EV equipped app, it could be more attractive to potential users.

The main reasons that respondents gave for participating in the pilot were financial, environmental, and the chance to try new software and technology as shown in Figure 4. A very small percentage of respondents were concerned about tracking energy usage or engaging in an energy management trend. Although customers do not consider home energy management to be a main reason to participate, utilizing the app could familiarize customers with the idea that home energy management can facilitate energy cost savings and carbon reduction. Respondents may not have made that connection yet.

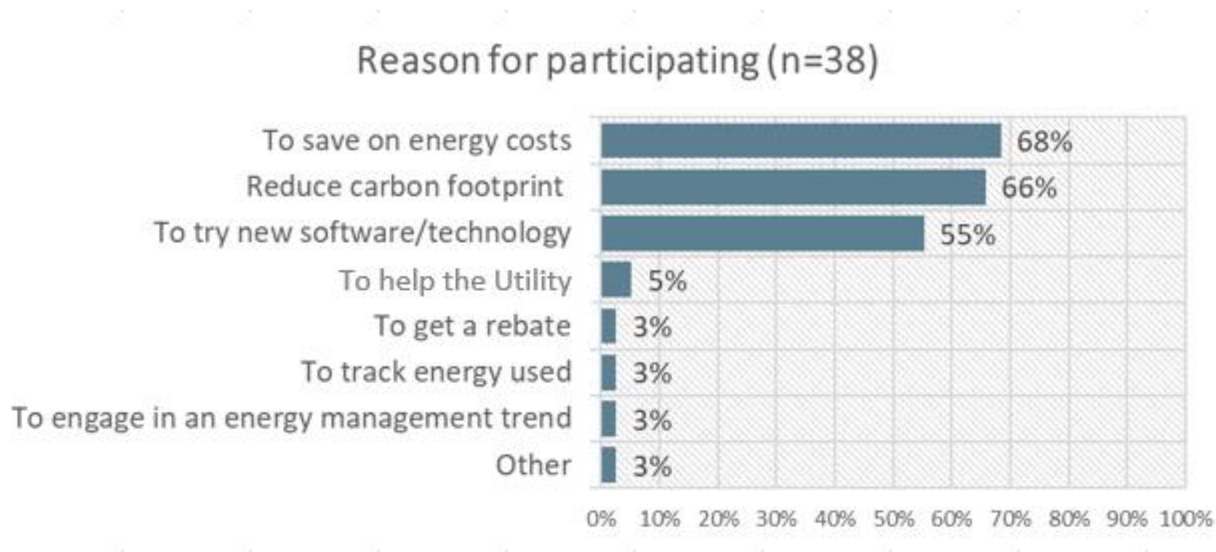

Figure 4 Reasons for Participating in EV Charging Management Pilot

Further, although customers claimed that they did not primarily participate to engage in energy management, 63% claimed that they used the app to view historical charging consumption and costs and 61% used the app to view electricity consumed as shown in Figure 5. This could arguably be considered a passive energy management system, even if not fully realized by participants.

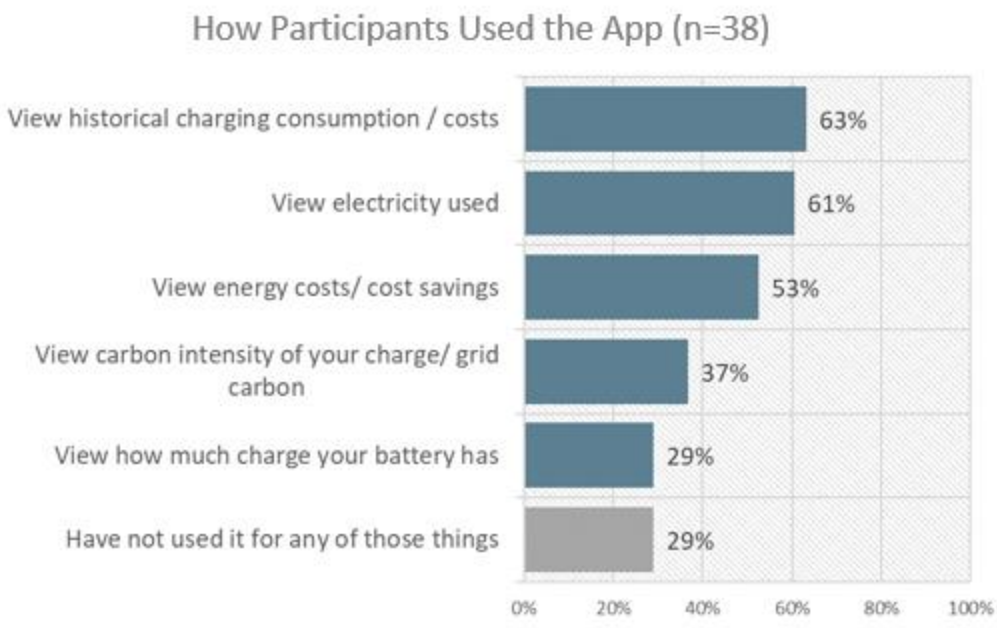

Figure 5 EV Charging Management App Features Used by Participants

Thirty-two percent (32%) of pilot participants took part in charging during a low-carbon event. Of those participants, 75% reported either no impact or a small impact on their ability to use their EV. Additionally, 51% did not recall seeing a low carbon event notification. The app still automated the charging process to charge the vehicle during the low carbon event if it was plugged in at that time. Twenty-five percent indicated that there was an impact on their ability to drive their vehicle due to an event.

As previously mentioned, automatically saving on energy costs, and automatically charging with low-carbon energy were the two largest perceived benefits. However, a more mixed opinion was gathered on actual energy bill cost savings with 68% saying it did not impact their cost, 14% saying it decreased cost, and 19% saying it increased their electricity costs.

Overall, app users reduced energy consumption on a behavioral level in addition to the automated charging optimization. Behavioral improvements are hypothesized to be because the app provides feedback on charging energy usage and costs which may contribute to better overall home energy management. Figure 6 shows that when customers have a way to continuously monitor their own energy usage in real time, the behavioral savings can be even more significant than charging optimization alone.

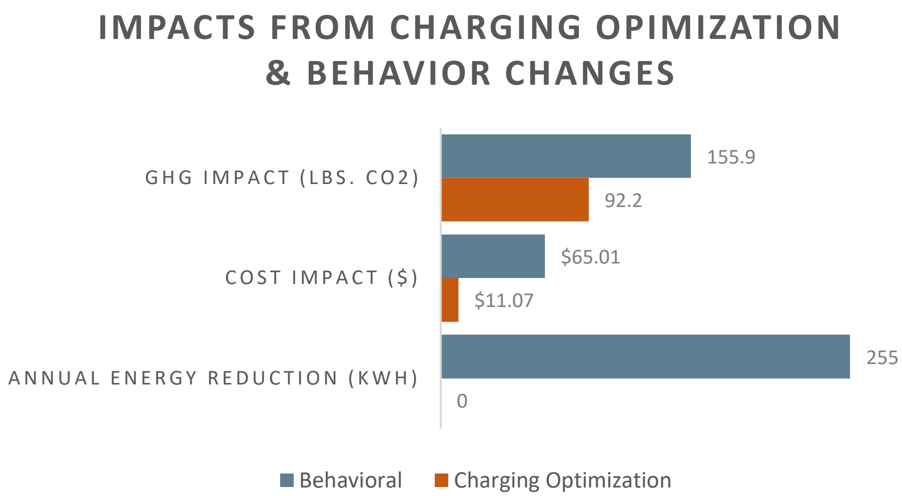

Figure 6 Charging Optimization and Behavior Impacts

The cost-benefit comparison of net present value of an app compared to smart charging hardware found that over a ten-year period, the telematics-based subscription had a lower cost than investing in smart charging hardware as shown in Figure 7. The app works by connecting to the Bluetooth of the electric vehicle and serving the same energy management technological function as smart charging hardware. In most cases, charging hardware that comes with the vehicle is able to be plugged into any standard electric dryer outlet and receive a 220v (level 2) charge, therefore negating the need to purchase a dedicated car charger for any reason other than convenience (US DOE).

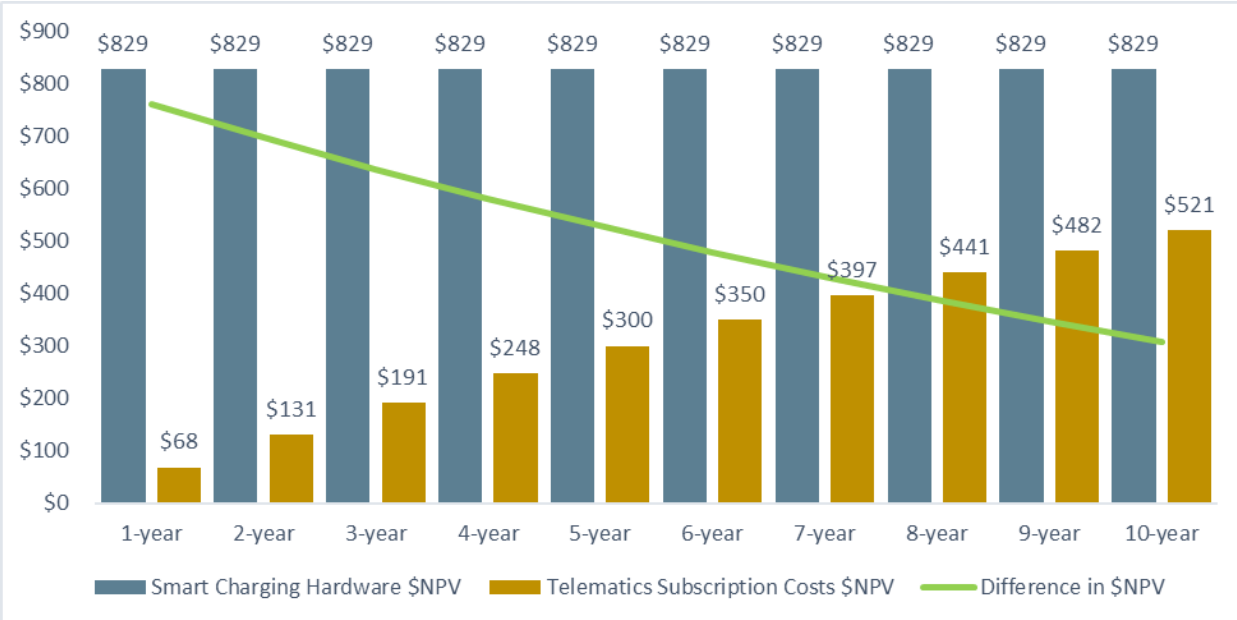

Figure 7 Comparison of $NPV at Differing Analysis Period Lengths

Overall, telematics-based approaches to establishing communication between the grid and customers have a 37% lower cost over 10 years than the installation of smart charging hardware, as shown in Figure 8.

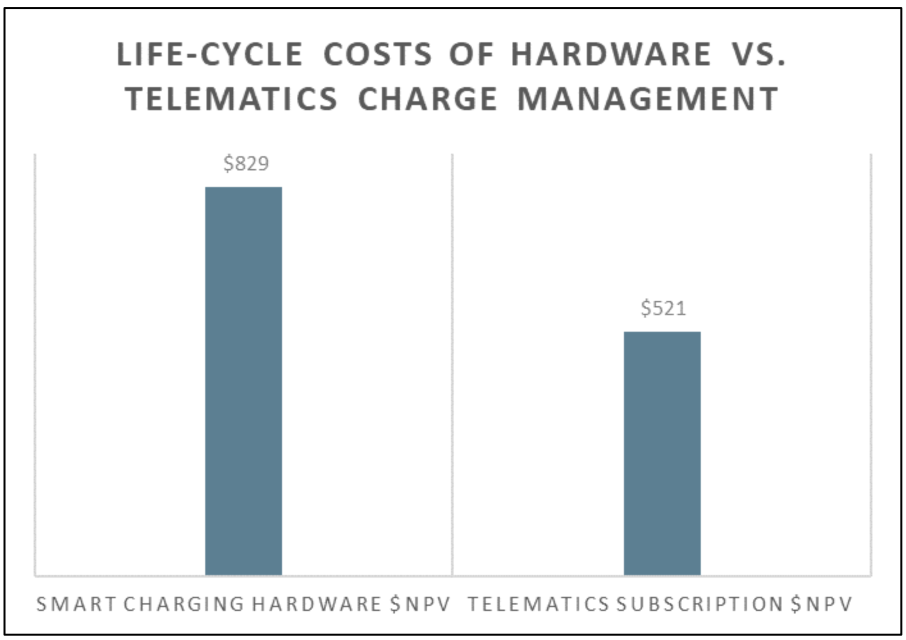

Figure 8 Life Cycle Cost Comparison

The Pilot shows that even a small group of app users can create significant kW savings and carbon reductions which could improve renewable energy supply stability and improve local air quality for all communities. Were this pilot to be expanded to all customers with electric vehicles within a given utility territory, it could make a significant difference in peak load reduction and grid stability for entire communities, not just the customers who can afford EVs and broadband internet.

Conclusion

Several valuable insights can be gained from this pilot research, especially when viewed through a lens that considers sociological studies aimed at new technology adoption in society. Policy makers, utility decision makers, researchers, and industry leaders are situated at the initial juncture of smart grid technology advancement. It is imperative to act in this moment to influence large-scale positive societal acceptance of smart grid technology. The preeminent points of this research study are:

1) Consumers are initially more likely to adopt an app over SG hardware because of lower costs over a 10-year period, lower upfront costs, and perceived large benefits.
2) The app led to annual kWh savings (due to behavioral changes), demand reduction, and CO_2 reduction, which indicates that the initial communication facilitated through an app would help optimize renewable energy supply given the influx of EV charging demand, until a more permanent communication system can be established.
3) Higher initial buy-in rates due to app accessibility will increase societal familiarity with the benefits of SG technology, resulting in a net gain of future public SG technology acceptance and engagement.

Even though only 14% of respondents claimed to see a reduction in their energy bill, 67% still perceived energy cost savings as a large benefit (Thomas, Offenstein, Johnson 2023). This suggests that even though participants didn't necessarily notice the difference, they trust that the technology could potentially deliver that benefit. This suggests an initial positive societal view of smart charging systems pertaining to cost savings. Conducting a longer-term study on telemetric-based smart charging software may provide further insight into app usage and the likelihood that participants will notice a difference in their energy bill.

The perceived beliefs of individual's close to the person will influence whether that person will engage in such behavior (Perri et al 2020). Creating positive familiarity of the benefits of SG technology through apps could normalize the existence of other Smart Grid systems among EV owners, eventually allowing for a more complete and effective Smart Grid system.

Lower lifecycle costs and comfort with app technology make it more plausible that EV owners would adopt EV charging management systems through apps - which are already familiarized in society - rather than initially investing in smart charging hardware. Further, the lower upfront cost of a smart charging app subscription as opposed to smart charging hardware could increase the initial rate of public buy-in to a level efficient enough to see kWh savings, peak demand management, and carbon reduction at a significant level in the near future.

The top two factors that can influence customers' willingness to accept and adopt new technology include:

1) Showcasing the ease and simplicity of the user interface through clear visuals, intuitive settings, and simple steps for setting preferences, and pre-programmed default settings.
2) Highlighting the benefits of SG, including long-term financial benefits, which is vital to its social marketing and political success (Ellabban and AbuRub 2016). It is

also important to give customers various options that suit their needs and meet them where they are (Paqueo 2024).

Utilizing an opt-in design for programs with participant ability to opt out after DR event notification is a more successful and reliable model than attempting behavioral change with the opportunity to opt in (Paqueo 2024).

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