**INTRODUCTION**

Due to climate change causing rising global temperatures, countries around the world are starting to take action to fight these harmful effects. A big focus for climate scientists and policy makers alike is to reduce the amount of CO2 that is emitted into the atmosphere. One of the biggest contributors to CO2 emissions is the transportation system, which in the United States is responsible for 29% of the total CO2 emissions. The biggest reason for the high level of transportation system emissions is due to reliance of oil and gas, which power the majority of private vehicles in the United States. Producing oil and gas emits lots of CO2; the total amount of GHG emissions from the oil and gas industry is over 5 billion tons, which represents roughly 15% of the total energy sector emissions. These emission levels are exacerbated by driving patterns by citizens in the United States, which are much longer distances than other countries due to the geography and city planning trends that are common in the US. Because of the high amount of transportation system emissions due to the reliance on oil and gas, vehicle electrification is widely regarded as a critical tool for climate change mitigation in the transportation sector [@musti2011]. Researchers at Princeton University have worked to set aggressive targets to increase vehicle electrification in the United States, with some plans coming close to 95% of vehicles being electric [@Larson2021]. Less aggressive plans from the same researchers put the market share of electric vehicles around 60%. Despite this and the United States seeing an increasing share of electric sales, the pace of adoption remains well below the necessary level to mitigate climate change impacts.

Electric vehicle adoption is driven by a number of factors related properties of the electric vehicles, such as price, driving range and charging time, and by factors outside of the vehicles, such as consumer characteristics, fuel prices, and government policy. The purchase price is one of the main properties that influences consumers to purchase electric vehicles. When surveyed about reason why they would choose to not purchase an EV, potential buyers cited the price as the biggest deterrent [@Hirdue2011]. Additional research has found that drastically increasing the battery size of the vehicle while not changing the price did very little to persuade buyers to purchase electric vehicles [@Adepetu2017]. The least influential factor related directly to the vehicle properties is the charging time. One analysis found that reducing the charging time from 10 hours to 10 minutes while changing no other factors, buyers were still more likely to pick gas powered cars [@Hirdue2011]. There are many factors not directly related to electric vehicles that are influential in increasing EV adoption. The strongest of these factors is the price of fuel. One study found that an 10% increase in fuel prices resulted in an up to 90% increase in the market share of hybrid vehicles [@Diamond2009]. In addition to fuel prices, the characteristics of consumers influences how electric vehicles are adopted. Characteristics like age and education are the most significant predictors in how likely a person is to purchase an EV [@Hirdue2011]. Another outside factor that affects the market share of EVs is government policy. Most government policy is targeted at reducing the price of EVs, but it can encompass many other strategies like creating a more robust charging infrastructure, which is the focus of this paper.

The lack of charging infrastructure is another large barrier to widespread adoption [@sullivan2021]. A common policy put forward to increase electric vehicle adoption is a federal income tax credit for EV buyers. However, spending similar amounts on increasing deployment of charging stations could yield more effective results [@Li2017]. Governments are starting to utilize this knowledge when drafting spending policy; recently, the US Federal Government passed an infrastructure bill that allocates roughly $5 billion to creating a network of charging stations. The network of charging stations setup by this spending will be placed along designated roads, particularly the US Interstate System.The fact that government spending on charging station deployment can yield better results is especially the case in the early stages of EV market penetration; EV markets that have critical-mass constraints have the most success in increasing market penetration with a subsidy policy that deals with indirect network effects [@Zhou2018]. One of the indirect network effects on the EV market comes from the charging station market. Subsidies for charging stations are found to be most effective because of the low-price sensitivity of early EV adopters [@Li2017]. This is intuitive because early EV adopters are more eager to purchases EVs, which makes them more willing to pay for higher prices. The issue these consumers are concerned with is their ability to utilize this new technology, which is affected by the existing charging station infrastructure. Because of this, understanding consumer’s preferences for charging station infrastructure is crucial. Consumers are willing to pay about 5 cents per mile for plug-in electric vehicles and about 10 cents per minute of wait time while refueling. Consumers are also willing to wait up to 8 minutes longer during refueling [@Sheldon2019]. Knowing this information can allow policy makers to create subsidy programs that produce more effective outcomes.

**THE ELECTRIC VEHICLE AND CHARGING STATION PROBLEM**

Electric vehicle ownership is often referenced as exhibiting a "chicken and egg" behavior arising from the supply and demand relationship. Individual demand for electric vehicles is influenced by the available supply of charging points. Consumers are unwilling to purchase vehicles due to range anxiety and a perceived lack of charging stations. Suppliers are not incentivized to provide charging stations unless there is sufficient demand to warrant their cost. There is a clear role for public policy in such situations. The government deems electric vehicles as a solution to a public ill (i.e., climate change) and can incentivize either suppliers by providing installation subsidies or consumers by installing charging stations. While the problem has been recognized in the literature [@melliger2018], empirical analysis is minimal.

An important consideration to the analysis is how electric mobility system may differ from one based on fossil fuels. In the conventional private mobility model, the individual owns the vehicle and purchases fuel from centralized and privately owned refueling stations. These vehicles typically have a greater driving range associated with them. While the increased range increases a vehicle’s mobility, refueling at a place of residence is not viable. Electric vehicles do not have as great of a driving range as gas-powered vehicles. However, electric vehicles may be charged in the home using previously existing electrical infrastructure. The presence of charging points in the home begs the questions 1) if (or to what extent) out-of-home charging stations are required for travel, and 2) to what extent is range anxiety a perception versus a reality.

According to the Bureau of Transportation Statistics, 98% of trips made in the US are less than 50 miles [@vehicletechnologyoffice2022]. Given that most battery-electric vehicles (BEVs) have a range greater than 200 miles [@elfalan2021], it is feasible to make most trips on a single charge. However, long-distance trips (over 50 miles) comprise 30% of total vehicle-miles traveled (VMT) [@aultman-hall2018]. There is clearly a need for out-of-home charging stations to accommodate these trips. Even if most trips can be accommodated by in-home charging, the vehicle purchase decision will be influenced by consideration of these longer trips that require charging stations [@silvia2016]. Additionally, Wolbertus et al. [@wolbertus2018] find that there is still a demand for charging stations in places where public daytime charging is the only option, such as at the workplace.

**DISCUSSION**

A key climate change policy challenge in the transportation sector is how to transition the private vehicle fleet to PEVs. As in many product markets, there is an indirect network effect between household goods purchases and the supply of complementary infrastructure. Zhou and Li (REF) found a critical mass hurdle may exist in the PEV market, beyond which PEV sales may revert to a no-adoption outcome. Their analysis was based on 2011-2013 data, which we are able to expand upon by making use of an updated and longer time series. We find that many US counties (239 out of 3273 as of 2020) have no registered PEVs (measured as the number of battery-electric and plug-in hybrid electric vehicles). Among those counties that have seen PEV adoption, there is a clear pattern of concurrent charging station installations. We are unable to confirm a causal phasing between the two actions using non-linear Granger causality-type testing. It appears there is a feedback relationship whereby PEVs are purchased and in response suppliers install charging stations, and vice versa. There also appears to be an equilibrium point, an ESCE penetration rate beyond which PEV adoption does not increase absent supporting policies and incentives - see the comparison between California and Vermont in @fig-state-compare. Despite progress in some regions, PEV adoption and EVSE infrastructure in most of the country is limited as of 2020. The high rate of zero valued observations in these datasets suggests that PEV adoption and infrastructure networks are still more concentrated. This concentration decreased in the time period of the study, but still remained high in 2020.

In addition to the lack of findings from the causality models, the GPS model returned significant findings on the affects of race on charging station access. There is a correlation between counties with higher representations of racial minorities and a lower rate of charging stations. There were no significant findings on the effects of income. The dose-response model finds that charging station access encourages PEV adoption up until a certain point, then PEV adoption becomes discouraged by increasing charging stations. Furthermore, the mediation effect results, which studied grid emissions and Democratic voter share per county, showed that both of these effects are mediated by charging station infrastructure at higher levels of emissions and Democratic voter share.

We find support for the Biden administration's focus on equitable distribution of charging infrastructure within regions. Historically segregated cities (e.g., Chicago and Detroit) lack EVSE in their predominantly minority communities, while appearing to have an overabundance of EVSE in their peripheral suburbs. There are also inequities across regions. The Great Plains has very little charging station infrastructure built, as seen by Omaha where EVSE is sparse outside its downtown.