Transport equity considerations in electric vehicle charging research: a scoping review

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Abstract:

Many communities have been marginalised in the ongoing policy and planning debates surrounding transportation electrification, even though well allocated charging infrastructure is essential for the environmental and societal benefits of Electric Vehicles (EVs) to be realised. This scoping review aims to synthesise the current state of knowledge and gaps surrounding transportation equity in EV charging research. Following PRISMA-Scr protocols, a literature search is conducted to locate articles that explicitly or implicitly discuss EV charging equity. Our review finds that research on charging equity is nascent and lacking in clear normative evaluations of equity compared to the wider body of transportation equity literature. Only slightly more than one-in-four of an identified 37 articles discuss equity and justice explicitly. Equity perspectives in charging research are dominated by North American and European perspectives, with limited perspectives from the rest of the world. Charging incentivisation schemes and planning efforts may not be equity focused and may favour wealthier individuals, and there are differences in the charging needs and desires of high adoption groups compared to low adoption groups. These findings, however, often come from geographically and philosophically limited contexts and there are gaps in the literature for new methodological and topical contributions to this area.

Keywords: transportation equity | electric vehicle charging | transportation justice | plug-in electric vehicles | charging accessibility

Article:

Introduction

Electric vehicles (EVs) such as Plug-in Electric Vehicles (PEVs) and Plug-in Hybrid Electric Vehicles (PHEVs) have become a major focus of transportation planning efforts across the developed world for combating climate change (Barkenbus, 2020), boosting the green economy (Krishnan & Butt, 2022), and providing potential public health benefits (Requia et al., 2018). Government mandates are being pressed requiring the exclusive sale of EVs and other alternative fuel vehicles in major economies such as California (Newsom, 2020), New York (Governor's

Office of New York, 2021), and the European Union (Carey & Steitz, 2021). Likewise, corporate actors like Chevrolet and Volvo have announced that they plan to fully transition their manufacturing to EVs within the span of the next two decades (Ornes, 2021). With these changes, EVs appear poised to rapidly replace traditional internal combustion vehicles in many developed economies (Dennis, 2021) even though they are currently marketed as luxurious goods for only a small subset of consumers.

While charging infrastructure is critically needed for increasing EV adoption (Dixon et al., 2020; Ma & Fan, 2020; Zhang et al., 2018), concerns about a lack of EV charging infrastructure are present in many traditionally disadvantaged communities (e.g. Canepa et al., 2019; Carlton & Sultana, 2022; Hsu & Fingerman, 2021). A short, yet powerful statement on charging disparities comes from a transportation electrification focus group led by Blomqvist (2021) where a resident from Cleveland, Ohio poignantly opined – "We don't have charging stations in our communities". As this individual connotes, the potential mass-scale benefits of transportation electrification can only be realised if EV charging infrastructure facilities are adequately deployed (Chinnam & Murat, 2016) and if distributional equity is an important consideration. As charging infrastructure planning and modelling efforts hasten, an emerging cohort of researchers has called elements of the ongoing electrification push into question. Much of this critique has centred around issues of transportation equity and justice. One of the most critical of these papers is by Henderson (2020), who ties the emergence of EVs to elitist and exclusive societal elements. Henderson also argues that the adoption of EVs may lead to the appropriation and commodification of public spaces, causing unequal impacts for individuals based on their access to curb space. Jenkins et al. (2018) similarly notes that EVs can perpetuate gaps between higher-income and lower-income groups, giving rise to new injustices, while Sovacool et al. (2019) describes that several energy experts interviewed by their research team had concerns about potential injustices (e.g. affordability, unfair access) in the transition to electric mobility. Guo and Kontou (2021) have demonstrated that EV rebate programmes have primarily favoured wealthy car buyers in California, which leads the United States in EV sales and ownership. Likewise, Hsu and Fingerman (2021) have found disparities in charging access between income and racial groups in the state of California, which continues to lead the United States in EV adoption. Collectively, this research suggests that transportation electrification is not being designed to meet the needs of a broad cohort of end users, leading to inequities in adoption between groups.

There are multiple schools of thought in transportation equity describing how resources should be distributed between populations. Citing the definition of Boucher and Kelly (1998) which compares the equity and justice concepts to a vacuum, Lewis et al. (2021) notes that there is an agreement among researchers about the importance of equity concepts in transportation, yet they often rush to fill the research void with implicit and intuitive notions of equity rather than explicit and well-defined ones. Hence, two types of transportation equity analyses emerge: those that descriptively study distributional effects of transportation projects and investments without clearly stating an ideal outcome (e.g. implicit studies), and those that make explicit comments about equity and provide normative evaluations and judgements towards attaining an ideal outcome (e.g. explicit studies) (Lewis et al., 2021). Among the latter group of studies, different researchers lean on their own philosophical conceptualisations of equity and justice to make normative assessments. Some of the most used approaches include utilitarianism, libertarianism, intuitionism, egalitarianism, and capability approaches (readers interested in learning about these approaches may refer to Pereira et al., 2017) but other approaches such as simple and formal

equality also exist (Lewis et al., 2021). These approaches often conflict with one another, muddling definitions of equity and justice and inhibiting progress towards a "fair" transportation resource allocation.

Differences between the definitions of "equity" and "justice" create further confusion in this space. As a product of framing, Karner et al. (2020) suggests that "transportation equity" can generally be tied to the distributional equity philosophies used by state actors such a planners and government agencies to study transportation, while "transportation justice" is generally used by those who follow more engaged social activist mentalities. Pereira et al. (2017), on the other hand, describe these terms as being used synonymously with one another. Regardless of how justice is conceptualised, geographic scale also needs be taken into consideration when discussing ideas of transportation equity and justice. Sheller (2018) suggests that markedly different justice concerns occur across different scales of analysis, from an individual bodily scale to a global scale. Indeed, the meanings of justice and equity themselves may be locationally dependent and vary based on local cultural and institutional conditions (Karner et al., 2020). These discussions, however, have yet to widely permeate into transportation electrification research.

Multiple reviews covering equity issues in transportation electrification have been published in recent years, but none have systematically reviewed this topic in relation to EV charging infrastructure. Hardman et al. (2021) reviewed social equity issues in the context of American transportation electrification, broadly discussing issues pertaining to EV incentivisation schemes, adoption rates, and infrastructure placement, but not systematically reviewing any topic through a global lens. A similar approach was taken by Fleming (2018), but with a wider focus on equity issues in multiple modes of transportation. Other reviews touch on equity and electrification, but within the context of specific research questions. For example, Winjobi and Kelly (2020) wrote a focused review on the barriers to EV adoption in low-income American communities, while Sovacool et al. (2018) systematically reviewed equity and V2G transitions. Charging infrastructure is broadly considered in all of these studies, but it is not the focal point of the analysis. Considering the importance of charging infrastructure in EV adoption and the acknowledgement of equity issues in transportation electrification by multiple researchers, we contend that a timely review of transportation equity and EV charging is of high importance for researchers.

This paper conducts a scoping review of equity issues in EV charging infrastructure deployment by using the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-Scr) (Tricco et al., 2018) search protocol. The intent of this review is to identify knowledge gaps and explore the overall body of literature relating to transportation equity and EV charging, making scoping review procedures a more appropriate choice than systematic review procedures (Munn et al., 2018). Scoping reviews often predate systematic reviews by synthesising evidence in a certain field so that it can be made more useful in the development of specific research questions (Munn et al., 2018). We specifically search the literature in order to answer the following questions: (1) What role does EV charging play in promoting or hindering social and transportation equity? (2) What insights about charging equity can be gleaned from both explicit and implicit discussions of charging equity? (3) How are transportation equity philosophies applied in the context of electric vehicle charging research? We conduct this review from a global perspective, covering recent and relevant literature from the past decade. The aim of this review is to identify the current state of knowledge surrounding transportation equity and EV charging and to cohesively synthesise the results and gaps of

studies in this area to make them more useful for researchers working in this field. Since the intersectionality between transportation equity and EV charging is a fledgling topic, this scoping review will help provide transportation researchers with a much-needed exploration of the relevant literature and a timely synthesis of research findings in this area.

Methodology

Eligibility criteria

For the sake of this review, we draw a distinction between utilitarian welfare and distributional equity approaches. Here, we describe distributional approaches as research that highlights disparities in charging resources or behaviours between the high and low ends of various distributional groups (i.e. income groups, age groups, mobility groups). To be included in this review, articles had to demonstrate a connection to distributional equity issues and EV charging infrastructure either through explicit language or through implicit links. "Explicit" refers to articles that use clear justice or equity language or make normative judgements about equity. "Implicit" refers to articles that tacitly describe equity issues without using specific equity terms and tend to be descriptive about distributional disparities or differences without making any normative judgements. Articles included in this review are peer-reviewed and original research rather than review articles. Grey literature such as conference papers, theses, and book chapters were not considered. Research was included if it: (1) was published and indexed prior to early April 2022, (2) was written in English, and (3) included clear distributional equity considerations, (4) or demonstrated distributional biases in EV charging through implicit comparisons of communities and distributions.

Whereas this review is focused on distributional equity philosophies, utilitarianism is predicated on ideas of aggregate welfare and not typically distributional differences between groups (Nahmias-Biran et al., 2017). Though various strands of utilitarianism can be distributional in nature (Audi, 2007), traditional aggregative utilitarian viewpoints represent a diverging viewpoint on equity by treating societal welfare as a function to be maximised while lacking in critical evaluations of what "welfare" is or what it means for the disadvantaged segments of communities. This makes utilitarian equity philosophies difficult to scope in relation to distributionally-derived equity and justice research. Utilitarianism is also the most prevalent form of analysis within transportation research and is especially ubiquitous in the form of cost-benefit analyses which are the standard used for *ex ante* evaluations in Western countries (Van Wee & Roeser, 2013). In order to ensure that this review is succinctly focused on research that has not already been covered extensively in other literature, we have made a conscious decision to exclude aggregative utilitarian welfare approaches from content evaluation in this paper. This, however, does not mean that we completely neglect utilitarian viewpoints. Any research that was found to use utilitarian welfare equity with no distributional considerations was excluded from the "Content Analysis" of this review, but it was still documented and included in the statistical analysis of this review paper in order to draw out meaningful findings about how equity is considered in EV charging research. Figure 1 provides an overview of how utilitarian equity research is included in this review in comparison to distributional forms of equity.

Information sources

This review queried and retrieved articles from the Scopus database first in October 2021, with a follow-up search in early April 2022 to find relevant research. Scopus was chosen due to its wide coverage of peer-reviewed journals from many subject areas, and its high curation standards (Baas et al., 2020).

Search procedures and selection of sources of evidence

In our protocol we conduct an iterative search to account for potential complexities in the way that distributional transportation equity research is reported. In our first round of querying, we identified relevant peer-reviewed articles from Scopus by combining equity terms with charging-related terms (Figure 2). We searched article abstracts, titles, and keywords for equity terms from the year 2010 until the present. Since equity and justice are often used synonymously (Pereira et al., 2017), including both terms in our querying was a logical choice. Synonyms for equity were also included, despite the fact that there are some semantic differences between each (i.e. equity vs. equality).

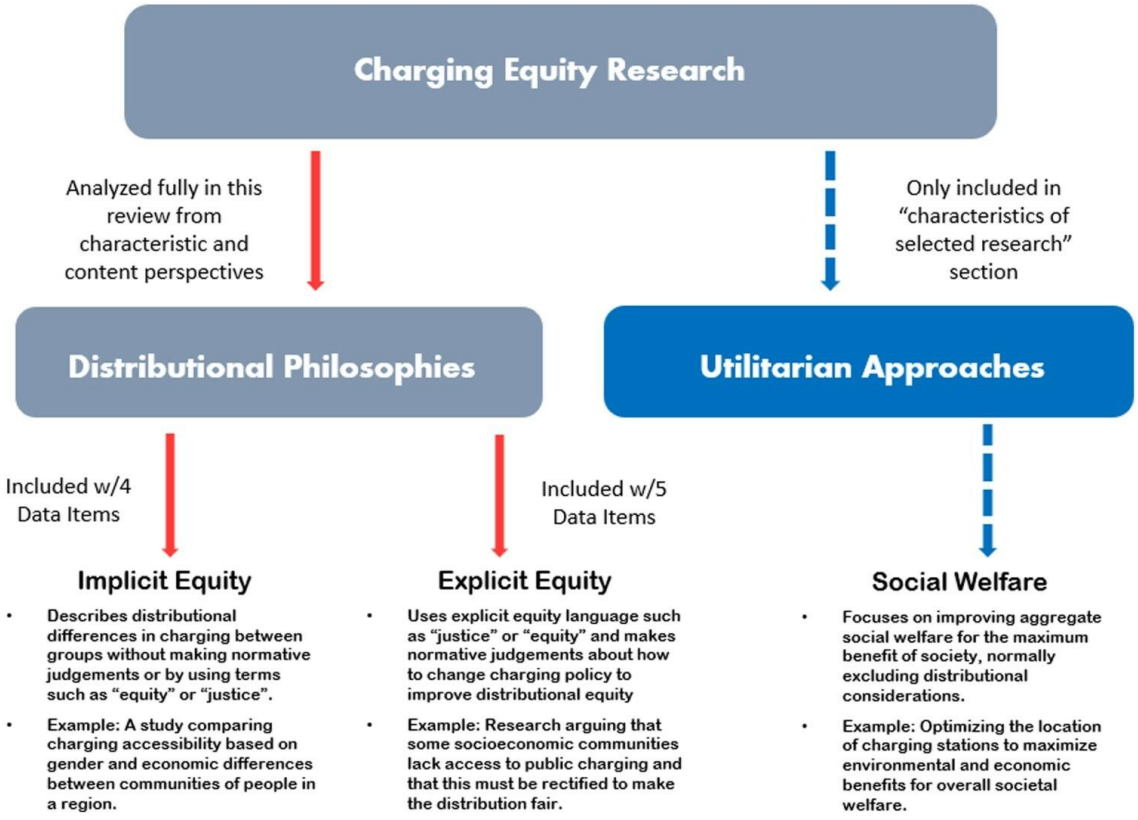

Figure 1. A model demonstrating how different equity research is included in this review.

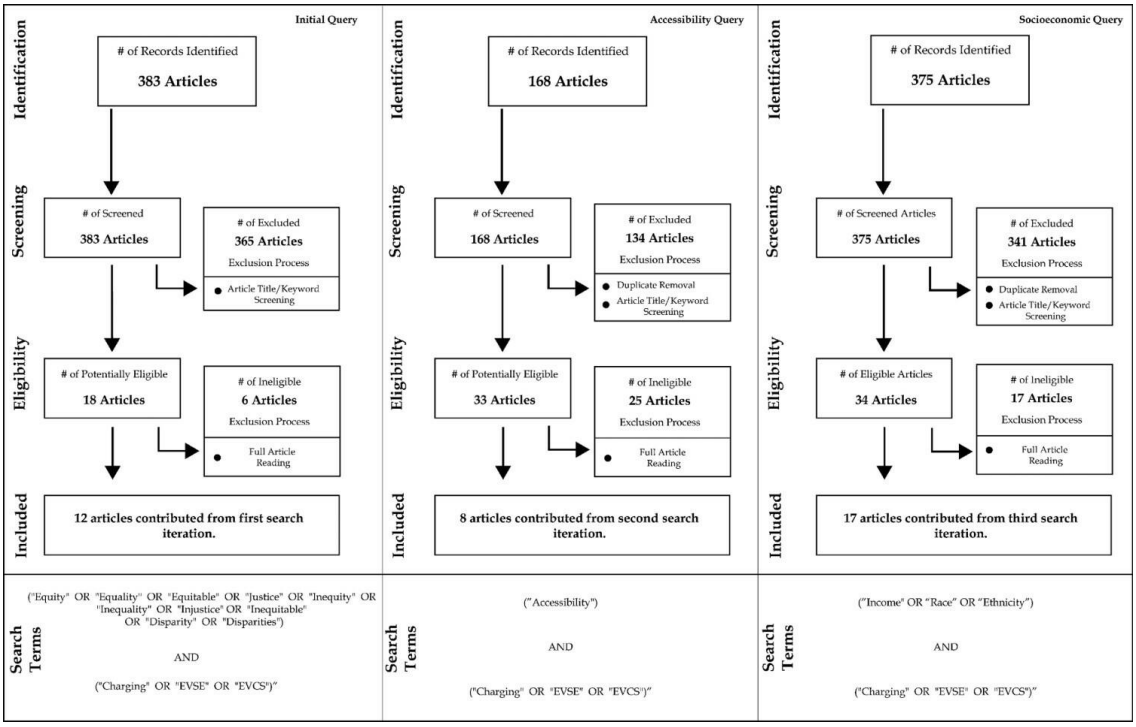

Figure 2. PRISMA Flow Model showing article selection process and queries through three search iterations.

The term "disparity" was also used, since social equity issues are often expressed in terms of distributional disparities between different groups of individuals. The inverse versions of these terms were included for consistency. "Charging" and common acronyms for charging infrastructure were used as a filter to limit results. We screened records to ensure that they discussed either distributional transportation equity issues or justice content in their abstract, title, or keywords. Articles unrelated to electric vehicle charging, or those with a focus on tangentially related topics (e.g. equity in electrical systems) were excluded. The remaining articles were then assessed for eligibility through a complete review of their contents, leaving 12 articles that met the full selection criteria.

We completed two additional search iterations focusing on accessibility and socioeconomic variables (Figure 2). We chose these topics after reviewing the articles from the initial search iteration and examining the themes that they most frequently discussed. We conducted these subsequent searches using the same general search procedures as the initial query, while also screening for duplicates. These searches were designed to locate relevant articles discussing distributional differences between groups without using explicit equity terms like "justice" or "inequality". In the screening phase, we reviewed article titles and abstracts to ensure that they discussed accessibility to charging or socioeconomic variable influences on charging placement. In the eligibility stage, the remaining articles were read to ensure that they focused on distributional inequities in charging or accessibility. In total, 25 more articles were identified in these second and third search iterations yielding a combined 37 articles that are included in this review.

In summary, this paper is primarily focused on distributional equity concerns related to EV charging. Although utilitarian welfare approaches are not the focus of this review, a fourth search was conducted using the terms "social welfare" and "spatial welfare" to find

utilitarian-focused research. 62 such articles were found and included in the statistical analysis portion of this review in order to draw comparisons in the overall research record between distributional approaches and aggregate welfare approaches. Even though these articles were searched for distributional equity considerations, none were found. Instead, most utilitarian models prescribe social welfare maximising calculations as part of their modelling. These articles are not included in the content analysis of this review, but we record these articles in supplemental Table 1. For replicability, all specific search terms for the first three search iterations can be found in Figure 2 and full queries can be found in supplemental Table 2.

Data charting process

The data items used in this scoping review were extracted from each selected article and then charted in separate Microsoft Excel spreadsheets for each search iteration. The authors agreed on the data items to be considered in advance (see the "data items" section), and we validated and discussed the spreadsheets throughout the process.

Data items

The data items used in this review are (1) categorisations of topical focus, (2) study methodologies, (3) implicit or explicit discussions of equity, (4) specific approaches used to study equity, and (5) regional/geographic coverage. Specific topical foci considered in this review include adoption, consumer behaviour, geographic accessibility, location allocation, and planning/policy. We chose these categorisations after conducting a preliminary search to document the broad types of literature in the charging research field. The study methodology data item details the specific approaches (i.e. regression, agent-based modelling) used by the authors in their study and provides contextual details. We also categorise articles on whether they explicitly or implicitly discuss charging equity (more details on this data item are discussed in the section on eligibility criteria). For articles with a clear explicit equity contribution, we carefully documented the equity approach that best encapsulates the author(s) main normative discussion of equity using the typology established by Lewis et al. (2021). Lastly, the content of each article was reviewed to understand the geographic/regional context of the research at a continental scale.

Synthesis of results

This scoping review presents its findings as a narrative synthesis of information in different topical areas of charging equity work, with a focus on individual studies and connections between these studies. The results of this review are presented in two sections. The first of these is the "Characteristics of selected research" which provides a statistical overview of the data items associated with the research that is documented as part of this review. The second "Content analysis" section provides a deeper narrative discussion of distributional equity research which is organised into two subsections centred on explicit and implicit discussions of charging equity.

Results

Characteristics of selected research

37 articles are identified that consider equity issues in EV charging using explicit terminology (i.e. “equity”, “justice”) or that describe distributional differences in charging between communities implicitly, without using equity terms. Even though articles are considered from the year 2010 until present, we did not locate relevant research before the year 2015. This suggests two things: (1) equity issues were not widely considered by the academic community during the incipient years of EV infrastructure deployment, and (2) that the expanding adoption of EVs over time has increased interest in the topic. This is also reflected in the fact that studies mentioning distributional equity in EV charging have increased at a steady pace since 2015, with 75.6% of articles having been written within the past three and a half years. However, most articles still discuss equity issues implicitly while only 29.7% use explicit equity terms. Of these, the majority are written by North American authors, suggesting that the social and political climate of the region may encourage discussions of distributional differences using intentional equity perspectives. The sparsity of specific and deliberate discussions of charging equity and justice is an important finding of this analysis. 2021 and 2022 have seen more explicit mentions of equity in charging research than prior years (Figure 3), but it remains to be seen whether this is the start of a trend or merely coincidental.

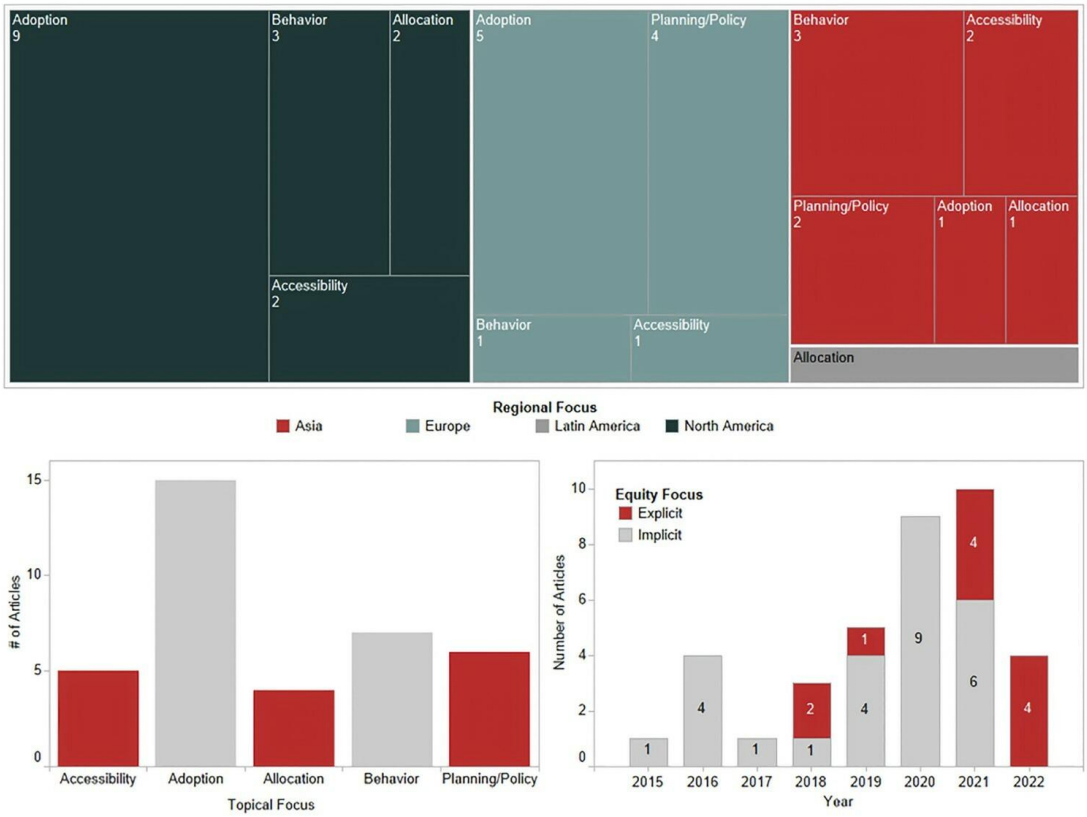

Figure 3. (Top) A tree map depicting distributional charging equity research by region. (Bottom left) Distributional equity articles by topic, (Bottom right) Explicit and Implicit Equity Articles by year.

Additionally, equity related content is found more in studies pertaining to EV adoption rather than any other category with 15 identified articles. Charging behaviour contributes 7 articles to this review and planning/policy studies contribute 6 articles. With a much smaller impact, geographic accessibility studies contribute 5 articles and location allocation studies contribute 4 (Figure 3). Given adoption studies are widespread in electrification research, it is not surprising that this is the most predominant group. The low number of equity articles related to EV charging station allocation is unexpected despite numerous and diverse modelling efforts over the past decade (for more details, see Deb et al., 2018). This suggests that charging station placement models lack a focus on transportation equity. More work needs to be done to prioritise equity and social variables as objective functions. Similarly, geographic accessibility measures, which can be used in transportation equity assessment frameworks (e.g. Lucas et al., 2016), are not present in most EV charging research.

Geographically, 16 (43.2%) articles are written focusing on North America, 11 (29.7%) on Europe, and 9 (24.3%) on Asia. Only a single article is written from a Latin American perspective, and no articles are written from African or Australian perspectives. The absence of articles on charging equity from the developing world is likely indicative of the low penetration of EVs in these markets and other local factors. In Latin American countries such as Mexico and Brazil, deeply entrenched industrial interests favouring conventional fuel vehicles and engines have hindered the adoption of electric vehicles (Galán et al., 2016; Velandia Vargas et al., 2020). Such barriers are also found in countries with rich crude oil reserves like Nigeria, where crude oil incomes may negatively impact EV adoption (Agunbiade & Siyan, 2020). In other regions like India, a multiplicity of infrastructural, financial, behavioural, and external factors may inhibit EV growth (Tarei et al., 2021). In turn, these factors likely also prevent the development of local charging equity considerations in research since researchers are more focused on understanding early-stage adoption in these areas.

Utilitarianism remains the dominant research paradigm within charging equity research. While 62 articles are identified as being premised on utilitarian social welfare maximisation (see supplemental Table 1), distributional perspectives constitute 37 articles split between explicit and implicit approaches (Figure 4). Among articles expressing explicit equity considerations, simple equality and prioritarian perspectives are the most prevalent representing 4 articles each. Formal equality, Rawls' egalitarian, and sufficientarian perspectives are each found in one article each. The implications of this finding will be further discussed in the subsequent sections, but this is indicative of a lack of diversity of thought in charging research.

Content analysis

Implicit equity articles

Echoing the findings of the social dimensions of transportation sustainability by Boschmann and Kwan (2008), we located many articles possessing socially relevant equity findings that did not use explicit equity related terms or frameworks. As Lewis et al. (2021) note, many implicit equity discussions express a viewpoint of how equity "does" or "could" function in a transportation system without suggesting how it "ought" to function. The findings from this section on implicit charging equity generally conform with

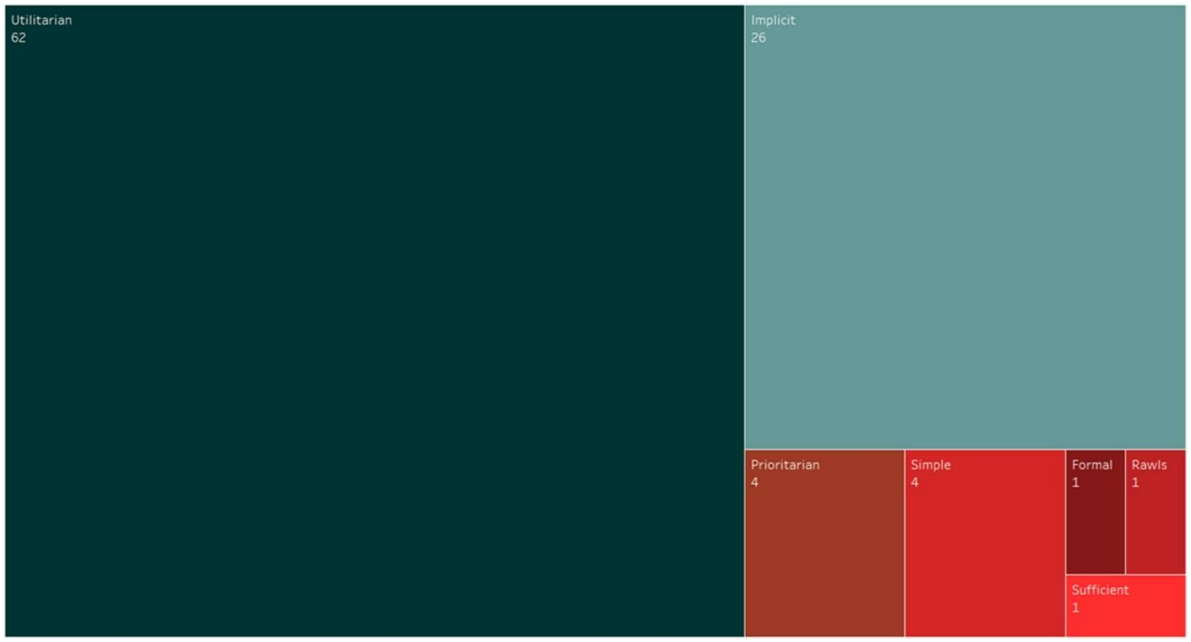

Figure 4. (Top) A tree map comparing distributional equity (implicit – blue-green, explicit – red) and utilitarian charging research.

this narrative. There are many articles that discuss distributional gaps in charging between groups, but they do so normally from a positivist lens and are predicated on techniques such a regression to imply causal relationships between charging and socioeconomic variables. Systems such as EV charging, however, are generally influenced by a plethora of environmental, cultural, energy, and societal phenomena. Næss (2015) suggests that such open systems should be examined through a critical realist lens, and that a plurality of interdisciplinary methods should be used to document potential causal mechanisms. Considering this, the implicit equity articles found as part of this review do show some clear relational patterns between charging and socio-economic conditions (Table 1), but many of these observations still need wider confirmation through multiple methods of study (i.e. society-centric frameworks of justice) across diverse geographic scales. Taken wholly, however, these articles permit researchers to begin contemplating the distributional nature of charging access across a number of socioeconomic variables.

One of the most corroborated of these distributional relationships is between home-based charging access and EV adoption. Described by Davis (2019) as a "homeowner-renter gap", multiple studies (e.g. Chakraborty et al., 2019; Nazari et al., 2018) have demonstrated that residents who have charging available at their homes are more likely to adopt EVs than renters and multi-family residents who have less access to at-home charging (Table 1). Homeowners are more likely to own EVs than renters among populations who belong to the same income group (Davis, 2019), suggesting that a lack of home-based charging may negatively influence EV adoption. Wealthy and highly educated early EV adopters rarely charge their vehicles at public charging stations outside of their home and work (Javid & Nejat, 2017; Trommer et al., 2015). In essence, EV adoption may be greater among the higher end of the socioeconomic distribution partially due to the ability of wealthier individuals to charge their vehicles at their private residential garages or carports at any hour of the day. This represents a clear distributional disparity in charging access between homeowners and non-homeowners and lends.

Table 1. Studies considering EV charging equity implicitly.

Authors	Charging Equity Research Findings	Primary Focus	Study Methods	Regional Focus
Trommer et al. (2015)	(1) Early adopters rarely charge their vehicles outside of home or work, but future urban adopters may have different needs.	Adoption	Descriptive Analysis	Europe
Axsen et al. (2016)	(1) Pioneer EV adopters have more home-based charging than other adopters. 2 Differences in charging profiles, adoption motivations, and experiences exist between groups.	Adoption	Discrete Choice Modelling	North America
Zhang et al. (2016)	(1) Charging is effective at increasing demand and denser charging station networks may lead to increased EV adoption.	Adoption	Discrete Choice Modelling	Europe
Nienhueser and Qiu (2016)	(1) Willingness to pay for L2 and DCFCcharging options increases with age and income.	Consumer Behaviour	Mixed Methods	North America
Philipsen et al. (2016)	(1) There are differences in charging location preferences between groups with BEVexposure and groups without exposure toBEVs.	Consumer Behaviour	Mixed Methods	Europe
Javid and Nejat (2017)	(1) Charging, income, and education influence EV adoption. **2** Adding public charging stations may maximise adoption for certain groups.	Adoption	Multiple Logistic Regression	North America
Nazari et al. (2018)	(1) Homeowners with private charging are more likely to adopt EVs. **2** Public charging access plays a role in increasing adoption.	Adoption	Discrete Choice Modelling	North America
Abotalebi et al. (2019)	(1) Charging availability is a greater concern in an early adopter region in Canada compared to leading adopter regions.	Adoption	Latent Class Modelling	North America
Davis (2019)	(1) A quantifiable EV adoption gap between homeowners and renters may be associated with charging access.	Adoption	Regression Analysis	North America

Chakraborty et al. (2019)	(1) Apartment dwellers are more dependent on non-home charging. **2** Long-range BEVs and PHEVs may have charging advantages/disadvantages over short-range PEVs.	Consumer Behaviour	Discrete Choice Modelling	North America
Yun et al. (2019)	(1) PHEV users are more likely to charge at home or work than in public, which may relate to their personal attributes such as income and age.	Consumer Behaviour	Mixed Methods	Asia
Chen et al. (2020)	(1) Current EV owners are less concerned about charging access than non-owners.	Adoption	Regression Analysis	Europe
Wee et al. (2020)	(1) Zip code based EV adoption is tied to public charging availability and fast charging infrastructure in Hawaii.	Adoption	Cross-sectional Regression	North America
Machado et al. (2020)	(1) Social inequalities impose boundaries on charging placement in São Paulo.	Location Allocation	Spatial Analysis	Latin America
Hu et al. (2020)	(1) Shared electric vehicle use is likely to increase in middle income communities with poor public transit access as long as charging accessibility is improved.	Consumer Behaviour	Gradient Boosting Decision Trees	Asia
Lee et al. (2020)	(1) 86% of consumers charge from home to some extent. **2** Workplace charging is more frequently used by multi-unit residential users. **3** Owners of certain vehicle models are more likely to charge at home.	Consumer Behaviour	Mixed Methods	North America
Azarova et al. (2020)	(1) Community-owned charging may serve as an alternative model to private charging, but there are differences in charging concerns between groups of users.	Planning/Policy	Mixed Methods	Europe
Li et al. (2020)	(1) Government charging incentives are important for all groups, but lower-income communities rank them slightly higher.	Planning/Policy	Conjoint Analysis	Asia
Tan and Lin (2020)	(1) Income, education levels, gender, and age are significant indicators of public willingness to pay for charging.	Planning/Policy	Logit Modelling	Asia

Zink et al. (2020)	(1) German government incentives predominantly benefit adopters who would have purchased an EV without a subsidy, **2** public charging is treated more as "marketing" than a public service.	Planning/Policy	Synthetic Control Method	Europe
Brückmann et al. (2021)	(1) Detached homeownership increases BEV adoption, likely due to the presence of at-home charging.	Adoption	Mixed-effects modelling	Europe
Gehrke and Reardon (2021)	(1) Higher-income, detached homeowners are more likely to adopt EVs. **2** Public charging may lessen the gap in adoption.	Adoption	Mixed Methods	North America
He et al. (2021)	(1) Charging piles and per capita income have the greatest positive effect on EV adoption.	Adoption	Spatial Analysis	Asia
Wang et al. (2021)	(1) There are two groups of charging users, and the "pragmatic" group is more concerned about charging costs.	Consumer Behaviour	Mixed Methods	Asia
Falchetta and Noussan (2021)	(1) Charging accessibility varies markedly within and between countries in Europe.	Geographic Accessibility	Spatial Analysis	Europe
Park et al. (2021)	(1) Accessibility to charging infrastructure varies temporally as well as spatially, suggesting a mismatch between supply and demand.	Geographic Accessibility	Mixed Methods	Asia

credence to Henderson's (2020) supposition that EV adoption is being driven by the kinetic elites of society. Further, many current EV owners are unconcerned or less concerned with their ability to find public charging (Chen et al., 2020; Trommer et al., 2015). In contrast, communities that have less EV adoption have more concerns about charging availability (Abotalebi et al., 2019; Hathaway et al., 2021). This represents a "chicken or the egg" justification problem as described by Zink et al. (2020) – should planners focus on creating new infrastructure around the needs of the existing adoption community, or should they plan for the needs of a wider-adoption community? This question likely has different answers based on individual philosophies. Research suggests (i.e. Axsen et al., 2016) that the initial wave of pioneer adopters has been motivated to purchase EVs by their tech-oriented lifestyles and movements such as environmentalism. If these are the only groups that charging is properly provisioned for, it does not seem unreasonable to suggest that many communities at the lower end of the socio-economic distribution may experience an exacerbation of existing mobility and accessibility issues as EVs proliferate faster than they may have budgeted for.

A finding across multiple implicit equity studies (e.g. Gehrke & Reardon, 2021; He et al., 2021; Nazari et al., 2018; Wee et al., 2020; Zhang et al., 2016) suggests that the instillation and densification of public charging is associated with increased EV adoption. While more charging appears to be conducive in promoting EV adoption, the willingness to pay for such charging may be a function of age, income, and mobility (Nienhueser & Qiu, 2016; Tan & Lin, 2020; Wang et al., 2021). Owning a newer long-range PHEV or BEV may also impact charging behaviour (Chakraborty et al., 2019; Yun et al., 2019), and since PHEV users are more likely to charge at home or work (Yun et al., 2019), many owners of newer and longer-range EVs may not be as likely to worry about accessibility to public charging. Differences in accessibility to charging exist at more than just a community scale, however, and from limited evidence they may be both interregional and intraregionaly variable (Falchetta & Noussan, 2021) and could exist within a system of temporal constrains and spatial mismatches (Park et al., 2021).

One other interesting implicit charging equity discussion revolves around the ownership and governance of charging infrastructure. Incentivisation programmes to install charging and support adoption are important to all vehicle users but perhaps slightly more so to lower-income groups (Li et al., 2020). In reality though, it is often users who do not personally need subsidisation who benefit the most from these incentives (Caulfield et al., 2022; Zink et al., 2020). In state-centric planning practices, it is also the case that modelling and deployment efforts tend to favour the high-resource communities that drive societal change rather than the lower resource communities that are expected to adapt to change at a slower pace. This is demonstrated by Machado et al. (2020) in São Paulo, Brazil where the modelling of new charging stations was heavily constricted by socioeconomic conditions in the city. As an alternative mode of charging governance, Azarova et al. (2020) suggest that community-financed charging be adopted to better address the needs of diverse users. Hu et al. (2020) suggest that vehicle sharing coupled with charging development may also help to drive an uptake in EV use in transit-poor communities. These suggestions may be hard to implement, however, given the diversity in willingness to pay for EVs among different communities. If community members do not see EVs as objects that are going to become relevant to their lives anytime soon, they may not be willing to create shared infrastructures or seek out subsidies to improve local infrastructure conditions. This potentially clouded foresight may leave them at a severe disadvantage as market and governmental actors continue to push for transportation electrification at an accelerated pace.

Explicit equity articles

Research using explicit equity terminology and expressing normative policy recommendations is less common in the charging literature (Table 2). As Brown (2022) opines, equity outcomes should be a central goal of transportation agencies, but such outcomes are still rarely considered or analysed in the context of applied transportation (Linovski et al., 2022). It is important to acknowledge that there is a reciprocal connection between basic and applied research (Sidman, 2011). Findings and frameworks from academic transportation can greatly influence policymaking and planning, just as the community-centric approaches of field practitioners can introduce new ideas to researchers. Yet, these connections seem to be disappointingly near absent or lacking in the charging equity research realm.

Outside of utilitarianism, which acts as a *de facto* form of equity analysis throughout transportation research, one of the most common types of equity consideration seen in EV charging research is the "simple equality" approach. This approach calls for all groups of people to have an equal amount of a transport resources per capita (Lewis et al., 2021) as a societal goal. For example, if a community has three chargers, a simple equality approach would dictate that other communities of the same size should also have three chargers. Among the authors who address charging equity using explicit terms, there are quite a few who prescribe an outcome of improved equality of charging resources between disadvantaged and leading adoption communities or who imply such outcomes through their writings. These approaches may often suggest interesting policy options to bridge the equity gap. Hathaway et al. (2021), for instance, suggest an approach where electric utility agencies sponsor the development of charging in traditionally disadvantaged communities in order to increase adoption in line with wider trends.

Two different accessibility approaches also demonstrate simple equality considerations in charging research. Khan et al. (2022) use expressly distributional language to discuss New York City charging station accessibility, where their main contribution is a correlation analysis demonstrating distributional differences in charging based on income, race, and mobility. In order to remedy these differences, the authors suggest that "justice-centric frameworks" should be used, but they do not elaborate on any specific policy recommendations for bridging the gap in charging between communities. Li et al. (2022) are more specific in their framework by suggesting that spatial inequalities in charging distributions can be analysed and addressed on a case-by-case basis through a multifaceted framework consisting of geographic accessibility measurement and spatial autocorrelation assessment coupled with local considerations. One hallmark seen across simple equality charging studies is that they tend to be analytically focused, and that the policy implementation aspect of the studies are often inferred rather than obviously stated. These studies tend to express a need for improved charging accessibility or incentivisation in disadvantaged communities in order to improve distributional conditions, but they do not necessarily suggest that these communities need to be prioritised over others. An example of this can be seen in the approach of Canepa et al. (2019) who demonstrate that EVs are not a viable option yet for disadvantaged communities in California. In their policy implications, they express that there are targeted investments and marketing that can be used to decrease distributional differences in charging and adoption between disadvantaged communities and leading adoption communities, but they fall short of recommending that disadvantaged groups should be absolutely prioritised in state EV planning efforts.

Table 2. Studies considering EV charging explicitly

Authors	Charging Equity Research Findings	Primary Focus	Equity Approach	Study Methods	Regional Focus
Ai et al. (2018)	(1) Solely considering market factors in charging station placement leads to inequities.	Location Allocation	Prioritarian Equity	Suitability Analysis	North America
Do Chung et al. (2018)	(1) Develops three different equity constrains for the AC-PC FRLM model, demonstrating a method to improve charging equity between regions.	Location Allocation	Sufficientarian Equity	Optimisation Modelling	Asia
Canepa et al. (2019)	(1) Disadvantaged communities in California have more public charging, but this is tempered by them having less homeownership.	Adoption	Simple Equality	Mixed Methods	North America
Hathaway et al. (2021)	(1) Home charging is the most important variable that explains EV adoption. **2** Justice communities are concerned about charging costs and access.	Adoption	Simple Equality	Descriptive Analysis	North America
Lee and Brown (2021)	(1) Charging electricity demand varies between socioeconomic groups. **2** Home and multi-car ownership influence adoption.	Adoption	Rawls	Agent Based Modelling	Europe
Hsu and Fingerman (2021)	(1) Charging accessibility varies based on race/ethnicity and income. **2** Charging accessibility is lower in multi-family residential settings.	Geographic Accessibility	Prioritarian Equity	Generalised Additive Modelling	North America
Asekomeh et al. (2021)	(1) Planning strategies for EV stations in Dundee, Scotland met many goals but fell short in income and gender equality.	Planning/Policy	Prioritarian Equity	Policy Analysis	Europe
Nazari-Heris et al. (2022)	(1) Creates a model to deploy mobile charging stations to socially vulnerable communities.	Location Allocation	Prioritarian Equity	Optimisation Modelling	North America
Khan et al. (2022)	(1) The distribution of charging stations in New York City is skewed towards less-dense neighbourhoods. **2** Charging placement is skewed against traditionally disadvantaged racial and ethnic communities.	Geographic Accessibility	Simple Equality	Correlation Analysis	North America

Li et al. (2022)	(1) Develops a multistep framework for assessing charging accessibility. **2** Intraregional charging accessibility inequalities exist between multiple Chinese cities. **3** Within Beijing accessibility is impacted by charging demand.	Geographic Accessibility	Simple Equality	Mixed Methods	Asia
Caulfield et al. (2022)	(1) Home-based charge points are more concentrated in wealthy communities in Ireland. **2** Government incentivisation schemes favour privileged groups.	Planning/Policy	Formal Equality	Mixed Methods	Europe

In contrast, Nazari-Heris et al. (2022) adopt a prioritarian framework when discussing the deployment of mobile chargers by calculating a demand priority function that explicitly takes social equity into account to provide better access to EV charging in disadvantaged communities. Similarly, Ai et al. (2018) prescribe that urban communities with lower densities of charging infrastructure should be given a priority in EV investments compared to communities that already have charging. The most direct statement of prioritarianism comes from Hsu and Fingerman (2021) who suggest that government funding should be prioritised for developing charging in disadvantaged communities since the private sector will likely already give priority to other neighbourhoods with more favourable market conditions. Asekomeh et al. (2021) similarly state that urban residents should be prioritised for EV policy interventions.

While simple equality and prioritarian modes of normative thinking pervade the nascent body of distributional charging equity research, other equity philosophies are also present. Do Chung et al. (2018) adopt a sufficientarian framework by creating a location allocation model that attempts to provide a sufficient amount of charging for all communities and not just for dense downtown corridors which are favoured in many current modelling solutions. Caulfield et al. (2022) take a highly nuanced stance from their findings that show a favouritism in charging incentivisation schemes and accessibility for wealthier individuals in Ireland. Rather than arguing for more EV charging stations to close the distributional inequality gap, they argue for more investment in other modes of transportation such as public transit and active travel modes that can better improve the lives of lower income residents. This approach appears to synchronise with calls by other researchers (e.g. Logan 2020) for deeper considerations of whether new transportation technologies are truly revolutionary or whether they merely reinforce automobile-dominant systems that create equity and justice challenges across many urban communities. Lee and Brown (2021) echo what can be described as a Rawls' egalitarianist approach, describing lower income households as "later adopters" of EVs who have a difference of needs at present compared to higher income households.

Outside of these contributions, EV charging research is still dominated by the utilitarian point of view. Criticisms of utilitarianism have caused some introspection within the wider transportation research network, and new forms of analysis such as the capabilities approach (CA) have emerged within transportation research to address the mobility needs of a wider swath of society. The growth of the CA in transportation has been steady since it was introduced by Sen (1999) and Nussbaum (2001) and recently re-introduced by Hananel and Berechman (2016) to the transportation research community. It has been successfully operationalised to study transportation accessibility and social exclusion in many recent applications (e.g. Bantis & Haworth, 2020; Cao & Hickman, 2019; Hickman et al., 2017), but this approach has not been found in EV charging equity research. Some authors (e.g. Nahmias-Biran et al., 2017) have even gone as far as to recommend the CA approach as the only potential alternative to utilitarian models of thinking at least in comparison to other equity philosophies such as Rawls' egalitarianism.

Discussion

This scoping review has demonstrated that there are limited studies on distributional charging equity. While 37 peer-reviewed articles are identified related to EV charging equity, most of these discuss equity issues implicitly. Only 29.7% of articles use overt and explicit equity terms for describing findings of non-utilitarian distributional disparities. Even though there has been a steady growth in distributional equity perspectives in EV charging research since the year 2015,

conceptualisations of equity are still nascent and poorly defined in this area. Though limited, charging equity research is still dominated by the North American and European perspectives and there is a vacuum in knowledge from wide geographic regions, especially from the developing world. Across the existing research on charging equity, only a small handful of articles have begun to consider what EV charging infrastructure means for communities at the lower ends of the socioeconomic distribution, but it is encouraging that researchers have started this conversation. More specific and deliberate considerations of transportation equity and justice from multiple methodological and geographic contexts would likely provide value to researchers and practitioners.

This scoping review found evidence of a gap in adoption between vehicle users who have home- and work-based charging, and those who do not. It appears as though a densification of public charging options may help to lessen this gap, but there are a host of mitigating behavioural and personal mobility factors that could alter the charging needs of different groups and communities. Some authors have begun to offer frameworks for solving these nuanced equity problems through actions such as prioritised investments in charging infrastructure planning for lower income communities, mobile charging station deployment, or novel community-based solutions for increasing charging accessibility. Overall, the charging equity discussion has only just started, and it also has much to discover from wider conversations within the existing concepts of transportation equity.

The past decades have witnessed a number of innovative ideas emerge into broader discussions of transportation equity and have generated robust discussions leading to the development of new analytical methods and equity philosophies. Society-centred justice approaches have re-contextualised transportation planning from a state-centric activity to a community-led practice of engagement (e.g. Karner et al., 2020) and a relative, albeit fluid shift has taken place in academia towards these viewpoints (Verlinghieri & Schwanen, 2020). Distributional and utilitarian viewpoints are now challenged by a need to recognise the rights of communities to directly shape and create new futures for themselves. Methods of equity appraisal such as the socially relevant accessibility impacts (SRAI) approach of Lucas et al. (2016) or the capabilities approaches of Sen (1999) and Nussbaum (2001) have also emerged at the same time to offer approaches combining philosophical definitions and assessments of equity with elements of empiricism in a way that is unique from the modelling-intense approaches of transportation planning that have dominated the field for a significant amount of time. These approaches have not been used to address charging equity yet. As noted, charging equity research is still generally based on circular discussions noting problems in charging availability and accessibility between groups, but without any clear frameworks for assessing or fixing these problems. We would encourage researchers in the nascent field of charging equity to evaluate how conceptions and methodologies from these other transportation equity research areas can be applied to the topic of EV charging.

Another discussion that is lacking but critical for charging equity is the looming arrival of EV purchase mandates and market-driven production changes that are taking shape at this very moment in major world economies such as the European Union and the United States. Thus far, EVs are often marketed as luxurious goods (Henderson, 2020), appearing irrelevant to some consumers who are more concerned with everyday mobility needs rather than big picture environmental goals and ideals (Bennett & Vijaygopal, 2018). What needs to be recounted, however, is that automobiles are ultimately a status symbol reflecting a consumer desire to show off the identity, autonomy, and individuality of their age and time (Gartman, 2004). As we have

entered into this epoch of transportation electrification, so far, the main symbols of electromobility have been primarily those of status and of wealth. In particular, Tesla has been cited by consumers as being trendy and desirable (Kurani et al., 2016) and owning luxury EVs has become a status symbol of environmentalism, technological savvy, and wealth. As Wirtz et al., 2020 notes, however, luxury goods can have varying degrees of exclusivity and extraordinariness. Recent years have seen affordable models of EVs enter development (i.e. the Nissan Leaf, Hyundai Kona, or Aptera Concept Car), and though these models are still expensive in comparison to many internal combustion vehicles, they represent a divergence in the exclusive nature of EVs.

The main question of this transition then is likely not whether EVs will overtake conventional fuel vehicle sales and predominate across communities, but it is rather an infrastructural one: will every community have the infrastructure that they need to benefit from the economic and environmental advantages of EVs, or will some communities get left behind in this transition? Planning only for the current adopters of EVs ignores the fact that governments and markets are likely going to force many users to adopt alternative fuel vehicles whether they are ready to afford them or not. As EVs become rapidly more affordable, a discussion needs to take place around whether current charging options in lower adoption communities are sufficient to accommodate a rapid shift in automobility or whether these communities will be left behind in such a shift. Without adequate charging infrastructure in lower income communities, new geographies of exclusion could emerge that systematically disadvantage whole communities of people from the benefits of EVs (Carlton & Sultana, 2022). EVs are relevant to all socioeconomic groups ultimately due to their positionality within ongoing technocratic debates and policymaking surrounding climate change. Even though many consumers have yet to develop a purchasing interest in EVs, we contend that governments, EV manufacturing companies, and market pressures will force automobile users to adopt EVs more quickly than the current market trends may indicate, and the research community needs to more deeply reflect on this trend.

Another reason to address charging equity concerns is the role that EVs may have in improving the environmental and health outcomes for traditionally disadvantaged communities. Historically, transportation paradigm shifts and investments have created spatio-temporal disparities in access to opportunities and polarisation among different groups (Brenman, 2007; Karas, 2015; Pereira & Karner, 2021). In the United States, lower income and non-white racial communities are exposed to air pollutants at higher rates than other groups (Miranda et al., 2011) while also having less green infrastructure to buffer pollutants (Jennings et al., 2021) leading to significant environmental justice disparities. Similar findings have been observed in Chinese (e.g. Liu et al., 2018; Wong et al., 2008) and European (e.g. Tonne et al., 2018) contexts. EVs can help to remedy these environmental issues by reducing local pollutants such as Nitrogen Dioxide (Soret et al., 2014). The environmental benefits of EVs may vary based on a number of factors including charging placement patterns and availability (Requia et al., 2018). Across urban regions, however, it is expected that EV adoption will result in improved health benefits for populations even if there is variation in the total air pollution impact (Choma et al., 2020). These transitions cannot be looked at absent local community input from disadvantaged communities whose voice as a stakeholder is vital but often ignored element in clean energy transitions (Finley-Brook & Holloman, 2016) or without considering the needs of employees in traditional energy industries who may be impacted by clean energy transitions (Carley and Konisky, 2020). Although many of these debates belong to the wider EV equity discussion, the role of charging

to act as a catalyst for transitioning to a low-carbon transportation system, improving local community health outcomes, and providing job opportunities for vulnerable populations needs to be more deeply considered.

Given that charging equity research is still developing with wide gaps available for topical and methodological contributions, equity discussions, regardless of their philosophical underpinnings, are vital for the continued growth of this fledgling research field and they should be encouraged. Ultimately, we do not endorse any one view of justice or equity as deserving prioritisation, but we instead recognise that introducing multiple conceptualisations of equity and justice into charging equity would likely lead to richer debates and the creation of innovative solutions for the EV charging equity problem. Now, as world governments and markets rush towards an electric future, these discussions are more vital and necessary than ever.

Conclusion

This scoping review has presented a summary and synthesis of findings on charging equity research from predominantly distributional equity philosophies. Charging equity research is still in its infancy, yet it is an emerging field with contributions in the literature starting from 2015. While some consistent themes emerge from these studies, notably when it comes to charging resource and access differences between homeowners and other residential groups, there are still many charging equity topics that warrant further exploration across different geographies and scales. The charging equity problem represents a topic that is lagging behind broader equity debates in transportation research, and there are abundant opportunities for researchers to address this problem using novel methodologies, state and society-centric equity frameworks, and through open dialogue and debate.

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