MIT CEEPR

MIT Center for
Energy and Environmental
Policy Research

RESEARCH BRIEF

Grid Impacts of Highway Electric Vehicle Charging and the Role for Mitigation by Energy Storage

Andrew M. Mowry and Dharik S. Mallapragada

Highway fast-charging (HFC) stations for electric vehicles (EVs) are necessary to address range anxiety concerns and thus to support economy-wide decarbonization goals through the electrification of transportation. The characteristics of HFC electricity demand – their relative inflexibility, high power requirements, and spatial concentration – have the potential to adversely impact grid operations as HFC infrastructure expands. In this research we quantify these impacts in the context of the Texas grid, and we compare the effectiveness of demand flexibility, energy storage, and transmission reinforcement to mitigate them.

The incoming Biden administration has positioned pro-climate infrastructure spending as the key pillar to support its ambitious economic and domestic policy goals. Already it has announced its intention to electrify the 600,000+ vehicle government-owned fleet (WH 2021) as well as to build 500,000 new EV charging stations (Biden 2020). The demand pull for more EVs and the anticipated monetary support for more charging stations should do much to accelerate the electrification of the American transportation sector, which contributed 28% of U.S. greenhouse gas emissions in 2018 (EPA 2020).

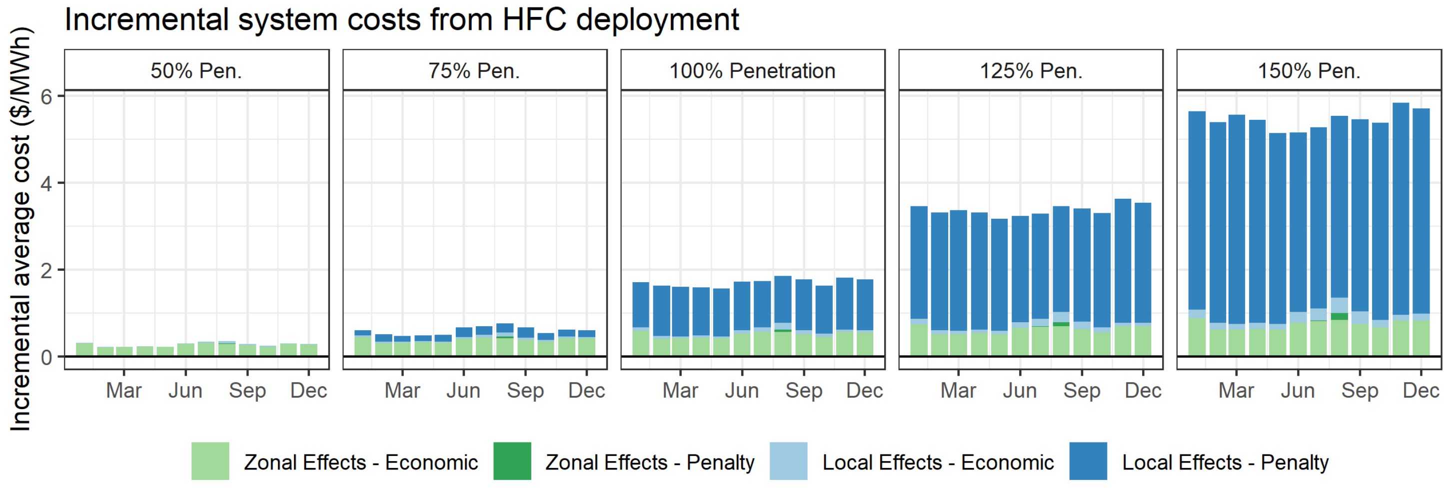
While vehicle electrification in the context of a low-carbon electricity generation mix will benefit air quality and mitigate climate effects, the additional electric demand from EV charging could pose challenges to the planning and operation of the electric grid. The impacts caused by workplace and home charging on distribution networks are well studied, but those caused by highway fast-charging (HFC) have not been examined in detail. The demand from these HFC stations, which are needed to alleviate "range anxiety" concerns and to enable EV travel between urban centers, is likely to be inflexible, high-powered, and spatially-concentrated. Moreover, these stations are often located in far-flung locations with weak transmission networks. Altogether, these qualities could lead HFC to have outsized costs and congestion impacts on the power grid (Burnham et al. 2017). In this research we probe this topic: what will be the impacts of large scale HFC network on the power grid? And how might they be mitigated?

To study these questions, we model a plausible HFC network and power system of Texas in 2033, when ERCOT (the Texas power grid operator) projects that 3 million passenger EVs will be on the road (ERCOT 2018). We account for ERCOT's estimated renewable energy and transmission buildout between now and 2033, and we use global EV charging infrastructure statistics and the present-day Tesla Supercharger network to estimate HFC locations and peak demand in 2033. To understand the impacts of HFC on the grid, we simulate the joint charger-power system operation for a full year at detailed spatial (~3500 buses and over 9000 transmission lines) and temporal (hourly) resolution for various levels of EV penetration.

A main result is shown in the attached figure, where the middle panel shows the incremental operational costs (above the case without HFC) associated with the 3 million EV base case: about \$2/MWh. (For context, the marginal cost of wholesale power in the ERCOT system is usually about \$20-30/MWh.) Importantly, about 50% of these incremental costs (shown in blue) are "Local Effects" caused by congestion in the transmission system around individual stations. These effects are not visible without a fully locationally resolved ("nodal") power system model, which previous studies have not used. As EV penetration increases, these "Local Effects" begin to dominate, and thus should not be overlooked.

After identifying the system costs that HFC stations could impose on the power system, we explore mitigation methods. We first demonstrate that demand flexibility, e.g. delaying charging by one hour until power is cheaper or the system is less constrained, is not as effective as the prototypical 4-hour energy storage, like the Tesla Powerpack, at reducing these grid operational costs. (This is convenient, since it is unlikely that hurried highway travelers would want to delay their travel plans for very long.) The intuition for this result is that demand flexibility can only shift a short period of charging by about an hour, whereas a battery can shift a longer period of charging much further into the future. Taking this logic further, we qualitatively asses transmission reinforcement as a mitigation strategy: transmission can act as an "infinite duration battery" by moving energy in space rather than time. While effective, the costs and timelines for reinforcement projects are difficult to generalize beyond case studies.

By identifying the local impacts of HFC stations and moving the discussion past demand flexibility (which often is an assumed default solution to all challenges relating to power demand from EVs) we hope to stimulate the discussion of charger-grid interactions at the large scale. As automakers and governments push for electrification of the transportation sector, this analysis highlights the need for effective planning for highway EV charging infrastructure that accounts for the impacts on local power infrastructure and considers appropriate mitigation strategies.



About the Center for Energy and Environmental Policy Research (CEEPR)

Since 1977, CEEPR has been a focal point for research on energy and environmental policy at MIT. CEEPR promotes rigorous, objective research for improved decision making in government and the private sector, and secures the relevance of its work through close cooperation with industry partners from around the globe. CEEPR is jointly sponsored at MIT by the MIT Energy Initiative (MITEI), the Department of Economics, and the Sloan School of Management.

References

Biden Campaign Website. 2020. "The Biden Plan to Build a Modern, Sustainable Infrastructure and an Equitable Clean Energy Future". Online resource accessed January 2021. https://joebiden.com/clean-energy/

Burnham, Andrew; Eric J. Dufek; Thomas Stephens; James Francfort; Christopher Michelbacher; Richard B. Carlson; Jiucai Zhang; Ram Vijayagopal; Fernando Dias; Manish Mohanpurkar; Don Scoffield; Keith Hardy; Matthew Shirk; Rob Hovsapian; Shabbir Ahmed; Ira Bloom; Andrew N. Jansen; Matthew Keyser; Cory Kreuzer; Anthony Markel; Andrew Meintz; Ahmad Pesaran; Tanvir R. Tanim. 2017. "Enabling fast charging – Infrastructure and economic considerations". Journal of Power Sources 367. Doi: https://doi.org/10.1016/j.jpowsour.2017.06.079

(EPA) US Environmental Protection Agency. 2020. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2018" (Annual Report). Online resource accessed January 2021. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2018

ERCOT. 2018. "2018 Long-term System Assessment for the ERCOT Region". Electric Reliability Council of Texas. Web resource accessed December 2020: http://www.ercot.com/content/wcm/lists/144927/2018_LTSA_Report.pdf

White House. 2021. "Remarks by President Biden at Signing of Executive Order on Strengthening American Manufacturing". Online resource accessed January 2021. https://www.whitehouse.gov/briefing-room/speeches-remarks/2021/01/25/remarks-by-president-biden-at-signing-of-executive-order-on-strengthening-american-manufacturing/

About the Authors

Andrew M. Mowry conducts post-graduate research with the MIT Energy Initiative, where he focuses on emerging challenges in power and transportation. He has studied short-term changes to capacity markets in PJM, the information content of smart meter data, and the impacts of EV charging on the power grid. At MIT he has also worked with the Sustainable Urbanization Lab to study autonomous vehicles in urban environments, particularly in Chinese cities. Andrew works with the strategy department of Ørsted A/S to accelerate the deployment of clean energy technologies, and he has previously held commercial responsibilities with LS Power and worked as a power and FTR trader with DC Energy. In these roles he has been involved with all of the major power markets in the USA and continental Europe. Andrew received his SM in Technology and Policy from MIT in 2020, and his BA in Physics from Amherst College in 2014.

Dharik S. Mallapragada is a research scientist at the MIT Energy Initiative. Dharik's current research focuses on advancing energy systems modeling tools to study implications of renewables integration in the power sector, economy-wide electrification and assessment of emerging energy technologies. Prior to MIT, Dharik spent nearly five years in the energy and petrochemicals industry working on a range of sustainability-focused research topics. Most recently, Dharik worked at ExxonMobil Corporate Strategic Research, where he contributed to research on power systems modeling, technology life cycle assessment and also led a research program to study energy challenges in developing countries. Dharik holds a M.S. and Ph.D. in Chemical Engineering from Purdue University and a B.Tech. in Chemical Engineering from the Indian Institute of Technology, Madras, India.