Renewable and Sustainable Energy Reviews 182 (2023) 113398

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Can the equitable roll out of electric vehicle charging infrastructure be achieved?

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ARTICLE INFO

Keywords:
Social equity"
"Social inequity"
"Electric vehicle"
"Electric vehicle charging infrastructure"
"Equitable"
"Charging infrastructure placement"
"Transport justice"

ABSTRACT

Equitable and sufficient charging infrastructure is required for transport decarbonization to reach its goals. Despite increased electric vehicle infrastructure roll out rates, there is still considerable uncertainty regarding the charging market. For example, studies have evidenced disparities in electric vehicle charging placement, however, predictable as the market caters for early adopters. While there is an emerging discourse surrounding social equity in charging infrastructure, this is scattered across interdisciplinary research covering broader aspects of electric vehicle infrastructure provision with a lack of studies consolidating issues. This study aims to synthesize evidence on social equity in various aspects of electric vehicle charging infrastructure provision and set an agenda for centering social equity in the debate. Findings of this critical synthesis of research have helped to draw out the complexities involved in the equitable roll out of electric vehicle charging infrastructure, which are interlinked with an array of other dimensions including the affordability of electric vehicle purchase. Research into solutions and best practice has shown examples of local target setting, monetary incentives (grants, loans and rebates for electric vehicle purchase and charging infrastructure and smart energy tariffs) and other policy incentives (increased public overnight charging, electric car-clubs, extended battery warranties for second-hand vehicles) that can or have been employed to redress the balance. The outcomes could be utilized when developing and implementing electric vehicle strategies to support uptake across all people. Policy implications and further study suggested could ensure that communities and individuals are not locked out of the benefits of investment.

1. Introduction

Several initiatives to decarbonize the road-transport system are focusing on policy strategies, the transformation of the energy system and the deployment of charging infrastructure to further promote the adoption of the electric vehicle (EV)[1] [1]. For example, in the UK, the Government's 2035 Delivery Plan [2] documents a commitment to stop the sales of new petrol and diesel cars and vans by 2030 and requires that all new cars and vans be 100% zero emissions at the tailpipe by 2035 [2,3]. In the meantime, the UK Government expects to have approximately 300,000 public chargers 'as a minimum by 2030' [4]. Alongside policy, the development and adoption of EV technology is moving at an exciting pace. Globally, there were over 450 electric car models available in 2021, an increase of more than 15% compared to 2020 and more than twice the number of models available in 2018 [5]. This trend has been accompanied by year-on-year increasing sales and market share of EVs worldwide [5]. EVs are generally becoming attractive to consumers as prices are becoming comparable to conventional cars relative to previous years. For example, between 2020 and 2021, the sales-weighted average price-per-range ratio for battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) fell by 10% and 14%, respectively [5]. These trends have also been facilitated by a suite of tax benefits and subsidies, ambitions and regulations, especially across the top-11 countries in terms of EV market share, namely Norway, Netherlands, Sweden, UK, Germany, France, China,

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[1] In this study electric vehicle (EV) is used to cover battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs). BEVs exclusively use rechargeable battery packs, with no secondary source of propulsion. PHEVs have a petrol engine combined with an electric motor and a battery. Internal Combustion Engine Vehicle (ICE) is used to describe a vehicle with an engine which generates motive power by the burning of petrol, diesel, or other fuel.

https://doi.org/10.1016/j.rser.2023.113398
Received 4 July 2022; Received in revised form 23 April 2023; Accepted 22 May 2023
Available online 31 May 2023
1364-0321/

Abbreviations

BEV	battery electric vehicle
EU	European Union
EV	electric vehicle
ICE	internal combustion engine
MUD	multi-unit dwelling
PHEV	plug-in hybrid electric vehicle
SDG	Sustainable Development Goals

Japan, Korea, Canada and US [6]. An effective transition and wider adoption of EVs is very much dependent on drivers' access to public and home-charging infrastructure. Globally in 2021, publicly accessible chargers increased by 37%, however, this was lower than the growth rate reported in 2020 (45%) and pre-pandemic roll out rates [5]. Despite these significant increase rates, there is still considerable uncertainty regarding the EV charging market. For example, across the 100 most populous US metropolitan areas, over four times the charge points these markets had at the end of 2017 will be needed by 2025, amounting to over 195,000 non-residential EV charging points [7]. In the European Union (EU), Member States' infrastructure planning "lacks, on average, the level of ambition and coherence needed, leading to insufficient, unevenly distributed infrastructure; " [8]. The 2022 Global EV Outlook attributed slower market uptake in emerging markets and developing economies to the lack of widely accessible charging infrastructure and weaker regulatory 'push' [5,9].

The reduction in dependency on fossil fuels imports, as well as improved air quality, are seen as the benefits of EVs; during the COVID pandemic, this positively led to greater interest and acceptance of EVs [10]. EVs were less affected by the COVID crisis than conventional car sales in Europe, but only due to purchase incentives and regulatory instruments increasing the number of EV models, and the reduction of global battery costs [10,11]. Hu et al. [12] identified increased charging infrastructure investment as a necessary component mechanism for China to recover the rate of EV sales to pre-pandemic sale rates sooner. The importance of transitioning to low-carbon technologies has been heightened by Russia's aggression against Ukraine, highlighting the energy mix and dependence on imported fossil fuels in the EU [13]. The sanctioning of Russia has stimulated oil production in other countries. There is an urgent need therefore to accelerate the transition by incentivizing the switching of fuels, including by subsidizing the purchase of EV and EV charging station infrastructure [14]. Accelerated EV market penetration will enhance emission savings and will enable a smoother technology uptake in advance of meeting global 2050 emissions targets [15,16] and support the delivery of United Nations Sustainable Development Goals (SDG) [17] and national ambitions. Sufficient and equitable public charging infrastructure is required for transport decarbonization to reach its goals [18]. The market will prioritize commercial interests rather than social equity and organic growth may not keep pace with vehicle purchases. This in turn will not provide the consumer or market confidence needed to increase further uptake and stimulate investment [19]. Well-designed, binding targets for EV charging infrastructure could reflect positively on government commitment, ensure social equity where public EV charging infrastructure utilization is lower/less investable, and provide long-term signals and direction for public-private investment in EV infrastructure and the upgrade of local electricity networks [19].

Equity analysis is frequently used in transportation-related studies to examine fairness in accessibility [20]. Spatial and temporal accessibility measures exist for access to a variety of infrastructure such as healthcare and parks and by transport modes including public transport and active travel, which can be used as targets at a local level [21,22]. In the context of 'decarbonization through electrification' of road transport, inequity is observed in two directions: (a) EV ownership/uptake and (b) in the provision of EV charging infrastructure. EV owners and those with the intention to adopt EVs have been consistently reported to have higher income [23], higher education qualifications, and live in single-family homes they own [24]. Lower income households and those from lower socioeconomic groups would be late adopters of EVs [25]. The majority of EV fiscal incentives are unlikely to make any difference in supporting those on lower incomes [20]. In the meantime, many countries are starting or planning to end purchase incentives and tax exemptions for EVs before these become accessible to the mass market [12,26]. It is a logical strategy for EV charging infrastructure investment to target early adopters to increase EV take up but funding to support local policy measures could be imbalanced within the same country leading to certain areas standing out in terms of offering effective EV policy interventions relative to other regions [6]. This work is important as it has practical implications for the linkage of intervention measures to the United Nations SDGs [17]. The implementation of SDG 13 regarding urgent action on climate needs to be implemented so as to not conflict with SDG 9.1 regarding equitable access to infrastructure, SDG10.1 reducing inequality within and among countries, and SDG11.2 regarding sustainable transport systems for all [27,28].

Discourse surrounding social equity in EV charging infrastructure is limited but also scattered across interdisciplinary research covering broader aspects of EV infrastructure provision and EV adoption with a lack of studies consolidating issues. The aims and novelty of this study is to synthesize evidence on social equity in the various aspects of EV charging infrastructure provision and to set an agenda for centering social equity in the debate. This study further focuses on the key issues relating to social equity in the context of EV charging infrastructure, by examining how this has been recognized in previous work, and what would be the potential corrective strategies or policies and funding based on measures employed to date. The study aims to demonstrate the dynamic relationship between charging infrastructure and EV take-up. Last but not least, the study considers how a tailored multi-layered interdisciplinary approach to EV charging infrastructure allocation policy, strategy and funding could potentially address equity in the context of charging point provision and related aspects across all people. The structure of this review is as follows; section two describes the methodology of undertaking the review of literature, and sections three and four summarise issues around social equity in the context of EVs and charging infrastructure and their potential solutions extracted from research, respectively. A discussion of findings and conclusions are presented in sections five and six.

2. Methodology

For the purposes of this analysis, a definition of social inequity in the context of EV charging infrastructure provision is suggested as:

> "An uneven opportunity for individuals or groups to benefit from electric vehicles due to the lack of provision, affordability or useability of charging infrastructure."

This definition considers the benefits from EV use or ownership as being a reduction in carbon emissions and in household transportation costs in terms of fuel, taxation and maintenance costs in relation to an internal combustion engine (ICE) vehicle, and improvements in health due to better air quality in areas of adoption [29]. There is evidence of environmental injustice where areas of higher deprivation are usually linked with higher levels of particulate matter [30] and people living in lower-income countries disproportionately experience the burden of outdoor air pollution [31]. The least responsible for climate change are often the least capable in terms of being able to benefit from low carbon technologies e.g. being unable to install EV chargers or solar panels in a rented property or live in a deprived local authority area less likely to be able to fund infrastructure [28]. Government action may be needed to make sure any social inequities recognized in EV infrastructure provision do not become self-perpetuating, where having fewer current and projected EV drivers attracts less infrastructure investment, further disincentivizing EV take-up and preventing areas from benefitting from air quality and health improvements [24].

A review of academic and grey literature has been undertaken to understand how inequity in the roll out of EV charging infrastructure and EV uptake has been recognized in the diverse and interdisciplinary body of research in this area. To identify the relevant literature for this review the Scopus database and Google Scholar were used. All searches looked for works that contained both a search term related to 'social equity' and EVs. Key terms used were: ("equality" OR "equity" AND "electric vehicle" OR "ev" AND "charg*"). Papers were screened to identify those that directly addressed the topics within the scope of this review. The screening process is based on the PRISMA flow diagram shown in Fig. 1.

The identification of additional articles was possible through reviews of the collected studies. Journal articles considering social equity and EV charging were selected for detailed review along with grey literature. These included nine (9) studies about 'social equity in charging placement models' and additional papers that did not directly consider social equity in charge point location but were nonetheless relevant to understanding other barriers to 'achieving equity in EV take-up'. Thirty-one (31) items were from grey literature sources including policy instruments, government strategies, and non-governmental organizational studies. Of the seventy (70) journal articles, all except two (2) items were published after 2018 with an increasing number year on year, twenty-six (26) were published in 2022. The identified journal articles were published in twenty-three (23) different journals covering the disciplines of transportation (11), energy (9), sustainability and environment (3), technology (3) and Geographic Information Systems (1). The geographic focus, where relevant, to academic studies is weighted most heavily to the US (6), followed by the UK (4), and China (3) with additional work covering Europe, Ireland, South Korea, Sweden, and Switzerland.

3. Issues around social equity in the context of electric vehicles and charging infrastructure

3.1. Categorization of issues

Table 1 summarises and categorizes the key issues and the related studies in which these issues were highlighted. The discussion that follows Table 1 has emerged from a thematic analysis of the interdisciplinary research. Issues were grouped into charging infrastructure and non-infrastructure related categories. EV charging infrastructure issues were further divided into those relating to the availability of charging,

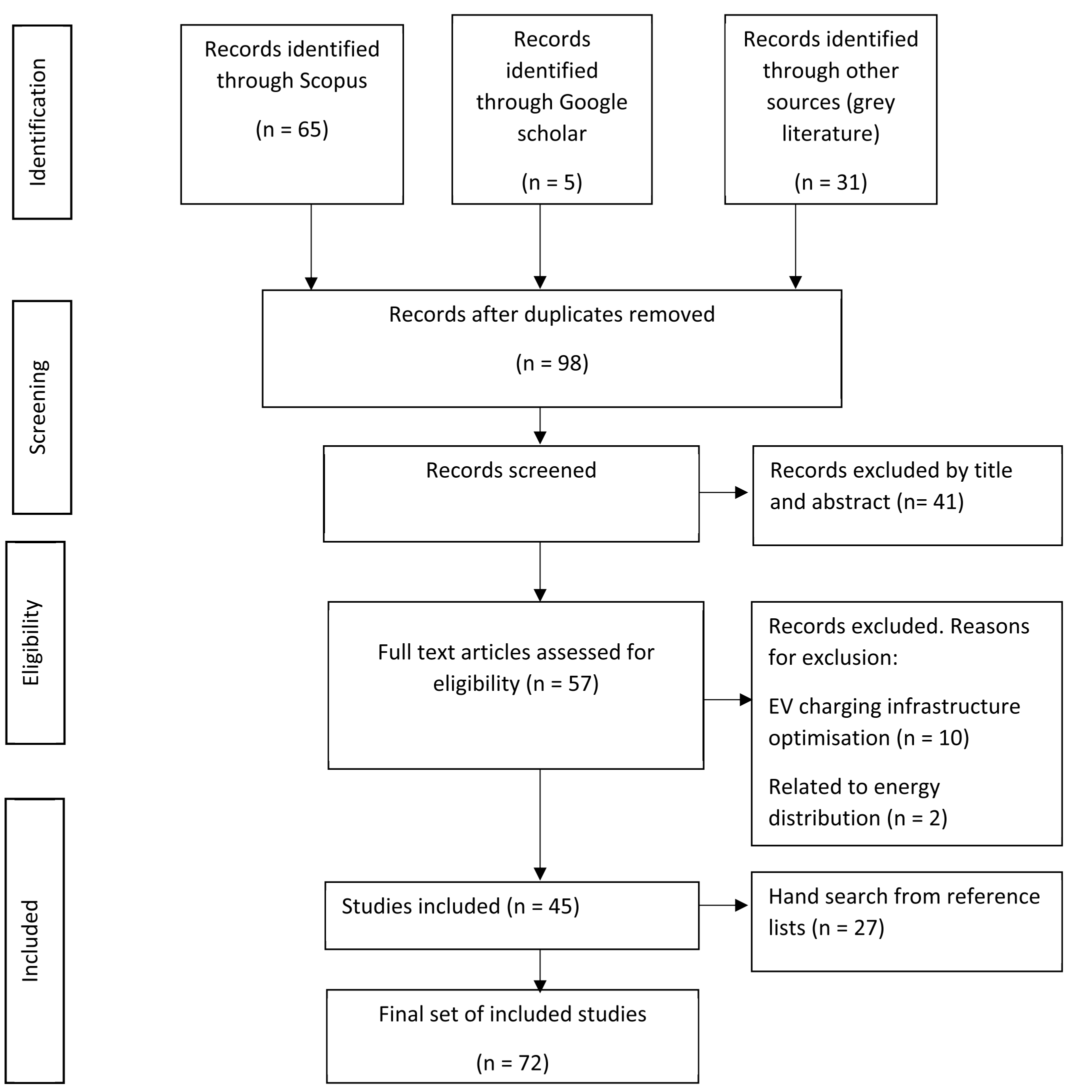

Fig. 1. PRISMA Diagram for the literature review
Source: The authors.

Table 1
Issues around social equity in EV and EV-charging infrastructure.

EV Charging Infrastructure Related	Relevant Studies
'Chicken and Egg' problem in EV infrastructure provision and availability of home charging	[5,25,32,33]
Social equity charging placement studies	[23–25,33–39]
Accessibility, useability and charging infrastructure funding barriers	[24,40]
Energy and fuel price	[11,25,41]
Indicators used to measure roll out and planning for EVs	[5,19,23,42]
Non-EV charging infrastructure related	**Relevant Studies**
EV Affordability – Price parity with ICE and second-hand EV market	[23–25,42]

charging placement studies, accessibility, useability and funding of infrastructure, affordability of charging and indicators used to measure roll out. Non-infrastructure issues identified relate to the affordability of EVs.

3.2. Chicken and egg dilemma

A 'chicken and egg' dilemma in EV infrastructure provision refers to the cycle of poor availability of charging, which is hampering the adoption of EVs, and then in turn is hampering the expansion of charging infrastructure [32,33]. Patt et al. (2018) who studied EV purchase intentions in Switzerland, suggested that consumers with their own parking space were almost twice as likely to indicate a high willingness to purchase an EV compared to those who parked their car on the street [32]. This would create a significant challenge for example, in the UK, where the Competition and Market Authority highlighted that in addition to meeting the demand for charging infrastructure whilst traveling for business or leisure, there are 8 million households who are unable to install charging infrastructure at home [43]. There are challenges with home-based charging "installing home chargers is also more challenging in rental residences as renters are less likely to bear the cost of an upgrade to a home they do not own, and owners are less likely to bear the cost of a charger they will not use" [24]. While the UK Government has provided subsidies for the installation of home chargers through the EV Homecharge Scheme, a recent review found that there was an uneven geographical uptake of the Scheme [44].

3.3. Social equity in charging placement models

Many studies approach EV charging infrastructure planning as an optimization issue where modeling sets a minimum number of charging points to achieve maximum profit/amount of 'vehicle miles being electrified'. Studies viewing EV charging infrastructure planning as an optimization issue neglect to consider how to layout EV charging infrastructure to enhance the social uptake rate of EVs effectively, which could magnify existing inequities and cause harm to the excluded population [33,38]. Guo et al. [39 p.3] noted that "inequity measurement compares the outcomes among the spatially distributed population (horizontal equity) or among population subgroups (vertical equity) and argued that both horizontal and vertical equity should be measured to understand the overall equity performance of a system". Horizontal equity considers that all groups should be treated the same in terms of transport resources. Measurements of horizontal equity would include the per capita share of public resources [45]. Vertical equity considers that different people have different needs e.g. based on income and resources should be prioritized accordingly [46]. Measurements of vertical equity include accessibility, quality of travel experience, cost burdens compared to income, etc [45]. Table 2 summarises EV charging location studies considering social equity. Of the nine (9) studies identified in the research capturing the aspects of social equity in charging placement all were located in North America with the exception of one in the UK [25] and one (1) in the Republic of Ireland [47]. Four (4) studies were based in US cities – Chicago [46], Los Angeles [34] New York [35] and Seattle [37]. Four (4) studies were conducted in California, two (2) of them state-wide [23,24], one (1) in Orange County [36] and one (1) citywide

Table 2
Studies of equity in EV charging infrastructure allocation.

Citation	Study area and geographic scale	Data	Methods
Carlton and Sultana, 2022 [46] [a]	Chicago Metropolitan Statistical Area, USA	- EV charge point data	- Unsupervised machine learning clustering algorithm - Density-based Spatial Clustering of Applications with Noise
Khan et al., 2022 [35] [a]	New York City, USA (Citywide)	- American Community Survey - Alternative Fuel Station Locator dataset	- Correlation analysis of median household income, population ethnicity, highways
Law et al., 2021 [36] [a]	Orange County, California, USA (County wide)	- EV charging station data, land use information, - American Community Survey	- Weighted Cost Raster and Least -Cost Path Model - Local Moran's I Anselin Moran's I - Kernel Density estimation
Hsu et al., 2021 [24] [a]	California, USA (State-wide)	- Public charging station location - American Community Survey	- Generalized additive model
Min et al., 2020 [37] [a]	Seattle, Washington USA (Citywide)	- American Community Survey - Electrical permits for home charging.	- Moran's I Generalized log-linear model (GLM) - Poisson lognormal spatial model - Bayesian method - Integrated Nested Laplace Approximations (INLA), - An Intrinsic Conditional Auto-Regressive (ICAR) - K-means clustering
Canepa et al., 2019 [23] [a]	California, USA (State-wide Disadvantaged communities)	- American Community Survey, - California Clean survey responses - Vehicle registration and rebate data	- Logistic regression model
Nazari-Heris et al., 2022 [34] [b]	Los Angeles, USA (Citywide)	- EV and charge point data, Quality of Life	- Mixed-integer linear programming - Demand priority Function - Analytical Hierarchical process
Lee and Brown, 2021 [25] [b]	UK (selected car owners from National Travel Survey)	- National Travel Survey - English Housing Survey	- Behaviour-based EV grid Integration (BEVI) model
Caulfield et al., 2022 [47] [a]	Ireland	- Small Area Population Statistics - EV charging station data - Census	- Linear regression modeling

[a] Review of existing EV charging infrastructure dispersal.
[b] Forecasting model.

[34]. Six (6) of the studies considered the distribution of public charging; one (1) in relation to mobile charging stations [34] and three (3) studies considered the distribution of residential charging [25,37,47]. Whilst most studies specifically focused on inequity in the distribution of EV charging infrastructure, Canepa et al. [23], Caulfield et al. [47], and Lee and Brown [25] studied EV uptake considering the effect of access to EV charging. Nazari-Heris et al. [34] looked at an optimization solution for mobile charging stations ensuring social equity of distribution. Finally, seven (7) of the studies [23,24,35–37,46,47] reviewed existing EV charging infrastructure and two (2) studies created forecasting models [25,34].

The American Community Survey and Alternative Fuel Station Locator data were common data sets utilized in US studies [23,24,35–37,46]. American Fuel Station Locator data contains a number of attributes on charging stations including their network status, hours of operation, and connection types, however, the data did not contain any spatial information about the stations beyond their geographic coordinates [46]. Carlton and Sultana [46] identified spatial clustering of public EV charging stations in Chicago followed by a manual review of each cluster, which determined the types of land-use setting of each cluster. The study found that clustered charging congregates around isolated land use regimes - e.g. shopping centers where they were located at higher-end car dealerships, restaurants, and stores, which may present additional costs in traveling to these locations and psychological barriers for lower income consumers [46].

There are similar findings from US studies examining associations across charging infrastructure dispersal and socio-demographic data, which found that the availability of EV charging stations was not determined by the population density [35,36], but correlated with the median household income [35–37,46], age [36] percentage of white-identifying population [35] and presence of highways within a zip code area [24,35]. Hsu et al. [24] compared the probability of public EV charger presence, defined as having at least one public EV charging station within the boundary of a given Californian census block group, based on the median income and race. The study also looked at the distance from the centroid of each census block group to the nearest freeway or highway. Using similar data and correlation analysis in New York, Khan et al. [35] compared zip codes with and without EV charging and obtained comparable positive correlations between EV charging presence/absence and income, race and highway presence. In contrast to other studies, Canepa et al. [23] found that public charging infrastructure was distributed similarly across disadvantaged communities and non-disadvantaged communities of California. This was the only study, which used vehicle registration and data from the Californian Clean Vehicle Rebate project to undertake a correlation analysis. Disadvantaged communities are not sociodemographically homogenous [23] and studies undertaken did not investigate the differential access to public charging infrastructure between different sociodemographic groups. For example, Canepa et al. [23] found from a survey of used EV owners that owners of used EVs in disadvantaged communities as a group have higher incomes, are higher educated, and fewer are home-renters than the disadvantaged community average, indicating that they are not representative of their surrounding community.

Min et al. [37] found that in addition to income, residential EV charger installations in Seattle were also correlated to housing stability (single family houses and housing ownership types). Several of the studies also discussed the greater need for public chargers adjacent to multi-unit dwellings (MUDs), which were in greater numbers in disadvantaged communities [23,24,34,46]. When high-income group areas had a high MUD density these areas had more than twice the probability of having access to public chargers than residents of the poorest areas with predominantly MUDs [24]. Mobile charging stations were also considered to offer particular benefits to inhabitants of MUDs lacking dedicated parking in a study by Nazari-Heris et al. [34], which discussed social equity access and mobile charging stations for EVs in Los Angeles. The study identified the drawbacks of stationary charging stations becoming stranded assets with the future uptake of shared vehicles, shared rides, or autonomous vehicles and the benefit of large-scale deployment of mobile EV charging stations in reducing exposure to car pollution and promoting health and wellbeing in low-income neighborhoods [34].

Lee and Brown [25] in a UK study suggested that 80% of adopters are second vehicle owners. They utilized an agent-based model to explore adoption rates and charging profiles according to socioeconomic groupings and income quintiles and identified that an increase in the rate of addition of public charging and an increase in the range of available vehicles in the model was adequate to overcome home charging concerns and reduce the future need for a second reserve vehicle [25]. Similarly, Caulfield [47] identified that areas in the Republic of Ireland with higher numbers of EV charging points also had higher levels of car ownership, suggesting that an EV may be the second or third car in the household. This points to a continued reliance on ICE vehicles as a backup vehicle to overcome range anxiety which is likely to favor higher income groups.

3.4. Accessibility, usability and funding

There are challenges related to the need for disability-specific provision such as accessibility issues (built environment, the charging process and information about charging points) and other useability issues that could be experienced by any user, such as reliability, availability, and the complexity which could have a disproportionately negative effect on disabled people [49]. There are also concerns at a EU level [8] regarding the many approaches to finding, accessing, using and paying, for EV charging infrastructure including information on availability, price transparency and payment services. A Which? 2022 report [50] identified that in the UK there is “a confusing maze of 60 networks with limited interoperability, little consideration for disabled drivers’ needs.” [49 p.3]. This was echoed by user feedback, which described the complexities of different providers requiring different apps and processes to enable charging to take place, which was confusing or frustrating for some participants and lacking in information on accessibility [49]. To fund EV charging infrastructure Local Authorities often enter into a public-private partnerships e.g. concession business models where the authority retains some control over the specification but the risk and capital and maintenance costs and also revenue are retained by the private sector [51]. Bonsu [40] explored the UK EV infrastructure network challenges through interviews with key EV infrastructure players such as Local Authorities, vehicle manufacturers, academics and energy companies. This study identified that Local Authorities could explore a concession business model with the private sector to increase the number of chargers but highlighted risks as service providers could be more inclined towards prioritizing new investments in profitable markets [40]. Barriers also exist for Local Authorities when implementing EV charging for car clubs as authorities need to consider matters relating to subsidy control, which apply if the chargers are not publicly available [52].

3.5. Measuring and planning for EVs

Targets are key for the roll out of public charging infrastructure but quantitative requirements alone are not sufficient to guarantee the most effective and equitable roll out of charging infrastructure [53]. Clean Transport Campaign Group, Transport and Environment, offered a supply metric and sufficiency indicator to take account of various charging powers, availability to the public, and charging requirements from BEV and PHEVs by weighting [53]. EST EV Demand Forecasting paper supported a combined index of existing metrics used in the UK and EU to allow for a comparison of quality, quantity and regional differences [48]. The suitable number of public chargers per EV for a country depends on a number of factors, including housing stock, the average distance traveled and population density and EV type. Contrasting findings in studies from different countries are to be expected due to market differences as discussed in Global EV Outlook 2022 [5]. For example, fewer public chargers can serve a higher number of EVs in countries with high shares of residential charging. This is seen in Norway and the United States which have a high share of single-family dwellings (with garages) [5]. The UK has set a target for all new cars and vans to be zero emission by 2035, but despite setting ambitions, is yet to set any similar mandate for delivering the required charging infrastructure to support this. The Global EV Policy Explorer summarises the ambitions and/or targets by country. As shown in Appendix A out of fifty three (53) countries, thirty (30) have set a target for EV share but only half of these fifteen (15), have set ambitions for EV charging infrastructure and less than half again, seven (7), have set EV charging infrastructure targets. Only four (4) countries that are members of the Electric Vehicle Initiative have both a target for vehicles and chargers [9]. The worldwide average EV to charger ratio in 2021 was 10 EVs per charger and 2.4 kW per EV. European countries for the most part failed to meet the recommended electric vehicle supply equipment (EVSE) of 1 public charger per 10 EVs, a ratio of 0.1 in 2020 [5]. The Proposed Alternative Fuels Infrastructure Regulation requires mandatory minimum targets for EV charging infrastructure power output by market share [54].

Table 3 describes the drawbacks of the use of ratios alone to measure EV charging infrastructure penetration. Ratios fail to consider the full picture of charging infrastructure type (speed of chargers, availability of chargers, Number of PHEVs vs BEVs, access to off-street parking for overnight charging) and do not accurately reflect the needs of different communities [48]. For example, Canepa et al. [23] found that the number of chargers per 1000 new and used EVs was high in disadvantaged communities. This proportion can be explained due to the low number of EVs in the communities therefore each charging station would serve less EVs. Nordic countries with the highest EV penetration tend to have the lowest EV charging points per EV ratios because they have more fast chargers and more home charging available [5]. A larger market share of PHEVs would require less public charging than BEVs [5]. Measuring the charger power (kilowatts per EV) is also a more meaningful measure than the EV-per-charger ratio as fast chargers can serve a higher number of EVs compared to slow chargers [5]. Data on available charging infrastructure is not comprehensively available to monitor against targets set and equity of provision. There are global differences in EV charging infrastructure information availability. In the UK, the Department for Transport Electric Vehicle Charging Device Statistics: January 2022 presents experimental data on the number of publicly available EV charging devices in the UK, using data provided by the EV and charging point platform Zap-Map as there is no central publicly owned repository [55]. There is, however, more information available on publicly available infrastructure in the US, for example, the Alternative Fuel Station Locator data set.

Table 3
EV charging infrastructure metrics.

EV: Charging Infrastructure Metric	Challenge	Social Equity Implications
Total number of charge points	Difficult to compare across regions. Does not distinguish between charge point types [48]	Charge points could be clustered to serve demand
Number of EVs per charging point	A low ratio can be indicative of a high number of charging points, but also a low EV stock [5]	The number of chargers found to be high in disadvantaged communities can be explained due to the low number of EVs therefore each charging station is serving less EVs [23]. Could be further broken down e.g. BEVs per rapid charge point
Number of charging points per x EVs	Does not reflect the full picture of the speed of chargers, availability of chargers, Number of PHEVs vs BEVs, and access to off-street parking for overnight charging [48].	Nordic countries with the highest EV penetration tend to have the lowest EV charging points per EV ratios because they have more fast chargers and more home charging available [5].
Number of charging points per x population	Will not accurately reflect the needs of different communities [19] or different types of charging points available [48].	Some rural populations may have relatively fewer plug-in vehicles, while others may have off-street parking and electrical wiring that allow for the installation of dedicated home chargers [19]. Could be further broken down e.g. charge point per on street household or proportion of residents within x walk of a public charge point [48].
Charge points per km	Number per x km on major roads or motorways does not account for regional differences such as vehicle ownership or traffic volumes [48].	Supports long distance journeys but not the population without access to overnight charging at home.

3.6. Energy and fuel prices

Measures to disincentivize ICE vehicles could have a negative effect on socio-demographic groups that are unable to switch to an EV. The 2021 Global EV Outlook recognized that measures are needed to balance reduced revenue from fuel taxes associated with EV uptake and taxation to discourage the use of ICE vehicles [11]. These could include coupling higher taxes on carbon-intensive fuels with distance-based charges [11]. Global EV Outlook 2022 called for the adoption of vehicle efficiency and/or CO2 standards by all countries [5]. Because fuel taxes, registration fees and user charges, zoning restrictions and bans against ICEs raise the costs of driving an ICE, they can create financial barriers to mobility [63] and a double injustice for low-income and rural drivers particularly if sustainable alternatives are not available [28]. Access to energy and fuel poverty presents an additional challenge for the wider affordability of EV charging. Policy tools for reducing risks/costs for energy providers, reaching economies of scale and bringing down the market price have not been able to bridge the affordability gap that prevents the poorest consumers from obtaining cheaper electricity [64]. The cost of increasing the capacity of the electricity network to support EV charging infrastructure is shared evenly through increased charges for all customers. This is unlikely to be socially equitable because the impact from lower income households is delayed as they are late adopters of EVs [25]. Forecast modeling of EV use by socio-economic characteristics by Lee and Brown [25] also showed a later peak charging period for low income groups, contributing less to peak evening demand. In the UK, there is a benefit from charging EVs at home in terms of VAT on energy being 5% rather than 20% at public EV charge points, which increases the charging cost for those unable to charge at home. The cost of home charging for those on prepayment meters, likely to be low income groups and renters, is higher. Prepayment meters have higher tariffs, it is difficult to change payment method back to direct debit and therefore to benefit from more competitive deals [41].

3.7. EV affordability

EV prices are becoming more affordable and price parity with conventional vehicles is expected to be reached within 5–10 years [25]. Despite this, even with incentives for new vehicles, the cost of purchasing an EV remains high. Without subsidies for second-hand EVs, there are high proportions of the population who cannot afford an EV [24,25]. Another barrier to EV take-up is the absence of a mature second-hand market and resale values achieved by EVs are low when compared to ICE alternatives [65]. Lower resale values could however support EV take-up by low income drivers. Greater numbers of EVs are now entering the secondary market making EV adoption more economic for disadvantaged communities [23,24]. Second-hand EVs could be seen as a high-risk purchase where low priced used EVs may be approaching the end of their warranty periods and their battery packs may have begun to degrade [23]. Vehicle replacement by EV is unlikely to see a significant change in vehicle emissions without the replacement of older vehicles with EVs to reduce emissions sooner [66]. Vehicle replacement over time generally follows the fleet's age distribution. The median vehicle in many markets (and most likely to be replaced) is a sports utility vehicle where there are few all-electric choices for these types of vehicles and the purchase price is higher. The most common vehicles in the fleet will also be those already near-zero emissions vehicles where replacement would reduce emissions reduction realized [66].

4. Policy mechanisms/potential solutions

4.1. Categorization of solutions

The review has identified policy mechanisms/solutions that are being implemented to overcome EV charging related inequity. Table 4 provides a summary of proposed and implemented policy mechanisms including subsidies, grants, regulations and standards, and innovative business models.

4.2. Charging placement and accessibility

Local Authorities could explore delivery via a concession business model with the private sector to increase the number of chargers including packaging of sites to ensure equitable delivery [40]. Mobile Charging Stations are also seen as a flexible solution which allows charging providers to quickly set up infrastructure or test for the optimum sites while retaining the ability to relocate [34]. Intended to address the absence of universal accessibility standards for charging infrastructure UK Electric Vehicles Accessible Charging Specification sets out requirements to support useability and access for all [56]. The charging network should be convenient with acceptable charging prices to the user but also needs to ensure a return on investment for the provider. To reconcile this contradiction, Shi et al. [33] proposed that government should subsidize the relevant charging facilities and suggests a subsidy calculation method. National targets for EVs and charging infrastructure should be set to guide local governments, and funding from the central government should also be allocated reasonably across regions [6]. This is seen in China in the official guidance for accelerating electric vehicle charging stations where access-based targets are outlined in terms of reaching minimal coverage across a city or region, in accordance with projections of EV demand [38].

Table 4
Solutions/Policy Mechanisms to overcome EV Inequity.

Issue	Best Practice Mechanism/Solution
Social equity in charging placement and accessibility	Access-based targets and funding/subsidy to reaching the minimal coverage at local/regional level[a] [6,33,38]. Concession business model with the private sector [40]. Mobile charging stations to test demand [34]. Accessible charging specification to address the absence of universal standards [56].
Availability of Home Charging and workplace charging	Regulations for new development to provide electric vehicle charging infrastructure [57]. Grant schemes to support landlords and MUDs [58]. Smart chargers and dynamic tariffs to incentivize off-peak charging[a] [59]. Development of a public charging network where vehicles are "naturally sat" including on-street charging [60].
EV Affordability	New business models to reduce the need to own an EV e.g. e-car sharing [6]. Grants/loans for new and second-hand vehicle purchase [23,61]. Battery swapping stations[a] [62] and replacement programs[a] [23].

[a] Measures proposed in literature sources without examples of implementation.

4.3. Availability and affordability of charging

Regulations can be used to ensure minimum standards of provision for new development. In England, HM Government Building Regulations from June 2022 require all new residential, mixed-use and other buildings with more than 10 car parking spaces to provide EV charging infrastructure [57]. The scaling back of eligibility for grant funding to specifically underserved groups has been seen in the UK where the Electric Vehicle Homecharge Scheme is now only available to flat owner-occupiers and people living in rented properties and the EV charge point grant for landlords gives financial support to landlords to install EV charge points at residential or commercial properties [58]. The flexibility of when people charge vehicles also creates an opportunity to balance electricity supply with demand. Smart chargers and dynamic tariffs can provide incentives for EV users to charge during off-peak periods and sell energy back to the grid during peak periods [59].

In the UK, under the provisions of the Automated and Electric Vehicles Act 2018 [67], regulations may impose requirements on large fuel retailer service area operators to provide public charging or refueling points. The UK Government has not yet used the powers to require large fuel retailers to provide charging infrastructure, but will "continue to monitor the delivery of EV charging infrastructure and will use these regulations should we feel that further progress is needed to meet ambitions" [68]. A betterRetailing article [69] advised how forecourt retailers have been told to watch and wait before investing in EV chargers, as they will not see a return on investment at this point in time on expensive electricity reinforcement to install EV chargers because of low demand. A BBC News article [70] predicted that the demand at forecourts may never materialize. The article highlighted that fuelling cars with petrol and diesel is dangerous, which is why we do it at specially-designed centralized refueling points. EV charge point locations are not limited in this way so long as electricity is available, so providing or repurposing petrol stations may not be the most convenient solution for users or cost effective for forecourt retailers [70]. This aligns with deliberative research with drivers without access to off-street parking in the UK finding a preference for providing a public charging network where vehicles are "naturally sat", near home being the most desirable in conjunction with rapid charging at destinations [60].

4.4. EV affordability

Attempts have been made to address the issue of EV affordability as a barrier to wider take-up. To increase EV affordability residents who live in disadvantaged communities in the Enhanced Fleet Modernization Program areas in California may be eligible to receive an additional \$3000-\$5000 (dependent on income and type of EV) plus \$2000 for the installation of an EV charger [23]. Transport Scotland in 2020 introduced a Low Carbon Transport Loan of up to £20,000 for second-hand vehicle purchase [61]. Battery Swapping Station strategies are emerging as a promising alternative to the traditional EV battery charging station approach [62]. Support warranties for the battery packs in used EVs, or battery pack replacement programs could be offered to address battery warranty and degradation issues in second hand vehicles [23]. New business models reducing the need to own an EV including e-car sharing, e-hailing, or peer-to-peer e-car rental and lease should be progressed [6]. For example, in Shanghai, the local government offered free parking spaces to shared vehicle operators and subsidies for introducing low emissions vehicles [71]. The introduction of car sharing and EVs share the intention of developing a system capable of reducing humans negative impact on the environment and e-car sharing could support the implementation of an EV charging network [72]. The ability to rent shared EVs when they are needed could reduce the expense to purchase underutilized owned assets and energy used in their production [73]. The use of e-car sharing allows people to "become friendly with a technology that remained otherwise still difficult to access (and therefore reduce scepticism against electric vehicles)" [72 p84]. This would also apply to shared autonomous EVs. Langbroek et al. [74] in a Gotenburg case study of EV rental and EV adoption caveated that EV rental is not likely to be chosen by persons who are not already contemplating EV use or purchase. For those people, mass media campaigns are suggested [74].

5. Discussion

5.1. Findings

Firstly, this study critically reviews the emerging body of knowledge concerning social equity in the provision of EV charging infrastructure. Emphasis is placed on capturing the complexities involved in the equitable roll out of EV infrastructure including location (lack of home charging for renters or those with off-street parking and less public charging in lower income areas), affordability (higher cost of public charging) and useability (lack of standard specification, information on charger availability). Studies have evidenced disparities in EV charging placement, however predictable as the market caters for early adopters, and forecasting models have been developed to support redressing the balance in charging placement. Issues have been assimilated into Fig. 2 which highlights the breadth of issues and cross-sector challenge in relation to social equity in EV charging including charging infrastructure location, charging cost, accessibility and useability of infrastructure and effective measurement and planning for infrastructure roll-out. Although the focus of this review is the consideration of social equity in EV charging infrastructure, secondly, this study further looks at how EV charging provision is interlinked with an array of other dimensions including the affordability of EV purchase (lack of price parity with conventional vehicles and an immature secondary EV market).

Thirdly, this study consolidates empirical evidence to suggest measures which could be packaged into holistic strategies and implemented at the appropriate national, regional and local levels according to local challenges and demographic characteristics. Research into the incentives in encouraging the purchase of EVs and best practice has shown examples of local target setting, monetary incentives (grants, loans and rebates for EV purchase and charging infrastructure and smart energy tariffs), other policy incentives (increased public overnight charging, standard operability, EV car clubs, extended battery warranties for second-hand vehicles) that can or have been employed to redress the balance.

Best practice is summarised in Fig. 3 which demonstrates the dynamic relationship between charging infrastructure and EV take-up. A package of incentives and investment in securing social equity in EV infrastructure and affordability (government targets & subsidy, information, infrastructure location and accessibility and energy pricing) to tackle issues could increase take-up across all people. These incentives and investment are interlinked with a cross-sectoral comprehensive approach. Targets can increase all charging investment by sending direction to the market [19]. The use of locally specific targets and strategies can ensure the identification of locations for public overnight charging where vehicles are naturally sat [60]. It is vital to engage across all disciplines including the energy sector to facilitate affordable tariffs where home charging is unavailable or properties are rented. Support should be provided to renters and landlords wishing to provide EV charging [58]. Charge point operators are key players in providing accessible and user-friendly charging points in terms of cables, access, payment method, cost and reliability [60]. In addition to addressing charging issues measures to increase EV affordability and EV take-up will increase charging demand leading to more investment in infrastructure in areas not seen as investable. Non-ownership solutions such as e-car clubs and rental can also bring this technology to a wider cross-section in addition to reducing overall car dependency [72]. A more mature EV market with increasing EV adoption supports car manufacturers to offer less expensive mass-market car models [5] increasing EV affordability and leading toward price parity with ICE vehicles. Increased EV adoption through a feedback-reinforcing effect could result in increased charging demand and demand for further infrastructure helping to solve the chicken and egg problem and towards meeting climate change goals [33].

5.2. Policy implications

Finally, this study considers key policy implications across a number

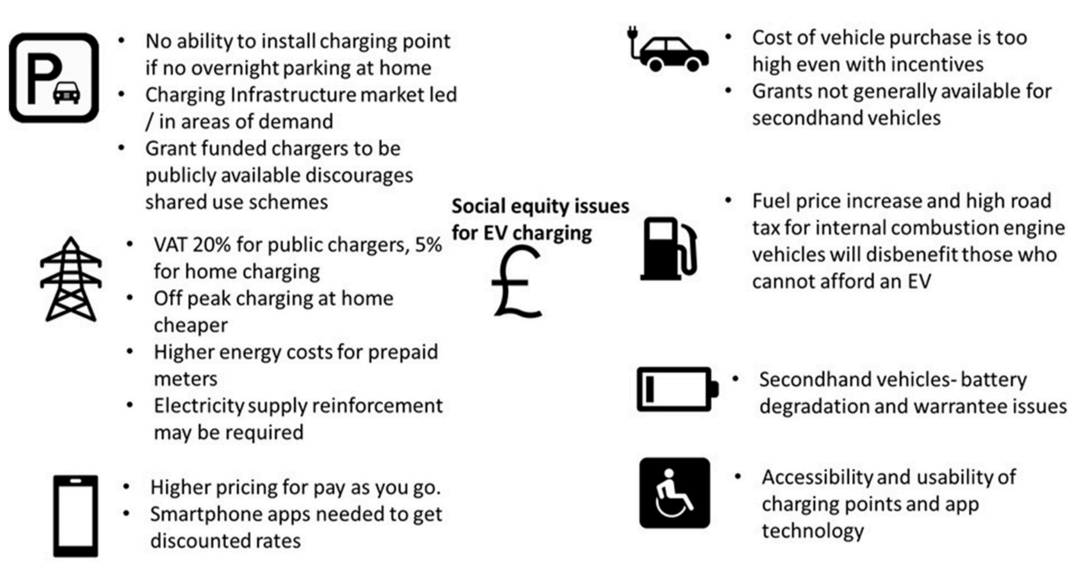

Fig. 2. Social Equity Issues for EV Charging
Source: The authors.

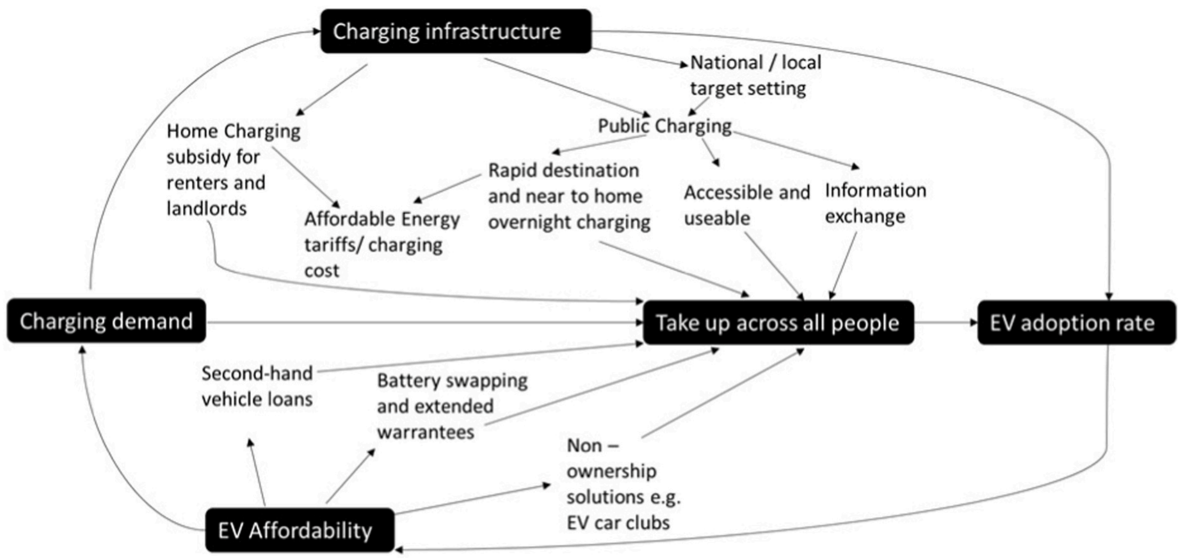

Fig. 3. Dynamic relationship diagram between EV interventions and take up
Source: The authors.

of different sectors and governmental levels. This work is important as it has practical implications for the linkage of intervention measures to the United Nations SDGs [17] and national and international ambition [9, 16]. Policy changes are required to increase access to EVs and reduce individual car purchases through supporting other business models – e.g. e-car club/EV rental infrastructure. From different perspectives and geographical scales, effective EV take-up and EV infrastructure roll out will not be achieved by the market without intervention [19]. Car scrappage schemes may be required to target the replacement of older vehicles with all-electric vehicles to reduce emissions sooner [66]. Fiscal incentives such as grants, loans and rebates for EV purchase and charging infrastructure have supported EV uptake and infrastructure roll out and energy policies such as no VAT on public charging and smart energy tariffs could reduce additional barriers to take up. Mandatory targets for EV infrastructure at a national and local level could support a "right to charge" just as previous broadband targets have supported the "right to connect" setting the signals to providers to encourage investment in social equity, supporting fair distribution [19]. If setting targets for EV infrastructure, however, the right ratio of a combination of metrics at the local level should be considered to measure equity [48]. Future EV infrastructure guidance papers could increase focus on social equity as an integral part of EV infrastructure roll out strategy rather than one approach for consideration. Social equity should also be ensured within the evidence base utilized in informing EV Strategy development to make sure all demographics are represented in data, surveys, and models.

5.3. Limitations

The literature review in this study has highlighted policy and practical mechanisms and best practice identified or employed to tackle issues around social equity in EV and EV charging, it does not however review the extent to which these measures could or have been successful. The literature review relies on English based studies with many studies based in the US or the UK. Further expansion of the review in other EV markets is required to consider common or contrasting issues and solutions to social equity in EV uptake and charging provision. This work only examines equity in the roll out of EVs and EV charging at the point of use. The transition to EVs as with other low carbon technologies generates both benefits and burdens, with strong winners and losers that should be considered on the global as well as local scale, for example, social and environmental impacts from mining lithium, cobalt, and nickel in South America and Africa [10,75]. Investment in EVs and EV infrastructure may still result in increased demand for cars and continued car dependence, which raises questions about transportation injustice, which is defined as a "lack of transportation options or a lack of access to transportation that leads to a lack of opportunities and further social exclusion" [23], as well as social and environmental impacts and issues of road safety [23]. Pendall [42] asked how could we reconcile the apparent benefits of car access for disadvantaged families, in terms of access to employment, with serious concerns about climate change and the need to reduce car emissions. The scale of carbon reduction required cannot be achieved with EVs alone but requires a reduction in distance traveled, delivered through investment in active travel and not the further expansion of road networks [73].

The source of electricity generation for EV chargers impacts the ability of EVs to deliver toward the decarbonization of transport [7,76]. Ajanovic [10] highlighted the variance of the environmental benefits of EV use in different EU countries due to the different carbon content of the electricity mix, "for example, EV use in Sweden can significantly reduce local air pollution, as well as contribute to the reduction of the global greenhouse gas emissions. However, in countries with a very high share of coal in the electricity generation mix, such as Poland or Estonia, EVs could contribute just to the reduction of local air pollution without significant benefits for the reduction of the global greenhouse gas emissions" [10 p8]. Despite the issues with lifecycle greenhouse gas emissions from EVs, long term improved energy mixes, increased battery manufacturing efficiency, and increased battery production in other markets is able to cut most of the manufacturing emissions and nearly all electricity use emissions from EVs making them preferable to ICE vehicles [76,77].

5.4. Setting the agenda for future work

From the findings and discussions of this literature review, the following recommendations for future research have been identified:

Despite the identification of inequities in EV infrastructure provision there needs to be further qualitative study with the breadth of EV charging infrastructure "players", particularly Local Authorities, who have been identified to 'plug the gap' where the market will not provide [78]. Research in this area will enable a more in-depth understanding of delivery challenges globally, country by country and on a regional/local scale and to identify innovation in how they are being overcome. Qualitative information can be compared with data on EV take up, charging infrastructure and charging events to identify areas which have been effective in achieving a wider take-up towards vertical equity through intervention.

To achieve equity in transportation provision, we need data [79]. The availability of open and big data supports high level analysis to reveal patterns and trends, but this data is unable to provide the full understanding of who is purchasing and using EVs. There appears to be a knowledge gap in understanding regarding socio-economic data of who is using charging infrastructure for what purpose and how much they are paying. Disaggregated anonymized demographic data from users is required to overcome this. There is a need for further work to identify groups with different socio-economic characteristics and psychological preferences to enable improved targeting of potential groups of adopters [6].

Further study is required to examine existing EV policy and strategy against the three pillars of justice -distributive, procedural and recognition [80], to review the extent to which social equity has been considered. There is a significant body of research covering stated preference and user surveys for planning for EVs and EV infrastructure. The extent to which social equity has been considered and a representative sample has been used is a key area for research expansion. A review of the consideration of social equity in EV charging infrastructure models has been undertaken in this study. This body of research mainly models the coverage of existing EV charging infrastructure rather than how social equity is being considered when planning EV infrastructure roll out.

Research considering the effectiveness of mandatory targets for infrastructure at various levels of government and in particular for EV use is required. Metrics for EV infrastructure measurement can however have drawbacks in the fact they can mask social inequity in provision [48]. Further research in this area could support the equitable roll out of infrastructure. A consideration would be the identification of an appropriate measure of accessibility for EV infrastructure. The literature review has not identified a metric for the measurement of EV accessibility. Similar to other topic areas such as healthcare and open space and widely used in transport accessibility [20] a measurement of EV accessibility could allow the identification of inequity of provision.

Expansion of knowledge and research to increase access to EVs and reduced individual car purchases through supporting e-car club infrastructure would address the ongoing issue of continued car dependence on social equity [72,74]. The focus of this study is equity at the point of use which is only part of the equity in the life cycle assessment of EVs. The research synthesizing the whole life cycle equity considerations should be expanded including raw materials, disposal and the country energy mix powering EV charging stations [76,77].

6. Conclusion

This study has synthesized evidence on social equity in the various aspects of EV charging infrastructure provision to set an agenda for centering social equity in the debate. This review of interdisciplinary research assimilates progress in the field of equity in EV charging infrastructure to provide direction in taking into account equity aspects for practitioners and policy makers. Electric vehicles and low carbon technology is evolving and moving at a fast pace, however, the debate around ensuring equity of provision (as with equity of access to all goods and services) and how this can accelerate EV take-up to meet climate goals is ongoing.

This study brings together a dispersed cross-sectoral body of research enabling the identification and categorization of factors relating to social equity in EV infrastructure provision. Key issues or factors influencing social equity in infrastructure roll out include charging infrastructure location [33], charging cost, accessibility and useability of infrastructure [49,50] and effective measurement and planning for infrastructure roll out [5,48]. There are several complexities involved in the increased and equitable roll out of EV infrastructure. Other non-infrastructure interdependencies impacting EV take up across underserved socio-economic groups observed in research relate to EV ownership, where lack of price parity with conventional vehicles and an immature secondary EV market are key issues [24]. This study also documents global best practice from the literature review to assimilate potential solutions for consideration by EV stakeholders in addressing the issues identified. Research identifies that a cross-sectoral approach will be required to reduce inequity including energy supply, and tariffs, urban planning – provision of EV charging in development, landlords – provision for tenants, transport authorities – strategy direction and funding, transport providers – e-car rental/e-car club, charging providers – design, useability applications and information exchange, car manufacturers –mass market car models and battery warranties. This study provides a pictorial summary of the inter-relationship between factors related to EV infrastructure and EV adoption to demonstrate the influence of implementing supporting measures to increase equity in EV infrastructure provision to increase overall EV take-up.

The literature review identifies that EVs cannot achieve the targets for decarbonization of transport alone but in combination with other measures to reduce the need to travel and investment in active and sustainable travel [73]. Continuing with individual car ownership and car dependence leaves challenges for transport injustice [23], social and environmental impacts and issues of road safety [39]. There is a ceiling on what can be achieved by EVs and EV infrastructure investment if charging infrastructure is being powered from fossil fuel energy sources [13] and there are issues relating to equity in the EV life cycle including mining of minerals [10,75]. From these different perspectives, the literature review highlights that effective EV take-up, EV infrastructure roll out and its contribution to reducing climate change will not be achieved by the market without intervention.

This study brings together previous research, although limited to English based studies many from the US and UK, regarding social equity and EV charging infrastructure issues and potential solutions. It does not however review the extent to which these measures could or have been successful. The assimilation of research provides academic researchers and policy makers with direction for future policy and areas for further study, including the need for qualitative research with key players and users and improved metrics to measure the roll out of EV charging infrastructure. The outcomes from this study could be utilized at a local and governmental level when developing EV strategy and at the program implementation level to avoid exacerbation of social inequity in EV infrastructure provision evidenced and to support wider EV uptake. This is important as it has practical implications for the linkage of intervention measures and strategy to the United Nations SDGs [17] and national and international ambition [9,16]. This study contributes to the broader debates about achieving equity in transportation and climate action to achieve ambitions by highlighting barriers to equity in EV take up and EV infrastructure charging resources and how this can be addressed.

Author contributions

Conceptualization, E.H., D.P, SO and LC; Investigation, E.H.; Writing – original draft, E.H Writing – review & editing, D.P and SO.; Supervision, D.P., LC and SO. All authors have read and agreed to the published version of the manuscript

Funding

Emma Hopkins acknowledges the financial support of the EPSRC Engineering and Physical Science Research Council.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

Appendix A

Table of Global EV Ambition / Targets

	Number of EVs		Charging Infrastructure	
	Ambition	Target	Ambition	Target
Korea	Yes	Yes	43,000 charging stations in residential apartments 146,000 charging stations in commercial areas and 12,000 fast chargers along highways by 2025.	No
Chile	Yes	No	No	No
Indonesia	Yes	Yes	No	30,000 charging stations and 67,000 battery swap stations by 2030.
Netherlands	Yes	Yes	Charging infrastructure to meet the needs of 1.9 million BEVs on the road by 2030	No
South Africa	Yes	No	No	No
China	Yes	Yes	Charging infrastructure sufficient to meet the needs of more than 20 million NEVs by 2025. 60% of expressway service areas to have rapid charging by 2025. 13 million slow charging stations and 0.8 million fast charging stations by 2025.15 million (cumulative) slow charging stations and 1.46 million (cumulative) fast charging stations by 2035. 1000 battery swap stations and production of more than 100,000 vehicles capable of battery swapping. Guangxi ambition: 80,000 public charging stations and 147,000 private public chargers by 2025 Shaanxi ambition: 102,800 charging stations to meet the demand of 600,000 NEVs by 2025	No
Italy		Yes	No	21,400 fast and ultra-fast charging stations by the end of 2025 (7500 on motorways or extra-urban areas, 13,755 in urban centers and 100 experimental chargers with energy storage technology).
Japan	Yes	Yes	No	150,000 EV charging points (including 30,000 fast chargers) and 1000 hydrogen refueling stations by 2030.
France	Yes	Yes	No	100,000 public EV charging points by December 31, 2023. 7 million public and private EV charging stations by 2030.
Greece	No	Yes	No	No
Switzerland	Yes	No	No	No
Spain	No	Yes	No	500,000 EV charging stations in 2030.
Belgium	No	Yes	No	No
Finland	Yes	No	Yes	No
United Kingdom	Yes	Yes	300,000 public charging stations by 2030	No
Poland	Yes	Yes	No	No
Thailand	Yes	No	12,000 public fast charging stations by 2030 and 1450 battery swapping stations for electric motorcycles by 2030.	No
Germany	Yes	No	50,000 EV charging stations (20,000 of which are fast chargers) by 2025. 1 million EV charging stations by 2030	No
Canada	Yes	Yes	No	50,000 charging and hydrogen stations to the charging network.
Sweden	Yes	Yes	2400 km of electrified road by 2037. An electric road is supplemented by an electrical installation intended for the transmission of electrical energy to vehicles while driving	No
United States	Yes	Yes	No	National level 500,000 charging stations. State of California target: 250,000 charging stations by 2025
Portugal	Yes	Yes	No	No
Denmark	Yes	No	No	No
India	Yes	No	2877 charging stations in 25 states and 1576 charging stations across 9 expressways and 16 highways. Charging stations every 40–60 km on national highways or 700 charging stations by 2023 covering 35,000–40,000 km of national highways.	No
Norway	No	Yes	No	No
Iceland	No	Yes	No	No
New Zealand	Yes	No	Nationwide coverage of fast/rapid direct current charging stations every 75 km across state highway networks.	No
Carbo Verde	No	Yes	No	No
Egypt	No	No	42,000 public charging stations across governorates, with 3000 stations to be built in phase one of the program.	No
Kenya	Yes	Yes	No	No
Malaysia	Yes	No	9000 alternating current charging stations and 1000 direct current charging stations by 2025.	No

(*continued on next page*)

(*continued*)

	Number of EVs		Charging Infrastructure	
	Ambition	Target	Ambition	Target
Nepal	No	Yes	No	No
Pakistan	Yes	No	Fast charging stations every 10 km^2 in all major cities and every 15–30 km on all motorways (convert 3000 CNG stations to charging stations) in next four years.	No
Singapore	No	Yes	60,000 charging stations by 2030 (40,0000 in public car parks and 20,000 in private premises)	No
Sri Lanka	No	Yes	No	No
Brazil	Yes	Yes	No	No
Columbia	Yes	No	No	No
Costa Rica	Yes	Yes	No	No
Ecuador	Yes	No	No	No
Panama	Yes	No	No	No
Uruguay	Yes	No	No	No
Kazakhstan	Yes	No	No	No
Turkey	Yes	No	No	No
Austria	Yes	No	No	No
Hungary	No	Yes	No	No
Ireland	No	Yes	No	No
Luxembourg	Yes	No	No	No
Slovenia	No	Yes	No	No
Scotland	Yes	No	No	No
United Arab Emirates	No	Yes	No	No
Qatar	No	Yes	No	No
Australia	No	No	Deploy EV charging stations in over 400 businesses, 50,000 households as well as access to 1000 public fast charging stations.	No
Israel	Yes	No	No	No

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