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Challenges to Expanding EV Adoption and Policy Responses

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ABSTRACT

The transportation sector is pivotal in global decarbonization efforts, given its significant contribution to greenhouse gas emissions. This paper examines the challenges hindering the widespread adoption of electric vehicles (EVs) and the policy responses to address these barriers. Despite advancements in EV technology and an increase in global EV sales, adoption rates in the U.S. remain low due to high upfront costs, range anxiety, and insufficient public charging infrastructure. The study analyzes various financial incentives, such as tax credits and rebates, and the impact of these policies on EV adoption. It also highlights the importance of expanding EV charging infrastructure, reviewing federal and state initiatives aimed at enhancing the availability and accessibility of charging stations. By comparing international policies and their effectiveness, the paper provides insights into potential strategies for overcoming obstacles and promoting sustainable transportation in the U.S.

KEY WORDS

Electric Vehicles (EVs), Greenhouse Gas Emissions, Tax Credits, Sustainable Transportation

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1. Introduction

In the worldwide efforts to combat climate change, decarbonizing the transportation sector stands as a critical and pressing objective. In the U.S., despite significant efforts by the federal government to mitigate vehicular emissions, such as implementing fuel economy standards and gasoline taxes, vehicle emissions have shown little reduction over the past two decades (Figure 1 Panel A). Currently, vehicular emissions are the largest source of greenhouse gas (GHG) emissions in the U.S., accounting for over one-quarter of total emissions (Figure 1 Panel B). Globally, the transportation sector contributed approximately 15% of total GHG emissions in 2020, making it the second-largest contributor after the electricity sector (Figure 1 Panel C). Thus, the transportation sector's transformation from relying on gasoline and diesel fuels to relying primarily on electricity generated by a decarbonized electricity sector plays a crucial role in global efforts to address climate change, aligning with the ambitious goals outlined in the Paris Agreement.

The widespread adoption of electric vehicles (EVs), especially zero-emission vehicles (ZEVs), offers a compelling alternative to traditional gasoline-powered internal combustion engine vehicles, providing a significant means to curb carbon emissions with zero tailpipe emissions. It is important to note that effectively addressing this challenge requires not only transforming the transportation sector but also decarbonizing the electricity sector, ensuring that the electricity used to power electric vehicles comes from clean and sustainable sources.

In response to the growing environmental concerns and the proliferation of EV models, the EV market is experiencing remarkable growth, with global sales surpassing 10 million in 2022 (IEA 2023). During the same year, electric cars accounted for 14% of all new car sales worldwide, marking a substantial increase from approximately 9% in 2021 and less than 5% in 2020. China continues to hold its leading position, contributing around 60% to the total electric car sales worldwide, with EVs accounting for 22% of domestic vehicle sales. In Europe, Norway stands out with 80% of passenger vehicle sales being electric, followed by Iceland at 41% and Sweden at 32%, contributing to an overall growth of more than 15% in EV sales in 2022 (Jaeger 2023).

On the other hand, the adoption rate of EVs in the U.S., the third-largest market, remains relatively low compared to conventional internal combustion engine vehicles. In 2021, EV registrations constituted a mere 0.5% of total vehicle registrations, with the majority of vehicles on the road continuing to be powered by gasoline. Additionally, despite the record-breaking growth over the past several years, the share of new EV sales compared to overall light vehicle sales remains small, standing at approximately 6% in 2022, falling significantly short of President Biden's target of reaching 50% electric vehicle sales by 2030.[1]

Several significant barriers continue to impede the rapid transition to EVs. First, EVs are relatively more expensive than their gasoline- and diesel-powered counterparts. In response to this price disparity, various central and local governments around the world have implemented a range of financial incentives, such as tax credits, rebates, and subsidies, to bridge the gap.

[1] Executive Order 14037 of August 5, 2021

While extensive studies have shown that these government policies have had a positive impact on promoting individual EV adoptions,[2] their overall effectiveness on an aggregate scale remains a subject of debate, particularly in the U.S. For instance, it might be anticipated that a certain percentage of EV sales would have occurred even without financial incentives (Xing et al. 2021). Indeed, some countries, such as the UK, have achieved a substantial share of new car sales as EVs (16.6% in 2022)[3] with relatively modest subsidies that still fall short of equalizing the cost differential. This raises questions about the overall effectiveness of policies and underscores the role of factors beyond financial incentives in driving EV adoption. Moreover, the projection of EVs reaching price parity with conventional vehicles within five to ten years, attributed to technological advancements (Baik et al., 2019; Lutsey and Nicholas, 2019), is complemented by an increasing number of EVs entering the secondary market with much lower vehicle prices, thereby making EV adoption more financially viable for a wider range of consumers.

The second major barrier to adopting EVs is range anxiety, which refers to the fear of running out of battery power before finding a charging point. However, many current EVs boast comparable traveling ranges to conventional vehicles, capable of covering similar distances on a single charge as a conventional vehicle can on a full tank of fuel. Notably, the average range of EVs on a single charge has significantly increased from 127 km (79 miles) in 2010 to 349 km (217 miles) in 2021, with numerous models offering over 300 to 400 miles of range.[4] In contrast, the median range for gasoline vehicles in 2021 was about 649 km (403 miles).[5] These driving ranges by EVs meet the demand of vehicle usage for the average American driver, who drives approximately 13,476 miles (21,687 km) per year, roughly equivalent to 37 miles (59.5 km) per day.[6]

The third crucial aspect involves the expansion of public EV charging infrastructure. Extensive research has highlighted the vital role of robust charging infrastructure in driving the adoption and market penetration of EVs (Tran et al. 2013, Sierzchula et al. 2014, Mersky et al. 2016, Coffman et al. 2017, Egnér and Trosvik 2018). While most people charge their EVs at home, the availability of reliable and accessible public charging infrastructure is important for residents, especially those living in multi-unit dwellings or rental apartments, without access to off-street parking and home chargers (Dunckley and Tal, 2016; Funke et al., 2019). Additionally, public fast-charging infrastructure is essential for long-distance travel and can alleviate range anxiety, further encouraging EV uptake.

However, the current public charging infrastructure in the U.S. is insufficient to meet the growing demand. A recent analysis by McKinsey suggests that achieving the U.S. administration's goal of having 50% of all vehicles sold as zero-emission vehicles by 2030 would require 1.2 million public EV charging stations and 28 million private chargers nationwide, with an estimated cost of nearly $35 billion over the period leading up to 2030 (Kampshoff et al. 2022).[7] As of the end of 2022,

[2] Zhou et al. (2015), Lévay et al. (2017), Hardman et al. (2017), Clinton and Steinberg (2019), Jenn et al. (2018), Münzel et al. (2019), Yan (2018), DeShazo et al. (2017), Sierzchula et al. (2014), Muehlegger and Rapson (2020), Archsmith et al. 2021, Wee et al. (2018).
[3] Tromans (2024).
[4] https://www.iea.org/data-and-statistics/charts/evolution-of-average-range-of-electric-vehicles-by-powertrain-2010-2021
[5] https://www.energy.gov/eere/vehicles/articles/fotw-1221-january-17-2022-model-year-2021-all-electric-vehicles-had-median
[6] https://www.fhwa.dot.gov/ohim/onh00/bar8.htm
[7] Another estimate by U.S. Department of Energy suggests that meeting the charging needs of an anticipated 15 million EVs on the road by 2030, which will account for roughly 5% of the total light-duty vehicle stock at that time, would require approximately 25,000 DC fast chargers plugs and 600,000 public Level 2 plugs (Wood et al., 2017).

there were slightly over 130,000 public chargers in the U.S., underscoring the need for substantial investment and expansion to support the widespread adoption of EVs. As a response, the federal government has recently taken a significant initiative to accelerate the expansion of charging infrastructure nationwide, aiming to establish 500,000 EV charging stations by 2030.

In this chapter, we delve into the incentives and policies designed to facilitate the widespread deployment of EV charging stations at the federal, state, and electric utility company levels. Our comprehensive review aims to examine the current programs, policies, and funding mechanisms related to the expansion of EV charging infrastructure. By doing so, we seek to gain valuable insights into the ongoing efforts and potential challenges concerning the development and accessibility of charging infrastructure across the country.

Our review primarily focuses on initiatives related to EV charging infrastructure rather than those targeting EV adoption. This choice is motivated by the abundance of existing studies evaluating the efficacy of incentives on EV adoption,[8] while comparable analyses for EV charging infrastructure are still limited. The emphasis on EV charging infrastructure is particularly relevant to the broader context of electricity regulation, as the expansion and regulation of EV charging networks intersect with key considerations in the electricity sector. Nevertheless, we also acknowledge the key role of EV adoption in driving increased investments in charging networks. As such, we also present an overview of policy initiatives specifically designed to promote and boost EV adoption.

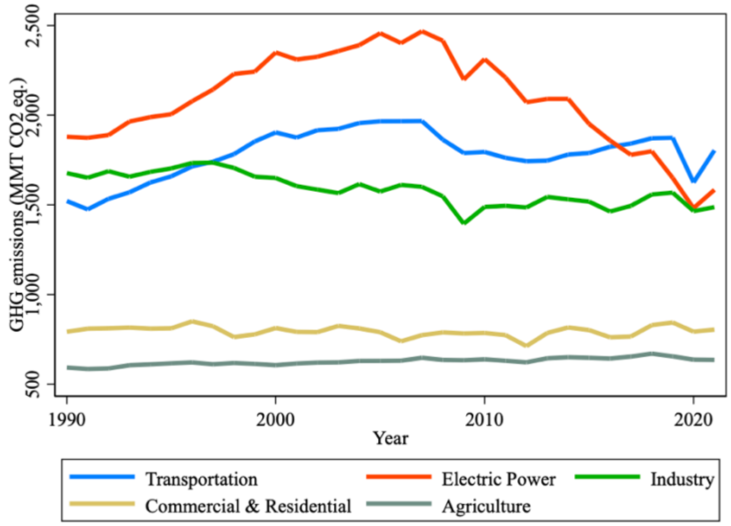
The primary geographical scope of our review is the U.S. market, while we offer an overview of policies from other select countries. Acknowledging variations in road and grid structures, economic conditions, and social contexts among nations, the strategies for charging infrastructure planning might vary widely. Despite these differences, our comparative analysis aims to unveil commonalities and innovative solutions that can offer insights to enhance the U.S.'s endeavors in promoting widespread EV adoption and infrastructure development.

The review is structured as follows. Section 2 provides insights into the policies and legislations enacted to facilitate the installation and expansion of EV charging infrastructure, drawing experiences from both the U.S. federal and state levels, along with perspectives from other selected countries. Section 3 presents the policies and legislations aimed at promoting the expansion of EV adoption, covering aspects from the U.S. and other selected countries. Section 4 addresses the policy challenges that arise in this context of developing the EV charging network. Lastly, Section 5 concludes.

[8] For example, Hardman et al. (2017), Jenn et al. (2018), Münzel et al. (2019).

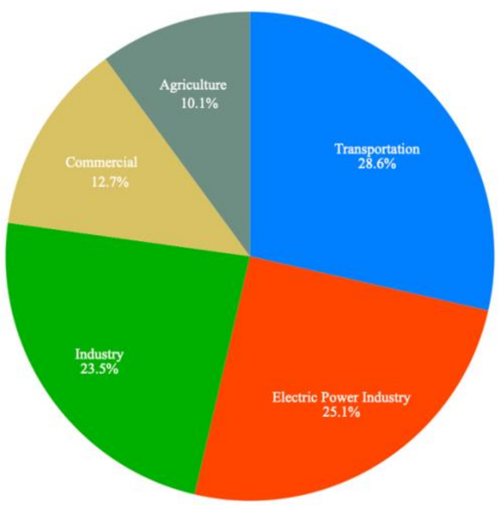
Figure 1: GHG Emissions by Sector

Panel A: Trends over Time by Sector in the U.S.



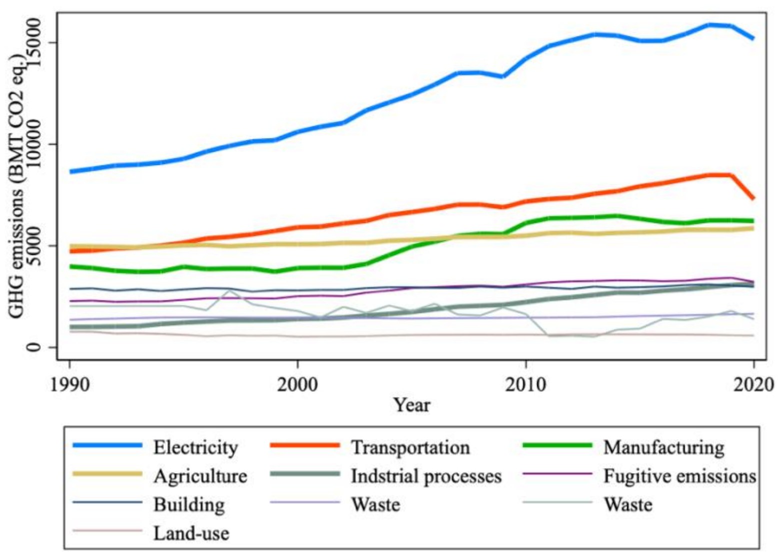
Panel A shows U.S. GHG emission trends by sector between 1990 and 2021, based on data from the U.S. EPA. (2023).

Panel B: Percent Share by Sector in 2021 in the U.S.



Panel B shows the percent share of U.S. GHG emissions by sector in 2021, based on data from the U.S. EPA. (2023).

Panel C: Trends over Time by Sector, Global



Panel C shows global GHG emission trends by sector between 1990 and 2020, based on data from the World Resource Institute (2020).

2. Policy Initiatives on EV Charging Infrastructure

In this section, we delve into the policy initiatives aimed at fostering the widespread deployment of EV charging infrastructure in the U.S. Section 2.1 focuses on federal level policies, providing insights into the initiatives that shape the landscape of EV charging in the U.S. In Section 2.2, our focus shifts to state and utility levels, exploring the diverse strategies and programs implemented across different regions in the U.S. The impact of these policies on the development of the EV charging infrastructure network is explored in Section 2.3, drawing upon available data on actual development trends. To broaden our perspective, Section 2.4 extracts valuable insights from the experiences of selected countries beyond the U.S.

2.1. US: Federal Policies

Since 2008, the federal government has made significant investments in the electrification of the transportation sector. Initially, these programs primarily emphasized the research and development, manufacturing, and deployment of EVs. However, a portion of the funding allocated through these programs has also been dedicated to the establishment of charging infrastructure, recognizing the crucial role it plays in supporting the widespread adoption of EVs.

The American Recovery and Reinvestment Act (ARRA) of 2009

The American Recovery and Reinvestment Act (ARRA) of 2009, enacted as a response to the 2008 financial crisis, played an important role in initiating major federal efforts to expand the EV charging network in the U.S. With a total appropriation of $787 billion, the ARRA aimed to stimulate economic growth, generate employment opportunities, and invest across multiple sectors. Notably, the ARRA included a range of initiatives and programs specifically designed to foster the development and deployment of EV infrastructure.

In particular, as part of the ARRA, the Transportation Electrification Program emerged as a notable initiative. It allocated $2 billion toward advanced battery manufacturing and an additional $400 million for transportation electrification projects. Through $100 million grants awarded to ECOtality (now Blink) and Coulomb Technologies (now ChargePoint) among others, a network comprising over 17,000 was established (Francfort et al. 2015).[9]

In addition, under the ARRA, substantial funding was allocated to support projects within the Clean Cities program, with a focus on propelling the transition of vehicle fleets. Approximately $300 million was invested, leading to the installation of 1,380 alternative fueling stations.[10] Notably, 62% of these stations were dedicated to EV charging, bolstering the infrastructure necessary for EV adoption and enabling convenient charging options across various regions (Kelly and Singer 2016).

These efforts have triggered an ongoing growth of EV charging station expansion, significantly advancing the accessibility and availability of charging infrastructure for EVs nationwide.

The Fixing America's Surface Transportation (FAST) Act

The Fixing America's Surface Transportation (FAST) Act, signed into law in 2015, represented a significant milestone as the first federal legislation in over a decade to provide long-term funding

[9] https://inldigitallibrary.inl.gov/sites/sti/sti/6799570.pdf

[10] The Clean Cities Alternative Fuel and Advanced Technology Vehicles Pilot Program supported 25 cost-share projects in collaboration with 50 Clean Cities coalitions.

certainty for surface transportation infrastructure planning and investment. One notable provision within the FAST Act was the authorization of the Alternative Fuel Corridor (AFC) Program. This program's primary objective is to designate and promote alternative fuel corridors, including corridors for EV charging, along major highways and transportation routes across the nation.

By establishing these AFCs, the aim is to develop a comprehensive network of refueling or recharging stations that support the travel needs of alternative fuel vehicles along the designated routes. This promotes the wider adoption of such vehicles and mitigates barriers to long-distance travel. The Department of Transportation (DOT) has been annually updating and redesignating the corridors by seeking nominations from state and local officials.

Importantly, the AFC Program also provides funding to support the deployment of publicly accessible charging stations, contributing to the growth and accessibility of EV charging infrastructure throughout the designated corridors. This investment further supports the transition toward cleaner transportation and encourages the use of alternative fuel vehicles.

The Bipartisan Infrastructure Law (BIL)

The Bipartisan Infrastructure Law (BIL) was passed, enacted as the Infrastructure Investment and Jobs Act (IIJA), on November 15, 2021, marking a significant milestone in the advancement of electric transportation. The legislation provides a significant funding allocation specifically dedicated to the expansion of EV charging infrastructure. This financial support is intended to facilitate the installation of a substantial number of charging stations nationwide. Notably, it includes a substantial allocation of $7.5 billion to establish a nationwide network comprising 500,000 electric vehicle charging stations by 2030 (Table 1).

This funding is allocated across two key newly-established programs aimed to expand the development of EV charging infrastructure: the National Electric Vehicle Infrastructure (NEVI) Formula Program and the Charging and Fueling Infrastructure (CFI) Discretionary Grant Program.

The NEVI Formula Program, a $5 billion initiative spanning five years, is dedicated to establishing a comprehensive coast-to-coast network of charging stations to facilitate long-distance travel for EVs. These funds, allocated through the NEVI Formula Program, will be specifically directed to roadways identified as "corridor ready."[11] It follows specific criteria for Alternative Fuel Corridor designation, such as i) Publicly available, ii) maximum distances of 50 miles between public charging facilities, iii) being located within one mile of an interchange exit of highway intersection, iv) with a minimum of four ports, v) with a minimum of 150 kW per port, and vi) is equipped with a CCS port. Additionally, NEVI funds will prioritize zones with high underserved demand, with particular attention given to areas inhabited by environmental justice communities. The goal of the NEVI program extends beyond the installation of public EV charging stations nationwide; it also aims to cover a portion of the operating costs associated with the designated projects.

The CFI Discretionary Grant Program allocates the remaining $2.5 billion over a five-year period through two separate $1.25 billion discretionary grant programs.

One of these programs is the Corridor Grants, which align closely with the goals of the NEVI program. Both programs aim to establish an extensive network of charging infrastructure along designated Alternative Fuel Corridors.

[11]https://www.fhwa.dot.gov/environment/alternative_fuel_corridors/nominations/2023_request_for_nominations_r7.pdf. Note that the criteria for corridor-ready was different for previous designations of alternative fuel corridor.

Another program is the Community Charging and Fueling Grants. This program provides funding flexibility for projects that specifically target particular regions and communities. The grants are intended to support the installation of EV charging stations and alternative fuel infrastructure in various locations, including public roads, schools, parks, and publicly accessible parking facilities. The Community Grants prioritize the inclusion of rural areas and low- to moderate-income neighborhoods that have limited access to private parking or a higher concentration of multiunit dwellings.

In addition, the BIL introduced new initiatives as well as continuing existing funding and financing programs with a renewed attention to projects aimed at promoting the deployment of EV charging stations. While these programs do not exclusively focus on the expansion of EV charging stations, they are designed to support and contribute to the broader goal of promoting the growth and development of EV charging infrastructure. For example, there are other formula programs[12] that provide support for the construction and installation of EV charging stations. These programs include:

- The National Highway Performance Program (NHPP): This funding program focuses on enhancing the performance, efficiency, and safety of the National Highway System. States can incorporate the deployment of EV charging stations into their transportation plans and project proposals to access NHPP funding.
- The Surface Transportation Block Grant (STBG) program, formerly known as the Surface Transportation Grant: This federal transportation funding program provides states and local transportation authorities with flexible funding for a wide range of state and local transportation projects. The BIL has broadened the eligibility criteria for STBG, encompassing the construction and installation of EV charging infrastructure, vehicle-to-grid infrastructure, as well as the deployment of intelligent transportation technologies.
- The Congestion Mitigation and Air Quality Improvement (CMAQ) program: This federal initiative focuses on improving air quality and reducing traffic congestion in areas that do not meet national air quality standards. As part of its primary goal to improve air quality, it provides funding for the installation of EV charging stations.
- Carbon Reduction Program (CRP). This federal program was established under the BIL with the goal of reducing transportation emissions by promoting State carbon reduction strategies. In line with this objective, the program also dedicates funding for the deployment of EV charging stations.

In addition to formula grant programs, there are several federal discretionary programs that provide funding support for the deployment of EV charging stations. One such program is the Rebuilding American Infrastructure with Sustainability and Equity (RAISE) program, formerly known as Transportation Investment Generating Economic Recovery (TIGER) and Better Utilizing Investments to Leverage Development (BUILD), which promotes electrification in surface transportation infrastructure projects, including the deployment of EV charging stations. The Infrastructure for Rebuilding America (INFRA) grants also contribute to the installation of EV charging stations along the National Highway System. Furthermore, the Advanced Transportation Technologies and Innovative Mobility Deployment (ATTIMD) program focuses on deploying advanced technologies that enhance access to EV charging stations. The newly established Rural Surface Transportation Grant (RSTG) Program aims to expand surface transportation infrastructure in rural areas, including the provision of EV charging stations. Additionally, the newly

[12] Formula programs are designed to offer a systematic, transparent, and equitable approach for allocating funds or benefits to specific recipients. This allocation is determined based on specific criteria such as population, geographic considerations, or other relevant metrics.

established Reduction of Truck Emissions at Port Facilities (RTEPF) Program supports advancements in port electrification for trucks.

Recognizing the unique challenges faced by underserved areas, the legislation provides support for the installation of charging infrastructure among tribal communities through Tribal Transportation Program (TTP), among rural areas through Rural Surface Transportation Grant Programs, and among Puerto Rico and the U.S. territories through Territorial and Puerto Rico Highway Program (TPRHP). These initiatives ensure that the deployment of EV charging stations is not limited to urban regions and promotes equitable access to charging services.

The BIL has expanded the scope of the Federal Lands Transportation Program (FLTP) to place a renewed emphasis on the installation of EV charging stations. It now includes the deployment of EV charging stations as a significant objective within the FLTP framework, encompassing both public use and transit systems on federal lands, including national parks, forests, and recreational areas.

The BIL introduced several updates to the federal Transportation Infrastructure Financing and Innovation Act (TIFIA) loan program. TIFIA is a low-cost credit assistance program that supports eligible transportation projects. The BIL included revised rules for public-private partnerships, ensuring greater clarity and effectiveness in the implementation of such partnerships for eligible projects.

Inflation Reduction Act (IRA)
The federal government provides tax credits and incentives aimed at promoting the extensive installation of EV charging stations.

The Alternative Fuel Refueling Property Tax Credit, also known as the Alternative Fuel Infrastructure Tax Credit, is a federal tax credit designed to promote the adoption and expansion of facilities for storing and dispensing alternative fuels throughout the U.S. It was initially introduced as part of the Energy Policy Act of 1992 and later formally signed into law in the Energy Policy Act of 2005.

Under this tax credit program, both individuals and businesses can qualify for a tax credit equal to 30% of the expenses incurred for purchasing and installing alternative fuel infrastructure.[13] The maximum credit amount is capped at $30,000 for businesses and $1,000 for individuals. These tax credits were available through December 31, 2022.

Starting from January 1, 2023, the Inflation Reduction Act of 2022 renewed the Alternative Fuel Refueling Property Tax Credit, incorporating several changes. The revisions include an increase in the maximum credit amount from $30,000 per property to $100,000 per property item for businesses. Additionally, a base credit of 6% of project costs is provided, with the potential to reach a maximum credit of 30% if certain conditions are met, such as meeting prevailing wages and apprenticeship requirements, and installing the facilities in rural and low-income areas.[14] Individuals who purchase eligible residential fueling equipment can still benefit from a tax credit

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[13] These fuel types include biodiesel, ethanol, electric, hydrogen fuel cells, natural gas, and propane.
[14] To qualify for the tax credit, the installation of fueling equipment must adhere to specific census tract requirements. These requirements are as follows:
i) The census tract should not be classified as an urban area,
ii) The census tract should have a poverty rate of at least 20% for population census tracts, or
ii) In the case of metropolitan and non-metropolitan area census tracts, the median family income should be less than 80% of the state’s median family income level.

equal to 30% of the cost, with a maximum credit amount of $1,000. These tax credits will remain in effect until December 31, 2032.

Table 1: List of Federal Initiatives to Fund Deployment of Charging Stations

Programs	FAST	BIL
Panel A: Formula programs		
National Electric Vehicle (NEVI) Program	NA	5,000
National Highway Performance Program (NHPP)	140,638	147,999
Surface Transportation Block Grant Program (STBG)	70.407	71,999
Congestion Mitigation & Air Quality Improvement Program (CMAQ)	14,516	13,200
Carbon Reduction Program (CRP)	NA	6,419
Panel B: Discretionary programs		
Discretionary Grant Program for Charging and Fueling Infrastructure	NA	2,500
Rebuilding American Infrastructure with Sustainability and Equity (RAISE)	5,400	7,500
Infrastructure for Rebuilding America (INFRA) Grant Program	4,500	8,000
Advanced Transportation and Technologies and Innovative Mobility Deployment (ATTIMD)	360	300
Rural Surface Transportation Grant Program (RSTG)	NA	1,900
Reduction of Truck Emissions at Port Facilities Program (RTEPF)	NA	400
Panel C: Other programs		
Federal Lands Transportation Program (FLTP)	2,150	2,195
Tribal Highway Program (TTP)	2,930	3,011
Territorial and Puerto Rico Highway Program (TPRHP)	1,200	1,141
Panel D: Finance Programs		
Transportation Infrastructure Financing and Innovation Act (TIFIA)	1,432	1,250

This table shows federal funding (millions of USD) for EV charging stations, with only NEVI funds dedicated solely to EV charging infrastructure.

2.2. US: State/Regulated Utilities Policies

All 50 states and the D.C. in the U.S. have actively engaged in the NEVI grant program, as evidenced by the submission of their action plans in August 2022, each of which has subsequently been approved in September. Implementation is already underway, with several states anticipating the availability of funding in the first half of 2023. State governments typically do not intend to directly own or operate EV chargers; rather, they are establishing competitive grants to facilitate the installation and maintenance of chargers.[15]

[15] For specific details on individual state plants under the NEVI program, see https://driveelectric.gov/state-plans/.

Apart from the NEVI program, numerous states have made substantial investments in charging infrastructure and technologies to facilitate the shift toward clean and zero-emission EVs.

California has been at the forefront of promoting EVs and has implemented a range of state-level initiatives to expand the EV charging station network. Some notable examples of initiatives in California include:

California Electric Vehicle Infrastructure Project (CALeVIP): CALeVIP is a statewide initiative funded by California Energy Commission that offers financial incentives to promote the installation of EV charging infrastructure in targeted regions. During CALeVIP 1.0, spanning from 2017 to 2022, 13 regional projects were initiated across 36 California counties, resulting in the funding of over 1,000 Level 2 chargers and nearly 380 DC fast chargers with nearly $30 million in rebates issued.[16] Building on this success, in 2021, the Energy Commission granted a second phase to further advance EV charging infrastructure. This new phase is exclusively dedicated to the installation of high-speed DC fast chargers, with a commitment to allocating 50% of the overall 2.0 project funding toward installations in low-income and disadvantaged communities.

The EV Charging Stations Open Access Act: Since 2013, the California Air Resource Board has implemented the EV Charging Stations Open Access Act, mandating that public charging stations must be accessible to all EV drivers and offer payment options without imposing subscription fees or membership.

The Clean Transportation Program: The Clean Transportation Program, established in 2008 (previously known as the Alternative and Renewable Fuel and Vehicle Technology Program), has allocated up to $100 million in annual funding through 2024. This funding is geared toward accelerating the development of EV charging infrastructure, promoting innovation, and facilitating the advancement and deployment of alternative fuel and advanced technology vehicles. Under this program, the Energy Commission collaborates with both public and private investments, working together to enhance the adoption of cleaner transportation powered by alternative and renewable fuels.

Zero-Emission Vehicle (ZEV) Action Plan: California's ZEV Action Plan sets forth targets and strategies aimed at expediting the deployment of EVs and the essential charging infrastructure.

Mandatory EV Charging Station Building Standards: The California Building Standards Commission has issued mandatory building standards mandating the installation of electrical conduit capable of supporting a Level 2 EV charging station. This requirement applies to new one- and two-unit single-family dwellings or townhouses with attached private garages, commercial facilities, and public buildings.

Utility/Private Incentives: The California Public Utilities Commission has adopted a five-year, statewide, $1 billion transportation electrification program, establishing a cohesive and policy-driven funding structure for utility transportation electrification initiatives from 2025 to 2030. This program introduces rebates for EV infrastructure investments, with a notable allocation of 70 percent directed toward charging medium- and heavy-duty vehicles. These charging stations will be strategically located at diverse sites, including truck stops, ports, and facilities managed by fleet-operating companies. The remaining 30 percent of the funds will target the installation of

[16] https://www.energy.ca.gov/programs-and-topics/programs/clean-transportation-program/california-electric-vehicle

charging infrastructure for light-duty electric vehicles in proximity to multi-unit dwellings.[17] To ensure equitable access, the program prioritizes projects in underserved, disadvantaged, and tribal communities, offering higher rebates to ensure the deployment of charging infrastructure in these areas. The associated costs will be distributed among utility ratepayers throughout California, with the estimated impact on SDG&E ratepayers being less than $1 per month. This initiative reflects a statewide commitment to advancing transportation electrification while addressing the needs of diverse communities and promoting accessibility to clean energy solutions.

In response to the challenging economic landscape facing the EV charging industry, especially in regions where EV adoption has not yet been sufficiently high to offset utility costs, states are exploring policies and retail electricity rate designs. These initiatives aim to provide the industry with operational cost relief, thereby stimulating increased investment.

For instance, the New York State Public Service Commission took significant steps in 2023 by approving a range of incentives, programs, and tariffs aimed at reducing utility costs for commercial EV charging. In particular, the Commission tasked utilities with developing alternative utility rate structure distinct from traditional demand-based rates, which are typically determined by peak electricity usage. These alternatives include a demand charge rebate, offering a 50% credit on demand charges for commercial EV charging use cases. Additionally, the Commission introduced a commercial managed charging program as an alternative to the demand charge rebate, providing value-based bill credits, offering relief in operating costs for EV charging stations that strategically avoid charging during peak grid demand periods. Furthermore, the introduction of the EV phase-in rate, starting as a time-of-use rate, gradually incorporates a demand charge as charging station utilization improves. Collectively, these measures are designed to alleviate the economic challenges faced by the EV charging industry, particularly during the early stages of low EV penetration or limited utilization of charging stations, aiming to encourage increased investment in the EV charging infrastructure sector.

The Department of Public Utilities in Massachusetts has also adopted EV programs for the three regulated distribution utilities in 2022, which include make-ready distribution infrastructure and rebates to customers for the deployment of make-ready EV charging infrastructure. The Department also approved EV-related rates, including customer charge, kilowatt hour base distribution rate, and time-of-use rate as demand charge alternative rates.

2.3. Selected Countries

In this subsection, we provide an overview of policy initiatives related to EV charging infrastructure from selected countries. By examining the strategies and approaches adopted by these nations, we aim to draw insights into global practices that contribute to the successful deployment and expansion of EV charging networks. Each country's unique policies reflect a response to the specific challenges and opportunities in their respective contexts, offering valuable lessons for the broader discussion on sustainable transportation infrastructure.

Norway: The substantial adoption of EVs, as will be described later, has been facilitated by public investments directed toward establishing an extensive network of charging stations. Notably, the Norwegian government has already established fast-charging stations positioned at intervals of

[17] There is no designated funding for the development of EV charging infrastructure at individual households.

50 kilometers along all major roads. In 2022, Norway built over 17,000 charging points, including nearly 3,000 high-speed charging points.[18]

The establishment of such an extensive network of charging stations received support through public subsidies. Enova, the Norwegian government enterprise overseeing funding and guidance for energy and climate projects, initially financed a 7 million Euro EV infrastructure program, resulting in 1,900 charging points by 2011. Enova has continued to support charging infrastructure projects, most recently allocating NOK 50.5 million for fast charging infrastructure, leading to the installation of 230 stations to date.[19]

Moreover, a significant component of Norway's EV charging infrastructure investment strategy involves extending financial assistance to housing associations for the acquisition and installation of chargers. Grants ranging from 20% to 50% of the cost are provided in various cities.

Furthermore, regulations concerning EV charging infrastructure in new constructions and parking facilities stipulate that, for parking lots and areas of new buildings, a minimum allocation of 6% must be designated for EVs.

However, Békés et al. (2023) reports several challenges confronting Norway's EV charging network faces, as highlighted in a recent survey by the Norwegian EV Association. The abundance of public charging vendors leads to inconvenience as users struggle with managing multiple mobile apps. System glitches, including limited payment options, poorly designed parking spots, short cables, and hardware malfunctions, contribute to customer frustration and anxiety over charger availability. Half of respondents in a survey reported occasional non-functioning of fast chargers. The highly dispersed charging system and low chargers per site create queues and extended wait times, prompting the need for larger, purpose-built charging sites in high-use locations, particularly along highways. Charger utilization depends on the time of day and location, emphasizing the importance of securing prime sites for competitive advantage.

China: The development of EV charging infrastructure in China faced challenges arising from political conflicts between government agencies and property management companies (Wu et al., 2015). Additionally, home charging poses challenges in many Chinese cities, particularly for residents without access to garages or private parking spaces. Despite these hurdles, recent efforts showcase significant advancements in China's EV charging infrastructure landscape. These circumstances led to a significant gap between the availability of charging infrastructure and the actual need, as well as the targets set by the relevant authorities.

In 2015, the State Council issued guidance aiming to establish infrastructure capable of supporting five million EVs by 2020, requiring new residential constructions to include EV charging facilities and allocating 10% of parking spaces in large public buildings for the installation of charging equipment. The inclusion of charging infrastructure in China's 13th Five-Year Plan (2016-20) demonstrates the government's commitment to this sector. Notably, a unified national standard for DC fast charging and communication protocols between chargers and a central system have been developed by Chinese authorities.

Chinese provincial and municipal governments have also implemented various targeted incentive policies to support the deployment of electric vehicle charging infrastructure. These typically

[18] https://uk.mer.eco/news/ev-charging-infrastructure-best-practice-learnings-from-norway/
[19] https://uk.mer.eco/news/ev-charging-infrastructure-best-practice-learnings-from-norway/

include total investment subsidies, construction subsidies, operation subsidies, and charging subsidies.

These incentives contributed to substantial progress in China's EV charging infrastructure in recent years. As of 2022, China boasts nearly 1.8 million publicly accessible electric vehicle chargers, establishing itself as the world's largest public charging infrastructure.[20]

China also stands out as a pioneer in adopting battery swapping as an alternative charging model, particularly for trucks and passenger cars, with substantial policy backing. As of the end of 2022, the country has established nearly 2,000 battery swapping stations, with plans to increase this number to 23,000 nationwide by 2025. NIO, a prominent Chinese automaker, has further expanded its battery swapping initiatives by announcing plans to construct battery swap stations in Europe, aligning with the launch of their battery swapping-enabled car models in European markets in late 2022.

UK: The UK's Road to Zero strategy, designed to achieve carbon-neutral transportation by 2040, includes incentives for both commercial and residential EV charging. Commercially, the Workplace Charger Grant operates as a voucher-based program that covers up to 75% of purchase and installation costs for a maximum of 40 stations. Additionally, it offers tax benefits, including a 100% first-year allowance for EV charging equipment.

On the residential front, Home Charger Grant offers private individuals a grant covering 75% of purchasing and installation costs, with a cap at £350 per installation. This grant is applicable to all residents, including homeowners and renters.

Further, the On-Street Residential Chargepoint Scheme (ORCS) assists UK local authorities in establishing EV charging infrastructure for residents lacking off-street parking. The scheme provides a grant covering 75% of the capital costs associated with installing on-street EV charge points in residential areas.

As of October 2023, the UK has an extensive network of nearly 50,000 public EV charging points, marking a 90% growth from October 2022 and more than a doubling compared to October 2021 (The UK Department for Transportation 2023).

2.4. Policy Impacts

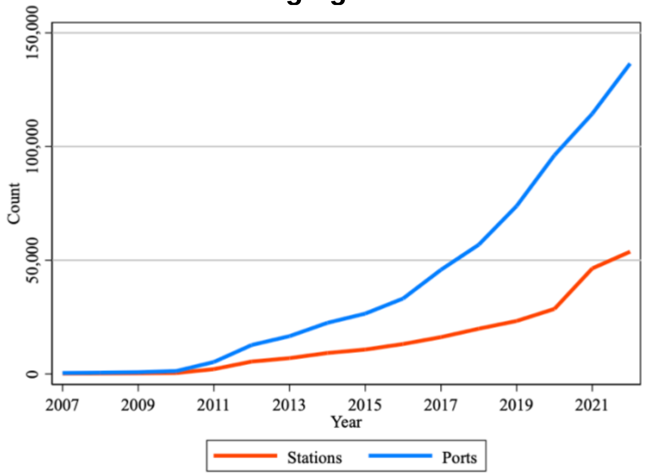
While establishing direct causal impacts of federal and state incentives on the deployment of EV charging infrastructure can be challenging, the statistics suggest significant progress in the accessibility and availability of charging options for EVs over the past decade in the U.S., aligning with the implementation of major federal initiatives outlined in the previous subsections.

Figure 2 illustrates the historical growth of EV stations and ports since 2007, utilizing data from the U.S. Department of Energy's Alternative Fuel Data Center (AFDC). The red line represents the number of stations, which are the physical interface and access point for drivers to connect and charge their EVs. The blue line represents the number of ports, indicating the capacity for simultaneous vehicle charging.

[20] https://www.statista.com/statistics/571564/publicly-available-electric-vehicle-chargers-by-country-type/

It is evident that both the number of EV charging stations and ports exhibits a consistent upward trajectory over time. Initially, the number of stations was minimal, with only approximately 600 stations recorded until 2010. However, a significant increase in station numbers began in 2011.[21] In both 2011 and 2012, the number of stations nearly tripled each year. From 2013 to 2022, station growth exhibited a steady upward trend, averaging around a 25% annual increase. Correspondingly, the number of ports grew at an average rate of 2.6 ports per station. Notably, the majority of these stations and ports are attributed to public EV charging infrastructure, which are located in publicly accessible areas, including commercial sites and along highway corridors (see Appendix Figure A1).

Figure 2: Number of EV Charging Stations and Ports over Time



This figure shows the number of EV charging stations (red) and ports (blue) between 2007 and 2022, using data from AFDC for public stations.

Table 2 provides a breakdown of the growth in the number of chargers categorized by country and charging level, with data reporting since 2015. Notably, the majority of EV chargers globally fall under the slow category. In the U.S., specifically, Level 1 and 2 chargers, constituting slow chargers, represent approximately 80% of the available chargers in 2021. Given that fast chargers possess the highest power output, enabling the fastest charging times, the expansion of public fast chargers networks across the country becomes crucial for facilitating EV adoption. Between 2020 and 2021, slow chargers experienced a 12.2% growth rate, whereas fast chargers demonstrated a more substantial growth rate of 29.4%.

Europe mirrors the trend observed in the U.S., with a slightly higher share of slow chargers at 86.2%. The growth rates for slow and fast chargers between 2020 and 2021 are 30.1% and 28.9%, respectively. In 2021, the Netherlands takes the lead with over 80,000 slow chargers, followed by France with 50,000, Germany with 40,000, the UK with 30,000, Italy with 20,000, and just over 12,000 each in Norway and Sweden.

China exhibits a distinctive scenario, with around 59% of chargers falling into the slow category, indicating a substantial presence of fast chargers. From 2020 to 2021, there was a notable growth

[21] As described earlier, the American Recovery and Reinvestment Act of 2009 funded the substantial build-out of charging stations, with the majority of these installations occurring between 2011 and 2014.

of 35.9% in slow chargers, while fast chargers also experienced considerable expansion, with a growth rate of 30.1%.

Table 2: Number of Public EV Chargers by Country and Type

	Slow			Fast		
Year	China	Europe	U.S.	China	Europe	U.S.
2015	47	61	28	12	6	4
2016	86	113	35	55	9	3
2017	131	122	40	83	11	3
2018	164	136	50	111	16	4
2019	301	187	64	215	25	13
2020	498	236	82	309	38	17
2021	677	307	92	470	49	22

This table presents the number of public EV chargers (in thousands) categorized into slow chargers and fast chargers, using data from IEA (2022).

Table 3 presents the number of electric light-duty vehicles per charging point in selected countries over time. While the EV-per-charger ratio is a useful metric for evaluating the charging network, the optimal number of chargers per EV varies based on factors such as housing stock, average distance travelled, and population density. The last row provides the charger power (kW) per EV in 2021. This is a key metric as fast chargers have the capacity to accommodate a larger number of EVs compared to slow chargers, reflecting their efficiency in serving the growing electric vehicle market.

The data shows notable spatial and temporal variations in the availability of EV charging stations. In the U.S., although the ratio of EVs per charging point increased from 12.9 in 2015 to 20.7 in 2018, the number of public charging points has grown faster than the number of EVs on the roads in recent years, resulting in a slight decline to 18.2 EVs per charging point in 2021. In contrast, Norway has consistently increased its EV-per-charger ratio, indicating that the growth in the number of EVs on the roads has continued to outpace the growth of public charging points. While both the U.S. and Norway heavily rely on home charging, facilitated by a high prevalence of single-family dwellings, enabling fewer public chargers to serve a greater number of EVs, these countries exhibit relatively higher EV-per-charger ratios compared to others.

In the EU, the 2014 Alternative Fuel Infrastructure Directive (AFID) set guidelines for public EV charger deployment, aiming for 10 EVs per public charger by 2020. In 2021, the European average EV-to-charger ratio was 15.5, above the recommended 10.

Although China has significantly increased the number of chargers, there has been modest decrease in the availability of chargers per EV. This reflects a charging infrastructure deployment that has not kept pace with the rapid growth of the EV stock, despite the heavy reliance on public chargers in urban areas.

In terms of the average electric power provided by these chargers per EV, we observe that chargers in both the U.S. and Norway offer relatively low power at 1.0 kW and 0.7 kW, respectively, significantly below the global average of 2.4 kW. Further, the EU legislation, the Alternative

Fueling Infrastructure Regulation, suggests 1 kW per Battery Electric Vehicle (BEV) and 0.66 kW per Plug-in Hybrid Electric Vehicle (PHEV) by 2030. While the average kw per EV in Europe reached 1.0 kW in 2021, several European countries still fall below the guidelines set by AFID.

In contrast, chargers in China provide 3.8 kW, ranking among the highest power levels worldwide, indicating a prevalence of fast chargers in the country.

Table 3: Electric Light-Duty Vehicles per Charging Point

Year	China	U.S.	Norway	World
2015	5.2	12.9	12.8	7.2
2016	4.8	14.9	15.4	6.4
2017	6.2	17.8	19.5	7.6
2018	9.1	20.7	24	9.9
2019	7	18.8	23.4	8.4
2020	6	18	29.1	8.3
2021	7.2	18.2	33.6	9.6
kW per EV	3.8	1.0	0.7	2.4

This table shows electric light-duty vehicles per charging point and kW per EV (11 kW for slow, 50 kW for fast) using IEA (2022) data.

The availability of EV charging stations across the U.S. exhibits significant spatial variation. Figure 3 Panel A shows that out of the estimated 146,600 public EV charging ports nationwide, California accommodates the highest number, with around 41,000 ports, accounting for approximately 28.1% of the total. California also leads in terms of stations, with roughly 15,700 stations, representing about 27.3% of the overall count. Following California, other states like New York, Florida, Texas, and Massachusetts each have an average of around 3,088 stations and 7,887 ports.

Panel B illustrates the normalized data per 100 EV registrations, offering insights into the number of ports relative to EVs on the road. Among the states, North Dakota (47.5), Wyoming (43.2), West Virginia (37.0), Arizona (31.2), Maine (30.9), emerge as the top five with the highest number of stations per 100 EVs. In contrast, California ranks one of the lowest with approximately 7.3 ports stations per 100 vehicles. This can be attributed to California having the largest number of EV registrations, surpassing 563,000 EVs on the road by a considerable margin.[22]

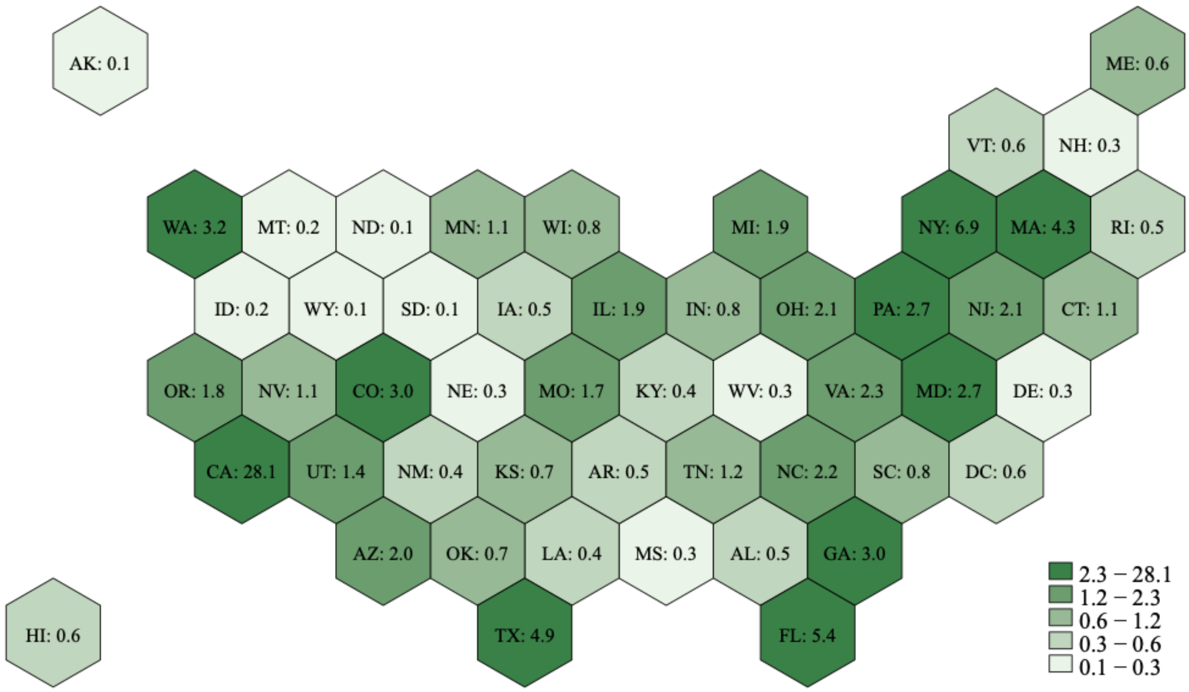
In assessing the readiness of regions to alleviate range anxiety, a useful metric is the availability of charging stations per 1,000 highway lane-miles. Washington, D.C., leads in this regard with the

[22] To offer a more comprehensive perspective, it is also useful to consider the density of charging infrastructure. For example, the number of chargers per square mile provides a measure of dispersion, addressing the need for adequate charging infrastructure across various geographic areas. It is also important to highlight that the optimal number of chargers is not necessarily one port per vehicle, particularly for fast chargers, where a specific threshold may be required to ensure economic viability. For instance, Fröde et al. (2023) demonstrated that achieving 20% utilization, equivalent to approximately ten 30-minute charging sessions per day, with a price of $0.45 per kWh, would render public fast charging stations profitable, even without relying on government subsidies or credits.

highest number of ports at 256.6 per 1,000 lane miles, indicating a robust infrastructure that significantly contributes to mitigating range anxiety. California (104.1), Hawaii (86.8), and Massachusetts (80.6) closely follow suit in this measure (refer to Panel C).

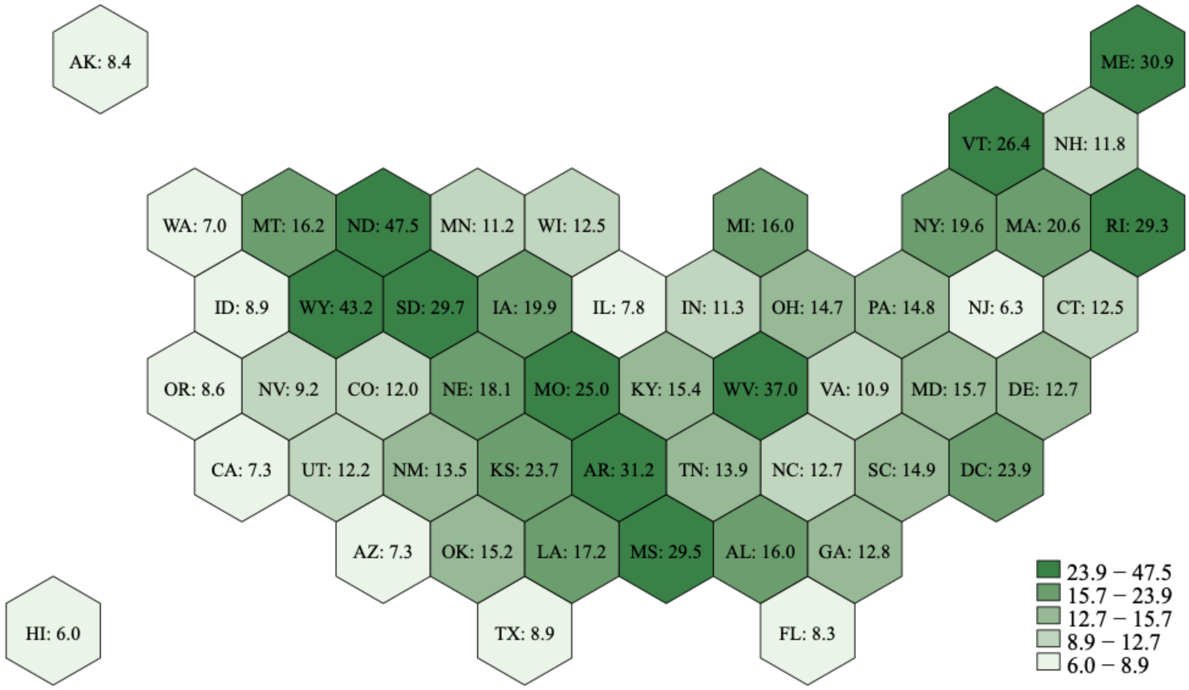
Figure 3: Distribution of Public EV Charging Ports by State

Panel A: Percent Share



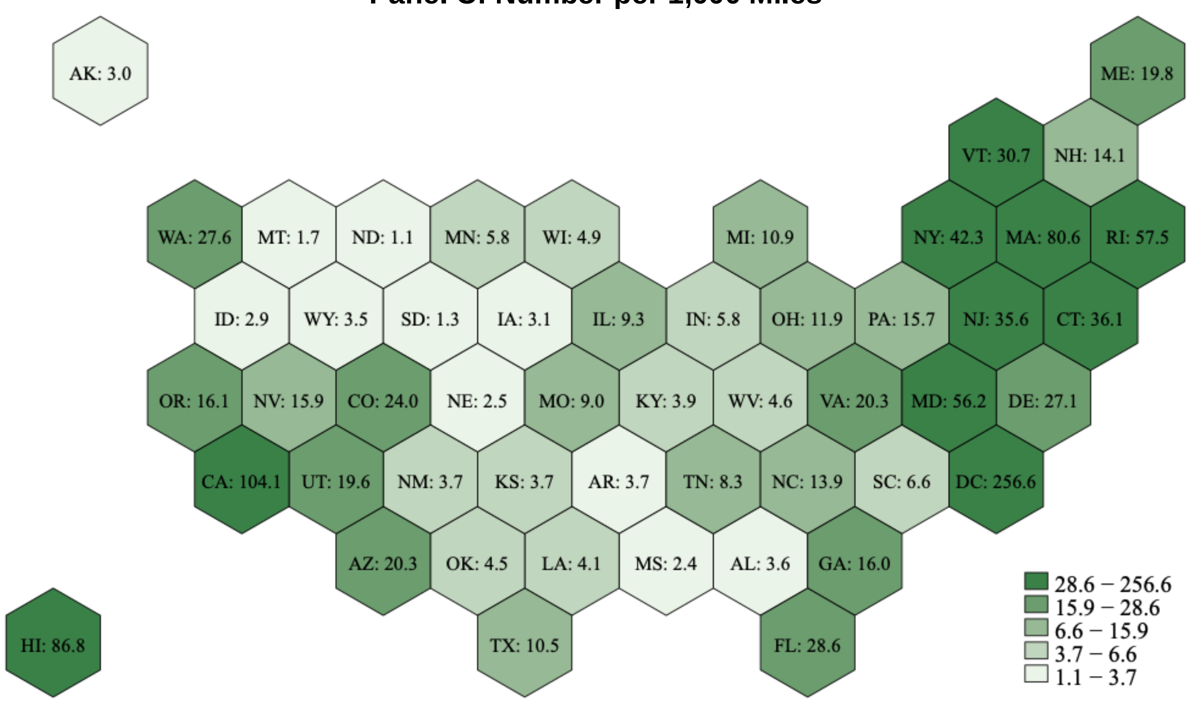
This figure shows the percentage share of public EV charging ports by state, based on data from AFDC Locator.

Panel B: Number per 100 EV Registrations



This figure shows the number of public EV charging ports per 100 EV registrations, using data from AFDC vehicle registration counts.

Panel C: Number per 1,000 Miles



This figure shows public EV charging ports per 1,000 miles, using highway lane-miles data from the U.S. DOT Federal Highway Administration.

3. Policy Initiatives on EV Adoption

Although this chapter predominantly explores the deployment of EV charging infrastructure, recognizing the key role of EV adoption in stimulating increased investments in charging networks is imperative. Consequently, this section provides an overview of policy initiatives aimed at promoting EV adoption, shedding light on both the U.S. and international landscapes.

3.1. US: Federal Policies

One of the most significant barriers to widespread EV adoption is the substantial upfront purchase cost. EVs, in comparison to their gasoline-powered counterparts, tend to be more expensive, and battery costs constitute the primary factor contributing to this price disparity. Despite a substantial reduction in battery prices over the past decade, leading to a remarkable decline in EV purchase costs relative to battery range, the timeline for achieving parity in both cost and range remains a subject of ongoing debate. Projections vary, with some indicating the potential for price parity, roughly at $90/kWh, with conventional vehicles within the next five to ten years (Baik et al., 2019; Lutsey and Nicholas, 2019). Conversely, other perspectives suggest a more extended timeframe (Tsiropoulos et al., 2018).

In this context, financial incentives, such as tax credits and subsidies, have emerged as the primary policy instrument targeting the significant upfront cost barrier affecting consumer decisions on EV adoption. The U.S. has employed the electric vehicle tax credit, initially introduced under the Energy Policy Act of 2005, to incentivize both the production and adoption of electric vehicles. These credits, offered to taxpayers purchasing or leasing hybrid vehicles, were available with potential benefits of up to $3,400.[23]

In 2009, the American Recovery and Reinvestment Act expanded the credit to include plug-in EVs, increasing the maximum credit to $7,500. Subsidies depended on the battery capacity, starting at a minimum of $2,500 for vehicles equipped with a 4-kWh battery. The full amount of the credit falls once a manufacturer has sold at least 200,000 vehicles.[24]

The Inflation Reduction Act (IRA) of 2022 represents probably the most significant piece of legislation in the advancement of transportation electrification in U.S. history. This act significantly extends tax incentives to include all types of electric vehicles (light-, medium-, and heavy-duty), thereby further mitigating the higher upfront costs associated with EVs. The extension of the light-duty EV tax credit, amounting up to $7,500 per vehicle, spans through 2032, fostering a trajectory toward more sustainable, equitable, and secure clean transportation. The previous credit, which had a cap of 200,000 vehicles per automaker, had already phased out for Tesla and General Motors and was on the brink of conclusion for other automakers.

The specific amount of credit is contingent on several conditions, including an MSRP cap, income cap, and assembly/sourcing requirements. These conditions also vary depending on whether consumers opt to purchase or lease the vehicle. Notably, the IRA marks the first legislation to provide a tax credit for the acquisition of a used EV, with the amount of up to $4,000 or 30% of the vehicle sale price, whichever is lower.

[23] https://www.irs.gov/pub/irs-news/fs-06-14.pdf
[24] https://www.irs.gov/pub/irs-news/fs-09-10.pdf

3.2. US: State/Regulated Utilities Policies

Currently, all individual states and numerous local utilities in the U.S. implement a variety of financial and non-financial incentives to encourage EV adoption. These incentives include rebates, tax credits, excise tax credits, discounted time-of-use rates, exemptions for High Occupancy Vehicle (HOV) lanes, sales and use tax exemptions, reduced vehicle registration fees, free Smart Electric Vehicle Chargers, and various other offerings. The costs associated with these incentive programs are often recovered through regulated electricity distribution charges, ensuring the financial viability and continued support for such initiatives within the broader framework of the regulated electricity distribution system.

Notably, the California Clean Vehicle Rebate Project offers rebates of up to $7,500 for the purchase or lease of new, eligible zero-emission vehicles. These include electric vehicles, plug-in hybrid electric vehicles, and fuel cell vehicles.

Moreover, the California Clean Cars 4 All program aims to assist lower-income consumers residing in or near disadvantaged communities, with a household income equal to or less than 400% of the Federal Poverty Level, by providing rebates of up to $12,000 when purchasing a new EV.

3.3. Selected Countries

This subsection presents an overview of government policies designed to promote the adoption of EVs across the same set of countries examined in the context of EV charging infrastructure deployment.

Norway: Norway remains at the forefront of EV penetration, with over 20 percent of passenger vehicles in the country being electric and an 88% share of electric car sales in 2022.[25] The country's success in promoting EVs is primarily attributed to generous tax incentives. These incentives include the exemption of zero-emission vehicles (ZEVs) from the registration tax, value-added tax (VAT), and motor fuel taxes. Additionally, there is a substantial reduction of at least 50% in road taxes, ferry fees, and parking charges. The strategic implementation of these fiscal incentives has played a crucial role in steering demand toward zero-emission vehicles and significantly increasing their share in the overall car fleet.

China: Since 2009, the Chinese government has actively promoted EV adoption through various incentives, including exemptions from consumption tax and vehicle & vessel tax for EV producers, purchase subsidies (which ended in 2022), and purchase tax exemptions for consumers. Over the period from 2009 to 2022, more than 200 billion yuan (US$28 billion) was allocated to EV subsidies and tax breaks in China. In 2022 alone, the country achieved remarkable success with over 6 million EVs sold, constituting 60% of global EV sales (IEA, 2023).

In June 2023, China announced a significant extension of EV tax breaks totaling 520 billion yuan ($72.3 billion) for a four-year period spanning from 2024 to 2027. During this period, new energy vehicles purchased will be entirely exempt from purchase tax for the first two years and receive a 50% reduction for the subsequent two years, resulting in potential savings of up to 30,000 yuan ($4,170) per vehicle.

[25] https://insideevs.com/news/628846/norway-fifth-car-fleet-electric/

UK: The British government has supported the transition to EVs by offering a range of incentives to encourage their adoption. The Plug-In Car Grant, initiated in 2011, provides buyers of EVs with significant financial benefits, offering up to 35% off the purchase price, capped at £5,000 for new zero-emission cars and £2,500 for plug-in hybrids. Moreover, most electric EV owners benefit from exemptions on vehicle excise duty, an annual tax for drivers. In a recent initiative, the government has introduced green number plates for electric car owners, providing them with various advantages such as free parking, reduced parking costs, access to bus lanes, and entry into zero-emission zones at no charge. Further, EV charging is also exempt from the car fuel benefit charge, a tax imposed on drivers provided with a company car and free fuel from their employer. Additionally, electricity incurs a reduced 5% VAT, as opposed to the 20% VAT applicable to combustible fuels. These incentives collectively aim to enhance the accessibility and attractiveness of EVs, aligning with the government's commitment to building a sustainable and environmentally friendly transportation system in the UK.

3.4. Policy Impacts

The impact of incentive programs on EV adoption has been extensively examined in the literature, documenting consistent evidence of positive effects on market growth.[26] For instance, a comprehensive review conducted by Hardman et al. (2017), covering 35 studies on financial purchase incentives for various types of EVs, demonstrated increased EV sales across diverse regions, reinforcing the effectiveness of such incentives. Similarly, Zhou et al. (2016) found in their review that a majority of studies supported the efficacy of purchase rebates and tax credits in boosting the market penetration of plug-in electric vehicles.

However, the efficiency of certain incentives, particularly the federal tax credit, has been questioned in some studies (Gallagher and Muehlegger, 2015; Johnson et al., 2017; DeShazo et al., 2017; Clinton and Steinberg 2019). Notably, a survey by the Center for Sustainable Energy (2017) revealed that consumers in California placed equal importance on the $2,500 state rebate and the $7,500 federal tax incentive when making a decision to purchase an EV. Additionally, Xing et al. (2021) showed that a significant proportion of households benefiting from federal tax credits would have opted for an EV even without the credit.

This divergence in findings has sparked debates about the overall effectiveness of incentives on an aggregate scale. On one hand, the global EV market has experienced an unprecedented surge with remarkable growth in sales in recent years. In 2021 alone, the sales of EVs reached 6.6 million units, nearly doubling from the previous year. The total number of EVs on the road more than tripled in three years to over 16.5 million EVs. This surge contributed to a substantial increase in the total number of EVs on roads, exceeding 16.5 million globally and more than tripling over the course of three years. Notably, battery electric vehicles constituted a significant majority of these sales.

China emerged as a key driver of this growth, registering 3.3 million new EVs in 2021, tripling the figures from the preceding year and surpassing the entire world's EV registrations in 2020 (Table 4). China, together with Europe, which sold 2.3 million units, collectively represented over 85% of the global EV sales in 2021, with the U.S. contributing 10% to the global market. This data highlights the accelerating momentum and widespread adoption of EVs on a global scale.

[26] Zhou et al. 2015, Lévay et al. (2017), Hardman et al. (2017), Clinton and Steinberg (2019), Jenn et al. (2018), Münzel et al. (2019), Yan (2018), DeShazo et al. (2017), Sierzchula et al. (2014), Muehlegger and Rapson (2020), Archsmith et al. (2021), Wee et al. (2018).

The data from the U.S. also points to a substantial increase in EV presence on the roads, with sales more than doubling in 2021, adding 460 thousand units of BEVs (Figure 4). The momentum continued in 2022, with a 76.1% increase and a record-breaking addition of 810 thousand units of BEVs, despite an overall decline in new light vehicle sales since 2019, further decreasing by 5.6% in 2022. As of 2021, the total number of registered EVs reached approximately 1.45 million vehicles (Figure 4 Panel B).

On the other hand, despite these positive trends, the penetration of EVs remains relatively modest in many countries. Globally, EV sales accounted for 9% of the global car market in 2021, marking a four-time increase from their market presence in 2019. In the U.S., the share of EV sales was 5% in 2021, constituting just 0.5% of the overall registered vehicles in the country. This growth, while commendable, lags behind the rapid advancements observed in other regions, such as China (16%) and Europe (17%). This discrepancy underscores the need for a more nuanced understanding of the intricate dynamics between incentives and EV adoption to further refine policy strategies for sustainable growth in the electric vehicle market. Notably, Norway achieved the highest market share for new EV sales in 2021 in Europe at 86%, with the sale of 152,000 EVs.

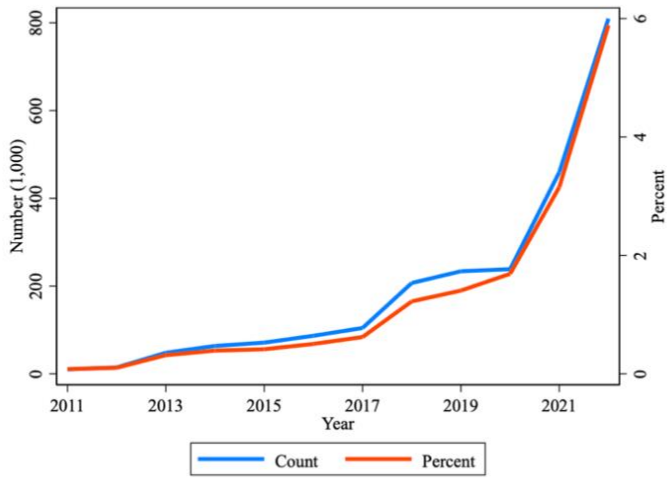
Table 4: Number of EVs around the World, 2021

Country/region	Sale (1,000)	EV sale share
China	3,334	16%
U.S.	631	5%
Europe	2,284	17%
U.K.	312	19%
Norway	152	86%

The table presents EV sales and sale shares for battery electric and plug-in hybrid vehicles in 2021, using IEA (2022) data.

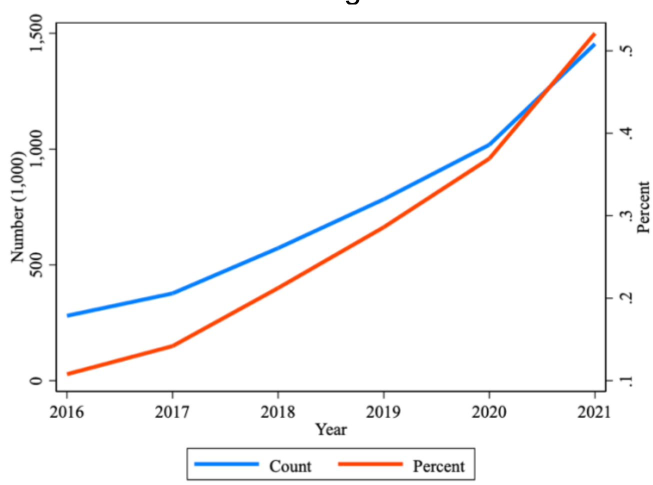
Figure 4: Number of EVs over Time in the U.S.

Panel A: Sales



This figure shows EV sales, excluding HEVs/PHEVs, and their share of light-duty vehicle sales.[27]

Panel B: Registrations



This figure shows EV sales, excluding HEVs/PHEVs, and their share of light-duty vehicle registrations, with registration data from AFDC[28].

4. Policy Challenges

[27] EV sales up to 2021 come from Davis and Boundy (2022). The EV sales in 2022 come from Kelley Blue Book Electric Vehicle Sales Report Q4 2022 (https://www.coxautoinc.com/wp-content/uploads/2023/01/Kelley-Blue-Book-EV-Sales-and-Data-Report-for-Q4-2022.pdf). The light-vehicle sales in 2022 come from Statista (https://www.statista.com/statistics/199983/us-vehicle-sales-since-1951/).

[28] https://afdc.energy.gov/vehicle-registration?year=2021

Navigating the landscape of EV charging infrastructure expansion brings forth a myriad of policy challenges that demand careful consideration and strategic planning. As the adoption of EVs continues to surge, the need for a robust charging network becomes increasingly apparent. Policymakers face challenges ranging from identifying economically efficient and effective ways to expand EV charging infrastructure to establishing regulatory frameworks aimed at mitigating grid burden. This section explores the policy challenges associated with the expansion of EV charging infrastructure, shedding light on the aspects that demand attention for the development of a sustainable and widespread charging network.

4.1. Chicken or egg?

Many studies have highlighted the positive associations between EV adoption and the availability of local charging stations. On one hand, the presence of charging stations plays a crucial role in determining the adoption of Evs (Sierzchula et al. 2014, Egnér and Trosvik 2018, Clinton and Steinberg 2019, Patt et al., 2019). While most EV owners charge their vehicles at home,[29] many face challenges when parking on the street or residing in multi-unit dwellings with limited charging capacity (Axsen and Kurani 2012, Lopez-Behar et al. 2019). On the other hand, a higher number of charging stations are strategically located in areas where EV adoption is already high due to profit-maximizing behaviors of companies. This "chicken-or-egg" problem explains the limited infrastructure as a barrier to EV adoption, whereas investment in charging infrastructure depends on the number of Evs on the road (Schroeder and Traber, 2012; Gnann and Plotz, 2015).

Understanding the causal relationship between EV adoption and charging station availability is crucial from a policy perspective. Government incentives have primarily focused on promoting EV purchases through substantial tax credits or subsidies. If EV adoption drives the increased availability of charging stations, these government programs have proven effective. However, if the availability of charging stations drives greater EV adoption, government initiatives should prioritize the expansion of charging infrastructure.

Empirical investigations of these causal pathways require research contexts that leverage exogenous variations in these variables. For example, state subsidies for Evs and charging stations can serve as instrumental variables when the timing of subsidy implementation is plausibly random, given market and time fixed effects. Nevertheless, utilizing such subsidies as instruments may encounter challenges related to endogeneity if tax incentives for EV purchases are correlated with incentives for charging station construction. Take, for instance, the NEVI program, which operates on a formula-based approach, leading to varying allocation amounts to each state based on multiple factors, some of which may be associated with or directly linked to EV stocks and projected EV market growth.

Bruckmann and Bernauer (2020) conducted a choice experiment among car holders in Switzerland (n = 5325) with varying levels of purchase subsidies and the availability of charging infrastructure. They find that increasing the number of public charging stations beyond the current levels had a more significant impact on public support and EV adoption compared to the impacts of EV purchase subsidies and even more so than other policies such as banning gasoline vehicles or implementing carbon taxes. These findings indicate that expanding charging infrastructure is the most politically feasible and effective policy option for promoting EV adoption.

[29] Multiple surveys indicate that more than 80% of EV owners charge their EVs at home (Idaho National Laboratory 2015, EECA 2021).

Two studies have attempted to address the issue of simultaneity and network externalities in both sides of the EV market in distinctive manners. First, Li et al. (2017) employed instrumental variables to address these feedback loops between new EV sales and charging station deployment at the quarterly level across 353 Metropolitan Statistical Areas from 2011 to 2013. They used current and historical gasoline prices as instruments for the current stock of Evs, while they used national changes in charging station stock, interacted with the number of local grocery stores and supermarkets, as instruments for the stock of charging stations. Their findings suggest that providing subsidies for building charging stations would make tax incentives for EV purchases twice as effective, given that the impact of charging station deployment on EV sales is of greater magnitude than the impact of EV sales on charging station deployment. Additionally, early EV adopters tend to be less price sensitive.

Second, Springel (2021) examined the two-sided EV markets in Norway. She used the size of the incentives for EV charging infrastructure installations to instrument for the installed number of charging stations, while gas station density is used as an instrument for the cumulative EV base. Using a structural model, she also finds that subsidizing the charging infrastructure is over twice as cost-effective compared to subsidizing EV purchases.

Overall, the studies examining the association between the availability of EV charging stations and EV adoption have provided valuable insights into the critical role of charging infrastructure in encouraging the uptake of Evs. However, it is essential to acknowledge that there remains an identification issue concerning whether the exclusion restriction assumption is satisfied. To fully grasp the causal relationship between charging infrastructure and EV adoption, more research is warranted to address this potential limitation and to offer more conclusive evidence on the significance of charging infrastructure in promoting widespread EV adoption.

Further, the existing findings primarily pertain to early adopters, who are typically wealthier and less sensitive to price changes. However, as the demographics of the EV market shift and encompass a more diverse consumers, the catalysts of network effects are expected to exhibit significant variations. This emerging group of consumers may face barriers to home charging accessibility, making the availability of charging stations an even more important factor influencing their EV adoption decisions. On the other hand, for this segment of consumers, EV subsidies are likely to have a more pronounced impact.[30] This also raises practical considerations, including cabling and health and safety issues associated with running cables in basements and across pavements. Improved regulations in this regard might adopt a more permissive stance in certain areas or advocate for appropriate street architecture, integrating features like ducting or streetlight and utility pole charging points. A better understanding of the relationship between EV adoption and charging station availability will help design policies to effectively meet the evolving needs and demands of the expanding EV market.

4.2. Compatibility

EV charging connectors exhibit significant variations in design, creating a crucial factor that influences the effectiveness and convenience of charging options for EV owners. The ongoing debates surrounding standardization emphasize the need for a universal plug technology.

In Europe, the IEC 62196 Type 2 connector, commonly referred to as Mennekes, stands as the standardized connector used by all manufacturers across the continent. Tesla, however, utilizes

[30] Muehlegger and Rapson (2020) finds a higher price elasticity of EV demand among low- and middle-income households.

its proprietary connector, although there is a gradual shift toward the Type 2 connector for European models. The Combined Charging System (CCS) supports DC fast charging in Europe, seamlessly merging the Type 2 connector with two DC quick charge pins, allowing vehicles to be charged using both levels of charging equipment.

China has successfully established standardization, with all Chinese Evs adopting the GB/T type nationwide. This lack of competition from alternative connectors has been instrumental in driving the growth of the charging infrastructure network, establishing China as the global leader in both the number of charging stations and the percentage of electric cars.

Japan has played a unique role in the realm of plug standards. Five Japanese automakers introduced CHAdeMO as the original DC plug in 2010, attempting to promote it as a global standard. Although widely adopted in Japan and previously dominant in North America and Europe, CHAdeMO's popularity has waned in recent years, as fewer new vehicle models in North America support CHAdeMO, and the European Parliament sought to gradually reduce its usage by requiring every fast-charging stations to include at least one CCS connector.

In the U.S., the diversity in connector types presents a unique and significant challenge, underscoring the necessity for addressing compatibility issues. The existence of three incompatible types of outlets for EV charging infrastructure—J1772 for AC Level 1 using a 120-volt plug, J1772 and Tesla's NACS for AC Level 2 using a 240-volt plug, and CCS, CHAdeMo, and NACS for DC fast chargers using 50–350 kW— gives rise to several challenges.[31] First, firms may hesitate to make substantial investments in the EV charging infrastructure market due to uncertainties and risks associated with predicting market demand and consumer preferences. Additionally, limited coordination across firms and reduced economies of scale contribute to increased costs, further hindering the expansion of charging networks. Consumers also encounter difficulties in locating suitable charging stations that match their vehicles' plugs. This issue not only intensifies range anxiety while driving but also leads to negative experiences, influencing the overall perception of Evs. Consequently, these challenges create barriers to the widespread adoption of Evs, impeding their growth in the market.

Li (2019) examined the welfare implications of incompatible standards in the EV charging infrastructure market. Using a structural model that incorporates vehicle demand and charging network investment, she found that a uniform charging standard would incentivize car manufacturers to construct a reduced number of charging stations. This result demonstrates that firms tend to overinvest when faced with an incompatible environment, where each product they offer serves as a substitute for others. In contrast, her findings also indicated that implementing a uniform charging standard would result in increased sales of Evs. Furthermore, consumer surplus would also be enhanced primarily through savings on the costs associated with purchasing adaptors for different plug types. These findings shed light on the potential benefits of adopting a standardized charging plug in the EV charging infrastructure market, emphasizing the positive impact it can have on both industry investment decisions and consumer welfare.

In recent years, significant efforts have been made to bring an end to the "plug war." One notable development has been the gradual phase-out of the CHAdeMO DC fast chargers standard in the U.S., despite its continued popularity in other countries, especially Japan. This shift gained

[31] Level 1 charging is not available in Europe due to the standard household electricity being 230 volts, nearly double the voltage used in North America. Residential chargers in the U.S. are generally Level 1 or Level 2, while DC fast chargers are commonly found in public locations due to the higher costs of equipment and installation, ranging from $20,000 to $200,000 (Appendix Table A1).

momentum when Nissan, formerly a major player in the U.S. EV market, announced its decision to abandon the CHAdeMO standard in favor of the CCS standard for their new Evs.[32] Following suit, Electrify America made a similar commitment to phase out new CHAdeMO installations after 2022. As a result, the number of charging stations equipped with CHAdeMO connectors, constructed after 2022, is now less than 10%.

Second, with the phasing out of CHAdeMO, the market for DC fast chargers now primarily consists of two standards: Tesla's NACS and CCS, which is adopted by all manufacturers except Tesla. Despite this, a significant majority of DC fast chargers stations are Tesla Superchargers (Appendix Figure A2), reflecting the substantial presence of Tesla Evs on the roads.[33] Notably, in November 2022, Tesla took a significant step by making NACS open for adoption by other charging network operators and vehicle manufacturers. Subsequently, Ford, the second largest seller of Evs, made announcements in May 2023, stating their plans to adopt the Tesla connector in their new EV models starting in 2025, while the existing EV owners will be able to charge their vehicles at Tesla Superchargers via an adaptor as early as 2024.[34] SAE International has also officially announced its decision in June 2023 to standardize the EV charging connector based on Tesla's NACS. These moves have encouraged other automakers to follow suit, leading other automakers[35] to make similar agreements with Tesla to adopt their NACS connect, reinforcing its standardization within the EV industry.

Automakers are incentivized to adopt Tesla's NACS due to the potential for substantial cost savings and the utilization of Tesla's already extensive charging network. For instance, in October 2021, GM announced its plan to invest $750 million in EV charging infrastructure in the U.S. and Canada, but integrating Tesla's NACS could lead to savings of up to $400 million from the original budget (Wayland 2023). Moreover, there is a compelling economic incentive for local governments to support Tesla chargers to save significant public funds, as Tesla's deployment cost for charging stations is less than one-fifth of the cost incurred by many other competitors, including ChargePoint and Evgo.[36] However, it is important to note that the complete phase-out

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[32] Despite the Nissan Leaf continuing to utilize the CHAdeMO plug, this model will eventually be phased out. In contrast, while their latest EV model, the Ariya, embraces the CCS standard, the Ariya will transition to Tesla's NACS connector starting in 2025, making them the first Japanese automaker to adopt NACS for its EVs. Additionally, the Mitsubishi Outlander PHEV is the only other vehicle that currently utilizes the CHAdeMO plug. It is worth noting that both the Nissan Leaf and Mitsubishi Outlander also feature a J1772 port, enabling Level 2 AC charging.

[33] The extensive deployment of DC fast charging ports by Tesla underscores the company's strong position as the leading brand in the EV industry. While their share of new EV sales has experienced a relative decline since reaching a peak of nearly 80% in 2018, with the ongoing introduction of new models by other automakers, Tesla alone accounts for nearly 64.5% of total EV sales in 2022 (Appendix Figure A3). This far surpasses the second-largest seller, Ford, which accounted for a mere 7.6% market share.

[34] Note that Tesla vehicles can be connected and charged to CCS plugs by using an adapter, enabling them to access not only Tesla's extensive and reliable charging network but also other stations equipped with CCS connectors. However, prior to the deal, Tesla chargers were exclusive to Tesla vehicles. In addition, Tesla plans to equip at least 7,500 chargers with CCS ports, making them accessible to non-Tesla vehicles by the end of 2024.

[35] As of January 2024, the list of automakers that have agreed to adopt Tesla's NACS include: Audi, BMW, Fisker, Ford, Genesis, GM, Honda, Hyundai, Jaguar, Kia, Lexus, Lucid, Mazda, Mercedes-Benz, Mini, Nissan, Polestar/Volvo, Porshce, Rivia, Rolls-Royce, Scout Motors, Toyota, and Volkswagen (Stafford 2024).

[36] https://digitalassets.tesla.com/tesla-contents/image/upload/IR/Investor-Day-2023-Keynote

of CCS is currently expected to face delays due to the requirements of the NEVI program, which mandates the inclusion of a CCS connector for DC fast chargers ports.

Overall, ensuring compatibility in EV charging plugs is vital for the efficient and cost-effective expansion of EV charging infrastructure. The existing regulation mandating the use of a CCS connector at EV charging stations poses a potential challenge to the ongoing market-driven initiatives aiming to establish uniformity and compatibility among charging infrastructure. These initiatives, driven partly by economic incentives, are focused on promoting ease of use and expanding the charging network.

Given this situation, further research is warranted to assess the welfare implications of ensuring charger compatibility with a diverse range of electric vehicles. We do not expect that the adoption of the unified charger with the NACS standard will make Tesla a monopoly in the public charging provide market, as other network operators are likely to follow suit and adopt NACS plugs for their chargers as well,[37] fostering a diverse and competitive landscape in the EV charging market. However, future research would help shed light on the benefits of integration and user convenience, while also promoting innovation, competition, and the overall expansion of the EV charging system.

4.3. Income Distribution Considerations

The growing body of literature emphasizes that low-income and minority communities often experience a disproportionate burden of environmental damages, giving rise to concerns regarding environmental justice. Considering the positive impact of Evs on air quality, it becomes crucial to prioritize policies that promote greater EV adoption among disadvantaged populations. Further, these populations cannot be precluded to achieve the ambitious targets of widespread adoption of Evs.

However, the early adopters of Evs tend to be individuals with higher wealth (Borenstein and David, 2016, Lee et al. 2019). Consequently, there is greater economic incentives for developing public charging infrastructure in their communities, while individuals in disadvantaged communities face significant barriers due to limited access to public charging stations. This issue is particularly prevalent for those residing in multi-unit dwellings, as they often encounter challenges related to the availability and affordability of residential chargers (Fleming, 2018; Canepa et al., 2019; Pierce et al., 2020; Hardman et al., 2021; Hsu and Fingerman, 2021). Additionally, residents of rental housing are often hesitant to invest in home charger installations, and property owners may be less inclined to bear the cost of a charger that they themselves do not use. This might point to the need for prioritizing subsidies for home charging as a priority, recognizing that the importance of home and public charging may vary based on different needs and purposes.

Although previous studies have shed light on the unequal distribution of public charging stations in specific regions such as California (Hsu and Fingerman, 2021) and New York City (Khan et al., 2022), there is a lack of comprehensive analysis examining the relationship between charging station distribution and the socio-demographic characteristics of communities nationwide.

Thus, we utilize Census tract-level data to examine the association between the presence of EV stations and local socio-demographic factors. To this end, we match each station’s longitude and

[37] For example, public charging networks, such as ChargePoint and Electrify America, have announced plans to add NACS- connector to their stations (Stafford, 2024).

latitude coordinates to the corresponding Census tract on the 2020 Census tract map. Additionally, we obtained Census tract characteristics from the U.S. Census Bureau for the year 2020. The summary statistics and variable definitions can be found in Appendix Table A2. We utilize regression analysis to investigate the relationships between the availability of charging infrastructure and census tract characteristics. The individual coefficients estimated from the regression analysis are presented in Appendix Table A3.

Our analysis reveals a positive correlation between the number of ports and stations and median income. Specifically, a ten-percent increase in median income corresponds to an additional 0.199 ports and 0.062 stations, which represents an approximate 11.73% increase in the average number of ports and a 9.27% increase in the average number of stations, respectively. These findings suggest that the distribution of public charging stations is disproportionately skewed toward affluent communities.

In contrast, our analysis also uncovers indications of public charging station deployment in vulnerable communities. For instance, we observe a higher presence of charging infrastructure in communities characterized by a larger percentage of apartments (compared to single- and multi-family houses), a lower homeownership rate, and a greater proportion of minority residents (compared to white populations). These findings suggest that there are siting decisions for the rollout of charging stations that prioritize locations where they are most needed, demonstrating a degree of equity in their distribution.

However, our analysis also uncovers evidence of inadequate access to charging stations in areas where they are most needed. For instance, we find limited associations between access to charging infrastructure and factors such as education level, unemployment rate, and the percentage of households below the poverty line. Additionally, while the availability of charging stations shows little correlation with the percentage of households without a vehicle, it exhibits a strong negative association with the average number of vehicles. Furthermore, the presence of charging stations is positively linked to the percentage of individuals working from home, while negatively associated with the percentage of people with commutes exceeding 30 minutes. These findings collectively indicate an inefficient targeting of charging stations, potentially leaving certain communities underserved.

Further, we investigate the relationships between changes in charging infrastructure since 2022 and socio-demographic factors. This analysis aims to determine whether the expansion of charging infrastructure under the BIL has followed a distinct trajectory compared to previous trends in the early phase. Notably, the BIL incorporates grants that specifically target the expansion of charging stations in low-income neighborhoods. Overall, the findings align with those observed above, indicating that the construction of additional stations has primarily occurred in areas where a higher number of stations already existed.[38]

It Is Important to emphasize that the purpose of the analyses above Is not to establish a causal mechanism. Instead, our objective is to highlight the correlations observed in the data, providing valuable insights to inform the design of policies that promote a more equitable expansion of EV charging infrastructure.

It is also worth noting that improving and ensuring equitable access to public charging stations in low-income communities does not necessarily serve as a substitute for home charging. Electricity

[38] The historical observations of stations in our dataset are limited to the ones that are currently operational. There may have been stations that were active in 2021 but have since been phased out or decommissioned, and as a result, they are not captured in the present dataset.

purchased at public charging can be significantly more expensive, costing 5-10 times more than home charging (Kampshoff et al. 2022),[39] thereby diminishing the cost-saving benefits of Evs compared to gasoline vehicles (Scorrano et al., 2020).

Overall, our findings indicate that the current targeting of charging infrastructure falls short in addressing the unequal distribution of charging stations in disadvantaged communities, presenting a significant barrier to EV adoption. Policies need to be developed to promote equal distribution of charging infrastructure in these communities, while also addressing the affordability of home charger installations. Future research is expected to evaluate the extent to which current federal initiatives, which prioritize underserved communities, effectively address equitable access to charging options and their impact on EV adoption across a broader set of communities.

4.4. Grid Burden

The proliferation of Evs and the associated expansion in charging infrastructure pose unique challenges to the existing electrical grid, giving rise to concerns about reliability, load balancing, and overall stability. An understanding of EV users' charging behaviors is a critical aspect of gauging the overall impact on the grid. This subsection explores the challenges the grid face associated with the expansion of the EV charging network.

How extensively are Evs being utilized? This is an important policy question to understand the energy quantity Evs require. Burlig et al. (2021), using data from residential electricity meters in California, found that the EV load is unexpectedly modest. The adoption of an EV increases household electricity consumption in California by 2.9 kWh per day, markedly lower than official estimates ranging between 6 and 9.8 kWh per day. Coignard et al. (2018) corroborate these findings, projecting that the transition of the automotive fleet to Evs may not significantly impact the system-wide net load in California. This conclusion broadly holds true across various countries. Table 5 shows that on a global scale, the electricity demand attributed to Evs constitutes merely 0.5% of the current total final electricity consumption worldwide and is still less than 1% in China, which accounts for a quarter of the total EV electricity consumption (IEA 2023). Even by 2030, the projected demand for electricity to power Evs constitutes just over 3% of the total global final electricity consumption.

Table 5: Share of Electricity Consumption by Evs

County/region	2022	2030
China	0.8%	3.8%
U.S.	0.4%	5.4%
Europe	0.7%	4.7%
Japan	0.1%	1.7%
India	0.1%	1.7%
World	0.5%	3.2%

This table shows EV electricity consumption as a share of total final consumption, using data from IEA (2023).

[39] The higher cost of charging at public stations is partly attributed to the fact that most public charging occurs during the day when the cost per kilowatt-hour is generally higher compared to those who charge their EVs at home overnight.

However, challenges arise during peak charging times, particularly with the increased penetration of EVs (Azadfar et al. 2015; Morrissey et al. 2016; Schäuble et al. 2017). The surveys have also revealed that consumers tend to charge their EVs around the same time, coinciding with an existing demand peak (Zhang et al. 2011; Schäuble et al. 2017). The simultaneous charging of numerous EVs during peak hours stresses the grid, potentially requiring upgrades to accommodate heightened loads. Consequently, with the continued increase in EV adoption, strategic planning is essential to mitigate potential burden on the grid. Two key strategies explored are the deployment of workplace chargers and charging management initiatives.

Workplace chargers strategically placed offer distinctive advantages, allowing for daytime charging when solar generation peaks. This aligns with the high availability of solar energy, optimizing resource utilization and reducing grid strain during peak periods. Currently, most EV owners charge at home in the U.S. and EU (Hardman et al. 2018), but China, with fewer single-family homes, leans more toward public charging.

Engel et al. (2018) estimates that in the EU, the charging landscape for EVs is expected to transition toward greater reliance on public charging options as EVs become more prevalent. Projections indicate a decline in the share of home charging from roughly 75 percent in 2020 to about 40 percent by 2030. This shift is attributed to the increasing adoption of EVs among middle- and lower-income households that may lack access to home-charging facilities. In China, a similar trend is anticipated, with public charging projected to dominate, rising from 55 to 60 percent in 2020 to approximately 80 percent by 2030.

Enhancing the availability of workplace charging stations can have a considerable impact on the electrical power system. Needell et al. (2023) estimates, based on data from New York and Dallas, increased access to workplace charging stations helps address challenges related to both elevated evening peak electricity demand and excess solar energy during daytime. Failing to address these challenges could lead to a substantial increase in energy costs and pose potential obstacles to the advancement of transportation electrification.

Another effective strategy involves delayed home charging, where the charging of an electric vehicle battery is strategically scheduled or deferred to off-peak hours, typically during the night. This strategy aligns with the implementation of time-of-use rates, which offer lower electricity rates during off-peak hours and higher rates during peak times. Varying electricity prices based on demand levels induce delayed peak charging, resulting in a flattened demand curve, a more evenly distributed load, and financial savings for consumers. This approach has been adopted by many local utilities across the U.S. and Europe. Studies have shown the effectiveness of such pricing schemes in inducing consumers to charge their EVs during off-peak hours, both in the U.S. (Dunckley and Tal 2016) and in the UK (Hamidi et al. 2009).

Smart charging harnesses advanced technologies and communication systems to optimize the charging process of EVs. This includes strategic control over factors such as the timing, speed, and charging method. It takes into account the current supply and demand dynamics of electricity along with the needs of drivers. Research indicates that the implementation of smart charging technologies brings about notable benefits. For instance, a study conducted in the Netherlands by Gerritsma et al. (2019) highlights the significant flexibility achievable in determining the timing and duration of EV charging. Their simulations reveal that a substantial portion, specifically 59% of the EV demand, can be effectively deferred over more than 8 hours. This underscores the potential of smart charging to optimize the utilization of electricity resources, enhance grid management, and cater to the varying charging requirements of EV users.

5. Conclusion

This chapter provides a review of initiatives, policies, and funding programs that have played a crucial role in driving the expansion of EV charging networks and EV adoption, examining experiences in the U.S. and other selected countries. While there has been substantial progress in expanding the EV charging network in recent years, it falls short of supporting the rapid growth of the EV market in many countries, particularly meeting the ambitious goal of achieving set by the U.S. administrations. Throughout this review, we have identified four key challenges that need to be addressed to ensure the development of an inclusive, dependable, and sustainable charging network.

First, it is important to analyze the interdependency between the deployment of EV charging stations and the adoption of EVs, as they both constitute two-sided markets. Existing evidence indicates that subsidizing the development of EV charging stations proves more cost-effective in driving EV adoption than subsidizing the purchase of EVs. However, these findings predominantly stem from early adopters, who typically possess higher wealth and lower price sensitivity. The catalyst for network effects is likely to vary as a more diverse group of consumers from different socio-economic backgrounds participate in the EV market. Furthermore, there remain significant challenges in the identification for establishing causal relationships empirically. A better understanding and reliable estimates of the network effects will help policymakers and stakeholders make informed decisions and allocate resources more effectively to further EV uptake.

Second, the standardization of charging connectors presents a unique set of challenges particularly in the U.S. On one hand, the industry is progressively integrating to a dominant charging connector type, Tesla's proprietary connector NACS. As of June 2023, Tesla represents only 11.3% of Level 2 public charging ports but holds a significant share of 61.6% in DC fast charging ports (Appendix Figure A2). This convergence offers the advantage of enhanced compatibility and user convenience. On the other hand, federal regulations that mandate the use of a specific connector type, CCS, have the potential to distort the market-driven process toward a uniform standardization. The rationale for implementing such a mandate arises from a concern that federal support should not be given to facilities benefiting only one company. However, recent developments have considerably altered the landscape. In recent months, an increasing number of major automakers have made agreements with Tesla to adopt NACS for their EVs, and this trend is expected to gain further momentum with many others likely to follow suit. As a result, the landscape of EV charging infrastructure market is rapidly evolving, with broader industry participation fostering a collaborative and standardized approach. It is essential for policymakers to balance between the potential advantages of uniformity while also encouraging competition and innovation, and without harming consumer choice within the integrated market.

Third, we have highlighted the concerning disparity in the distribution of EV charging stations, with a clear imbalance disproportionately affecting low-income and environmental justice communities. This issue is closely tied to the chicken-and-egg dilemma mentioned earlier, as the current concentration of EV owners predominantly resides in wealthier communities. However, it is vital to recognize that the welfare implications of EV adoption and the expansion of charging infrastructure hold greater significance for low-income communities, where access to home charging is limited, and residents already bear the burden of other environmental challenges, including lower air quality. Addressing the equity concerns related to charging infrastructure access, especially in rural and underserved regions, requires ongoing cooperation among federal agencies, state governments, local authorities, and private sector stakeholders.

Last, we have explored the concerns about reliability, load balancing, and overall grid stability associated with the expansion of EV charging infrastructure. Peak charging times were identified as potential stress points for the grid, necessitating upgrades to handle increased loads. Strategies such as deploying workplace chargers and incentivizing delayed peak charging through pricing mechanism and use of innovative charging technology were proposed to mitigate grid burden, align charging with renewable energy availability, and promote more efficient electricity consumption. The careful consideration of these challenges and strategic planning were emphasized to ensure the sustainable growth of EV adoption and charging infrastructure.

The primary objective of the regulation is to enhance the accessibility and affordability of EV chargers. However, several economic considerations must be addressed to elucidate the implications for other countries and the future of regulation. For instance, while the need for subsidies is evident, it is crucial to scrutinize the cost per charger and the degree of innovation induced by various subsidy mechanisms. Furthermore, determining which entities should invest in chargers and identifying the beneficiaries of these incentives—be they car companies, local authorities, utilities, charging companies, petrol retailers, supermarkets, etc.—is fundamental. The coordination of comprehensive coverage, especially concerning the alleviation of range anxiety, represents another key aspect. Notably, local authorities possess a unique position due to their control over street infrastructure, making them key stakeholders in this discourse.[40]

To accelerate the electrification of the transportation sector, it is essential to assess the effectiveness of federal and local initiatives, identifying areas for improvement, and fostering public-private partnerships to build out a reliable and inclusive EV charging network nationwide. This review underscores several key regulatory insights. First, governments should continue to support the establishment of EV charging infrastructure through federal fiscal policies and local incentives. Second, in addition to incentivizing the installation of home chargers, regulations mandating the expansion of charging stations in both new and existing buildings, workplace, as well as parking spaces, are crucial to ensure a more inclusive and equitable transition to electric mobility, as the demographic of EV consumers continues to evolve. Last, strategic initiatives, including grid expansion, digital technology adoption facilitating smart charging, and the implementation of pricing mechanisms, play a key role in optimizing the efficiency and effectiveness of EV charging infrastructure.

[40] See additional relevant points in Pollitt et al. (2022).

References

Archsmith, James E., Erich Muehlegger, David S. Rapson. 2021. Future Paths of Electric Vehicle Adoption in the United States. Predictable Determinants, Obstacles and Opportunities. NBER Working Paper 28933.

Axsen, Jonn, Kenneth S. Kurani. 2012. Who can recharge a plug-in electric vehicle at home? Transportation Research Part D, 17: 349-353.

Azadfar, Elham, Victor Sreeram, David Harries. 2015. The investigation of the major factors influencing plug-in electric vehicle driving patterns and charging behaviour. Renewable and Sustainable Energy Reviews, 42: 1065-1076.

Baik, Y., Hensley, R., Hertzke, P., Knupfer, S., 2019. Making Electric Vehicles Profitable. McKinsey Co. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/making-electric-vehicles-profitable.

Békés, Márton, Mladen Fruk, Eugen Hildebrandt, Kjartan Kalstad, Klaas Mantel, Florian Nägele, Swarna Ramanathan. 2023. What Norway's experience reveals about the EV charging market. McKinsey & Company.
https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/what-norways-experience-reveals-about-the-ev-charging-market#/

Borenstein, Severin and Lucas W Davis. 2016. The distributional effects of US clean energy tax credits. Tax Policy and the Economy, 30 (1): 191–234.

Brückmann, Gracia, Thomas Bernauer. 2020. What drives public support for policies to enhance electric vehicle adoption? Environmental Research Letters, 15: 094002.

Burlig, Fiona, James Bushnell, David Rapson, Catherine Wolfram. 2021. Low energy: Estimating electric vehicle electricity use. Working paper.

Canepa, Kathryn, Scott Hardman, Gil Tal. 2019. An early look at plug-in electric vehicle adoption in disadvantaged communities in California, 78: 19-30.

Clinton, Bentley, Daniel C. Steinberg. 2019. Providing the Spark: The Impact of financial incentives on battery electric vehicle adoption. Journal of environmental economics and managements, 98: 102255.

Coffman, Makena, Paul Bernstein, Sherilyn Wee. 2017. Electric vehicles revisited: a review of factors that affect adoption, Transport Reviews, 37:1, 79-93.

Coignard, Jonathan, Samveg Saxena, Jeffery Greenblatt, and Dai Wang. 2018. Clean vehicles as an enabler for a clean electricity grid. Environmental Research Letters, 13: 054031.

Davis, C. Stacy, Robert G. Boundy. 2022. Transportation Energy Data Book, Edition 40. Oak Ridge National Laboratory. https://tedb.ornl.gov/wp-content/uploads/2022/03/TEDB_Ed_40.pdf

DeShazo, J.R., TamaraL. Sheldon, RichardT. Carson. 2017. Designing policy incentives for cleaner technologies: Lessons from California's plug-in electric vehicle rebate program. Journal of Environmental Economics and Management, 84: 18-43.

Dunckley, J., G. Tal. 2016. Plug-In Electric Vehicle Multi-State Market and Charging Survey. EPRI, Palo Alto, CA: 2016. 3002007495.

Egnér, Filippa, Lina Trosvik. 2018. Electric vehicle adoption in Sweden and the impact of local policy Instruments. Energy Policy, 121: 584-596.

Energy Efficiency and Conservation Authority (EECA). 2021. Electric Vehicle Charging Survey – Insights into EV owners' charging habits, and use of public EV charging. Wellington, New Zealand.

Engel, Hauke, Russell Hensley, Stefan Knupfer, Shivika Sahdev. 2018. Charging ahead: Electric-vehicle infrastructure demand. McKinsey & Company. https://www.mckinsey.com/~/media/McKinsey/Industries/Automotive%20and%20Assembly/Our%20Insights/Charging%20ahead%20Electric-vehicle%20infrastructure%20demand/Charging-ahead-electric-vehicle-infrastructure-demand-final.pdf

Fleming, Kelly L. 2018. Social Equity Considerations in the New Age of Transportation: Electric, Automated, and Shared Mobility. Journal of Science Policy & Governance, 13(1).

Francfort Jim, Brion Bennett, Richard "Barney" Carlson, et al. 2015. Plug-in electric vehicle and infrastructure analysis. Idaho National Laboratory. https://inldigitallibrary.inl.gov/sites/sti/sti/6799570.pdf

Fröde, Peter, Morgan Lee, Shivika Sahdev. 2023. Can Public EV fast-charging stations be profitable in the United States? McKinsey & Company. https://www.mckinsey.com/features/mckinsey-center-for-future-mobility/our-insights/can-public-ev-fast-charging-stations-be-profitable-in-the-united-states

Funke, Simon Árpád, Frances Sprei, Till Gnann, Patrick Plötz,2019. How much charging infrastructure do electric vehicles need? A review of the evidence and international comparison. Transportation Research Part D, 77: 224-242.

Gallagher, K.S., Muehlegger, E., 2011. Giving green to get green? The effect of incentives and ideology on hybrid vehicle adoption. Journal of Environmental Economics and Management, 61 (1), 1-5.

Gerritsma, Marte K., Tarek A. AlSkaif, Henk A. Fidder, Wilfried G. J. H.M. van Sark. 2019. Flexibility of Electric Vehicle Demand: Analysis of Measured Charging Data and Simulation for the Future. World Electric Vehicle Journal, 10(14).

Gnann, Till, Patrick Plötz. 2015. A review of combine models for market diffusion of alternative fuel vehicles and their refueling infrastructure. Renewable and Sustainable Energy Reviews, 47: 783-793.

Hamidi, Vandad, Furong Li, Francis Robinson. 2009. Demand response in the UK's domestic sector. Electric Power Systems Research, 79: 1722-1726.

Hardman, Scott, Chandan, Amrit, Tal, Gil, Turrentine, Tom, 2017. The effectiveness of financial purchase incentives for battery electric vehicles – a review of the evidence. Renew. Sust. Energ. Rev. 80 (C), 1100–1111.

Hardman, Scott, Alan Jenna, Gil Tala, et al. 2018. A review of consumer preferences of and interactions with electric vehicle charging infrastructure. Transportation Part D, 62: 508-523.

Hardman, Scott, Kelly L. Fleming, Eesha Khare, Mahmoud M. Ramadan. 2021. A perspective on equity in the transition to electric vehicle. MIT Science Policy Review, 2.

Hathaway, Zac, Polis, Hilary, Loomis, Jen, Boroski, John, Milano, Aaron, & Ouyang, Jas-mine. 2021. A Utility Roadmap for Expanding Customer Adoption of Electric Vehicles. World Electric Vehicle Journal, 12(2): 81.

Hsu, Chih-Wei, Kevin Fingerman. 2021. Public electric vehicle charger access disparities across race and income in California. Transport policy, 100: 59-67.

Idaho National Laboratory. 2015. Plugged In: How Americans Charge Their Electric Vehicles. https://avt.inl.gov/sites/default/files/pdf/arra/PluggedInSummaryReport.pdf

International Energy Agency (IEA). 2022. Global EV Outlook 2022.

International Energy Agency (IEA). 2023. Global EV Outlook 2023.

Jaeger, Joel. 2023. These countries are adopting electric vehicles the fastest. World Resources Institute. https://www.wri.org/insights/countries-adopting-electric-vehicles-fastest

Jenn, Alan, Katalin Springel, Anand R. Gopal. 2018. Effectiveness of electric vehicle incentives in the United States. Energy Policy, 119: 349-356.

Johnson, Clair, Brett Williams, Carlos Hsu, John Anderson. 2017. The Clean Vehicle Rebate Project: Summary Documentation of the Electric Vehicle Consumer Survey, 2013–2015 Edition. Center for Sustainable Energy, San Diego CA, June 2017.

Kampshoff, Philipp, Adi Kumar, Shannon Peloquin, and Shivika Sahdev. 2022. Building the electric-vehicle charging infrastructure America needs. McKinsey & Company. https://www.mckinsey.com/industries/public-sector/our-insights/building-the-electric-vehicle-charging-infrastructure-america-needs

Khan, Hafiz Anwar Ullah, Sara Price, Charalampos Avraam, Yury Dvorkin. 2022. Inequitable access to EV charging infrastructure. The Electricity Journal, 35: 107096.

Lee, Jae Hyun, Scott J. Hardman,Gil Tal. 2019. Who is buying electric vehicles in California? Characterising early adopter heterogeneity and forecasting market diffusion. Energy Research & Social Science. 55: 218-226.

Lévay, Petra Zsuzsa, Yannis Drossinos, Christian Thiel. 2017. The effect of fiscal incentives on market penetration of electric vehicles: A pairwise comparison of total cost of ownership, Energy Policy, 106: 524-533.

Li, Jing. 2019. Compatibility and Investment in the U.S. Electric Vehicle Market. Working Paper.

Li, Shanjun, Lang Tong, Jianwei Xing, Yiyi Zhou. 2017. The Market for Electric Vehicles: Indirect Network Effects and Policy Design. Journal of Association of Environmental and Resource Economists, 4(1): 89-133.

Lopez-Behara, Diana, Martino Tranb, Jerome R. Mayaud, Thomas Froese, Omar E. Herrera, Walter Merida. 2019. Putting electric vehicles on the map: A policy agenda for residential charging infrastructure in Canada. Energy Research & Social Science, 50: 29-37.

Lutsey, N., Nicholas, M., 2019. Update on Electric Vehicle Costs in the United States through 2030.

Mersky, Avi Chaim, Frances Sprei, Constantine Samaras, Zhen (Sean) Qian. 2016. Effectiveness of incentives on electric vehicle adoption in Norway. Transportation Research Part D, 46: 56-68.

Morrissey, Patrick, Peter Weldon, Margaret O'Mahony. 2016. Future standard and fast charging infrastructure planning: An analysis of electric vehicle charging behavior. Energy Policy, 89: 257-270.

Muehlegger, Erich and David S. Rapson. 2020. Subsidizing Low- and Middle-Income Adoption of Electric Vehicles: Quasi-Experimental Evidence from California. Working Paper.

Münzel, Christiane, Patrick Plötz, Frances Sprei, Till Gnann. 2019. How large is the effect of financial incentives on electric vehicle sales? – A global review and European analysis. Energy Economics, 84: 104493.

Needell, Zachary, Wei Wei, Jessika E. Trancik. 2023. Strategies for beneficial electric vehicle charging to reduce peak electricity demand and store solar energy. Cell Reports Physical Science 4: 101287.

Patt, Anthony, David Aplyn, Philippe Weyrich, Oscar van Vliet. 2019. Availability of private charging infrastructure influences readiness to buy electric cars. Transportation Research Part A 125: 1-7.

Pierce, Gregory, Britta McOmber and J.R. DeShazo. 2020. Supporting Lower-Income Households' Purchase of Clean Vehicles: Implications From California-Wide Survey Results: A Policy Brief. The UCL A Luskin Center for Innovation (LCIlci).

Pollitt, Michael, Monica Giulietti, Andrei Covatariu, Daniel Duma. 2022. The active distribution system operator (DSO): An international study. Centre on Regulation in Europe. https://cerre.eu/wp-content/uploads/2022/09/CERRE_DSO_FinalReport_2709.pdf

Schäuble, Johannes, Thomas Kaschub, Axel Ensslen, Patrick Jochem, Wolf Fichtner. 2017. Generating electric vehicle load profiles from empirical data of three EV fleets in Southwest Germany. Journal of Cleaner Production, 150: 253-266.

Schroeder, Andreas, Thure Traber. 2012. The economics of fast charging infrastructure for electric vehicles. Energy Policy, 43: 136-144.

Scorrano, Mariangela, Romeo Danielis, Marco Giansoldati. 2020. Dissecting the total cost of ownership of fully electric cars in Italy: The impact of annual distance travelled, home charging and urban driving. Research in Transportation Economics, 80: 100799.

Sierzchula, W, Bakker S, Maat K and van Wee B. 2014 The influence of financial incentives and other socio-economic factors on electric vehicle adoption. Energy Policy 68 183–94.

Springel, Katalin. 2021. Network Externality and Subsidy Structure in Two- Sided Markets: Evidence from Electric Vehicle Incentives. American Economic Journal: Economic Policy, 13(4): 393-432.

Kelly, Kay and Mark Singer. 2016. American recovery and reinvestment act: Clean cities project awards. National Renewable Energy Laboratory.

Stafford, Eric. 2024. Tesla Charging Network: All the Upcoming Compatible EVs. Car and Driver. https://www.caranddriver.com/news/a44388939/tesla-nacs-charging-network-compatibility/

The UK Department for Transportation. 2023. Electric vehicle charging device statistics: October 2023. https://www.gov.uk/government/statistics/electric-vehicle-charging-device-statistics-october-2023/electric-vehicle-charging-device-statistics-october-2023

The United States Environmental Protection Agency (U.S. EPA). 2023. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021. U.S. Environmental Protection Agency, EPA 430-R-23-002.
https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2021

Tran, M., Banister, D., Bishop, J., McCullogh, M. 2013. Simulating early adoption of alternative fuel vehicles for sustainability. Technological Forecasting & Social Change, 80, 865–875.

Tromans, Phill. 2024. Electric car statistics – data and projections. Heycar. https://heycar.com/uk/blog/electric-cars-statistics-and-projections

Tsiropoulos, I., D. Tarvydas, N. Lebedeva. 2018. Li-ion batteries for mobility and stationary storage applications – Scenarios for costs and market growth, EUR 29440 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-79-97254-6, doi:10.2760/87175, JRC113360

Wayland, Michael. 2023. GM CEO Mary Barra says Tesla charging deal will save the automaker up to $400 million. https://www.cnbc.com/2023/06/08/gm-says-tesla-charging-deal-will-save-the-automaker-up-to-400-million.html

Wee, Sherilyn, Makena Coffman, Sumner La Croix. 2018. Do electric vehicle incentives matter? Evidence from the 50 U.S. states. Research Policy, 47: 1601-1610.

Wood, Eric, Clément Rames, Matteo Muratori, Sesha Raghavan, and Marc Melaina. 2017. National Plug-In Electric Vehicle Infrastructure Analysis. Washington, D.C.: U.S. Department of Energy Office of Energy Efficiency & Renewable Energy. DOE/GO-102017-5040. https://www.nrel.gov/docs/fy17osti/69031.pdf.

World Resource Institute. 2020. Historical GHG Emissions.
https://www.climatewatchdata.org/ghg-emissions?end_year=2020&start_year=1990

Wu, Tian, Lin Ma, Zhonggen Mao, Xunmin O. 2015. Setting up charging electric stations within residential communities in current China: Gaming of government agencies and property management companies. Energy Policy, 77: 216-226.

Xing, Jianwei, Benjamin Leard, Shanjun Li. 2021. What does an electric vehicle replace? Journal of Environmental Economics and Management, 107: 102432.

Yan, Shiyu. 2018. The economic and environmental impacts of tax incentives for battery electric vehicles in Europe. Energy Policy, 123:53-63.

Zhang, Li, Tim Brown, G. Scott Samuelsen. 2011. Fuel reduction and electricity consumption impact of different charging scenarios for plug-in hybrid electric vehicles. Journal of Power Sources, 196: 6559-6566.

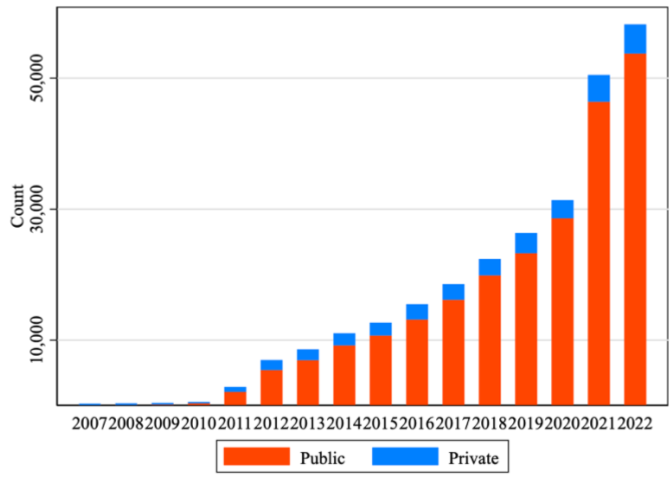
Zhou, Yan, Michael Wang, Han Hao, Larry Johnson, Hewu Wang, Han Hao. 2015. Mitigation and Adaptation Strategies for Global Change, 20:777-795.

Zhou, Yan, Todd Levin, and Steven E. Plotkin. 2016. Plug-in electric vehicle policy effectiveness: Literature review. Argonne National Laboratory. ANL/ESD-16/8.

Appendix

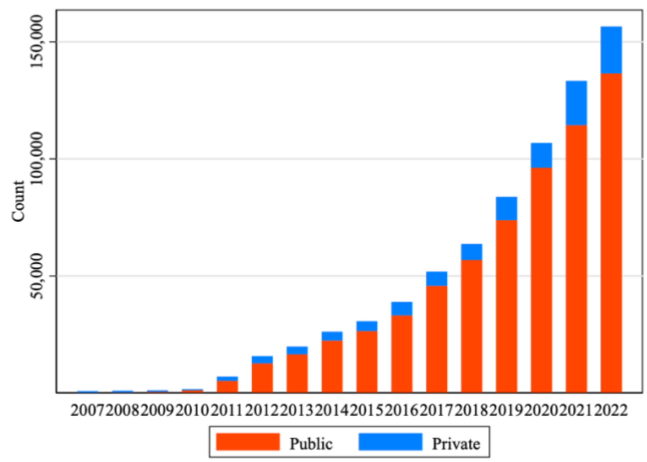
Figure A1: Number of EV Charging Stations and Ports by Ownership

Panel A: Stations



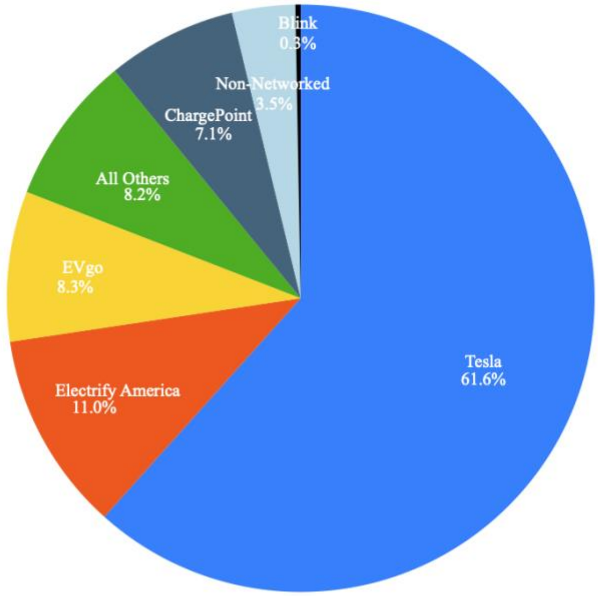
This figure breaks down EV charging stations by public and private ownership, using AFDC data.

Panel B: Ports



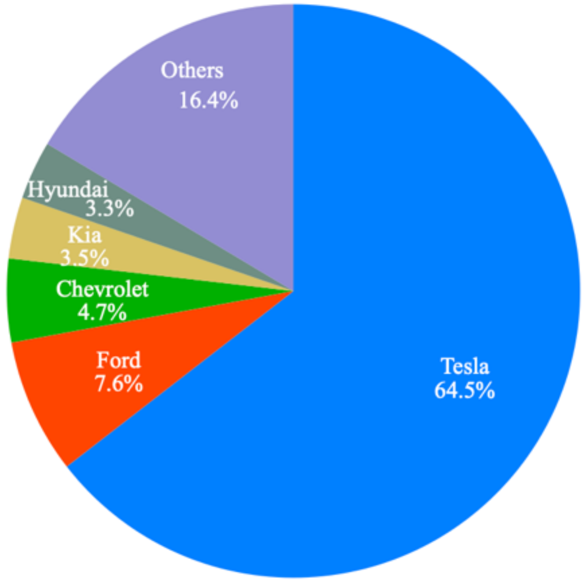
This figure breaks down EV charging ports by public and private ownership, using AFDC data.

Figure A2: Percent Share of DC fast charging Ports by Network, June 2023



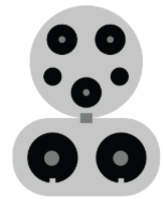
This figure shows the percentage of DC fast charging ports by network, with major ones highlighted and smaller ones as All Others using AFDC data.

Figure A3: Percent Share of EV Sales by Automaker (2022)



This figure shows the percent share of EV sales (excluding PHEVs) in 2022, based on Kelley Blue Book Electric Vehicle Sales Report Q4 2022.

Table A1: Overview of EV Chargers

	Level 1	Level 2	DC Fast
Connector Type	J1772 	J1772  Tesla 	CCS  CHAdeMO  Tesla 
Typical power Output	1 – 2 kW	7 – 19 kW	50 – 350 kW
Voltage	120 V AC	208 – 240 V AC	400 V – 1000 V DC
Charging time	40 – 50 hours	4 – 10 hours	20 minutes – 1 hour
Electric range per 1 hour of charging	2- 5 miles	10 – 20 miles	180 – 240 miles
Typical locations	Home	Home, Public, Workplace, Shopping Centers	Public
Equipment cost	$700-$900 for residential $596-$813 for commercial	$1,400-$4,100 for residential $938-$3,127 for commercial	$28,400-$140,000 for public
Installation cost	$400-$600 for residential	$680-$3,300 for residential $3,000 for commercial	$18,000-$66,000 for public

This table shows estimated charging time for a 60-kWh battery from empty, using US DOT data[41] and cost info from AFDC[42].

[41] https://www.transportation.gov/rural/ev/toolkit/ev-basics/charging-speeds
[42] https://afdc.energy.gov/fuels/electricity_infrastructure_development.html

Table A2: Variable Definitions and Summary Statistics

Variable	Definition	Mean	St. dev.
ln(Median income)	Log of median household income in the past 12 months (in 2020 inflation-adjusted dollars)	11.096	0.450
Median age	Median age	39.324	7.676
% Male	Percent of male population	49.137	4.383
ln(House value)	Log of median value (dollars) of owner-occupied housing units	12.342	0.701
% Single-family house	Percent of a one-family house detached from any other houses out of total housing units	63.891	25.890
% Multi-family house	Percent of a one-family house attached to one or more houses out of total housing units	6.092	9.929
ln(Housing units)	Log of total housing units	7.475	0.368
% Home owner	% of owner-occupied housing units	65.585	21.635
% pop with less than high school degree	% of population w/ less than high school degree	11.764	10.103
% unemployed	% of unemployment in civilian labor force	5.492	4.096
Gini	Gini index	0.415	0.066
% below poverty level	% of households below poverty level	12.387	9.589
% White	% of white alone population	70.746	24.097
% Black	% of black of African American alone population	12.434	19.554
% of pop with no vehicle	% of housing units with no vehicle available	7.723	10.647
Average num of vehicles	Average number of vehicles per occupied housing unit	1.869	0.433
ln(Population)	Log of population	8.197	0.432
Pop density	Total population / land area (square meters) *10^6	2030.5	4436.1
% drive to work	% of population whose means of transportation to work is car, truck, or van	84.718	14.186
% use public transit to work	% of population whose means of transportation to work is public transportation	4.187	9.770
% work from home	% of population whose means of transportation to work is walk or worked at home	9.318	7.299
% spend more than 30 min to work	% of population whose travel time to work is more than 30 minutes	38.436	16.886
Suburban	Census tract is classified as suburban	0.532	0.499
Rural	Census tract is classified as rural	0.200	0.400

This table shows definitions, population-weighted mean, and standard deviation of census tract characteristics using IPUMS NHGIS[43] and AHS 2017.

[43] Manson, Steven, Jonathan Schroeder, David Van Riper, Tracy Kugler, and Steven Ruggles. IPUMS National Historical Geographic Information System: Version 17.0 [dataset]. Minneapolis, MN: IPUMS. 2022. http://doi.org/10.18128/D050.V17.0

Table A3: Associations between station availability and tract characteristics

	(1)	(2)	(3)	(4)
	No of ports	No of stations	Change in ports	Change in stations
ln(Median income)	1.987***	0.623***	0.523***	0.195***
	(0.324)	(0.128)	(0.110)	(0.040)
Median age	-0.033***	-0.016***	-0.006	-0.004***
	(0.010)	(0.005)	(0.004)	(0.001)
% Male	0.055***	0.023***	0.008*	0.004***
	(0.009)	(0.004)	(0.004)	(0.001)
ln(House value)	-0.346*	-0.080	-0.005	-0.002
	(0.184)	(0.085)	(0.065)	(0.026)
% Single-family house	-0.040***	-0.015***	-0.007***	-0.003***
	(0.005)	(0.002)	(0.001)	(0.000)
% Multi-family house	-0.044***	-0.016***	-0.009***	-0.004***
	(0.007)	(0.003)	(0.002)	(0.001)
ln(Housing units)	2.338***	0.853***	0.669***	0.228***
	(0.363)	(0.135)	(0.182)	(0.049)
% Home owner	-0.016***	-0.006***	-0.006***	-0.002***
	(0.004)	(0.001)	(0.002)	(0.001)
% pop with less than	-0.017	-0.009	-0.000	-0.001
high school degree	(0.011)	(0.006)	(0.003)	(0.001)
% unemployed	0.002	0.001	-0.002	-0.000
	(0.008)	(0.003)	(0.003)	(0.001)
Gini	2.362**	1.146**	0.763***	0.330***
	(1.002)	(0.497)	(0.278)	(0.127)
% below poverty level	-0.007	-0.004	-0.001	-0.001
	(0.010)	(0.005)	(0.004)	(0.001)
% White	-0.024***	-0.009***	-0.005*	-0.003***
	(0.007)	(0.003)	(0.003)	(0.001)
% Black	-0.024***	-0.009***	-0.005*	-0.003***
	(0.008)	(0.004)	(0.003)	(0.001)

% of pop with no vehicle	0.019	0.007	0.005	0.001
	(0.014)	(0.006)	(0.003)	(0.001)
Average num of vehicles	-0.887***	-0.354**	-0.175**	-0.117***
	(0.331)	(0.158)	(0.083)	(0.029)
ln(Population)	-0.773**	-0.232*	-0.315*	-0.094**
	(0.307)	(0.127)	(0.186)	(0.039)
Pop density	-0.000***	-0.000***	-0.000***	-0.000***
	(0.000)	(0.000)	(0.000)	(0.000)
% drive to work	0.008	-0.001	0.012**	0.002
	(0.027)	(0.011)	(0.006)	(0.003)
% use public transit to work	0.009	0.002	0.007	0.002
	(0.026)	(0.010)	(0.007)	(0.004)
% work from home	0.113***	0.042***	0.025***	0.011***
	(0.029)	(0.011)	(0.007)	(0.004)
% spend more than 30 min	-0.029***	-0.012***	-0.005***	-0.002***
to work	(0.004)	(0.002)	(0.002)	(0.001)
Suburban	0.016	-0.010	0.056	0.006
	(0.127)	(0.059)	(0.044)	(0.015)
Rural	0.272	0.090	0.066	0.023
	(0.202)	(0.103)	(0.054)	(0.023)
Constant	-21.741***	-7.244***	-7.489***	-2.411***
	(4.420)	(1.832)	(1.192)	(0.503)
N	79,135	79,135	79,135	79,135
adj. R-sq	0.08	0.07	0.00	0.02
Mean	1.697	.669	.414	.178

This table shows associations between station availability and tract characteristics, with county fixed effects and population weights.

Contact.

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