Systematic Review of Social Equity for Installing Public Electric Vehicle Charging Stations (EVCS)

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ABSTRACT

The site selection of public electric vehicle charging stations (EVCS) will have a long-lasting impact on people's access to and use of EV, and thus long-term social equity. Since it is hardly possible to reinstall a public EVCS once it is built, site selections for EVCS should consider a fair share of benefits. In this respect, this research explores the evaluation criteria of social equity for guiding public EVCS installations through a comprehensive systematic review. This study will provide a comprehensive social aspect which synthesizes evaluation indicators and socioeconomic and demographic variables regarding EVCS installations toward fair infrastructure investment. The proposed complete social equity criteria can be utilized to investigate the patterns of community and social features so that socially acceptable, preferable, and equitable sites for EVCS can be suggested. This study will advance the body of knowledge on planning, design, and installation decisions of equitable public infrastructure.

INTRODUCTION

Major infrastructure development is being planned and expected to promote electric vehicle (EV) transportation in the next decade, including installations of public EV charging stations (Satchwell and Cappers 2018). Today's planning decisions on public EV charging stations (EVCS) can leave long-lasting impact on people's access to and use of EV transportation, which are associated with fair treatment of all people based on environmental justice (US EPA 2015), and thus affect a long-term social equity. However, existing studies on the site selection for public EVCS tend to be focused on techno-centric or efficiency-related considerations, such as simulation-based demand hotspots, accessibility in terms of distance travelled, and cost-benefit ratios. These studies often lack a long-range perspective of the social fabric. According to the theory based on environmental justice (US EPA 2015), the two critical elements of social equity that are increasingly held responsible by all US federal and state-level administrators are ensuring fair treatment for all individuals (meaning no group of people should disproportionately bear the benefits or negative consequences resulting from public EVCS) and their meaningful involvement of all groups in decisions related to the siting of public EVCS, regardless of their race, color, or income. These crucial elements are often overlooked, given less importance, or only given superficial acknowledgement. The lack of considering social aspects can result in inadequate charging infrastructure (Romero-Lankao et al. 2022). It has also been shown that public charging infrastructure is less accessible in low-income and minority communities (Dhakal and Zhang 2020; Hsu and Fingerman 2021). Still, guiding socially equitable public EVCS installations is challenging due to the lack of a complete list of evaluating social equity criteria.

The goal of this research is to explore evaluation criteria of social equity for installing public EVCS using a systematic literature review. In this study, social equity is defined as equal treatment (Dhakal and Zhang 2020) and equal opportunities (Bhugra 2016) provided to all people influenced by infrastructure. This research conducts systematic review by following the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) approach and reports the findings social equity criteria for guiding public EVCS investments. The comprehensive list of social equity criteria for EVCS installations proposed in this study can serve as a guiding framework for evaluating equitable infrastructure investments and making informed planning decisions. In addition, the socioeconomic and demographic variables identified in this study can offer measurable elements for systematically assessing qualitative social equity criteria. By providing potential impacts of considering the social equity of EVCS installations on community stakeholders, this study can promote equitable infrastructure planning and evaluation. Finally, the current patterns of considering the social equity indicators are explored and will guide the future direction of embracing all equity indicators for infrastructure planning decisions. These findings contribute to expanding the existing knowledge base related to the planning, design, and installation of equitable public infrastructure, including EVCS.

METHODOLOGY

This research conducts a systematic literature review by following the PRISMA framework, as shown in Figure 1. We used preliminary search teams in Web of Science, the Database from the Office of Scientific and Technical Information (OSTI) by the U.S. Department of Energy, and the American Society of Civil Engineering (ASCE) Database. In Web of Science, we used the search term "((EVCS) OR (Electric Vehicles) OR (Charging Station) OR (Charging Infrastructure)) AND ((Social) AND (Equity))", and 71 articles were found. In the OSTI database, we used "Charging Infrastructure" AND "Social Equity", and 14 reports and research outcomes were found. In the ASCE database, we used "(Charging Infrastructure) AND Social AND Equity", and 34 research findings including journal articles, conference proceedings, and book chapters were found. Two research records were duplicated from multiple sources. Out of 117 records, research that was not related to public EV charging infrastructure, such as research focused on electrification of public transits, shared autonomous vehicles, or energy environment policy, were excluded from the study area. We then applied the following eligibility criteria: (1) full text is available, (2) research scope is within the site selection of public EVCS (not private) or infrastructure investment decisions, (3) sufficient details about social aspects need to be contained, and (4) research impacts are not limited to specific geographical regions or government situations. Fifteen records, including ten journal articles, two conference proceedings, two technical reports, and one book chapter remained to review.

FINDINGS

Based on the systematic literature review, this study investigated (1) social equity evaluation indicators and dimensions, as well as the socioeconomic and demographic variables that need to be considered to evaluate each indicator; (2) potential impacts of considering social equity on community stakeholders; and (3) current patterns of studies considering the social equity evaluation indicators.

Social equity evaluation indicators and socioeconomic and demographic variables. Social equity can be evaluated using indicators of equitability including deprivation index and accessibility, affordability, and acceptability (Asekomeh et al. 2021). Participatory modeling methods have found accessibility, affordability, and community livability as socio-demographic equity indicators (Penn et al. 2022). Additionally, Ku et al. (2021) added an environmental justice (EJ) index that considers air quality and pollution as a social equity criterion in transportation systems in addition to the criteria of accessibility and affordability. These evaluation indicators of social equity of EVCS investment can be categorized into two dimensions: (1) distributive justice, which concerns the equitable distribution of social and economic benefits, and (2) procedural justice, which ensures fair and adequate public participation (Sovacool et al. 2019). Table 1 shows the social equity evaluation indicators and dimensions for EVCS investment.

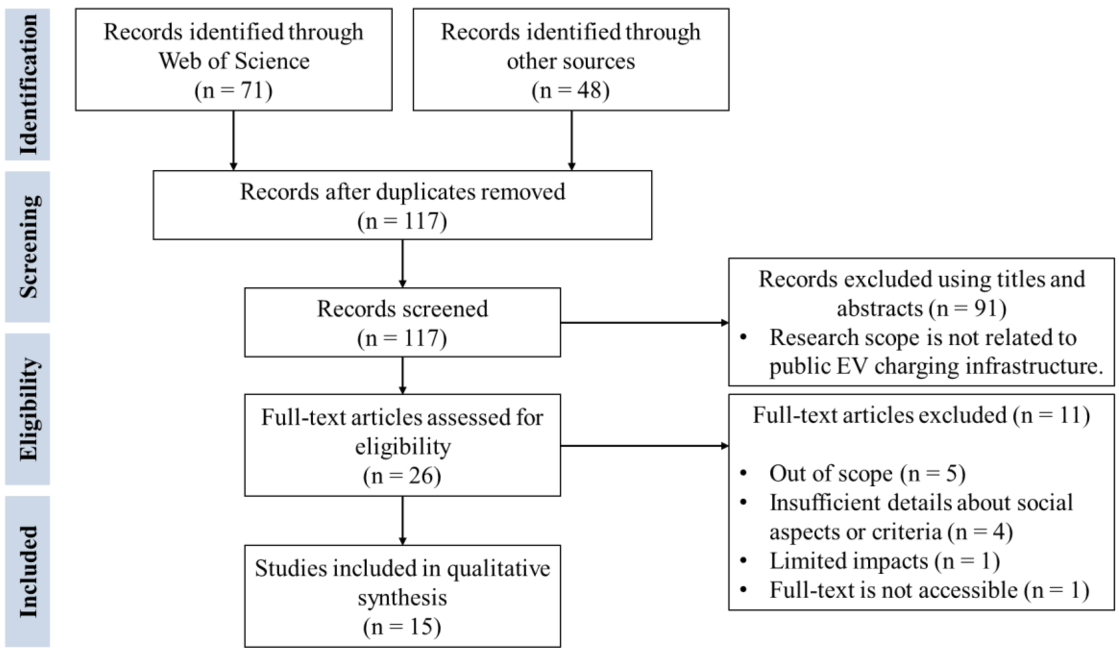

Figure 1. PRISMA Framework for Systematic Review.

Then, this study identified socioeconomic and demographic variables that can be used to measure social equity evaluation indicators for EVCS installations. Sovacool et al. (2019) indicated that the lack of adequate EVCS can marginalize rural poor areas and exclude the elderly from the EV transition. Roy and Law (2022) identified socioeconomic characteristics such as commute time, population density, and poverty level can guide the deployment needs of EVCS. For instance, areas with high commute times, higher levels of minority populations, and high population densities may require EVCS more urgently as affordable cars become available in the EV market. Min and Lee (2020) revealed that the installation of EV charger infrastructures can be sensitive to communities' income level and inequality, as well as housing stability.

Table 2 presents a set of socioeconomic and demographic variables that can be used to measure the six evaluation indicators of social equity for EVCS installations including affordability, health and safety, distributional equity, accessibility, environmental justice, and social inclusion. Affordability can be measured using variables such as income, education level, employment status. Health and Safety, or livability, can be assessed using variables such as air quality index, traffic congestion, and public safety. Distributional equity can be measured based on variables such as population density, spatial distribution of charging stations, and location relative to disadvantaged communities. Accessibility can be identified through variables such as proximity to public transit, proximity to highways, and availability of public parking. Environmental justice can be assessed using variables such as proximity to environmental hazards, pollution, and climate vulnerability. Finally, social inclusion, which refers to open participation and fair representation regardless of people's diversity, can be measured by including representation of diverse populations in decision-making, cultural and social norms, language access.

Table 1. Social Equity Evaluation Indicators and Dimensions for EVCS Investment.

Dimensions	Evaluation Indicators	Description
Distributive justice	Affordability	Are charging station fees affordable and accessible to low-income individuals and families?
	Livability (Health and Safety)	Are charging stations designed and installed in a way that minimizes negative impacts on public health, such as by reducing air pollution or noise pollution, particularly in neighborhoods and communities that have been disproportionately affected by these issues?
	Distributional equity	Are charging stations distributed equitably across different geographic areas, including low-income and minority neighborhoods or those with higher levels of deprivation or lower car ownership?
Procedural justice	Accessibility	Are charging stations accessible to all members of the community, regardless of socioeconomic status or physical ability, especially those who may not have access to private charging facilities?
	Environmental justice	Are charging stations powered by renewable energy sources or designed to minimize their carbon footprint, particularly in neighborhoods and communities that have been disproportionately affected by environmental pollution?
	Social inclusion	Are the needs and preferences of diverse communities including low-income and minority groups, considered in decision-making processes related to the planning, design, installation and operation of charging stations?

Potential impacts on community stakeholders. The six social equity evaluation indicators of affordability, health and safety, distributional equity, accessibility, environmental justice, and social inclusion for electric vehicle charging station installations can have significant impacts on community residents and stakeholders. For instance, ensuring affordability can make EVs and charging stations accessible to low- and moderate-income communities, as well as those who live in disadvantaged communities (Min and Lee 2020). Health and safety considerations can help minimize potential risks associated with charging stations and EV batteries, such as fire hazards, and address concerns related to air quality and noise pollution (Sovacool et al. 2019). Achieving distributional equity can help ensure that EV charging infrastructure is located in a way that is accessible to all residents, regardless of their income or race, and can also help address potential disparities in access to EV charging infrastructure in rural and urban areas (Li et al. 2022).

Table 2. Socioeconomic and Demographic Variables for Social equity Evaluation Indicators.

Evaluation Indicators	Socioeconomic and Demographic Variables	Source
Affordability	Median household income, poverty rate, unemployment rate, vehicle ownership rate, electric vehicle ownership rate, percentage of low-income households.	(Dhakal and Zhang 2022; Ku et al. 2021; Kuiper et al. 2022; Li et al. 2022; Min and Lee 2020; Roy and Law 2022; Sovacool et al. 2019).
Livability (Health and Safety)	Air quality, traffic density, health indicators (e.g., respiratory disease rates), proximity to sensitive populations (e.g., schools, hospitals).	(Asekomeh et al. 2021; Dhakal and Zhang 2022; Fadda et al. 2021; Field et al. 2022; Ku et al. 2021; Penn et al. 2022; Sovacool et al. 2019).
Distributional equity	Population density, spatial analysis of station locations, distance to nearest station, distribution of stations across different neighborhoods or regions, percentage of minority and disadvantaged populations in the service area.	(Dhakal and Zhang 2022; Ku et al. 2021; Kuiper et al. 2022; Li et al. 2022; Min and Lee 2020; Roy and Law 2022).
Accessibility	Distance to charging stations, public transportation availability, population density, percentage of households without access to a private vehicle, and percentage of households with low income.	(Dhakal and Zhang 2022; Ku et al. 2021; Kuiper et al. 2022; Li et al. 2022; Min and Lee 2020; Roy and Law 2022).
Environmental justice	Proximity to sources of pollution, proximity to environmentally sensitive areas (e.g., wetlands, parks), impact of electric vehicle charging on energy grid and associated emissions, as well as demographic characteristics such as race and income that may increase vulnerability to environmental harms.	(Asekomeh et al. 2021; Dhakal and Zhang 2022; Field et al. 2022; Ku et al. 2021; Penn et al. 2022; Sovacool et al. 2019).
Social inclusion	Demographic characteristics such as age, gender, race, ethnicity, and disability status, as well as community preferences for charging station locations and designs.	(Dhakal and Zhang 2022; Kelly et al. 2017; Ku et al. 2021; Kuiper et al. 2022; Li et al. 2022; Min and Lee 2020; Mostafa and El-Gohary 2015; Roy and Law 2022).

Improving accessibility can increase the convenience and ease of using EVs and charging stations, particularly for those who rely on public transportation, and can also help reduce transportation-related greenhouse gas emissions (Roy and Law 2022). Ensuring environmental justice can help prevent the disproportionate impact of pollution and climate change on low-income communities and communities of color, which are often located near highways and other sources of pollution, and can also help promote the use of clean energy (Ku et al. 2021). Finally, promoting social inclusion can help ensure that EVs and charging infrastructure are designed to meet the needs of all users, including those with disabilities (Jones and Armanios 2020).

Patterns of considering the social equity evaluation indicators. We found that the literature reviewed has adequately considered all six evaluation indicators for social equity in electric vehicle charging station installations. However, some indicators were emphasized more than others. The distributional equity and accessibility indicators were the most commonly emphasized across the 15 papers. Many studies used various methods and indicators to measure the distributional equity and accessibility of electric vehicle charging station installations, such as the Gini coefficient, spatial analysis, and machine learning models. On the other hand, the affordability and social inclusion indicators were underestimated in some studies. Fewer papers explored the socioeconomic and demographic factors that could affect the affordability and social inclusion of electric vehicle charging station installations. Regarding the health and safety and environmental justice indicators, most papers have mentioned them in their studies. However, they were not as emphasized as distributional equity and accessibility indicators. Overall, while most studies have considered all six indicators, there is still a need for more comprehensive studies that give equal attention to all indicators, especially affordability and social inclusion.

DISCUSSION AND CONCLUSION

The installation of electric vehicle charging stations (EVCS) is an important step towards promoting sustainable transportation and mitigating the negative impacts of fossil fuel-powered vehicles on the environment. In that EVCS investment has long-lasting impacts on society, it is crucial to ensure that the installation of EVCS is done in a socially just manner, taking into consideration the needs and concerns of all stakeholders, particularly those who are socioeconomically disadvantaged. In this study, we have identified six key evaluation indicators for social equity in EVCS installations: affordability, health and safety, distributional equity, accessibility, environmental justice, and social inclusion.

Our review of 15 papers on this topic revealed that while there is a growing interest in social equity considerations for EVCS installations, some evaluation indicators are over-considered while others are under-estimated. For example, while accessibility is often emphasized in the literature, social inclusion and affordability are less frequently discussed. This suggests that more attention should be paid to these aspects of social equity in future research and policymaking. For example, as presented in Table 1 and 2, future research and policymaking need to consider whether the capacity and frequency of EVCS investments can adequately form affordable charging rates for low-income households to address affordability. Also, the inclusion of demographic diversity and community preferences needs to be considered for EVCS site selection to address the social inclusion criterion.

Furthermore, the six evaluation indicators we identified have significant implications for community residents and stakeholders. For example, affordability is an important consideration, particularly for low-income households, who may not be able to afford an electric vehicle or the cost of charging at public EVCS. Health and safety are also important concerns, particularly in areas where the installation of EVCS may lead to increased traffic or noise pollution. Distributional equity is another important consideration, as the placement of EVCS may disproportionately benefit or harm certain neighborhoods or communities. Since the benefits of clean energy and reduced emissions should be distributed fairly across all communities, environmental justice needs to be considered in EVCS installations. The consideration of social inclusion should be executed in a way that promotes inclusivity and addresses the needs and concerns of marginalized communities, such as those with limited mobility or access to transportation.

Transitioning to cleaner modes of transportation, such as electric vehicles, is crucial to mitigate the impacts of climate change and reduce air pollution. However, not all communities have equal access to electric vehicles or the necessary infrastructure to support them. In addition, low-income communities are often disproportionately impacted by poor air quality due to their proximity to highways and industrial areas. Therefore, addressing social equity in EV and EVCS installations is important to mitigating the impacts of climate change and improving air quality in communities, particularly those that are disproportionately impacted by environmental inequities. Overall, this study emphasizes the necessity of adopting a comprehensive and integrated approach to social equity in EVCS installations. The research findings can inform ongoing research and community engagement, guiding the principles of equity, fairness, and inclusion in infrastructure planning, including EVCS. This approach promotes the consideration of the diverse and interconnected needs and concerns of both community residents and stakeholders in any new infrastructure planning.

Our future research will delve deeper into the systematic and quantitative integration of the six evaluation indicators identified in this study into the planning and decision-making processes for EVCS. We will combine the current team's efforts of developing a deep reinforcement learning algorithm to ensure that the EVCS site selections are made in a socially just manner. Additionally, future research will explore social equity concerns related to EVCS installations in different communities. This will help policymakers and community leaders prioritize EVCS investments.

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