Driving Electric with Equity: A Survey of Current Electric Vehicle Infrastructure, Policies and Planning

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Abstract

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Electric vehicles (EV) and the electrification of the transportation sector is critical to reduce carbon emission. Governments are implementing large scales of public policies, regulations, incentives, and disincentives to build more infrastructure to promote vehicle electrification. However, the equity impacts of these policies, especially the non-financial, planning-related policies, are rarely discussed and evaluated in existing academic literature and professional reports. This dissertation aims to explore different quantitative methods to evaluate the equity impact of EV policies. The dissertation is based comprised of three parts: (1) the theoretical and philosophical contexts of equity and justice in planning, transportation, and vehicular electrification, and a discussion of existing EV policies around the world; (2) three sets of

research that evaluate the equity impact of EV policies from different angles; and (3) the conclusions.

The first study is to explore how different socioeconomic groups weigh the importance of three non-financial incentives, namely charging infrastructure, free parking, and HOV lane access, and how they influence the EV purchase decision-making in California. An Ordered Logistic Regression and its time-modifying effects between 2017 and 2019 were applied with the data, the California Vehicle Survey from California Energy Commission. Both logistic regression model and the time-varying model suggest that the EV buyers from the marginalized group, including the low-income and non-single family homeowner groups, consider public charging availability the most crucial incentive to their EV purchase, while the more advantaged drivers find HOV lane access to be the most critical.

The second study aims to estimate the carbon reduction amount of each driver, and to forecast the carbon mitigation cost, as well as the transition cost to EV by socioeconomic groups under the scenario of a full transition to EV. We create the two scenarios using the assumptions that consumers switch to EV immediately with a new Tesla Model 3 and a used Chevrolet Bolt. Multiple regression tree and boosted regression tree algorithms were applied. The 2019 California Vehicle Survey is used as the database to provide existing driving behavior as input to the forecasting model. The result finds that a greater variations of carbon emission amount among racial groups, housing types, income levels, employment status followed by education achievement. It suggests that marginalized groups show higher quantity carbon emissions than the higher-income and white-only groups. The number of vehicles per household and annual household income are the two most important variables to impact the potential carbon mitigation cost for both scenarios, with education, race, and housing types less relevant. The lower-income drivers face a higher financial cost to switch to EV.

The third study aims to investigate the spatial association between current electric vehicle supply equipment (EVSE) availability and socioeconomic status of different areas within metropolitan areas. We choose six metropolitan areas in the U.S.: Los Angeles-Long Beach-Anaheim, San Francisco-Oakland-Berkeley, Portland-Vancouver-Hillsboro, Seattle-Tacoma-Bellevue, Detroit-Warren-Dearborn, and Atlanta-Sandy Springs-Alpharetta. The EVSE location data are from the Alternative Fuels Data Center, and the demographic and socioeconomic data are from the 2020 Census and the 2019 American Community Survey. After testing several geospatial statistics methods, we found that Geographically Weighted Regression (GWR) models offer better performance than Ordinary Least Square models. Results show heterogeneity among cities and neighborhoods. In general, we found that current EVSE density distributions are spatially correlated with certain socioeconomic variables in various cities: housing density (except San Francisco), poverty (except Los Angeles and San Francisco), and employment rate (except San Francisco and Detroit) are mainly negatively associated with EVSE densities, while rental rate (except San Francisco) and median household incomes (except Portland and Atlanta) are positively associated. White-only variable shows no significant relationship in all six metropolitan areas. Overall, availability and accessibility of EVSE in marginalized communities needs to be improved.

These studies and the methodologies could shed light for EV policymakers to better understand the equity implications of vehicular electrification, to equip with different quantitative methods to evaluate the policies present, and to improve the policies to achieve equity and climate goals in the future.

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LIST OF ACRONYMS AND ABBREVIATIONS

AIC	Akaike Information Criteria
BEV	battery electric vehicle
BRT	boosted regression tree
CO_2	carbon dioxide
CVRP	California Clean Vehicle Rebate Project
DC	Direct current
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
EV	electric vehicle
EVSE	electric vehicle supply equipment
GHG	greenhouse gases
GIS	Geographic Information System
GWh	gigawatt hour
GWR	geographically weighted regression
HOV	high-occupancy vehicle
ICE	internal combustion engine
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
kWh	kilowatt hour

LADWP	Los Angeles Department of Water and Power
MA	metropolitan area
MRT	multivariate regression tree
MWh	megawatt hour
OEM	original equipment manufacturer
OLS	ordinary least squares
PHEV	plug-in hybrid electric vehicle
SMUD	Sacramento Municipal Utility District
TCO	Total cost of ownership
tCO_2e	ton of carbon dioxide equivalent
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
VMT	vehicle miles traveled
ZEV	zero-emission vehicle

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DEDICATION

For Lily and Hana

Chapter 1. INTRODUCTION

The Greenhouse Gases (GHG) emissions and other air pollutants brought by the transportation sector have played a significant role in contributing to climate change and adverse health impacts, especially in urban areas. However, the development of alternative energy and electrification of the transportation sector offers hopeful signs, where replacing internal combustion engine (ICE) vehicles with new energy vehicles like electric vehicles (EV) is a major solution towards urban sustainability.

To achieve the objectives of a transition to EV, governments worldwide have taken steps to provide incentives for improving EV competitiveness or disincentives for abiding by the path dependence of using ICE vehicles. For instance, California has mandated EV-only sales from 2035, and other Zero-Emission Vehicles (ZEV) states are expected to establish similar measures[1]. In addition, China has announced a timescale of a ban on ICE and has put an EV mandate to take effect in multiple cities. In Europe, countries have established targets from as early as 2025 to as late as 2050 to achieve a 100% zero-emission transportation network by banning cars using combustion engines and providing necessary financial incentives and infrastructures to support the EV technologies[2]. In the United States, the strategies on the national level are falling behind. Still, many state and local governments have announced their roadmap to initiate the policy framework to accelerate EV adoption.

[1] "Governor Newsom Announces California Will Phase Out Gasoline-Powered Cars & Drastically Reduce Demand for Fossil Fuel in California's Fight Against Climate Change," California Governor, September 23, 2020, https://www.gov.ca.gov/2020/09/23/governor-newsom-announces-california-will-phase-out-gasoline-powered-cars-drastically-reduce-demand-for-fossil-fuel-in-californias-fight-against-climate-change/.
[2] Måns Nilsson and Björn Nykvist, "Governing the Electric Vehicle Transition – Near Term Interventions to Support a Green Energy Economy," *Applied Energy* 179 (October 1, 2016): 1360–71, https://doi.org/10.1016/j.apenergy.2016.03.056.

Although EV's economic and environmental aspects are frequently surveyed, the impacts of EV adoption are poorly understood in terms of the equity and justice issues during the adoption of the technology. Through the research regarding transportation equity, environmental equity, and health equity, we have learned that the locations of freeways and roads with high traffic volume near the less advantaged social groups have exposed them to higher environmental risks, and those who live in lower-income neighborhoods are often borne with lower transportation accessibility, although it is found in recent literature that accessibility for public transit has improved in certain cities[3]. Furthermore, the unbalanced contribution to climate change from the ethnic minority groups and the lower-income groups might impact themselves in a more threatening manner, as these people lack the financial resources to prepare for the negative impacts, including natural disasters and socio-economic difficulties[4]. Therefore, the transition from traditional fossil fuel-powered vehicles to EVs provides an opportunity to resolve the current environmental inequity by reducing the pollutants from vehicular tailpipes and the potential injustice from GHG emissions effects.

In the last decade, the broad adoption of EVs has gained momentum with government incentives and technological advancements. However, owning an EV requires a larger-than-usual upfront cost, including installing related electric vehicle supply equipment (EVSE), also known as charging stations. While the EV market is still growing, establishing a vast network of EVSE may require many different types of costly government incentives, whose burden could be

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[3] Gordon Mitchell, "Forecasting Environmental Equity: Air Quality Responses to Road User Charging in Leeds, UK," *Journal of Environmental Management* 77, no. 3 (November 1, 2005): 212–26, https://doi.org/10.1016/j.jenvman.2005.04.013.
[4] David Schlosberg, *Defining Environmental Justice: Theories, Movements, and Nature* (Oxford University Press, 2009).

transferred to taxpayers, especially those who have the lowest financial capabilities[5]. EVs are expected to emit less carbon dioxide than gasoline- and diesel-powered vehicles from the environmental perspective. However, one must consider the source of electricity generation to argue that the burden of reducing carbon emissions is equitably distributed[6]. Moreover, while EV technology promises to reduce carbon footprint, it is also essential to ensure accessibility, especially for the marginalized social groups at the same time. When the costs and benefits of transportation electrification are to be fairly shared among all users in all social groups, different equity perspectives will need to be purposefully explored in the planning process.

While incentives and disincentives are provided, EV sales and infrastructure investments are still largely market-driven, which could lead to various problems of market failure[7]. In the past, market failure examples in urban planning, in general, include rapid gentrification and redlining, which systematically excluded the disadvantaged groups, whether intentionally or unintentionally[8]. Similarly, failure to include public engagement in technological innovation and public policy decision-making processes could immediately surface the possibility of unjust results such as the exclusion of certain groups of people who are less advantaged in the society or extra burdens carried over from the negative externalities, which are also usually borne by the less advantaged. In addition, there could also be risks of citizen activism that affect the timelines of adopting such technology, and the enactment of local regulations designed to curb

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[5] Erin H. Green, Steven J. Skerlos, and James J. Winebrake, "Increasing Electric Vehicle Policy Efficiency and Effectiveness by Reducing Mainstream Market Bias," *Energy Policy* 65 (February 1, 2014): 562–66, https://doi.org/10.1016/j.enpol.2013.10.024.

[6] JongRoul Woo, Hyunhong Choi, and Joongha Ahn, "Well-to-Wheel Analysis of Greenhouse Gas Emissions for Electric Vehicles Based on Electricity Generation Mix: A Global Perspective," *Transportation Research Part D: Transport and Environment* 51 (March 1, 2017): 340–50, https://doi.org/10.1016/j.trd.2017.01.005.

[7] Andreas Schroeder and Thure Traber, "The Economics of Fast Charging Infrastructure for Electric Vehicles," *Energy Policy* 43 (April 1, 2012): 136–44, https://doi.org/10.1016/j.enpol.2011.12.041.

[8] Mrinal Datta-Chaudhuri, "Market Failure and Government Failure," *Journal of Economic Perspectives* 4, no. 3 (September 1990): 25–39, https://doi.org/10.1257/jep.4.3.25.

applications of the technology would be put in question. Therefore, public sectors, especially urban planning officials, must consider what role they should play to ensure social equity is thoroughly evaluated and researched during different stages of the vehicle life cycle, including the transaction of the vehicle purchase and the vehicle usage.

This dissertation aims to contribute to the theoretical synthesis of vehicle electrification and equity by implementing the following steps:

1) Chapter 2 surveys the existing literature regarding social justice and equity within the public policy and urban planning contexts, including transportation equity, environmental justice, climate justice, and urban spatial justice.
2) Chapter 3 investigates current vehicular electrification policies, incentives, and regulations. Briefly evaluate the equity performance of these measures. Finally, list the equity and justice challenges of current vehicle electrification agendas in the United States and worldwide.
3) Research 1 is presented in Chapter 4. The title of the research is "Different social groups' reactions to planning-related EV incentives: An example of California."
4) Research 2 is presented in Chapter 5. The title of the research is "Reducing carbon emission with smarter EV incentives: A regression tree model."
5) Research 3 is presented in Chapter 6. The title of the research is "Equity evaluation of charging station location selection: the case of six U.S. cities."
6) Finally, with the summary of the discussions and results from the equity evaluation of policies and the two case studies, Chapter 7 provide a list of policy recommendations for urban policymakers and planning to ensure better vehicle electrification governance.

Chapter 2. THE THEORETICAL CONTEXT OF EQUITY AND JUSTICE IN PLANNING, TRANSPORTATION, AND VEHICULAR ELECTRIFICATION

2.1 Overview

Urban planning has always been aimed at safeguarding the public interest and is often filled to promote social justice[9]. However, planners and city policymakers often have different values and interpret social equity and justice from different starting points when faced with the current realities of housing, transportation, and the environment[10]. For example, should the allocation of urban spatial resources be efficiency-first or equity-first? Should urban public services benefit all or focus more on those who are less advantaged? Should urban planning decisions be elite-driven, or should public participation be maximized? From the answers to these questions, we can see a divergence in the perception of social equity and justice values, reflecting the intersection of multiple ideological roots.

Social equity and justice touch on inner values and have strong ideological and political characteristics. The intuitive judgment of "fairness," "equity," and "justice" comes from both human's natural morality and ethical education and may be driven by interests and influenced by social institutions and norms. The value judgment of equity and justice varies according to the starting point of thought, and various criteria and interpretations have led to various trends and doctrines, all of which try to answer the questions "what is equity and justice" and "how to build an equitable and just society." Each of these competing ideas now has its adherents and has

[9] John Friedmann, "The Future of Comprehensive Urban Planning: A Critique," *Public Administration Review* 31, no. 3 (1971): 315–26, https://doi.org/10.2307/974890.
[10] John T. Metzger, "The Theory and Practice of Equity Planning: An Annotated Bibliography," *Journal of Planning Literature* 11, no. 1 (August 1, 1996): 112–26, https://doi.org/10.1177/088541229601100106.

become a political force for social change today. With this in mind, the overview in this chapter looks at the currently popular ideas of "just city," "spatial justice," and "the right to the city." and the collection and origination of the primary literature related to these theories, tracing them back to sources of urban theoretical thought of neoliberalism, communitarianism, and politics of differences, and neo-Marxism. This chapter aims to present the evolution of these four main types of ideas in terms of values and to identify the differences in perspectives and inheritance relationships among the various doctrines and scholars. It helps to understand better the connotations of various positions and perspectives in current urban equity and justice research inquiries, especially the EV-related policy topics that will be discussed later in this dissertation, and to serve as a reference for understanding equity and justice in urban planning from a broader point of view.

2.2 THE CONCEPT OF JUSTICE AND EQUITY

Justice, as a moral standard of macro-social institutions, is a cognitive rather than a legal norm rooted in moral conscience, and its object is primarily the fundamental political and economic systems of society and deeper values[11]. Rawls's *A Theory of Justice* argues that realizing a just society requires compliance with two basic principles: first, each individual in society must have fundamental freedoms consistent with other members of the social system; second, socioeconomic inequalities must be addressed in a *just society*. The concept of justice is to maximize the welfare of the most vulnerable in society with the notion of Rawls[12]. To this end, Rawls also set up a *veil of ignorance*, which assumes that the parties are unaware of particular facts, unbiased, and independent of any group interests to establish a concept of true justice

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[11] David K. Hart, "Social Equity, Justice, and the Equitable Administrator," *Public Administration Review* 34, no. 1 (1974): 3–11, https://doi.org/10.2307/974395.
[12] John Rawls, *A Theory of Justice* (Harvard University Press, 2009); H. George Frederickson, "Public Administration and Social Equity," *Public Administration Review* 50, no. 2 (1990): 228–37.

(righteousness)[13]. In contrast to justice, which focuses on basic moral standards, values, and legitimacy, equity emphasizes consistency in measurement standards, i.e., non-discrimination and the prevention of double or multiple standards. Moreover, the concept of equity is instrumental in public policy contexts. Thus, justice is a conceptual category that emphasizes more on morality and macro-institutions, i.e., the notion of whether the primary structural attributes of society are moral or not, while equity is more concerned with the empirical rationality of the distribution of benefits and interpersonal relationships and is an empirical instrumental concept.

Equity and equality also share common ethical norms and distributive principles, but there are essential differences between them[14]. The focus is on the distribution of benefits and the evaluation of such distribution. Equity has a broader connotation than equality. It refers to the non-discrimination of social institutions and rules, the proportionality or balance of interests between individuals and societies, and the reflection of the valuation of such relationships. Based on a comparison of justice, equity, and equality, we can clarify the conceptual and connotation differences between the three, which in turn can be extended to the similarities and differences between the concepts of social equity and social justice. Frederickson[15] concludes that social equity is a combination of a set of values, organizational design, and management styles; social equity emphasizes equality in public (government) services, the responsibility of public management for policy implementation, changes in public management, and responsiveness to citizens' needs. Four dimensions measure social equity: procedural fairness, i.e., equal rights and equal protection for all through due process, and any inequality must be redressed; accessibility,

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[13] John Rawls, *A Theory of Justice* (Harvard University Press, 2009).
[14] Karen S. Cook and Karen A. Hegtvedt, “Distributive Justice, Equity, and Equality,” *Annual Review of Sociology* 9, no. 1 (1983): 217–41, https://doi.org/10.1146/annurev.so.09.080183.001245.
[15] Frederickson, “Public Administration and Social Equity.”

i.e., equal or proportional availability of public goods and benefits, with public services and social benefits distributed equally or with more significant assistance to disadvantaged groups; assurance of quality, which involves the consistent provision of public services or benefits to different segments of the population, i.e., equity in the process; and outcome sharing, i.e., allowing all groups in society to share equally in the benefit of the economy[16].

On the other hand, social justice places greater emphasis on the extension of Rawlsian values of the two principles to society, pointing out that collective social efforts are more concerned with helping the disadvantaged, even if this does not imply the elimination of all inequalities or egalitarianism. Furthermore, the primary goal of social justice is self-respect, which means respect for others, and that no person or organization should infringe upon the respect amongst the society[17]. Thus, while social justice is concerned with the fundamental principles and values of the social system as a whole, social equity is more concerned with the equal treatment of different members of society by policies, including the equal provision of public services, public goods, and the equal distribution of social rights and wealth, such as freedom, opportunity, and income, as well as an analysis of the responsibilities and behaviors of the public sector concerning equity[18].

2.3 Neoliberalism Thoughts

Starting from the Enlightenment, liberal thinking and the rise and development of capitalism have gradually become more popular in western political theory. Under its influence, social justice thought has also undergone an evolutionary process from utilitarianism, classical liberalism, welfare society to neoliberalism.

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[16] James H. Svara and James R. Brunet, "Social Equity Is a Pillar of Public Administration," *Journal of Public Affairs Education* 11, no. 3 (July 1, 2005): 253–58, https://doi.org/10.1080/15236803.2005.12001398.
[17] Hart, "Social Equity, Justice, and the Equitable Administrator."
[18] H. George Frederickson, *Social Equity and Public Administration: Origins, Developments, and Applications* (Routledge, 2015).

2.3.1 *Utilitarianism*

Utilitarianism was an ethical idea that strongly influenced the early capitalist world. Jeremy Bentham's view of utilitarianism can be summarized as follows: it is human nature to seek pleasure and avoid pain, and the highest principle of morality is to maximize the collective happiness[19]. He believes that a just value judgment is a trade-off between cost and benefit, a comprehensive calculation of the social consequences that maximizes the utility of society as a whole, and the solution that maximizes the utility of society is optimal[20]. The fallacies of utilitarianism are apparent. First, individual rights are not duly respected, and under paranoid and cruel group pressure, individuals can quickly become victims of collective decisions. At this point, preserving the welfare of the majority becomes the best excuse to deny any individual his or her fundamental rights, and utilitarianism becomes a legitimate justification for oppressing minorities. Secondly, the calculation of happiness maximization is challenging to find a uniform measuring scale. Monetary value is often used to calculate cost and benefits. However, people at different income levels have different price sensitivities, and weighing the pros and cons in monetary values often ignores the welfare of low-income individuals. In addition, many ethical and moral elements are challenging to measure in monetary terms; life, health, suffering, dignity, honor, happiness, and civil rights cannot be priced. If one had to calculate how much a life is worth, the proposition itself would be ethically unacceptable[21].

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[19] Jeremy Bentham, *The Collected Works of Jeremy Bentham: An Introduction to the Principles of Morals and Legislation* (Clarendon Press, 1996).
[20] John Rawls, *Justice as Fairness: A Restatement* (Harvard University Press, 2001); P. J. Kelly, *Utilitarianism and Distributive Justice: Jeremy Bentham and the Civil Law* (Oxford University Press, 1990).
[21] Amartya Sen, "Utilitarianism and Welfarism," *The Journal of Philosophy* 76, no. 9 (1979): 463–89, https://doi.org/10.2307/2025934.

2.3.2 *Libertarianism and Neo-libertarianism*

John Mill tried to rescue the much-criticized utilitarianism. He agreed with utilitarianism's pursuit of utility maximization but argued that utility should not be interpreted as short-term happiness but rather as "individual liberty" that promotes the long-term development of society[22]. Moreover, utility maximization is not the maximization of happiness in a single case but the maximization of the utility of society as a whole; it is not the trade-off between income and expenditure in the short term but the optimal allocation of long-term social development. He then argues that preserving the "freedom" of those who disagree in social development may stimulate the improvement of customs and eventually become a driving force for social self-improvement[23]. Thus, respecting individual freedom is equivalent to maximizing the well-being of society as a whole in the long run. As a result, individual liberty became one of the values of capitalism and was continuously proclaimed. Libertarianism became a critical social ethic for the operation of capital, which was systematically interpreted and developed in social, economic, political, and cultural terms. In general, libertarian values favor undisturbed with free-market rules and oppose government intervention. This is not only for economic efficiency but also for the preservation of individual liberty. The two core elements of libertarian social justice theory are the minimal state and the free market.

Neo-liberals such as Friedrich Hayek and Milton Friedman opposed government intervention in economic activities and advocated minimal government[24]. Libertarian political theory believes that government power should be limited to the minimum necessary to preserve

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[22] John Stuart Mill, *On Liberty and Other Essays* (Oxford University Press, 1998).
[23] Mill.
[24] Milton Friedman, *Capitalism and Freedom* (University of Chicago Press, 2020); F. A. Hayek, *The Constitution of Liberty: The Definitive Edition*, *The Constitution of Liberty* (University of Chicago Press, 2021), https://doi.org/10.7208/9780226320519; Jeremy Shearmur, *Hayek and After: Hayekian Liberalism as a Research Programme* (London: Routledge, 1996), https://doi.org/10.4324/9780203438343.

contracts, protect private properties, and maintain world peace. Libertarianism claims that government policies and laws should (1) reject paternalism and that not an act of the individual as an independent, responsible person should be governed without endangering others; (2) reject moral legislation, in which laws should not be used for any moral or ethical praxis and become a tool to promote dominant values and lifestyles, thereby coercing a minority to comply; (3) reject wealth and income redistribution, as taxation aimed at supporting social welfare is theft of property, and the government has no right to force anyone to transfer wealth to others. Forced appropriation of another labor outcome is tantamount to the appropriation of labor time, and acquiescence to the unpaid appropriation of labor time is the road to serfdom[25].

Robert Nozick argues that the most influential justice in distribution is for individuals to make independent choices in a free market. He argues that the free-market logic is equally applicable in political theory[26]. The rationality of the free market is rooted in (1) freedom of choice, the idea that interfering with market freedom means interfering with the power to obtain economic benefits and with the freedom to pursue a better life; (2) maximizing resource efficiency, the idea that the regulation by the "invisible hand" of the market facilitates efficiency and expands the overall well-being of society, thereby improving the lives of all[27]. Nozick also believed that government should maintain minimal power and that enacting any other coercive policies would violate individual liberty. He argues that there is nothing wrong with individual differences in economic incomes and that there is no particular pattern of social wealth appropriation that should be redistributed in a certain way, provided that it is consistent with market rules. According to the free-market logic, the justice of distribution and redistribution of

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[25] F. A. Hayek and Bruce Caldwell, *The Road to Serfdom: Text and Documents: The Definitive Edition* (London: Routledge, 2014), https://doi.org/10.4324/9781315728124.
[26] Robert Nozick, "Distributive Justice," *Philosophy & Public Affairs* 3, no. 1 (1973): 45–126.
[27] Nozick.

wealth depends on only two aspects: the initial state of ownership with clear ownership and information symmetry and the process of transactions that are spontaneous, free, and voluntary[28]. For libertarians, the basic rules that the parties to a market transaction adhere to when entering into a contract can also be extended to the political ethics that underlie the formulation of the social contract. Thus, in the view of the advocates of free-market logic, the basic equity of rights of individuals in society is guaranteed, and then efforts are made to create more consistent equity of opportunity for all and to maintain process equity in the operation of society. Then we will be able to obtain equity in the outcome of the distribution of property.

However, the two tenets of freedom and well-being on which the logic of the free market is based are challenged by the realities of the current situation. First, individuals are not entirely free to make market choices, and many contractual transactions are based on limited mutual agreement and symmetrical information and then become the last resort in the absence of other options. When the job market shrinks, for instance, job seekers must choose more dangerous jobs and accept lower wages or harsher requirements without the possibility of bargaining. Second, if modest redistribution of social wealth is not insisted upon, market-generated welfare will increasingly be concentrated in the hands of a few. The widening gap between the rich and the poor in both developed and developing countries confirms this trend, leading to the intensification of social contradictions and ultimately to social unrest. This has forced capitalist societies to abandon the principle of minimum government and start the transition to a welfare society based on Keynesianism, which advocates for increasing government expenditures and lowering taxes to stimulate demand. However, how to supplement the existing utilitarian and

[28] "Nozick on Rights, Liberty, and Property on JSTOR," accessed January 14, 2022, https://www.jstor.org/stable/2265059?casa_token=7DVeItFODtQAAAAA%3AQPVXJJulrzeXnSqdkKObkXJ_fLZrOT9DmzUHrJ4zdv-OIP3yV2FImzduu9OrNHCNuGJe4WTj8sh-i2hxunPRT8A6PgBTwcIN-OVoqX-iUcFzKMwQZcM&seq=1#metadata_info_tab_contents.

liberal ideological framework with a theoretical support for the disadvantaged has become a key issue in improving the capitalist system, and this is where Rawls' contribution to the social justice theory lies.

2.3.3 *Fairness as Justice*

John Rawls constructed the theory of "fairness as justice," proposing two major principles: (1) the principle of fairness, in which all people should enjoy the broadest range of fundamental rights and freedoms equally; and (2) the principle of difference, in which economic and social differences must be more conducive to the well-being of the most disadvantaged the open to all under conditions of fair opportunity[29]. He also gives priority to the above principles. The first should be the priority of freedom, where freedom can only be restricted for the sake of freedom. The second is the priority of justice, where justice takes precedence over the pursuit of efficiency and profit and equitable opportunity over the principle of difference[30].

Rawls' theory is rooted in the social contract theory. First, socialized people sign an invisible social "social contract" by default and promise to abide by it, with moral justice judgments being one of the most important provisions. Second, rationalist thinkers argue that people should be bound by principles derived from rational thought, not just by "trade-offs." How to establish rational "principles of justice" and formulate the terms of the invisible "social contract" become the core of social justice theory. Rawls envisioned an invisible "social contract" as an initial state of "fairness" in which all people can agree[31]. This initial state, known as the "veil of ignorance," can be understood as a situation in which all people, without knowing their social identity before they are born, negotiate and agree on the basic rules of justice,

[29] Rawls, *A Theory of Justice*, 2009.
[30] Rawls.
[31] Rawls.

excluding such factors as birth family, socioeconomic status, and natural endowment[32]. Rawls believed that, under this assumption, justice is a natural choice made by "rational" and "utilitarian" people, who desire freedom (the principle of freedom) and compassion for the socially disadvantaged (the principle of difference) and to preserve the opportunity to develop for all possible destinations (the principle of fair opportunity). In this way, Rawls accomplished the political theoretical implantation required for a "welfare society" within the ideology of capitalism based on freedom and competition.

Rawls' idea of justice inevitably has a certain tendency of egalitarianism, and the principle of difference, which favors the rights of the disadvantaged, in fact, affirms that act of redistribution of social wealth[33]. Therefore, the opinions of egalitarianism as "inefficient" and "uninspiring" have also become a criticism. However, the most significant challenge Rawls faced was the challenge from the elite. Under the assumption of a veil of ignorance, Rawls argued that no one is deserving of natural abilities or advantages in life's beginnings and that success is simply the result of a birth, skill, or quality that society happens to favor. Rawls' distributive justice denies moral "entitlement" and establishes the need for redistribution of wealth on this basis. On the one hand, it contradicts the "hard work leads to opportunity" rule of success that the elite promotes, which is perceived by the gifted, intelligent, and hard-working social elite as denigrating their labor earnings. On the other hand, it also conflicts with the traditional social tenet that "those who are virtuous deserve more social recognition (the moral righteousness of success)," which conservatives believe dilutes the value of social solidarity and ignores the natural link between justice and "virtue." Despite the criticism and challenges from various

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[32] Rawls.
[33] Chandran KUKATHAS and Philip PETTIT, "Rawls: A Theory of Justice and Its Critics," *Research Collection School of Social Sciences*, October 1, 1990, https://ink.library.smu.edu.sg/soss_research/2973.

schools of thought, Rawls' ideas are considered the most influential theory to be adopted in the current study of political philosophy to create a just society.

2.3.4 *Moral Individualism*

Neoliberal ideas have become the basic ethics of the functioning of capitalist society, and they have had a significant impact on the world's perception of social justice in two ways. On the one hand, the moral position of justice based on liberal thought has gradually developed into "universal values" that have spread to all corners of the world economy, society, politics, and culture through globalization. On the other hand, the moral definition of justice in this value system is a continuation of Immanuel Kant's idea of "pure practical reason," that is, justice is neither "maximization of well-being" nor "promoting of virtue"; it is also not "market freedom" that only satisfies material desires, but is the moral value choice of rational, independent, and respectable people after careful consideration[34]. Rational moral choices are not influenced by material needs and are not based on personal interests, needs, desires, and preferences, and are ultimately free from the "motive of inclination" and voluntarily driven by the "motive of duty." Only in this way can the value judgment of justice change from obtaining or avoiding certain consequences of action to consciously complying with the established "principles" of behavior. In turn, the principle of just behavior evolves into a basic human right with universal value[35].

On the other hand, the neoliberal view of justice, which is rooted in classical liberalism, rationalism, and social contract theory, has a strong tendency towards "moral individualism." From these ideological roots, the individual is recognized as free and rational, so human nature

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[34] Alice Crary, "Minding What Already Matters: A Critique of Moral Individualism," *Philosophical Topics* 38, no. 1 (2010): 17–49; Immanuel Kant, *Critique of Practical Reason* (Hackett Publishing, 2002).
[35] Michael J. Sandel, Anne T. and Robert M. Bass Professor of Government Michael J. Sandel, and Sandel Michael J, *Liberalism and the Limits of Justice* (Cambridge University Press, 1998); Michael J. Sandel, "Justice: What's the Right Thing to Do," *Boston University Law Review* 91 (2011): 1303.

should be fully liberated, and the right of people to pursue their own good life should be fully respected. It is on this premise that we can reconcile the various problems caused by individualism. First, individuals from a government with limited power manage collective affairs through a social contract. Second, individuals care for the less fortunate out of compassion and empathy. Based on this, individual value choices are pluralistic; government and policy itself should remain neutral in this pluralistic orientation. Finally, the goal of freedom is objective and unquestionable, and there is no fixed picture of the goal of a good life.

2.4 MARXIST CRITIQUES

Marxism used to look for the causes and dynamics that trigger a social change in the unfair capitalist relations of production. Although the growth of the middle class has dissolved labor-capital conflicts, critical analyses based on structural contradictions in capital accumulation are still a valid perspective to explain many social inequities.

2.4.1 *Lefebvre*

For Henri Lefebvre, the development of urbanization brought about by modern industrialization was a continuous intrusion of industrial production into urban life. He argues that before industrialization, cities not only derived wealth from agriculture and commerce but were also able to achieve high levels of attainment in knowledge, skill, and art, and could be called "works" (oeuvres) of human civilization[36]. As a carrier of urban life, the pre-industrial city created a rich social life with a high use value. With the gradual invasion of industry into the core of the city, the city became a tool for efficient capital production, a "product" of commercial production, and a tool for accumulating "exchange value."[37] As society progressed, when

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[36] Henri Lefebvre, *Writings on Cities* (Wiley, 1996).
[37] Lefebvre; Susan S. Fainstein, "The Just City," *International Journal of Urban Sciences* 18, no. 1 (January 2, 2014): 1–18, https://doi.org/10.1080/12265934.2013.834643.

industrial society developed into a consumer society, urban life became part of capital production. Capital dominates the individual in the entire cycle from work to consumption. Lefebvre admired cities and urban life for their use value rather than their exchange value. The pervasiveness of commodities brought by industrialization was destroying the use-value of the city and diluting or commodifying urban life[38]. At the same time, he points out that "the capitalist elite has broken free from the shackles of urban 'everyday life; they are trapeze artists shuttling from hotel to hotel, directing deployments from yachts and estates, and they are everywhere and anywhere." The working class, migrant workers, the colonized or semi-colonized groups struggle daily with their elaborately designed daily lives. It is the humble and miserable lives of these people that are worthy of presentation. These people living in the suburbs, slums, and dilapidated old towns are subjected to exploitation beyond their means. It is the most apparent inequity of modern society that urbanites have been plunged into the humility and hardship of everyday life. Based on his critique of everyday life, Lefebvre calls for the return and reinvention of urban life, initiating a transformation of urban life by proclaiming the "right to the city" and allowing the urban way of life, such as the place of encounter, the priority of use-values, and the imprinting of time in space with the best resources, to find new spatial forms and material realizations.

2.4.2 *Harvey*

David Harvey inherited the "right to the city" from Henri Lefebvre and gave it a more profound revolution. First, he proposes that the "right to the city" is the power of individuals to access urban resources and the power to change themselves by changing the city. Society produces urban space, and in turn, urban space influences and shapes urban residents. In order to control

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[38] Lefebvre, *Writings on Cities*.

one's development prospects, one must also control the direction of urban development and make one's voice heard in the choice of values and paths of urban development. Also, he proposes that the "right to the city" is public rather than personal because advocating the "right to the city" inevitably requires the power of collective action to reshape the urbanization process[39]. The "right to the city" is an ideological banner that mobilizes and leads social forces for urban improvement and even revolution.

Drawing from Marxism, Harvey argues that the essence of equity and justice is ethical principles enforced by moral decree. Once established, these principles could be used to observe and analyze events and activities related to social justice in the city and to make value judgments[40]. However, theories of justice in the capitalist would speak only of "justice in distribution" and do not address "justice in production." It ignores the fact that the income to be distributed is itself derived from production and that the "consumption and demand" of goods and the "production of capital" are one and the same. In Marxist theory, production and distribution are linked systems, and therefore, productive efficiency and social justice cannot be discussed separately.

2.5 Communitarianism and Politics of Difference

Modern capitalist society has been reinforcing its esteem for individual freedom and rights, thus continuously diluting the sense of belonging and responsibility that people have acquired in traditional social life. Since then, based on communitarians' reformulation of the moral virtues of groups and postmodernist studies' examination of political power relations under group

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[39] David Harvey, "'The Right to the City,'" in *The Urban Sociology Reader*, 2nd ed. (Routledge, 2012).
[40] Harvey; David Harvey, *Rebel Cities: From the Right to the City to the Urban Revolution* (Verso Books, 2012).

differences, social equity, and justice studies have seen a return to the value of individual freedom to collective obligation.

2.5.1 *Communitarianism*

The communitarian view of justice was born out of a critique of Rawlsian theory by conservatives who espoused traditional values and religious beliefs. First, communitarians opposed discussing individual rights in isolation from the "common good" of society as a whole. Second, they oppose the discussion of equity and justice in isolation from the ultimate aims of social development and the attachments of human roles in the collectives. In short, for them, "communal encumbrance" is a prerequisite for the discussion of equity and justice[41].

The idea of communitarianism can be traced back to Aristotle's discussion of the relevance of justice and virtue. Liberal theory has sought to separate the discussion of justice from concepts such as virtue, morality, and honor to find an individual, neutral definition that is not influenced by group goals[42]. This would leave people free to choose their own picture of a good life. He felt that discussions of social justice were inextricably linked to the virtues needed to create the good life, that justice was often associated with the virtues we celebrate, and that many social institutions were themselves designed to celebrate certain virtues. From this understanding, and despite our efforts to make institutions, laws, and norms "morally neutral," the discussion of justice cannot be separated from the objective of creating a better society and the communal responsibility that goes with it.

Alasdair Macintyre explains the communal responsibility of the individual in modern society. He places modern life within various narratives, answering the questions "who am I and

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[41] Daniel Bell, *Communitarianism and Its Critics* (Clarendon Press, 1993).
[42] Michael Reisch, "Defining Social Justice in a Socially Unjust World," *Families in Society* 83, no. 4 (August 1, 2002): 343–54, https://doi.org/10.1606/1044-3894.17.

what am I going to do" in the context of "what story am I in."[43] Life is about writing a story and maintaining the continuity and integrity of the story. When individuals make moral choices, they are not so much embodying their own will as they write their storylines and perform the roles they have set for themselves. Thus, each individual carries moral and collective obligations that go beyond the social contract and, based on this, is bound by social ethics. For instance, a father, driven by family responsibility, prioritizes saving his son among children in the water, which most people do not consider morally wrong. Families, communities, nations, groups, or states, all of these communal organizations impose "collective responsibilities" on their members and consolidate their solidarity through the sense of "honor and shame."

According to communalist Michael Sandel, justice is also a social virtue. Justice is not just about distributing wealth in the right way but also about the values that society promotes, and it must work to cultivate social virtues and guard the public interest. A just society requires a strong sense of community belonging and must cultivate its members' responsibility for social solidarity and shared values in a variety of ways[44]. For this reason, many social activities that involve moral responsibilities and values (such as health care, education, and military service) cannot be organized by the rules of the market without imposing moral limitations. From this perspective, inequality in the distribution of income or human rights undermines social solidarity, with the side effect not only of depleting social well-being but also, more seriously, of eroding the civic virtues that hold society together. Liberalism's avoidance of a moral dimension of justice is not the right way to resolve value differences, and the mitigation of value differences

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[43] Alasdair MacIntyre, *After Virtue* (A&C Black, 2013).
[44] Sandel, "Justice."

lies in strengthening "moral participation" and respect for each other's values in different communities.

2.5.2 *The Politics of Difference*

Communitarianism taps into the "collective obligation" and "communal good" to regulate and constrain the behavior of group members. In socialist feminist Iris Marion Young's politics of difference perspective, equity also involves unfair social relations due to intergroup power competition, including "domination," i.e., the institutional and systematic exclusion of some people from participation in decision-making processes that have an impact on their behavior or the environment, and "oppression," i.e., the institutional and systematic suppression of some people's use of socially acceptable resources and skills to achieve self-worth and development[45].

Young rejects the logic of "distributive justice." She does not accept that justice is the distribution of social benefits and burdens among members in a morally justifiable manner. She is more opposed to the generalization of distributive justice from material to immaterial levels, such as the distribution of rights, opportunities, or dignity[46]. In her view, material modes of distribution are generated by specific social structures and processes rather than being the basis on which social structures are built. The modes of distribution themselves are not the problem, but the process and mechanism by which it is produced is the key to "justice." Thus, she argues that power is not a property to be distributed but rather a social relationship that determines the rules of behavior among groups and is the source of "injustice."[47] The discussion of justice does not aim to eliminate individual distributional differences but rather to promote social production

[45] Iris Marion Young, *Justice and the Politics of Difference*, *Justice and the Politics of Difference* (Princeton University Press, 2011), https://doi.org/10.1515/9781400839902.
[46] Young.
[47] Young.

and reproduction while respecting group differences, thereby eliminating the institutional basis for unfair social relations.

Young also rejects the welfare social system based on the morality of distributive justice, arguing that it avoids social structural contradictions and "depoliticizes" the problem of distributive inequity. Welfare society does not change the social objective of pursuing economic growth or capital accumulation but merely reconciles it with the basic needs of individuals, making the two mutually reinforcing. The tool for reconciling inequities in welfare societies is a democratic participation system based on "interest groups," where political lobbying and bargaining among interest groups become a way to mitigate social conflicts. However, this is a game of power with a very high threshold of human and material resources, technical operations, and information knowledge, and the truly "oppressed" often lack the ability to participate in it and do not have the right spokespersons. Moreover, this kind of pluralistic democracy turns the "righteousness of the oppressed" into the "self-appeal" of interest groups, and the political struggle becomes a trade and compromise for the purpose of gaining majority support, and its justice is often weakened or distorted in the process. Thus, the social welfare system, while mitigating distributional inequities, creates new "dominant relations" of power, placing the lives and work of individuals under the control of rational bureaucracies and further restricting individual participation with institutional authority and expert systems.

The "politics of differences" theory in the urban sphere advocates a reconceptualization of the concept of "community." Young rejects "community rights" or "community claims" based on the generalization of liberal individual rights and does not fully support communitarians' pursuit of "common moral standards" and uniform value principles. She then argues the appeal of the ideal city life lies in (1) the non-exclusive tolerance of social differences; (2) the richness of change brought about by the diversity of people and behaviors; (3) exoticism; (4) the communal life built on the basis of multiple differences. She, therefore, argues that in the open public space and places of communities, it is essential to hear the voices of different groups and to encounter people with different social understandings, experiences, and social affiliations. Urban communities should pursue a "politics of inclusion" and must promote the idea of a "heterogeneous" public society in which individual differences are fully recognized and respected, even if they are not understood by all. In this regard, Young follows Jane Jacobs in advocating that urban policy and planning must respect and encourage the spontaneous diversification that occurs in streets and neighborhoods[48].

2.5.3 *Summary*

What communitarianism and the politics of differences have in common is a shift in social justice theory from "liberating individual freedom" to "discovering the moral standards of collective life." Social justice, as proposed by communitarians, is about seeking common ground. The ethics of justice they advocate is about guarding, practicing, and promoting shared collective values and maintaining community solidarity through community indoctrination, creedal agreement, modeling, the admonition of responsibility, and celebration of virtue. The politics of difference advocates social justice in the sense of "living with differences." There are ineradicable indifferences between individuals and groups, such as gender, race, religion, class, and occupation, and society must be recognized as rich and diverse. Attempting to "assimilate" diverse groups with any universal values would be oppressive or self-defeating to marginalized groups. Therefore, a just and equitable society should respect these differences, allowing groups to have fair rights and to identify, affirm, and preserve each other's differences.

[48] Young; Jane Jacobs, *The Death and Life of Great American Cities* (Knopf Doubleday Publishing Group, 2016).

2.6 EQUITY DISCUSSIONS IN URBAN TRANSPORTATION

2.6.1 *Overview*

The concept of justice in political philosophy has spawned attention to fairness and justice in other fields. In urban planning, environmental justice movement raised attention during the 1980s[49]. It refers to an equitable distribution of environmental risks and benefits, and fairness is regarded as the core connotation of justice. In many parts of the world, the rapid urbanization process has brought economic development, but the ensuing environmental degradation and social conflicts are also prominent. In the United States, urbanization shows its own efficiency during the development process with economic development after the World War II, but the concept of fairness at the other end of the balance does not receive the attention it deserves. The complicated urbanization process involves the interests of various parties such as the environment, economy, and different stakeholders in the society and often becomes the focus of the appeal of fairness. In the process of motorization accompanied by urbanization, the rapid expansion of the automobile industry and related transportation facilities has encouraged the rapid increase of private automobile ownership. However, the transportation disparities, such as low-cost transportation modes, i.e., walking and cycling, as well as auto ownership and underserving public transit, have been overlooked, which has resulted in an urban transportation equity crisis prior to the 1990s. It can be concluded that the purpose of urban transportation research from the perspective of fairness is to seek a more reasonable value orientation and optimize the urban physical spatial pattern and distribution mechanism so as to start the formulation of relevant planning and public policies more comprehensively in practice.

[49] OP US EPA, "Environmental Justice Timeline," Collections and Lists, April 15, 2015, https://www.epa.gov/environmentaljustice/environmental-justice-timeline.

In the United States, the study of urban transportation equity was originated during the Post World War II period in which urbanization was accompanied by rapid growth in motorization. The data shows that from 1950 to 1970, the urban population of the United States increased by 71%, while urban land use increased by 176%; from 1950 to 1972, the rate of American household ownership of automobiles increased from 52% to 79%, and the number of households owning two or more vehicles increased from 7% to 30%[50]. Under the strategy of private automobile dominating urban transportation, the mobility of car-less groups has plunged dramatically. Intermixed with issues such as race issues at the time, African Americans with high unemployment rates were questioned as victims of inappropriate and wasteful transportation systems. Against this background, urban transportation equity has become a research theme in urban planning and related disciplines[51]. For example, Abe used the theory of Pareto Efficiency in the field of economics to discuss the optimal price of urban transportation, and the concepts of economic welfare and time value brought by transportation were also analyzed[52].

The study of transportation equity is divided into two concepts: horizontal equity and vertical equity[53]. Horizontal equity emphasizes the balanced distribution of benefits among members of the same group, while vertical equity pays more attention to the distribution of benefits among different groups[54]. The differences between these two distribution ideas are that vertical equity requires different groups to obtain different benefits, while horizontal equity

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[50] Sandra Rosenbloom and Alan Altshuler, "Equity Issues in Urban Transportation," *Policy Studies Journal* 6, no. 1 (1977): 29–40, https://doi.org/10.1111/j.1541-0072.1977.tb01163.x.
[51] John F. Kain and John R. Meyer, "Transportation and Poverty," *The Public Interest* 18 (1970): 75.
[52] Masatoshi A. Abe, "Distributional Equity and Optimal Pricing of Urban Transport," *Journal of Transport Economics and Policy* 9, no. 2 (1975): 178–85.
[53] Rosenbloom and Altshuler, "Equity Issues in Urban Transportation."
[54] Gavin Mooney, "And Now for Vertical Equity? Some Concerns Arising from Aboriginal Health in Australia," *Health Economics* 5, no. 2 (1996): 99–103, https://doi.org/10.1002/(SICI)1099-1050(199603)5:2<99::AID-HEC193>3.0.CO;2-N.

requires similar individuals in the same group to obtain similar benefits[55]. On this basis, Litman added the factor of group category to the concept of vertical equity and proposed three basic types of transportation equity: horizontal equity, vertical equity considering income, and vertical equity considering demand and ability. In a series of empirical studies, different transportation policies are selected for the evaluation of impact, including motor vehicle tolls, public transportation funding, and traffic control[56]. Transportation equity is also equivalent to spatial averaging and the satisfaction of basic needs in a more specific, narrower concept[57]. Procedural fairness, reasonable expectations, equal choice, fairness of returns, rights, and needs are also included in the connotation of transportation equity.

The imbalance of cost contributed, and benefit received by different EV buyers can also be treated as horizontal inequity, an essential concept in transportation equity[58]. It refers to equitable access to travel opportunities and the costs and benefits of travel, regardless of differences in travel abilities and needs among individuals or groups. In other words, everyone should have equal access to transportation resources, bear the cost reasonably, and be treated fairly in other aspects of transportation activities, in this case, EV costs and benefits. This form of equity requires that EV policies should prevent one individual or group of people from taking precedence over other individuals or groups and that each EV user should receive benefits commensurate with their contribution.

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[55] Timothy F. Welch, "Equity in Transport: The Distribution of Transit Access and Connectivity among Affordable Housing Units," *Transport Policy* 30 (November 1, 2013): 283–93, https://doi.org/10.1016/j.tranpol.2013.09.020.
[56] Chang-Hee Christine Bae and Inge Mayeres, "Transportation and Equity," in *Social Dimensions of Sustainable Transport: Transatlantic Perspectives* (Ashgate Aldershot UK, 2005), 164–94; Todd Litman, "Evaluating Transportation Equity," *World Transport Policy & Practice* 8, no. 2 (2002): 50–65.
[57] A Hay and E Trinder, "Concepts of Equity, Fairness, and Justice Expressed by Local Transport Policymakers," *Environment and Planning C: Government and Policy* 9, no. 4 (December 1, 1991): 453–65, https://doi.org/10.1068/c090453.
[58] Litman, "Evaluating Transportation Equity."

The imbalance of contributed cost and received benefit between EV buyers and non-buyers can also be treated as vertical inequity[59]. From the transportation equity perspective, there are two types of vertical equity. One is vertical transportation equity that considers differences in socioeconomic status, which means that policies should cater to the different travel needs of individuals or groups with different demographics and income levels by providing them with affordable modes of transportation and special services. In such a manner, disadvantaged groups do not bear a disproportionate share of the additional costs of travel, such as the externalities of environmental pollution and additional costs due to new technologies. The other one is vertical transportation equity that considers the differences in travel demand and ability, which refers to the concept that different individuals or groups should enjoy equity in the process of transportation activities for their different travel abilities and travel demands. Unlike the previous type of vertical equity, the urban transportation system should consider the difference in different groups' ability to pay for the transportation cost. The system should provide accessible services and convenient facilities for those individuals or groups with accessibility needs[60]. Although many existing EV policies and incentives fail to address both types of vertical equity, local governments have attempted to focus on electrifying public transit and car-sharing programs that target directly at low-income communities. We have learned that those who live in lower-income neighborhoods are often borne with lower transportation accessibility through transportation equity research. Emphasizing public transit, rather than private car ownership, will increase public welfare and enhance mobility more equitably[61].

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[59] Litman.
[60] Litman.
[61] Karel Martens, "Justice in Transport as Justice in Accessibility: Applying Walzer's 'Spheres of Justice' to the Transport Sector," *Transportation* 39, no. 6 (November 1, 2012): 1035–53, https://doi.org/10.1007/s11116-012-9388-7.

2.6.2 *Holistic Perspective*

From a holistic perspective, the research on urban transportation equity is aimed at a comprehensive and static state. This perspective analyzes the static conditions within a certain spatial range to explore the fairness of urban transportation under a certain point of time and also includes the cumulative effect before that point of time. Therefore, Litman believes that the corresponding benefit distribution in the complete cycle of the urban transportation system should be considered to achieve the optimized results with the most fairness[62]. Fruin and Sriraj used GIS simulation with time series analysis to study the environmental justice of communities with poor social and economic conditions, and based on this, they proposed the allocation of benefits for future transportation planning project investments[63]. Some studies have focused on the cost of dependence on private automobiles and the distribution of this cost among different social groups[64]. The concepts of the Lorenz Curve and the Gini Coefficient, which are commonly used in the field of economics, have also been introduced into the research on transportation equity[65]. In reality, however, the redistribution generated by equity-oriented urban transportation practices will involve public policies and financial investments and will affect the interests of certain groups, causing some groups to pay more than the previous state, thus creating controversies[66].

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[62] Todd Litman, "Full Cost Accounting of Urban Transportation: Implications and Tools," *Cities*, Transport: Counting the Costs, 14, no. 3 (June 1, 1997): 169–74, https://doi.org/10.1016/S0264-2751(97)00057-7.
[63] Geoffrey Fruin and P. S. Sriraj, "Approach of Environmental Justice to Evaluate the Equitable Distribution of a Transit Capital Improvement Program," *Transportation Research Record* 1924, no. 1 (January 1, 2005): 139–45, https://doi.org/10.1177/0361198105192400118.
[64] Sustainable Development Commission, "Fairness in a Car-Dependent Society," Report (Sustainable Development Commission, February 2011), https://research-repository.st-andrews.ac.uk/handle/10023/2290.
[65] Alexa Delbosc and Graham Currie, "Using Lorenz Curves to Assess Public Transport Equity," *Journal of Transport Geography*, Special section on Alternative Travel futures, 19, no. 6 (November 1, 2011): 1252–59, https://doi.org/10.1016/j.jtrangeo.2011.02.008.
[66] Paul George Lewis and Mary Sprague, *Federal Transportation Policy and the Role of Metropolitan Planning Organizations in California* (Public Policy Instit. of CA, 1997).

2.6.3 *Comparative Perspective*

The comparative perspective focuses on dynamic equity. By comparing the performance of urban transportation at two or more time points or spaces, the equity in this relative state is analyzed. Sanchez uses basic census tracts as the unit and conducts comparative spatial analysis based on socioeconomic characteristics, and measures the equity based on household income, the proportion of whites in the area, and distance to the central business district of Atlanta, Georgia, and the results suggest that "net personal transportation system benefits are not significantly biased toward particular income or racial groups."[67] The Oakland Metropolitan Transportation Commission modeled the prediction of the social impact of regional transportation plans based on Executive Order 12898 that was signed by President Clinton. This study focuses on changes in travel behavior in low-income communities and minority communities and compares it with other communities through three variable indicators: work accessibility, work/non-work commuting time, and commuting time to major job centers[68]. In contrast to mobility, accessibility focuses on the number of destinations one can reach in a given time by a variety of modes, and accessibility-focused planning provides incentives to dense urban forms, which are more efficiently served by active transportation modes[69]. Some studies focus on comparisons over more extended periods of time, sometimes longer than a decade. In the San Francisco Bay Area study, Cervero randomly selected 100 census tracts and the 22 largest job centers in the Bay Area and studied the characteristics of transportation equity based on the changes in

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[67] Thomas W. Sanchez, "Equity Analysis of Personal Transportation System Benefits," *Journal of Urban Affairs* 20, no. 1 (March 1, 1998): 69–86, https://doi.org/10.1111/j.1467-9906.1998.tb00411.x.
[68] Metropolitan Transportation Commission, "The 2001 Regional Transportation Plan: Equity Analysis and Environmental Justice Report," *Oakland, CA*, 2001, 8–1.
[69] Jonathan Levine et al., "Does Accessibility Require Density or Speed?," *Journal of the American Planning Association* 78, no. 2 (April 1, 2012): 157–72, https://doi.org/10.1080/01944363.2012.677119.

accessibility from 1980 to 1990[70]. The results show that low-income, inner-city communities face a more severe problem of separation of work and residence. Kawabata and Shen compared two different modes of private car and public transportation in 1990 and 2000 to study the accessibility of jobs and the length of transportation to study equity[71]. In addition to the comparison of time and space, the comparison of different policies has also received attention. Bureau et al. introduced computer-based simulation to study the impact of two basic transportation policies, namely reducing transportation-related monetary costs and increasing transportation speed. The results show that low-income residents can get more benefits with lower transportation costs[72]. Also, in conjunction with emerging planning concepts, the U.S. Environmental Protection Agency (EPA) analyzed how smart growth policies can provide more affordable housing, more diversified transportation options, and better community participation than traditional policies in order to promote social equity better[73].

2.6.4 *Stakeholders*

Research on environmental justice has shown that marginalized social groups, such as lower-income people, African Americans, and children are burdened by harsh environmental conditions, including waste disposal pollution, industrial emissions, and outdoor air pollution like transportation-related sources[74]. Research-based on the perspective of environmental justice

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[70] R Cervero, T Rood, and B Appleyard, "Tracking Accessibility: Employment and Housing Opportunities in the San Francisco Bay Area," *Environment and Planning A: Economy and Space* 31, no. 7 (July 1, 1999): 1259–78, https://doi.org/10.1068/a311259.
[71] Mizuki Kawabata and Qing Shen, "Commuting Inequality between Cars and Public Transit: The Case of the San Francisco Bay Area, 1990-2000," *Urban Studies* 44, no. 9 (August 1, 2007): 1759–80, https://doi.org/10.1080/00420980701426616.
[72] Benjamin Bureau and Matthieu Glachant, "Distributional Effects of Public Transport Policies in the Paris Region," *Transport Policy* 18, no. 5 (September 1, 2011): 745–54, https://doi.org/10.1016/j.tranpol.2011.01.010.
[73] Megan McConville, "Creating Equitable, Healthy, and Sustainable Communities: Strategies for Advancing Smart Growth, Environmental Justice, and Equitable Development," February 2013, https://trid.trb.org/view/1308223.
[74] Gordon Mitchell and Danny Dorling, "An Environmental Justice Analysis of British Air Quality," *Environment and Planning A*, 2003, https://doi.org/10.1068/a35240; Jamie Pearce and Simon Kingham, "Environmental Inequalities in New Zealand: A National Study of Air Pollution and Environmental Justice," *Geoforum*,

focuses on the environmental health effects of specific groups and tries to prove that the vulnerable groups with little responsibility for air pollution bear much more significant adverse environmental impact[75]. Recent studies on environmental justice have also tried to understand the evolution of environmental inequity through long-term dynamic analysis. For example, Mitchell et al. conducted an empirical analysis of the dynamic changes in air quality in the U.K. from 2001 to 2011 and the degree of pollution exposure suffered by different social groups, and this situation will further exacerbate the environmental injustice and health inequality[76]. Bae et al. concluded that minority and low-income households tend to live closer to transportation-related pollution sources and bear more negative environmental externalities[77]. Transportation is one of the essential factors that cause the occurrence and exacerbation of environmental justice and health inequities[78]. Vulnerable groups such as low-income people, the elderly, and the disabled are less able to benefit from technological convenience and comfort, but they are likely to endure more negative externalities brought by the automobile-dependent transportation mode, such as air pollution, noise pollution, and road traffic injuries.[79]

Conversations Across the Divide, 39, no. 2 (March 1, 2008): 980–93, https://doi.org/10.1016/j.geoforum.2007.10.007; Robert J. Brulle and David N. Pellow, "ENVIRONMENTAL JUSTICE: Human Health and Environmental Inequalities," *Annual Review of Public Health* 27, no. 1 (March 13, 2006): 103–24, https://doi.org/10.1146/annurev.publhealth.27.021405.102124.

[75] Pearce and Kingham, "Environmental Inequalities in New Zealand"; Laura Perez et al., "Near-Roadway Pollution and Childhood Asthma: Implications for Developing 'Win–Win' Compact Urban Development and Clean Vehicle Strategies," *Environmental Health Perspectives* 120, no. 11 (November 1, 2012): 1619–26, https://doi.org/10.1289/ehp.1104785.

[76] Gordon Mitchell, Paul Norman, and Karen Mullin, "Who Benefits from Environmental Policy? An Environmental Justice Analysis of Air Quality Change in Britain, 2001–2011," *Environmental Research Letters* 10, no. 10 (October 2015): 105009, https://doi.org/10.1088/1748-9326/10/10/105009.

[77] Chang-Hee Christine Bae et al., "The Exposure of Disadvantaged Populations in Freeway Air-Pollution Sheds: A Case Study of the Seattle and Portland Regions," *Environment and Planning B: Planning and Design* 34, no. 1 (February 1, 2007): 154–70, https://doi.org/10.1068/b32124.

[78] Mark Stevenson et al., "Land Use, Transport, and Population Health: Estimating the Health Benefits of Compact Cities," *The Lancet* 388, no. 10062 (December 10, 2016): 2925–35, https://doi.org/10.1016/S0140-6736(16)30067-8.

[79] Billie Giles-Corti et al., "City Planning and Population Health: A Global Challenge," *The Lancet* 388, no. 10062 (December 10, 2016): 2912–24, https://doi.org/10.1016/S0140-6736(16)30066-6.

There are different classification methods for the object of urban transportation equity research. In the United States, ethnic minorities are the focus of most research, but vulnerable groups are gradually gaining attention, such as people with disabilities, children, and elderly[80]. Some studies take the scope of urban transportation-related work as the boundary and regard the internal staff of the transportation system as a unique stakeholder to analyze the equity of the impact of transportation policies on them[81]. Differences in geographic space and the scope of administrative regions are also used as classification methods to analyze the impact of transportation projects in different regions and at different scales[82]. Some studies have also emphasized the concern for women. Dobbs conducted a detailed survey of female travel behavior in England[83]. The results show that the affordability of motor vehicles is significantly positively related to whether women can have jobs. Students as a special group have also become the targets of research. Hodgson et al. have analyzed the absorption of pollutants, traffic behaviors, and the sustainability of travel based on students' travel paths to school[84]. Feitelson believes that in future research on transportation equity, the comparison of the characteristics of urban transportation users and other affected populations needs more focused attention[85].

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[80] Irene Casas, “Social Exclusion and the Disabled: An Accessibility Approach,” *The Professional Geographer* 59, no. 4 (November 1, 2007): 463–77, https://doi.org/10.1111/j.1467-9272.2007.00635.x.
[81] Ralph Buehler and John Pucher, “Making Public Transport Financially Sustainable,” *Transport Policy* 18, no. 1 (January 1, 2011): 126–38, https://doi.org/10.1016/j.tranpol.2010.07.002.
[82] Emilio Ortega, Elena López, and Andrés Monzón, “Territorial Cohesion Impacts of High-Speed Rail at Different Planning Levels,” *Journal of Transport Geography*, Special Section on Theoretical Perspectives on Climate Change Mitigation in Transport, 24 (September 1, 2012): 130–41, https://doi.org/10.1016/j.jtrangeo.2011.10.008.
[83] Lynn Dobbs, “Wedded to the Car: Women, Employment and the Importance of Private Transport,” *Transport Policy* 12, no. 3 (2005): 266–78.
[84] Susan Hodgson et al., “Towards an Interdisciplinary Science of Transport and Health: A Case Study on School Travel,” *Journal of Transport Geography*, Social Impacts and Equity Issues in Transport, 21 (March 1, 2012): 70–79, https://doi.org/10.1016/j.jtrangeo.2012.01.011.
[85] Eran Feitelson, “Introducing Environmental Equity Dimensions into the Sustainable Transport Discourse: Issues and Pitfalls,” *Transportation Research Part D: Transport and Environment* 7, no. 2 (March 1, 2002): 99–118, https://doi.org/10.1016/S1361-9209(01)00013-X.

2.6.5 *Scales*

There is a precise spatial scale of the connotation of urban transportation equity, and academic research also reflects the scale characteristics of different levels. At the macro-regional scale, infrastructure such as railways often becomes the focus of transportation equity. Brocker et al. analyzed the Trans-European Transport Network as a regional project in Europe to change the accessibility of different urban areas[86]. Ortega et al. used accessibility as the most vital variable to analyze the endogenous impact of high-speed railway projects at three different scales: area, traffic corridor, and nation[87]. Monzon et al. studied the impact of high-speed railway projects by combining accessibility and population as evaluation indicators of transportation equity[88]. Macroeconomic policies with comprehensive coverage also received attention. Button studied the changes in public policy, the privatization process in the transportation sector, and the impact of deregulation in the United Kingdom since the 1970s[89]. Pucher took East Germany, which experienced a considerable change in social and political systems, as an example, to study the equity of economic growth in the process of motorization[90]. At a more local scale, the theme of urban transportation equity revolves around different modes of transportation. Research by Rodier et al. found that large-scale rail transit increases public welfare and reduces traffic

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[86] Johannes Bröcker, Artem Korzhenevych, and Carsten Schürmann, "Assessing Spatial Equity and Efficiency Impacts of Transport Infrastructure Projects," *Transportation Research Part B: Methodological*, Modelling Non-urban Transport Investment and Pricing, 44, no. 7 (August 1, 2010): 795–811, https://doi.org/10.1016/j.trb.2009.12.008.
[87] Ortega, López, and Monzón, "Territorial Cohesion Impacts of High-Speed Rail at Different Planning Levels."
[88] Andrés Monzón, Emilio Ortega, and Elena López, "Efficiency and Spatial Equity Impacts of High-Speed Rail Extensions in Urban Areas," *Cities*, Special Section: Analysis and Planning of Urban Settlements: The Role of Accessibility, 30 (February 1, 2013): 18–30, https://doi.org/10.1016/j.cities.2011.11.002.
[89] Kenneth Button, "Privatisation and Deregulation," *The Annals of Regional Science* 28, no. 1 (March 1, 1994): 125–38, https://doi.org/10.1007/BF01581352.
[90] John Pucher, "Modal Shift in Eastern Germany: Transportation Impacts of Political Changes," *Transportation* 21, no. 1 (1994).

congestion and exhaust emissions[91]. Kawabata and Shen[92] evaluated the commuting inequality between cars and public transit in the San Francisco Bay Area and found that public transit systems could better enhance equitable mobility and accessibility than driving alone. Case evaluates the accessibility of non-motor vehicle drivers based on the traffic generation rate of non-automobile users, and the accessibility of private cars and public transportation has also become the evaluation indicators of sustainable transportation and transportation equity[93].

2.6.6 *Benefits and Pitfalls*

In urban transportation equity research, spatial accessibility is often used as a representative evaluation indicator of benefits, which are the positive effects. Domanski found that centralized community layout in higher density residential areas, investment, and transportation systems are more advantageous in terms of spatial accessibility and economy than the homogeneous model[94]. Based on the equity theory of philosopher Michael Walzer, Martens pointed out that the fair distribution of accessibility should be independent of other social interests such as capital and power, without interfering with each other[95]. On this basis, Martens et al. further proposed that the preferred objective of the urban transportation planning equity policy should be to maximize the average accessibility while limiting the gap between the most and least advantaged[96]. In Delmelle's study of the accessibility change of the new BRT transportation system in Cali,

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91 Caroline J. Rodier, Robert A. Johnston, and David R. Shabazian, "Evaluation of Advanced Transit Alternatives Using Consumer Welfare," *Transportation Research Part C: Emerging Technologies* 6, no. 1 (February 1, 1998): 141–56, https://doi.org/10.1016/S0968-090X(98)00013-8.

92 Kawabata and Shen, "Commuting Inequality between Cars and Public Transit."

93 Robert B. Case, "Accessibility-Based Factors of Travel Odds: Performance Measures for Coordination of Transportation and Land Use to Improve Nondriver Accessibility," *Transportation Research Record* 2242, no. 1 (January 1, 2011): 106–13, https://doi.org/10.3141/2242-13.

94 R Domański, "Accessibility, Efficiency, and Spatial Organization," *Environment and Planning A: Economy and Space* 11, no. 10 (October 1, 1979): 1189–1206, https://doi.org/10.1068/a111189.

95 Martens, "Justice in Transport as Justice in Accessibility."

96 Karel Martens, Aaron Golub, and Glenn Robinson, "A Justice-Theoretic Approach to the Distribution of Transportation Benefits: Implications for Transportation Planning Practice in the United States," *Transportation Research Part A: Policy and Practice* 46, no. 4 (May 1, 2012): 684–95, https://doi.org/10.1016/j.tra.2012.01.004.

Colombia, accessibility is analyzed from various spatial locations in the city to the transportation system, hospitals, recreational facilities, and libraries[97]. The analysis results show that recreational and medical resources will be reallocated due to changes in the transportation system. At the same time, urban transportation will also have a promoting effect on other aspects of the social economy and create corresponding benefits. Shen evaluated and discussed the spatial disadvantage of low-income groups in Boston who depend on slow, inflexible, and limited public transit services[98]. This lack of job accessibility for transit commuters was also found more severe in the United States than in the Tokyo Metropolitan Area[99]. Cervero and Kang studied the BRT case in Seoul and found that urban transportation affected the land market and resulted in the redistribution of benefits, affecting the new pattern of transportation equity[100]. Jones et al. observed that in addition to accessibility, urban transportation also has an impact on mobility, economic activities, and other related aspects. However, these benefits have different distribution characteristics at different scales and need to be distinguished when evaluating equity[101].

Meanwhile, urban transportation has created many disadvantages while creating benefits. In terms of the environment, urban transportation generates noise and air pollution. In the study

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[97] Elizabeth Cahill Delmelle and Irene Casas, "Evaluating the Spatial Equity of Bus Rapid Transit-Based Accessibility Patterns in a Developing Country: The Case of Cali, Colombia," *Transport Policy*, URBAN TRANSPORT INITIATIVES, 20 (March 1, 2012): 36–46, https://doi.org/10.1016/j.tranpol.2011.12.001.
[98] Qing Shen, "Location Characteristics of Inner-City Neighborhoods and Employment Accessibility of Low-Wage Workers," *Environment and Planning B: Planning and Design* 25, no. 3 (June 1, 1998): 345–65, https://doi.org/10.1068/b250345; Qing Shen, "A Spatial Analysis of Job Openings and Access in a U.S. Metropolitan Area," *Journal of the American Planning Association* 67, no. 1 (March 31, 2001): 53–68, https://doi.org/10.1080/01944360108976355.
[99] Mizuki Kawabata and Qing Shen, "Job Accessibility as an Indicator of Auto-Oriented Urban Structure: A Comparison of Boston and Los Angeles with Tokyo," *Environment and Planning B: Planning and Design* 33, no. 1 (February 1, 2006): 115–30, https://doi.org/10.1068/b31144.
[100] Robert Cervero and Chang Deok Kang, "Bus Rapid Transit Impacts on Land Uses and Land Values in Seoul, Korea," *Transport Policy* 18, no. 1 (January 1, 2011): 102–16, https://doi.org/10.1016/j.tranpol.2010.06.005.
[101] Peter Jones and Karen Lucas, "The Social Consequences of Transport Decision-Making: Clarifying Concepts, Synthesising Knowledge and Assessing Implications," *Journal of Transport Geography*, Social Impacts and Equity Issues in Transport, 21 (March 1, 2012): 4–16, https://doi.org/10.1016/j.jtrangeo.2012.01.012.

of noise pollution caused by urban transportation, Brainard et al. analyzed and compared the noise pollution caused by urban roads, railways, and airports and evaluated the age, race, and poverty of people affected by noise. The result suggests that the less advantaged groups suffer more noise burden than others[102]. Morello-Frosch et al. established a comparative risk assessment framework based on the 148 hazardous air pollution sources (HAPs) listed in the Clean Air Act of 1990[103]. Based on the relevant characteristics of carcinogens, the life-long carcinogenic risk is inferred, and the results show that transportation-related land use has a significant positive correlation with carcinogenic risk among the less advantaged groups.

Urban transportation equity is also closely related to social equity. Stanley et al. believe that urban transportation has a social exclusion effect, which mainly includes five aspects: income, employment, political participation, participation in specific activities, and social support[104]. Casas found that individual age, family size, and other factors affect the evaluation of urban transportation equity[105]. Correspondingly, plans and policies formulated for the social exclusion of urban transportation have also received attention and inspection, and the synergy between policies is considered to be a necessary guarantee to achieve social integration[106].

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[102] Julii S Brainard et al., "Modelling Environmental Equity: Access to Air Quality in Birmingham, England," *Environment and Planning A: Economy and Space* 34, no. 4 (April 1, 2002): 695–716, https://doi.org/10.1068/a34184.

[103] Rachel Morello-Frosch, Manuel Pastor, and James Sadd, "Environmental Justice and Southern California's 'Riskscape': The Distribution of Air Toxics Exposures and Health Risks among Diverse Communities," *Urban Affairs Review* 36, no. 4 (March 1, 2001): 551–78, https://doi.org/10.1177/10780870122184993.

[104] John Stanley et al., "Social Exclusion and the Value of Mobility," *Journal of Transport Economics and Policy (JTEP)* 45, no. 2 (May 1, 2011): 197–222.

[105] Casas, "Social Exclusion and the Disabled," 200.

[106] Karen Lucas, "Providing Transport for Social Inclusion within a Framework for Environmental Justice in the UK," *Transportation Research Part A: Policy and Practice* 40, no. 10 (December 1, 2006): 200, https://doi.org/10.1016/j.tra.2005.12.005.

2.7 Environmental Justice

Environmental justice is a set of theoretical concepts based on the combination of environmental protection and social justice, trying to ensure that people with different socioeconomic attributes, that is, regardless of their socioeconomic status, should bear the same degree of negative impact to the environment brought by economic development[107]. Environmental justice originated in the United States, and the landmark incident was a prominent African American community in Warren County, North Carolina that opposed the establishment of toxic PCB landfills in 1982. Early environmental justice research was limited to the United States, and the research object focused on communities of color, mainly focusing on the unequal distribution of hazardous landfills and industrial pollution sources[108]. In the late 1990s, the concept of environmental justice was spread to Europe and was mainly studied using deprivation indicators. The environmental factors concerned not only include landfills and industrial pollution sources but also expanded to air quality, flood disasters, road traffic accidents, and accessibility of park and green spaces[109]. Related research shows that there are significant differences in the environmental burden borne by people with different socioeconomic attributes. For example, vulnerable groups such as racial minorities and low-income groups in the United States and the United Kingdom usually live more in places with more severe air pollution or near harmful

[107] Susan L. Cutter, "Race, Class and Environmental Justice," *Progress in Human Geography*, 1995, https://doi.org/10.1177/030913259501900111.
[108] Éloi Laurent, "Issues in Environmental Justice within the European Union," *Ecological Economics*, Special Section - Earth System Governance: Accountability and Legitimacy, 70, no. 11 (September 15, 2011): 1846–53, https://doi.org/10.1016/j.ecolecon.2011.06.025.
[109] Chang-Hee Christine Bae, "The Equity Impacts of Los Angeles' Air Quality Policies," *Environment and Planning A: Economy and Space* 29, no. 9 (September 1, 1997): 1563–84, https://doi.org/10.1068/a291563; Marco Martuzzi, Francesco Mitis, and Francesco Forastiere, "Inequalities, Inequities, Environmental Justice in Waste Management and Health," *European Journal of Public Health* 20, no. 1 (February 1, 2010): 21–26, https://doi.org/10.1093/eurpub/ckp216.

industrial facilities and landfills and bear more negative environmental impact, and their health status is also significantly below average[110].

The history of environmental justice research is a history of the development of the environmental justice movement. The research itself originated from the environmental protection movement and is based on the environmental justice movement that was influenced by the Civil Rights movement[111]. As people's environmental awareness increases, people are gradually aware of the environmental risks lurking around and the situation that different social groups (such as gender, class, race, nationality, and income) unfairly bear the environmental risks. The movement then gradually separated from the mainstream environmental protection movement. Although the environmental justice movement in the United States has focused its attention on siting waste/disposal facility issues and environmental racism, the fundamental proposition of environmental justice has emerged, emphasizing the fair distribution of environmental risks and responsibilities among all people[112]. Hence, the environmental justice movement provides live cases and resources for environmental justice research, and the results of environmental justice research also shape the environmental justice movement and provide legal evidence for the movement. The environmental justice movement is also regarded as an extension of the civil rights movement. The environmental justice movement emphasizes not only the protection of the natural environment but also the protection of fundamental survival rights and human rights among vulnerable groups in environmental risks. Environmental justice

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[110] Mitchell and Dorling, "An Environmental Justice Analysis of British Air Quality"; Brulle and Pellow, "ENVIRONMENTAL JUSTICE"; Bae et al., "The Exposure of Disadvantaged Populations in Freeway Air-Pollution Sheds."
[111] US EPA, "Environmental Justice Timeline."
[112] Laura Pulido, "Rethinking Environmental Racism: White Privilege and Urban Development in Southern California," *Annals of the Association of American Geographers* 90, no. 1 (March 1, 2000): 12–40, https://doi.org/10.1111/0004-5608.00182.

research combines environmental issues with civil rights and social justice. Therefore, environmental justice research has a special meaning and status in the history of the environmental movement. It promotes the in-depth development of environmental movements and the civil rights movement. The social crisis has attracted increasing attention from multiple disciplines and has become an interdisciplinary research field.

In as early as the 1970s, economists used air quality data to study the relationship between the economic status of American people and the risk of exposure to polluted air[113]. The studies in the 1970s were not specifically aimed at environmental justice issues, and the conclusions of various studies were inconsistent. Some studies have found that the urban poor, especially African Americans, are significantly more exposed to polluted air than other social groups; another study believes that exposure to polluted air depends on the specific way of living in each region regardless of income or race[114]. In the research conclusions of the 1970s, income rather than race was the core factor of the unfair distribution of environmental risks. After the 1980s, environmental justice research developed rapidly under the impetus of the actual environmental justice movement. The 1982 protest in Warren County, NC was the first time people combined race, poverty, and hazardous waste landfill and transformed a civil rights movement into an environmental justice movement[115].

Several seminal studies have laid the foundations of environmental justice research, all of which are related to African Americans' objections to the disposal of waste around the

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[113] Andrew Szasz and Michael Meuser, "Environmental Inequalities: Literature Review and Proposals for New Directions in Research and Theory:," *Current Sociology*, 1997, https://doi.org/10.1177/001139297045003006.
[114] I. I. I. Freeman, R. H. Haveman, and A. V. Kneese, "Economics of Environmental Policy," January 1, 1973, https://www.osti.gov/biblio/5273327; B. J. L. Berry, "Social Burdens of Environmental Pollution: A Comparative Metropolitan Data Source," January 1, 1977, https://www.osti.gov/biblio/5024064; Szasz and Meuser, "Environmental Inequalities."
[115] Robert D. Bullard, "Solid Waste Sites and the Black Houston Community*," *Sociological Inquiry* 53, no. 2–3 (1983): 273–88, https://doi.org/10.1111/j.1475-682X.1983.tb00037.x.

communities in which they live. The U.S. Government Accounting Office (GAO) under the U.S. Congress surveyed communities near several large hazardous commercial waste landfills in the southeastern United States and found that 3 out of 4 of these landfills are located in African American neighborhoods[116]. The second study was a survey conducted by the United Church of Christ's Commission for Racial Justice, which investigated and compared the areas with waste disposal sites and areas without waste disposal sites and found that race is an important influencing factor for choosing the location of commercial hazardous waste treatment sites. They published a research report entitled Toxic Waste and Race, which officially calls out the issue of environmental justice, which was hidden at the bottom of American society for a long time[117]. The classic study published by Bullard in 1983, Dumping in Dixie, found that 21 of 25 solid waste disposal sites in Houston are located around African American communities[118]. The National Law Journal published an article in 1992 pointing out that the government treats different races differently on environmental issues, emphasizing government inaction and legalization of discrimination are the main reason for the formation of environmental racism. Towards Environmental Justice: Research, Education, and Health Policy Needs, published by the Institute of Medicine in 1999, pointed out that government public health departments and medical-science groups should pay attention to environmental health issues in non-white communities[119]. These research agendas since the 1980s have provided strong evidence for the

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[116] U. S. Government Accountability Office, "Siting of Hazardous Waste Landfills and Their Correlation With Racial and Economic Status of Surrounding Communities," no. RCED-83-168 (June 14, 1983), https://www.gao.gov/products/RCED-83-168.

[117] United Church of Christ Commission for Racial Justice, *Toxic Wastes and Race in the United States: A National Report on the Racial and Socio-Economic Characteristics of Communities with Hazardous Waste Sites* (Public Data Access, 1987).

[118] Robert D. Bullard, *Dumping In Dixie : Race, Class, And Environmental Quality, Third Edition* (Routledge, 2018), 201, https://doi.org/10.4324/9780429495274.

[119] Institute of Medicine (US) Committee on Environmental Justice, *Toward Environmental Justice: Research, Education, and Health Policy Needs*, The National Academies Collection: Reports Funded by National Institutes of

existence of environmental injustice. The study found that race is the determinant of the unfair distribution of environmental risks. These research conclusions, on the one hand, benefited from the environmental movement in the 1980s. On the other hand, they provided a legal basis and empirical evidence for a new round of environmental movements.

2.8 Climate Justice

Climate change is one of the enormous global challenges facing humanity today. The prevailing scientific opinion is that the fossil energy burned by human production since industrialization has led to massive greenhouse gas emissions and that the greenhouse effect has contributed to the increase in global average temperature, leading to global glacial melting, ocean acidification, sea-level rise, extreme weather patterns, and a host of other problems. The IPCC concluded that human activities have most likely (over 95% probability) contributed to most (over 50%) of the increase in global average surface temperature since the 1950s[120]. This human-induced change in the natural world is unprecedented in both speed and scale, and it will have a significant impact on human well-being. IPCC states that if the current rate of emission growth is maintained, changes in the frequency and intensity of extreme weather events and sea-level rise are expected to have adverse effects on both natural and human systems.

The difficulty in addressing climate change lies not only in its scientific complexity and its close relationship with human production and life but also in its connection with the context of severe global development imbalances. Developed countries are more economically advanced

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Health (Washington (DC): National Academies Press (US), 1999), http://www.ncbi.nlm.nih.gov/books/NBK100862/.

[120] Intergovernmental Panel on Climate Change (IPCC), "Summary for Policymakers of IPCC Special Report on Global Warming of 1.5°C Approved by Governments," 2018, https://www.ipcc.ch/2018/10/08/summary-for-policymakers-of-ipcc-special-report-on-global-warming-of-1-5c-approved-by-governments/; P. R. Shukla et al., *Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems*, 2019.

and have a greater capacity to adapt to climate change, but their economies are large and still dependent on fossil energy consumption, so they will have a more significant influence on the future climate[121]. The same degree of climate change will have more severe consequences for developing countries because they will suffer more from the loss of basic subsistence livelihoods, while developed countries may have more significant book losses from disasters due to the higher value of fixed assets, but the impact of such losses on basic livelihoods will be smaller and more easily recovered than in developing countries. The same logic can be applied to a smaller scale that the better-off communities that reside in cities have the better financial capacity to adapt to the changing climate and potential disasters, while the less-advantaged groups are less resilient when a severe natural disaster happens with a much slower recovery speed[122].

The issue of justice has always been a primary concern of ethics. Liberalism, utilitarianism, communitarianism, Marxism, and other different streams of thought have had distinctive perspectives on justice. The 1992 Rio Declaration on Environment and Development[123] and the ensuing United Nations Framework Convention on Climate Change (UNFCCC) also include equity and justice in their statement of principles, bringing the concept of equity and justice to the core of global environmental governance[124]. The discussions of climate justice oftentimes adopt Rawls' Theory of Justice as a framework for research because his theory balances liberalism's emphasis on individual freedom and rights with egalitarianism's

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[121] Chukwumerije Okereke, "Climate Justice and the International Regime," *WIREs Climate Change* 1, no. 3 (2010): 462–74, https://doi.org/10.1002/wcc.52.
[122] Harriet Bulkeley et al., "Climate Justice and Global Cities: Mapping the Emerging Discourses," *Global Environmental Change* 23, no. 5 (October 1, 2013): 914–25, https://doi.org/10.1016/j.gloenvcha.2013.05.010.
[123] United Nations, "The Rio Declaration on Environment and Development," n.d., 8.
[124] Okereke, "Climate Justice and the International Regime."

pursuit of equality in distributive outcomes[125]. His Theory of Justice not only responds to the theoretical needs of modern society on how to practice equality by constructing a doctrinal system on equality but also responds to the challenges from extreme liberalism and extreme egalitarianism with an eclectic and integrated position[126].

In traditional discussions of justice, justice has been divided into retributive and corrective justice as well as distributive justice. This categorization can be adopted in the discussion of climate justice. At the same time, in Rawlsian principles of justice, equality of rights takes precedence over distributive justice, so there is also a need to incorporate a procedural justice perspective that guarantees equality of rights in the process[127]. When the Rio Declaration on Environment and Development and the UNFCCC refers to justice, the term was not interpreted, but rather through some of its provisions, such as the reference to 'common but differentiated responsibilities and respective capabilities in the principles of the Convention, and the reference to the protection of the climate system for the benefit of present and future generations of humankind[128]. These two points are clearly in line with the 1987 report 'Our Common Future by the World Commission on Environment and Development, which interprets sustainable development as the development that meets the needs of the present without compromising the ability of future generations to meet their own needs[129]. This establishes the core concepts of

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[125] O. Langhelle, “Sustainable Development and Social Justice: Expanding the Rawlsian Framework of Global Justice,” *Environmental Values* 9, no. 3 (August 1, 2000): 295–323, https://doi.org/10.3197/096327100129342074.
[126] Langhelle.
[127] Rawls, *A Theory of Justice*, 2009.
[128] United Nations, “The Rio Declaration on Environment and Development”; Intergovernmental Panel on Climate Change (IPCC), “Summary for Policymakers of IPCC Special Report on Global Warming of 1.5°C Approved by Governments.”
[129] Gro Harlem Brundtland, “Our Common Future—Call for Action*,” *Environmental Conservation* 14, no. 4 (ed 1987): 291–94, https://doi.org/10.1017/S0376892900016805.

intergenerational justice and intragenerational justice in formal international law documents, which are recognized and adopted by all parties.

The research topics in this dissertation are enlightened by the distributive justice concept, which is the allocation of fundamental rights and obligations. In the field of climate change, what needs to be allocated can be the space for emissions, the right to sustainable development, and the responsibility to mitigate emissions and support the less-advantaged groups in coping with climate change. From an intragenerational perspective, the right to development has primarily been secured or realized for the majority of people in developed, wealthier areas, while the right to development has yet to be limited for the majority of people in less-developed, financially challenged areas[130]. Nevertheless, because climate change requires a global reduction in greenhouse gas emissions, continued development as usual, or development that does not change quickly enough through high-emissions production and lifestyle, it will inevitably prevent others from realizing their right to development, and therefore is unjust and needs to be adjusted. From an intergenerational perspective, it is also unjust if the way in which the right to development is practiced by the present prevents future generations from practicing the right to development, and if the development of past generations prevents the present from achieving development in the same way as before[131]. This is the limit that 'sustainability' places on the right to development, that the freedom of citizens to pursue their individual well-being cannot interfere with each other, either intra- or intergenerationally. The allocation of responsibility for reducing emissions is based on 'common but differentiated responsibilities and respective capabilities, which intersects with compensatory justice, and the questions would be how to find ways to

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[130] Harriet Bulkeley, Gareth A. S. Edwards, and Sara Fuller, "Contesting Climate Justice in the City: Examining Politics and Practice in Urban Climate Change Experiments," *Global Environmental Change* 25 (March 1, 2014): 31–40, https://doi.org/10.1016/j.gloenvcha.2014.01.009.
[131] Langhelle, "Sustainable Development and Social Justice."

quantify and match responsibilities and capabilities. Similarly, this dissertation will focus on how responsibilities and capabilities will be quantified and matched in the EV policy discussion in later chapters.

One of the cornerstones of Rawls' doctrine of justice is based on the concern for human beings, and the 'least advantaged receive the most benefit' implies that even if inequalities in the distribution of wealth cannot be avoided, such inequalities are most just when they benefit the most vulnerable groups in the society[132]. This means that when the binding nature of the international system and the domestic laws and regulations cannot significantly adjust the distribution, for example, by the interventions in private property rights, the government should still prioritize the maximization of outcomes in favor of the interests of vulnerable groups, within the limits of what it can be constrained. Even in the absence of climate change, developed countries and the better-off communities still have a responsibility to help developing countries and the less-advantaged communities to achieve the development goals mentioned above. According to Rawls, institutions, regulations, and policies should be designed to benefit vulnerable groups as much as possible to alleviate the gap between the more-advantaged and the less-advantaged groups, especially in a world constrained by climate change.

2.9 Summary: Adopting the Rawlsian Theory

Urban planning and public policy are interdisciplinary fields of study, so are their equity and justice discussions. This chapter traces three schools of social equity and justice values: the neoliberalism thoughts, the neo-Marxism thoughts, as well as the communitarianism and

[132] KUKATHAS and PETTIT, "Rawls."

postmodernism thoughts. As noted by Lewis et al[133], the concept of equity is so expansive that researchers in transportation must explicitly define the normative criteria and assumptions used when equity is investigated. Precisely defining equity and justice is critical to avoid creating confusion by misusing the term in inappropriate contexts. Covering the predominant theories of equity in this chapter, thus, is a critical step prior to the quantitative research in the later chapters to evaluate equity and its relationship with EV.

Meanwhile, the emergence of EV is a hybrid of transportation, environment, and climate issues. Equity and justice issues are inseparable from these issues, whose core is often the fact that some groups in the society enjoy goods or services without bearing the externalities they create or the cost they consume, or the opposite situation that some groups in the society cannot enjoy goods or services while bearing the same burden as everyone. In the transportation equity discussions, it is found that the less-advantaged groups often reside in the neighborhoods that lack transportation infrastructure, which could undermine the mobility and accessibility of them. In environmental justice research, inequalities in access to environmental benefits, environmental losses, and environmental responsibility stem from elitism in the social structure, which leads to the systemic environmental injustice. The discussions in climate justice also notice that the less-advantaged groups are often exposed to the greater losses amid a disaster due to climate change. In addition, controversies arise when climate governance attempts try to reach a consensus on equal sharing of emission responsibilities, as the more-advantaged countries or groups of people generated more carbon emission in the past, and the current less-advantaged countries or groups of people are less capable of pay for the remedy of using carbon-extensive goods and services.

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[133] Elyse O'Callaghan Lewis, Don MacKenzie, and Jessica Kaminsky, "Exploring Equity: How Equity Norms Have Been Applied Implicitly and Explicitly in Transportation Research and Practice," *Transportation Research Interdisciplinary Perspectives* 9 (March 1, 2021): 100332, https://doi.org/10.1016/j.trip.2021.100332.

Given that, the research in this dissertation applies John Rawls' idea of justice as *fairness* and defines ***equity*** as a combination of *justice* and *fairness*, which is widely adopted in the above three disciplines. Rawls' theory balances the liberal emphasis on individual freedom and rights with the egalitarian quest for equality in distributive outcomes. His Theory of Justice not only responds to the theoretical needs of modern society on how to practice equality by constructing a doctrinal system on equality, but also responds to the challenges from liberalism, egalitarians, and Marxists with an eclectic and integrated position. Under the guidance of Rawlsian theories, the research topics aim to evaluate whether current EV-related measures and policies align with the Rawlsian principles, i.e., the least advantaged group of people receive the greatest benefits, and if not, what are some policy implications governments could adopt to make the transition to EV more equitable.

Chapter 3. OVERVIEW OF EV INCENTIVES

3.1 OVERVIEW

Different countries and regions have proposed a series of policies to promote the adoption of EVs. In the private sector, utility providers and automobile original equipment manufacturers (OEM) also enacted plans to promote EV adoption by providing their incentives to potential EV buyers. In general, the motivation of promoting EV purchase is to reduce the dependence on petroleum use, reducing the emission of greenhouse gas (GHG) emissions and thus reduce the negative impact of climate change, reduce air pollutant emissions, and promote economic growth. This section will discuss the primary forms of the incentives (and disincentives), the rationales for offering them, and in the end, their relationships to equity, which is surveyed in the previous section. As of 2022, the three economies with the most incentives for promoting EV adoption are the United States, the European Union, and China, which comprised of over 90% of world EV share[134]. This section will survey the incentives and disincentives, including the financial ones and non-financial ones, of these three economies.

Determining the total cost of ownership (TCO) for EV is critical for promoting the EV market penetration rate, as EV will be a much viable option for drivers as the TCO of EV decrease to the level of the TCO of an ICE, or even lower. The initial cost of electric vehicles has been much higher than conventional internal combustion engine (ICE) vehicles due to enormous costs of technology research and development of vehicles and batteries. The high price is one of the most critical market barriers of EV market penetration, and EV will not become the preferable option until it reaches a break-even point where the average price of buying an EV is

[134] IEA, "Global EV Outlook 2021," IEA, accessed February 25, 2022, https://www.iea.org/reports/global-ev-outlook-2021.

lower than that of buying a conventional ICE[135]. Therefore, financial incentives, including incentives on vehicle purchase, incentives on vehicle use/ownership, and incentives on charging infrastructure, are critical during the process of early stages of a transition to an electrified transportation system. Financial vehicle purchase incentives refer to direct discounts, payments, rebates, or tax credits to new EV purchases[136]. The discount of loan terms can also be regarded as a financial incentive for EV purchases. These benefits can be offered to the consumer at the time of purchase, applied as a discount to the vehicle purchase price, or be returned to the consumer after the purchase transaction is finished as a rebate. Other than the financial incentives, policymakers worldwide have also enacted non-financial incentives for owning or using an EV with non-monetary measures. These measures include allowing EV drivers to use dedicated high-occupancy vehicle (HOV) or public transit lanes, using certain parking areas that are not available to other vehicles, giving access to specific zones only to EV, and others[137].

3.2 Financial Incentives

3.2.1 *For EV Purchase*

The U.S. federal government incentivizes EV adoption by providing an income tax credit to consumers who purchase a qualified EV. Note that the content of the federal financial incentive is subject to change depending on whether the Build Back Better Act[138] will be introduced or not in 2022. The credit starts from $2,500 and has an incremental increase with larger battery

[135] Petra Zsuzsa Lévay, Yannis Drossinos, and Christian Thiel, "The Effect of Fiscal Incentives on Market Penetration of Electric Vehicles: A Pairwise Comparison of Total Cost of Ownership," *Energy Policy* 105 (June 1, 2017): 524–33, https://doi.org/10.1016/j.enpol.2017.02.054.
[136] Christiane Münzel et al., "How Large Is the Effect of Financial Incentives on Electric Vehicle Sales? – A Global Review and European Analysis," *Energy Economics* 84 (October 1, 2019): 104493, https://doi.org/10.1016/j.eneco.2019.104493.
[137] Scott Hardman, "Understanding the Impact of Reoccurring and Non-Financial Incentives on Plug-in Electric Vehicle Adoption – A Review," *Transportation Research Part A: Policy and Practice* 119 (January 1, 2019): 1–14, https://doi.org/10.1016/j.tra.2018.11.002.
[138] The White House, "The Build Back Better Framework," The White House, accessed February 25, 2022, https://www.whitehouse.gov/build-back-better/.

capacity, up to a maximum of $7,500[139]. The credit is capped for each company and is phased out at a discounted rate for a year, beginning approximately three to six months after the car OEM sells a total of 200,000 qualifying EVs. As of 2020, GM and Tesla have sold more than 200,000 and are no longer eligible for selling EVs with tax credit benefits[140].

The equity impact of this incentive was briefly discussed in the last section that the maximum tax credit amount is only offered to those who pay $7,500 or more federal income tax at the end of the year. Lower-income individuals or households are not likely to receive much from this financial incentive. For instance, a study by Liu et al[141] shows that the income threshold for a household with single filing status to receive the full federal EV incentive is $64,000 per year, and $89,700 for married filing jointly households. This incentive is not progressive for consumers as it is not widely available to the less advantaged groups in society. For automakers, EV market leaders will lose this financial incentive first, which may lead to a discouragement of technological innovation within the industry without further research and development subsidies.

The State of California offers an EV purchase rebate program, the California Clean Vehicle Rebate Program (CVRP). California EV buyers receive up to $2,500 to purchase or lease a new, eligible EV[142]. In March 2016, this rebate program included an equity improvement measure by making the rebate based on gross annual income, and no rebate will be available for

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139 Thomas Stephens et al., “Incentivizing Adoption of Plug-in Electric Vehicles: A Review of Global Policies and Markets” (Argonne National Lab. (ANL), Argonne, IL (United States), June 1, 2018), https://doi.org/10.2172/1480507.
140 U.S. Department of Energy, “Federal Tax Credits for Electric and Plug-in Hybrid Cars,” 2020, https://www.fueleconomy.gov/feg/taxevb.shtml.
141 Haobing Liu, Randall Guensler, and Michael Rodgers, “Equity Assessment of Plug-In Electric Vehicle Purchase Incentives with a Focus on Atlanta, Georgia,” June 2020, https://trid.trb.org/view/1737724.
142 California Air Resources Board, “Clean Vehicle Rebate Project,” Clean Vehicle Rebate Project, 2020, https://cleanvehiclerebate.org/eng.

those with a household income above a threshold, which is regulated by the CVRP program. For a household of 2 people, for instance, the household must have an annual income less than $68,960 in order to receive the incentive[143]. The State of New York also offers rebates of up to $2,000 for the purchase or lease of a new EV, but no equity considerations are included in the program[144]. In China, a direct purchase rebate for EV has been enacted since 2009. From 2009 to 2012, the central government provides EV purchase rebate for up to $7,800 U.S. dollars based on battery capacity. From 2012 to 2015, the rebate was decreased to $7,400, with the subsidy basis shifted to the electric vehicle range. The subsidy ramps down quickly from 2016, and the financial incentive program officially ended in 2021[145]. Instead of direct financial subsidies, China has changed its stance to a market-based approach that requires automakers to trade credits of low- or zero-emission vehicles. Also, subsidies will be offered to favor EV with more advanced technologies, such as more extended range and better battery quality, instead of a universal incentive system. In general, it is foreseeable that the financial incentives of purchasing EVs will phase out as the technology becomes increasingly available, as it will be more and more challenging to fund these programs from the public sector. However, programs like the California rebate program, which includes an equity consideration by giving the most benefits to the least advantaged, is much more desirable than the federal tax credit program, which provides the most benefits to the rich.

[143] California Clean Vehicle Rebate Project, "Income Eligibility, Clean Vehicle Rebate Project," accessed February 25, 2022, https://cleanvehiclerebate.org/en/income-eligibility.

[144] The New York State Energy Research and Development Authority, "Drive Clean Rebate for Electric Cars," NYSERDA, 2020, https://www.nyserda.ny.gov/All-Programs/Programs/Drive-Clean-Rebate.

[145] Zhenya Ji and Xueliang Huang, "Plug-in Electric Vehicle Charging Infrastructure Deployment of China towards 2020: Policies, Methodologies, and Challenges," *Renewable and Sustainable Energy Reviews* 90 (July 1, 2018): 710–27, https://doi.org/10.1016/j.rser.2018.04.011.

In Washington State, new EVs are exempt from state motor vehicle sales tax and use taxes. The EV must have a base model price of $42,500 or less, and the sales tax exemption applies to only up to $32,000 of a vehicle's manufacturer suggested retail price (MSRP)[146]. This tax benefit includes an equity consideration of providing the most benefits to those who cannot afford a more luxurious car that costs more than $32,000. In Norway, sales of EV have had an exemption from the sales tax on new vehicles, which is a flat rate, 25% of the purchase price for conventional vehicles and hybrid vehicles for all EVs[147]. Similar sales tax exemption programs can also be found in most European countries and most cities in China[148].

3.2.2 *Financial Incentives for EV Use and Charging*

Vehicle use and ownership incentives reduce the cost of owning and using an EV and can take multiple forms. Vehicle ownership taxes or fees, including annual taxes, registration fees, or license fees, may be reduced or eliminated. Some jurisdictions charge a registration fee for EV to compensate for the reduction in gasoline tax revenues. Financial incentives for EV charging infrastructure include subsidies, rebates, or tax credits to defer the purchase and installation costs of electric vehicle supply equipment (EVSE), also known as charging stations. Government-provided or subsidized charging infrastructure, frequently in conjunction with dedicated EV parking, can help address the problem of limited EV range and the inability to charge at home. Some jurisdictions offer free or discounted EV charging, and some EV manufacturers and utilities offer this incentive. Other infrastructure incentives, such as the development of building

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[146] Stephens et al., "Incentivizing Adoption of Plug-in Electric Vehicles."
[147] Slowik and Nutsey, "Evolution of Incentives to Sustain the Transition to a Global Electric Vehicle Fleet," 2016, https://theicct.org/publications/evolution-incentives-sustain-transition-global-electric-vehicle-fleet.
[148] Ning Wang, Linhao Tang, and Huizhong Pan, "A Global Comparison and Assessment of Incentive Policy on Electric Vehicle Promotion," *Sustainable Cities and Society* 44 (January 1, 2019): 597–603, https://doi.org/10.1016/j.scs.2018.10.024.

codes that require pre-wiring for EV charging in residential and parking structures, are mostly local.

Adopting EV depends on developing charging infrastructure, and they can be charged from a standard power outlet or at a direct current fast-charging station. Infrastructure is not a direct way to motivate consumers to adopt EV. However, increasing the number of EV charging stations could incentivize consumers to adopt the technology. Policymakers, workplaces, utility companies, and local agencies are promoting the introduction of such infrastructure in the hope of increasing EV's market share. In some areas, charging is free, giving consumers an extra incentive. Some U.S. states also proposed financial incentives for EVSE installations with an income tax credit at the state level. In Georgia, businesses could purchase or lease qualified EVSEs and receive 10% of the cost of EVSE as a tax credit, up to $2,500[149]. The State of New York also offers an income tax credit for 50% of the cost of charging infrastructure for up to $5,000[150]. This incentive's equity implication is similar to the income tax credit when making new EV purchases that only the higher-income consumers could enjoy the benefit of the incentive to the maximum level. In California, although no financial incentives for the private purchase of EVSEs, the California Capital Access Program and the Electric Vehicle Charging Station Financing Program provide loan guarantees to help finance the installation of EVSE at small businesses in the state[151].

In some countries and regions, vehicles are subject to an annual tax or fee. The tax or fee occurs every year a vehicle is registered on the road. Tax is calculated based on the vehicle's

[149] Stephens et al., “Incentivizing Adoption of Plug-in Electric Vehicles.”
[150] The New York State Energy Research and Development Authority, “Drive Clean Rebate for Electric Cars.”
[151] California Air Resources Board, “Low Carbon Transportation Investments and AQIP Grant Solicitations,” 2017, https://ww2.arb.ca.gov/our-work/programs/low-carbon-transportation-investments-and-air-quality-improvement-program/low.

carbon dioxide emissions or fuel-efficiency, vehicle weight, and class combined. Since EV emissions are considered lower than ICE emissions, this tax or fee is usually paid less or sometimes exempt. However, due to potential gasoline tax loss because of the EV adoption, some regions are increasing the fees for EV registration and thus provide financial disincentives for owning an EV. In Washington State, EV owners must pay an EV-specific annual vehicle registration renewal fee, directly contributing to the state's Electric Vehicle Infrastructure Bank to install more charging stations. The State of Michigan also charges an increased vehicle registration fee for EVs.

3.3 Non-Financial Incentives

3.3.1 *HOV and Transit Lanes*

High Occupancy Lanes (HOV), bus lanes, and bus rapid transit (BRT) lanes as restricted lanes are sometimes open to single-occupancy EVs in some regions. The HOV lane usually accommodates two or more vehicles. Rules that restrict access sometimes operate only during rush hour, and in some cities, open during rush hour and non-rush hour. A bus lane is a lane that is usually only open to buses, coaches, or public transit vehicles. A taxi, motorcycle, or cyclist can usually enter the lane. Some countries have priority lanes or bus rapid transit lanes, usually restricted or paid for with tolls. Some cities in the world have introduced incentives to allow EV unlimited access to these lanes. In California, EVs with a California Department of Motor Vehicles Clean Air Vehicle sticker may use HOV lanes regardless of the number of occupants in the car. In New York, EVs and hybrid vehicles may use the Long Island Expressway HOV lanes regardless of the vehicle's number of occupants. Cities in France, Germany, the Netherlands, and Hungary have also provided EVs access to restricted traffic zones, allowing their drivers to benefit from more flexibility.

Analysis of market data from existing literature indicates a statistical association between EV adoption rate and HOV incentives in California that up to 50% of EV adoption increase is associated with HOV policies[152],[153]. Qualitative analysis also found that potential EV buyers who live in areas with heavier traffic congestions tend to value HOV incentives more, although these incentives are not the most fundamental reason for luxurious EV[154]. Two stated preferences analyses in Norway could not conclude a statistical correlation between HOV policy intervention and increasing EV sales, as respondents were concerned about EVs causing congestion in bus lanes[155],[156] (Aasness and Odeck, 2015; Zhang et al., 2016). From the perspective of transportation equity, HOV incentives will not be the desirable transportation policy in urban areas, especially those with congestion problems in the city center and on freeways. As a common way of providing disincentives for taking trips in single-occupancy vehicles, the HOV lane is built to encourage people to share the vehicle, carpool, or take the public transit more often. The less advantaged groups usually are more sensitive to the out-of-pocket cost of transportation services and thus have fewer travel mode options[157]. As urbanization and suburbanization accelerate, the less advantaged are exposed to longer travel distance and travel time. Compared to public transportation, single-occupancy vehicles are providing less collective mobility with occupying more social resources and road space, and at the same time take much

[152] Alan Jenn, Katalin Springel, and Anand R. Gopal, "Effectiveness of Electric Vehicle Incentives in the United States," *Energy Policy* 119 (August 1, 2018): 349–56, https://doi.org/10.1016/j.enpol.2018.04.065.
[153] Lutsey et al., "Sustaining Electric Vehicle Market Growth in U.S. Cities," 2016, https://theicct.org/leading-us-city-electric-vehicle-2016.
[154] Scott Hardman and Gil Tal, "Exploring the Decision to Adopt a High-End Battery Electric Vehicle: Role of Financial and Nonfinancial Motivations," *Transportation Research Record* 2572, no. 1 (January 1, 2016): 20–27, https://doi.org/10.3141/2572-03.
[155] Yingjie Zhang et al., "The Impact of Car Specifications, Prices and Incentives for Battery Electric Vehicles in Norway: Choices of Heterogeneous Consumers," *Transportation Research Part C: Emerging Technologies* 69 (August 1, 2016): 386–401, https://doi.org/10.1016/j.trc.2016.06.014.
[156] Marie Aarestrup Aasness and James Odeck, "The Increase of Electric Vehicle Usage in Norway—Incentives and Adverse Effects," *European Transport Research Review* 7, no. 4 (October 8, 2015): 34, https://doi.org/10.1007/s12544-015-0182-4.
[157] Martens, "Justice in Transport as Justice in Accessibility."

more travel cost than public transit. HOV and transit lane incentives for EV undermine these lanes' purpose, which is reducing driving and encouraging more travel using public transit and carpooling. Therefore, these incentives are regressive, inequitable measures and challenge the unremitting efforts of promoting public transit by transportation planning policies.

3.3.2 *Road Pricing Incentive*

In some countries and regions, tolls are collected on certain roads, bridges, and tunnels. Drivers have to pay a fee to enter these places, and the toll revenue will fund the construction and maintenance of the transportation infrastructure. Some countries allow EV to travel on these roads without paying tolls or giving EV discounts. Road pricing zones, such as London's cordon congestion charge, require vehicles to pay a fee to enter any part of the area. Some congestion charging zones have a waiver for EVs[158]. In New York, EVs are eligible for a discounted toll rate on Port Authority of New York and New Jersey off-peak hour crossings. In Norway, EVs have free access to the tolled highways[159].

Looking at the toll exemption incentives for EVs from an equity perspective, one breakthrough point is to evaluate if current tolls provide equitable outcomes for transportation system users and predict if an exemption of toll for EVs will strengthen or undermine this positive outcome. Road pricing takes many forms, including tolls, cordon pricing, road use tax/fees based on mileage, and high-occupant toll (HOT) lanes. In Levinson's (2010) review of analyzing the literature of road pricing, it is found that "there are three decisions that affect equity: allocating the burden of charges, spending the revenue, and distributing the externalities.

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[158] Stephens et al., "Incentivizing Adoption of Plug-in Electric Vehicles."
[159] Zhang et al., "The Impact of Car Specifications, Prices and Incentives for Battery Electric Vehicles in Norway."

Road pricing also affects the amount and type of mobility that is subsequently consumed."[160] Therefore, the pricing system's design, including how the revenue should be distributed, such as to reduce taxes, build more roads, subsidize public transportation, or for other purposes, has significant implications for equity. Desired equitable outcomes could be achieved with the appropriate incentives to individual travelers and proper distribution of road pricing revenue. However, making EVs exempt from such a pricing scheme subverts road pricing's original purpose, which is a powerful instrument to smother congestion in urban traffic. Considering the circumstance that road pricing is usually exposed to a systematic hostile political environment[161], the attempt of excluding EV, whose market share will keep increasing, is not desirable for an equitable transportation system.

3.3.3 *Parking Benefits Incentive*

Parking incentives include free or discounted parking in fee-paying parking lots or garages. It can also include spaces reserved for EV or at concessionary locations. In many cases, EV parking spaces will also have EV charging capabilities, sometimes free of charge. However, free parking has long been considered undesirable in transportation planning scholarship, including evaluating from an equity perspective. In Donald Shoup's (2011) seminal work *The High Cost of Free Parking*, such argument was made that can fit perfectly in the EV's parking incentive context:

> *"Charging for curb parking that was formerly free may seem to be a "taking" by the community, but this is unfair only if motorists are assumed to have a private*

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[160] David Levinson, "Equity Effects of Road Pricing: A Review," *Transport Reviews* 30, no. 1 (January 1, 2010): 33–57, https://doi.org/10.1080/01441640903189304.

[161] Robin Lindsey, "Do Economists Reach A Conclusion on Road Pricing? The Intellectual History of an Idea," *ECON JOURNAL WATCH* 3, no. 2 (2006): 88.

right to public property without payment. Motorists have not earned a right to park free, so it is more appropriate to think of free parking as a "giving" than of charging for parking as a taking. The giving, not the taking, needs justification."[162]

Free parking has led to dependence on the automobile, endless sprawl processes, overconsumption of energy and resources, and transformed cities in the U.S. to a form more suitable for cars, not for people. A free parking benefit for EV patently deters the long-lasting endeavor to prioritize public transit, reduce car ownership, and improve street designs. Another factor to take into consideration is paid parking. Like road pricing, paid parking revenues could be redistributed purposefully to target the less advantaged groups to put the transportation policies in the position of the Rawlsian equity principles. For the revenue generated by parking, Shoup remarks:

"Charging for curb parking is fairer than requiring off-street parking, but will the resulting pattern of public spending also be fair? … the rich usually live far from land uses that create spillover parking. Still, many poor families also live in neighborhoods with no prospect of earning much curb revenue, and some rich people live at high densities on streets (such as Fifth Avenue or Wilshire Boulevard) that can earn substantial revenue. In these cases, a form of revenue sharing can counteract the potential for inequities in spending patterns.[163]*"*

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[162] Donald Shoup, *The High Cost of Free Parking: Updated Edition* (Routledge, 2017). "Part III. Cashing in on Curb Parking: The Idea Source of Local Public Revenue – Equity."
[163] Shoup.

Chapter 4. DIFFERENT SOCIAL GROUPS' REACTIONS TO PLANNING-RELATED EV INCENTIVES: AN EXAMPLE OF CALIFORNIA

4.1 INTRODUCTION

Different countries and regions have proposed a series of policies to promote the adoption of EVs. In general, the motivation of promoting EV purchase is to reduce the dependence on petroleum use, reducing the emission of greenhouse gas (GHG) emissions and thus reduce the negative impact of climate change, reduce air pollutant emissions, and promote economic growth[164]. This chapter will pinpoint three planning-related forms of the incentives, discuss the rationales for offering them, and in the end, evaluate their relationships to equity and justice.

Local governments around the world have implemented planning incentives for owning or driving an EV with non-financial measures. These measures include allowing EV drivers to use dedicated high-occupancy vehicle (HOV) or public transit lanes, using certain parking areas that are not available to other vehicles, giving access to specific zones only to EV, and others. Parking incentives include free or discounted parking in fee-paying parking lots or garages. It can also include spaces reserved for EV or at concessionary locations. In many cases, EV parking spaces will also have EV charging capabilities, sometimes free of charge. However, free parking has long been considered undesirable in transportation planning scholarship, including evaluating from an equity perspective[166]. High Occupancy Lanes (HOV) as restricted lanes are sometimes open to single-occupancy EVs in some regions. The HOV lane usually accommodates two or more person vehicles. Rules that restrict access sometimes operate only

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[164] Martino Tran et al., "Realizing the Electric-Vehicle Revolution," *Nature Climate Change* 2, no. 5 (May 2012): 328–33, https://doi.org/10.1038/nclimate1429.
[166] Shoup, *The High Cost of Free Parking*.

during rush hour, and in some cities, open during rush hour and non-rush hour. Some countries have priority lanes or bus rapid transit lanes, usually restricted or paid for with tolls. Some cities in the world have introduced incentives to allow EV unlimited access to these lanes[167] [168]. In California, EVs with a California Department of Motor Vehicles Clean Air Vehicle sticker may use HOV lanes regardless of the number of occupants in the car. In New York, EVs and hybrid vehicles may use the Long Island Expressway HOV lanes regardless of the vehicle's number of occupants. Cities in France, Germany, the Netherlands, and Hungary have also provided EVs access to restricted traffic zones, allowing their drivers to benefit from more flexibility.

To provide better incentives and disincentives for the transportation sector to electrification, the public sector must identify the population group that react to each incentive the most effectively. However, to our knowledge, there are no research demonstrate the effectiveness of these policies, especially among diverse income and racial groups. Answering this question will provide policy implication about which incentives and disincentives are desirable from the perspectives of equity and justice, and which are not.

There are three research questions for this study. First, how do different EV owner groups respond to various incentives differently, i.e., who are the intended target groups of the incentives. Secondly, whether these characteristics change in the last three years, and if so, how they changed. Thirdly, what are the policy implications, especially from the equity perspective, with the information of different incentive performance among different socioeconomic groups. The three planning-related EV incentives to be examined in this research are: (1) EV owners can

[167] Lutsey et al., "Sustaining Electric Vehicle Market Growth in U.S. Cities."
[168] Aasness and Odeck, "The Increase of Electric Vehicle Usage in Norway—Incentives and Adverse Effects."

use a public charging station nearby; (2) EV owners can have free parking; (3) EV owners can use the HOV lane on freeways, regardless how many passengers there are in the vehicle.

4.2 BACKGROUND

Recently, there is a large volume of literature that evaluated the three planning-related EV incentives and their effectiveness in the United States, European Union, and China (See Table 1). In this list of 58 publications between 2015 and 2021, EV adoption and charging infrastructure research tops with 25 articles (43%), followed by free parking incentivize EV purchase (14 articles; 24%) and the association between HOV lane policy and EV adoption rate (19 articles; 33%). In general, the research shows there is a statistically significant relationship between the corresponding incentives and EV adoption: among the 58 literatures for cities worldwide, 22 out of 25 (84%) EVSE incentives studies, 11 out of 14 (79%) parking incentives studies, and 10 out of 19 (53%) HOV incentives studies. For the articles indicating marked "no" in the table, it refers to either there is no statistical relationship between the policy and EV adoption rate, or the relationship has a weak significance that the level of association is inconclusive. Although the relationship between the planning-related incentives and EV adoption rate is broadly investigated in these studies, none of them surveyed the equity impact addressing how the results may vary among different income and racial groups.

Table 1. List of Literature on How the Planning-related EV Incentives Related to EV Adoption

Authors	**Region**	**EVSE**	**Free Parking**	**HOV lane**	**Remarks**
Aasness and Odeck (2015)	Norway		Yes	Yes	Free parking and HOV/bus lane access have positive impact on EV adoption[169]
Adepetu et al (2016)	California	Yes			Workplace charging has slight impact on EV adoption[170]
Ajanovic and Haas (2016)	Global	Yes	Yes	Yes	All three incentives are important for promoting EV[171]
Bjerkan et al (2016)	Norway		Yes	Yes	Free parking and toll-free & bus lane access are the most important incentives[172]
Bonges and Lusk (2016)	USA	Yes			Working on charging infrastructure will increase adoption rate[173]
Clinton et al (2015)	USA			No	Inconclusive result for HOV incentive[174]
Coffman et al (2017)	Global	No		No	Impact of HOV lane not well understood; EVSE to adoption rate causality not clear[175]
Egner and Trosvik (2018)	Sweden	Yes	Yes		Parking and EVSE incentives are both effective for increasing adoption rate[176]

[169] Aasness and Odeck.
[170] Adedamola Adepetu, Srinivasan Keshav, and Vijay Arya, "An Agent-Based Electric Vehicle Ecosystem Model: San Francisco Case Study," *Transport Policy* 46 (February 1, 2016): 109–22, https://doi.org/10.1016/j.tranpol.2015.11.012.
[171] Amela Ajanovic and Reinhard Haas, "Electric Vehicles: Solution or New Problem?," *Environment, Development and Sustainability* 20, no. 1 (December 1, 2018): 7–22, https://doi.org/10.1007/s10668-018-0190-3.
[172] Kristin Ystmark Bjerkan, Tom E. Nørbech, and Marianne Elvsaas Nordtømme, "Incentives for Promoting Battery Electric Vehicle (BEV) Adoption in Norway," *Transportation Research Part D: Transport and Environment* 43 (March 1, 2016): 169–80, https://doi.org/10.1016/j.trd.2015.12.002.
[173] Henry A. Bonges and Anne C. Lusk, "Addressing Electric Vehicle (EV) Sales and Range Anxiety through Parking Layout, Policy and Regulation," *Transportation Research Part A: Policy and Practice* 83 (January 1, 2016): 63–73, https://doi.org/10.1016/j.tra.2015.09.011.
[174] Bentley Clinton et al., "Impact of Direct Financial Incentives in the Emerging Battery Electric Vehicle Market: A Preliminary Analysis (Presentation)," 2015, 36.
[175] Makena Coffman, Paul Bernstein, and Sherilyn Wee, "Electric Vehicles Revisited: A Review of Factors That Affect Adoption," *Transport Reviews* 37, no. 1 (January 2, 2017): 79–93, https://doi.org/10.1080/01441647.2016.1217282.
[176] Filippa Egnér and Lina Trosvik, "Electric Vehicle Adoption in Sweden and the Impact of Local Policy Instruments," *Energy Policy* 121 (October 1, 2018): 584–96, https://doi.org/10.1016/j.enpol.2018.06.040.

Figenbaum and Kolbenstvedt (2016)	Norway	Yes	Yes		Free parking is the most important incentive. Free charging comes second.[177]
Hardman and Tal (2016)	California	No	No	No	Charging, free parking and HOV lane are not motivational factors[178]
Huang and Qian (2018)	China	Yes		No	Customers are the most sensitive to EVSE availability[179]
Javid and Nejat (2017)	California	Yes			Developing EVSE infrastructure can help increase EV sales[180]
Jenn et al (2018)	USA		Yes	Yes	HOV lane access could increase EV sales by around 50%.[181]
Jia and Chen (2021)	Virginia	Yes			EV owners value charging availability the most[182]
Kangur et al (2017)	Netherlands	Yes			Fast charging networks lead to higher EV adoption rate[183]
Levinson and West (2017)	USA	Yes			Fast charging is effective at encouraging EV sales.[184]
Liao et al (2017)	Global	No	No		Inconclusive result for free parking and EVSE incentives[185]

[177] Erik Figenbaum and Marika Kolbenstvedt, "Learning from Norwegian Battery Electric and Plug-in Hybrid Vehicle Users," Report (TØI Transportøkonomisk institutt, June 2016), https://vegvesen.brage.unit.no/vegvesen-xmlui/handle/11250/2684143.
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[184] Rebecca S. Levinson and Todd H. West, "Impact of Convenient Away-from-Home Charging Infrastructure," *Transportation Research Part D: Transport and Environment* 65 (December 1, 2018): 288–99, https://doi.org/10.1016/j.trd.2018.09.006.
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Lieven (2015)	Global	Yes	Yes	Yes	All incentives are effective, but different consumers value different incentives differently[186]
Liu et al (2021)	China	Yes			Charging infrastructure is the most significant factor for EV purchase[187]
Lutsey et al (2016)	USA	Yes	Yes	Yes	All incentives are significantly associated to EV market share[188]
Ma et al (2019)	China		No	No	Parking and HOV lane access not correlated to willingness to pay[189]
Mersky et al (2016)	Norway	Yes		No	Charging infrastructure is the most significant predictor of EV market share.[190]
Narassimhan and Johnson (2018)	USA	Yes		No	Charging incentives are correlated with EV sales; HOV lanes not significant[191]
Plotz et al (2016)	Global	Yes			EV adoption is correlated to availability of charging stations[192]
Sheldon and Deshazo (2017)	California			Yes	Early EV adopters before 2013 value HOV lane access[193]
Tietge et al (2016)	Global	Yes		Yes	Financial incentives not enough to encourage EV purchase; charging and HOV lane incentives could be encouraged[194]

186 Theo Lieven, "Policy Measures to Promote Electric Mobility – A Global Perspective," *Transportation Research Part A: Policy and Practice* 82 (December 1, 2015): 78–93, https://doi.org/10.1016/j.tra.2015.09.008.
187 Shuohan Liu et al., "Reservation-Based EV Charging Recommendation Concerning Charging Urgency Policy," *Sustainable Cities and Society* 74 (November 1, 2021): 103150, https://doi.org/10.1016/j.scs.2021.103150.
188 Lutsey et al., "Sustaining Electric Vehicle Market Growth in U.S. Cities."
189 Shao-Chao Ma, Jin-Hua Xu, and Ying Fan, "Willingness to Pay and Preferences for Alternative Incentives to EV Purchase Subsidies: An Empirical Study in China," *Energy Economics* 81 (June 1, 2019): 197–215, https://doi.org/10.1016/j.eneco.2019.03.012.
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192 Patrick Plötz, Till Gnann, and Frances Sprei, "Can Policy Measures Foster Plug-in Electric Vehicle Market Diffusion?," *World Electric Vehicle Journal* 8, no. 4 (December 2016): 789–97, https://doi.org/10.3390/wevj8040789.
193 Tamara L. Sheldon, J. R. DeShazo, and Richard T. Carson, "ELECTRIC AND PLUG-IN HYBRID VEHICLE DEMAND: LESSONS FOR AN EMERGING MARKET: DEMAND FOR PLUG-IN HYBRIDS," *Economic Inquiry* 55, no. 2 (April 2017): 695–713, https://doi.org/10.1111/ecin.12416.
194 Uwe Tietge et al., *Comparison of Leading Electric Vehicle Policy and Deployment in Europe*, 2016.

Wang et al (2017)	China	Yes	Yes	Yes	All three incentives are important but not the most significant in China[195]
Wang et al (2017)	China	Yes	Yes	Yes	All incentives are effective for EV purchase[196]
Wee et al (2018)	China	Yes			Public charging infrastructure have an impact, but not the most significant[197]
Wolbertus et al (2018)	USA	Yes	Yes	No	Charging is significantly related. Free parking effectiveness depends on parking costs. HOV lane not effective[198]
Zhang et al (2016)	Norway	Yes		No	HOV/bus lane not favored; charging infrastructure are significant to EV sales[199]

Yes: significantly positive effect reported; No: insignificant effect reported; blank: not mentioned

[195] Shanyong Wang, Jun Li, and Dingtao Zhao, "The Impact of Policy Measures on Consumer Intention to Adopt Electric Vehicles: Evidence from China," *Transportation Research Part A: Policy and Practice* 105 (November 1, 2017): 14–26, https://doi.org/10.1016/j.tra.2017.08.013.
[196] Ning Wang, Linhao Tang, and Huizhong Pan, "Effectiveness of Policy Incentives on Electric Vehicle Acceptance in China: A Discrete Choice Analysis," *Transportation Research Part A: Policy and Practice* 105 (November 1, 2017): 210–18, https://doi.org/10.1016/j.tra.2017.08.009.
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[198] Rick Wolbertus et al., "Fully Charged: An Empirical Study into the Factors That Influence Connection Times at EV-Charging Stations," *Energy Policy* 123 (December 1, 2018): 1–7, https://doi.org/10.1016/j.enpol.2018.08.030.
[199] Zhang et al., "The Impact of Car Specifications, Prices and Incentives for Battery Electric Vehicles in Norway."

4.3 METHODOLOGY

In this chapter, we focus on the equity aspects of incentives investigating how different socioeconomic groups react to various incentives in the case of California state from 2017 and 2019. To explore the demographic factors of the self-reported importance of each incentive, an ordered logistic regression will be used, because the dependent variable is categorical with multiple levels and a meaningful order. In common logistic regression, dependent variable Y is a dummy variable with two options, such as "important" and "not important". Multinomial logistic regression refers to the regression models with a categorical dependent variable Y with more than two options. Ordered logistic regression, meanwhile, have Y as a categorical variable with orders. In this study, the level of importance is reordered to five categories: "not at all important", "slightly important", "moderately important", "very important", and "extremely important". Ordered logistic regression is a special form of multinomial logistic regression[200]. The next section will describe the model and the modification to fit it in R program.

Assuming that the explanatory variable Y has J classes and ordered, then Y is less than or equal to the cumulative probability of a specific class j, which can be written as $P(Y \leq j)$, and $j = 1, \cdots, J-1$.

Thereby, less than or equal to a specific category j can be defined as the ratio of:

$$\frac{P(Y \leq j)}{P(Y > j)} \tag{1}$$

Taking the logarithm of this ratio is what we know as logit:

[200] Andrew S. Fullerton, "A Conceptual Framework for Ordered Logistic Regression Models," *Sociological Methods & Research* 38, no. 2 (November 1, 2009): 306–47, https://doi.org/10.1177/0049124109346162.

$$log\frac{P(Y\leq j)}{P(Y>j)} = logit\big(P(Y \leq j)\big)$$

(2)

The mathematical model of ordered logistic regression, then, is:

$$logit\big(P(Y \leq j)\big) = \beta_{j0} + \beta_{j1}x_1 + \cdots + \beta_{jp}x_p$$

(3)

where α is the intercept, β is the regression coefficient, and x_i (i = 1, 2, .. p) refers to each independent variable. Note that the ordered categorical logistic regression model has $J - 1$ logit models. For each model, the coefficients are the same and the intercepts are different.

The MASS:polr library in R will be used. It should be noted that using this function, the corresponding model expression needs to be modified, with the slope sign written as a negative sign.

$$logit\big(P(Y \leq j)\big) = \alpha_j - \beta_1 x_1 - \beta_2 x_2$$

(4)

The expression of proposed regression analysis is:

$$logit\big(P(Y \leq j)\big) = \alpha_j - \beta_1 x_1 - \beta_2 x_2 - \beta_3 x_3 - \beta_4 x_4 - \beta_5 x_5 - \beta_6 x_6$$

(5)

In which the independent variables, from x_1 to x_6 , refer to gender, race, low-income (or high-income) status, employment, education, and housing. For pooled two time period datasets, a common practice is to add a year dummy variable to assume a time modifying effect. The assumption is that there is a time trend in the change of the incentive importance of the total population, and the coefficient of year dummy captures the slope of the line of this trend. This analysis will use the function

$$logit\big(P(Y \leq j)\big) = \alpha_j - \beta_1 x_1 - \beta_2 x_2 - \beta_3 x_3 - \beta_4 x_4 - \beta_5 x_5 - \beta_6 x_6$$
$$-\gamma_1(x_1 * t) - \gamma_2(x_2 * t) - \gamma_3(x_3 * t) - \gamma_4(x_4 * t) - \gamma_5(x_5 * t) - \gamma_6(x_6 * t) \tag{6}$$

where t is the dummy variable indicating the time change from 2017 to 2019 as a before-after effect.

4.4 DATA

The 2017[201] and 2019 California Vehicle Surveys[202] will be used to build a framework to estimate the importance of each incentive to the decision-making process of EV buyers. Conducted by California Energy Commission, the California Vehicle Survey is one of the biggest vehicle surveys in the United States with a sizable sample. The survey provides information on shifting transportation choice trends by capturing consumer preferences of various vehicle attributes, especially for EV[203]. Demographic information and travel behavior of thousands of automobile drivers, including 279 EV drivers in 2017 and 316 EV drivers in 2019 in California are collected. In addition to economic and demographic data, the survey integrated light-duty vehicle ownership and use information with vehicle choice data collected via the stated preferences survey's set of eight vehicle and fuel type choice exercises. EV owner survey participants also provided additional data on charging behavior, electricity rates, and their main motivations for purchasing EVs. Table 2 lists the count of the EV driver sample size for 2017

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[201] National Renewable Energy Laboratory, "2017 California Vehicle Survey," accessed September 28, 2021, https://www.nrel.gov/transportation/secure-transportation-data/tsdc-california-vehicle-survey-2017.html.
[202] National Renewable Energy Laboratory, "2019 California Vehicle Survey," accessed September 28, 2021, https://www.nrel.gov/transportation/secure-transportation-data/tsdc-2019-california-vehicle-survey.html.
[203] National Renewable Energy Laboratory.

and 2019, as well as the breakdown of demographic and housing status. These variables will be used as independent variables in the ordered logit model.

Table 2. Sample Description of Battery Electric Vehicle Owners in California, Years 2017 and 2019

Variables		2017		2019	
Sample Size		172	(100%)	279	(100%)
Gender					
	Female	41	(24%)	129	(46%)
	Male	130	(76%)	149	(53%)
Income					
	< 50k	12	(7%)	8	(3%)
	50-100k	36	(21%)	57	(20%)
	100-150k	44	(26%)	45	(16%)
	150-200k	21	(12%)	51	(18%)
	200-250k	23	(13%)	49	(18%)
	> 250k	35	(20%)	68	(24%)
Race					
	Asian	21	(12%)	64	(23%)
	Black	2	(1%)	8	(3%)
	Hispanic/Latino	16	(9%)	27	(10%)
	White	132	(77%)	177	(63%)
Education					
	High School or less	4	(2%)	17	(6%)
	Some College	18	(10%)	51	(18%)
	Bachelor’s degree	62	(36%)	97	(35%)
	Post-Graduate Degree	87	(51%)	113	(41%)
Employment					
	Full-time	93	(54%)	142	(51%)
	Part-time	6	(3%)	35	(13%)
	Self employed	21	(12%)	27	(10%)
	Unemployed/Retired	51	(30%)	74	(27%)
Owner vs. Renter					
	Single Family Housing	139	(81%)	225	(81%)
	Townhouse/Duplex	13	(8%)	18	(6%)
	Condo/Apartments	19	(11%)	39	(14%)

The survey response includes the self-evaluation of importance of different financial and non-financial incentives, including the federal tax incentive, the state and the local rebate programs, charging infrastructure availability, free parking, HOV lane access, and better deal at the car dealership, during their vehicle purchase decision-making. Among these incentives, self-evaluated importance of three planning-related incentives, namely charging infrastructure availability, free parking, and HOV lane access, are analyzed as they are identified as three of the most important non-financial incentives investigated by existing literature. Five categories are applied to these responses from “extremely important” to “not at all important”. Considering the survey respondents may have different perceptions of the words like “extremely” and “slightly”, this analysis does not transform the categorical survey response to continuous scores. Figure 1 to Figure 3 demonstrate the distribution of importance evaluation of three incentives in the year of 2017 and 2019. The public leaned strongly to considering public charging infrastructure more important in 2017, as more people chose the option “extremely important” than other options. The distribution of option selection has become more like a normal distribution in 2019, where most people consider this incentive slightly, moderately, or very important, rather than “extremely important.” For the free parking incentive, EV owners were less enthusiastic about this incentive in 2017, that fewest considered this incentive “extremely important.” This observation becomes more perceivable in 2019, that an overwhelmingly large amount of survey respondents chose the options “not at all important”, “slightly important”, and “moderately important.” For HOV lane access, the distribution of importance reporting was evenly distributed, showing the incentive was conceived as being important by only selected groups. In 2019, the distribution demonstrated a trend that more people were considering the HOV lane access incentive more important, showing that the incentive was becoming more popular over time.

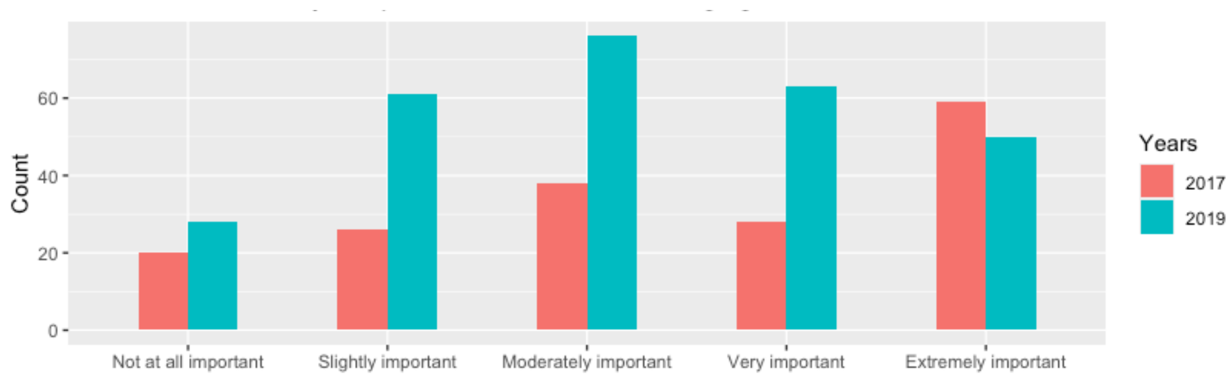

Figure 1. Distribution of Survey Response on Free Public Charging Incentive, 2017 and 2019

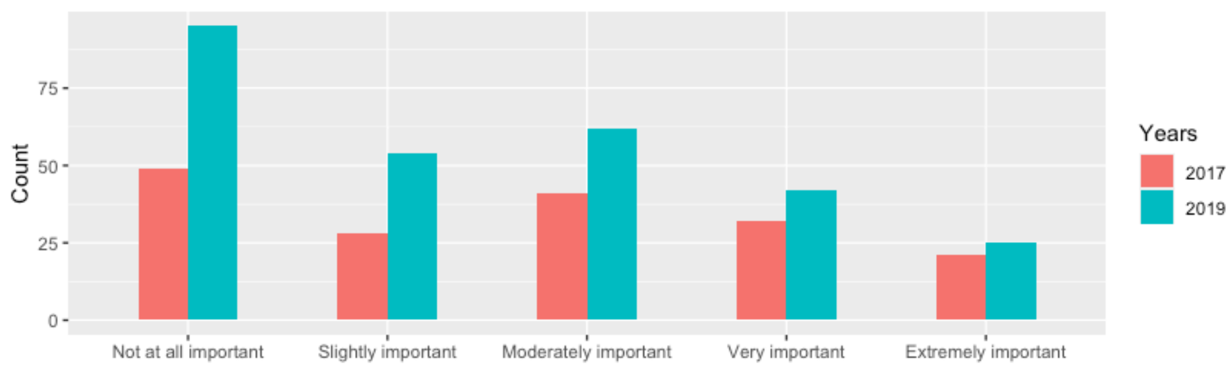

Figure 2. Distribution of Survey Response on Free Parking Incentive, 2017 and 2019

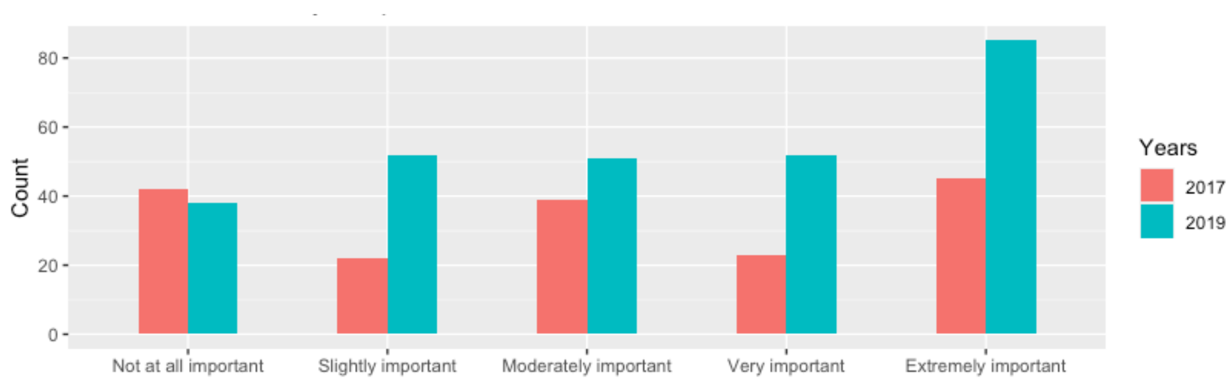

Figure 3. Distribution of Survey Response on HOV Lane Access Incentive, 2017 and 2019

4.5 RESULTS

The result of the ordered logit model suggests that there is a statistical significance for both public charging incentives and HOV lane access incentive for the low-income community. Numbers in parentheses stands for standard error, and asterisks refer to different levels of statistical importance. The low-income group consider public charging very important in their decision-making process. However, the sign for HOV lane is negative for the low-income group (-0.76), suggesting that HOV lane access is not among the priority of advantages of owning an EV for the low-income group. A significant correlation between importance of public charging and the minority group (0.478) is also found, as well as the non-single family housing group (1.097). For HOV lane, the only variable with positive correlation is full-time employment status (0.466), which is not surprising since that is the group who suffers the most from daily commuting traffic.

Table 3. Result of the Ordered Logit Model for the Three Selected Incentives in 2017 and 2019 Combined

	Public Charging		Free Parking		HOV Lane	
year	-0.524 (0.188)	***	-0.424 (0.182)	**	0.258 (0.182)	
lowincome	0.516 (0.265)	*	-0.388 (0.256)		-0.76 (0.267)	***
male	-0.015 (0.186)		-0.236 (0.185)		-0.318 (0.187)	*
minority	0.478 (0.277)	*	0.418 (0.263)		0.411 (0.274)	
college	-0.303 (0.22)		-0.289 (0.218)		-0.2 (0.222)	
non_sfhouse	1.097 (0.233)	**	0.301 (0.223)		-0.132 (0.227)	
fulltime_emp	-0.044 (0.177)		0.175 (0.178)		0.466 (0.178)	***

$^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$. Sample size: 401. R-squared: 0.17

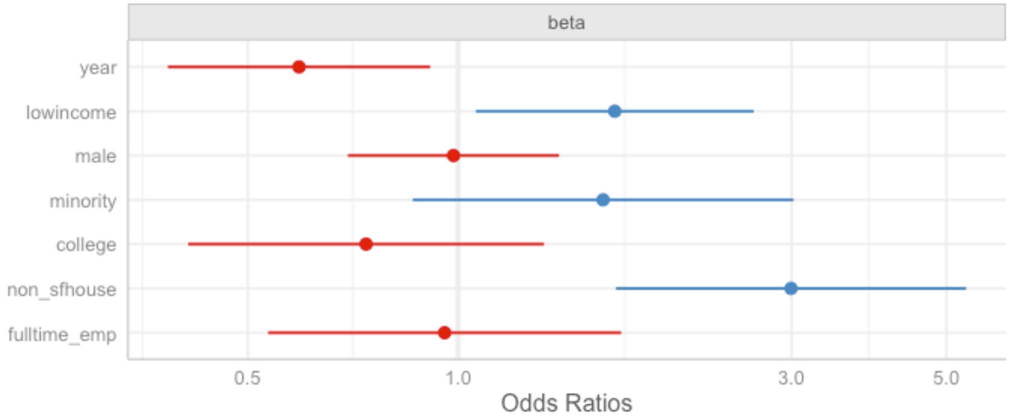

Figure 4. Visualizing the Result for the Ordered Logistic Regression, Public Charging Incentive

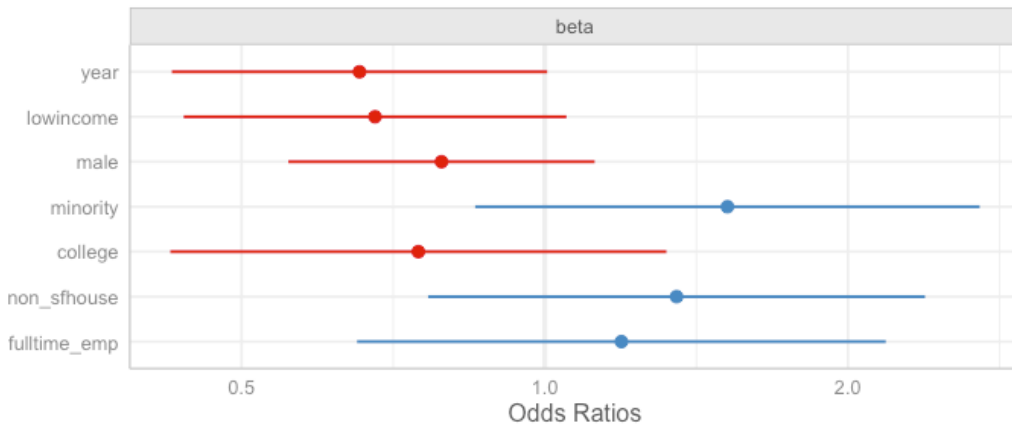

Figure 5. Visualizing the Result for the Ordered Logistic Regression, Free Parking Incentive

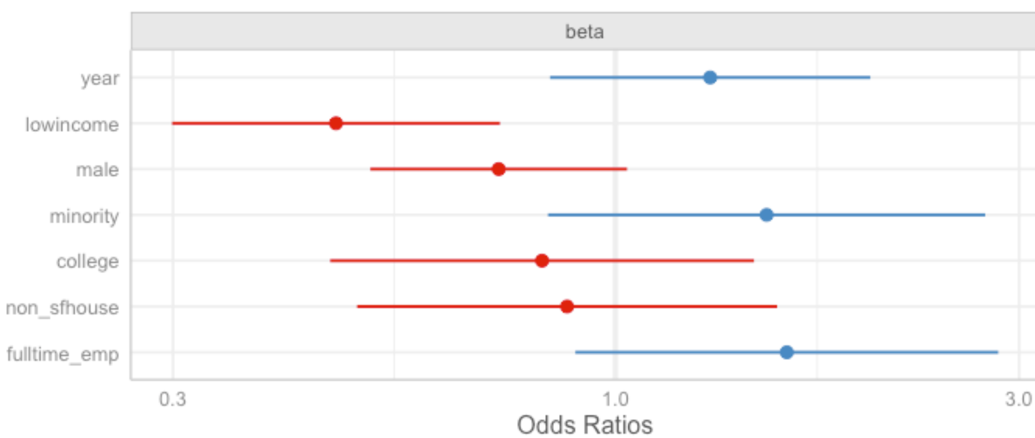

Figure 6. Visualizing the Result for the Ordered Logistic Regression, HOV Lane Incentive

Next, in order to investigate the time effects between 2017 and 2019, a modifying effect is added to investigate the association between importance of the incentive and socioeconomic variables that vary over a 3-year period. Adding the year dummy variable as a modifying effect, we could see that the result of the previous model does not significantly change. There is no significant change in the self-reported importance of incentives from 2017 and 2019. There is positive correlation for year vs. male variable for the public charging incentive (1.574) and the free parking incentive (0.444), and a positive correlation between HOV lane incentive and year vs. minority variable (1.547). An important observation from this result is that there is a significant negative effect of free parking for the low-income group, indicating the free parking incentives together with HOV lane incentives, are not considered important for most low-income drivers, at least not as important as the public charging infrastructure incentives. In the result table without time modifying effects, the sign of the coefficient is also negative, but the p-value suggests no statistical significance (p>0.1).

Table 4. Result of the Ordered Logit Model for Three Selected Incentives, with Time-Modifying Effects

	Public Charging		Free Parking		HOV Lane	
lowincome	0.65 (0.429)	*	-0.654 (0.395)	*	-1.145 (0.416)	***
male	-1.202 (0.38)	***	-0.548 (0.33)	*	-0.527 (0.344)	
minority	0.382 (0.506)		-0.623 (0.473)		-0.679 (0.488)	
college	-0.677 (0.483)		0.122 (0.428)		0.009 (0.432)	
non_sfhouse	0.797 (0.395)	**	0.194 (0.351)		-0.211 (0.371)	
fulltime_emp	-0.333 (0.295)		0.291 (0.282)		0.643 (0.287)	*
year:lowincome	-0.352 (0.547)		0.409 (0.52)		0.579 (0.544)	
year:male	1.574 (0.441)	***	0.444 (0.402)	***	0.32 (0.413)	
year:minority	0.216 (0.609)		1.498 (0.571)		1.547 (0.596)	***
year:college	0.513 (0.543)		-0.549 (0.498)		-0.291 (0.505)	
year:non_sfhouse	0.456 (0.489)		0.09 (0.455)		0.057 (0.471)	
year:fulltime_emp	0.291 (0.373)		-0.179 (0.368)		-0.256 (0.368)	

*p<0.1; **p<0.05; ***p<0.01. Sample size: 401. R-squared: 0.23

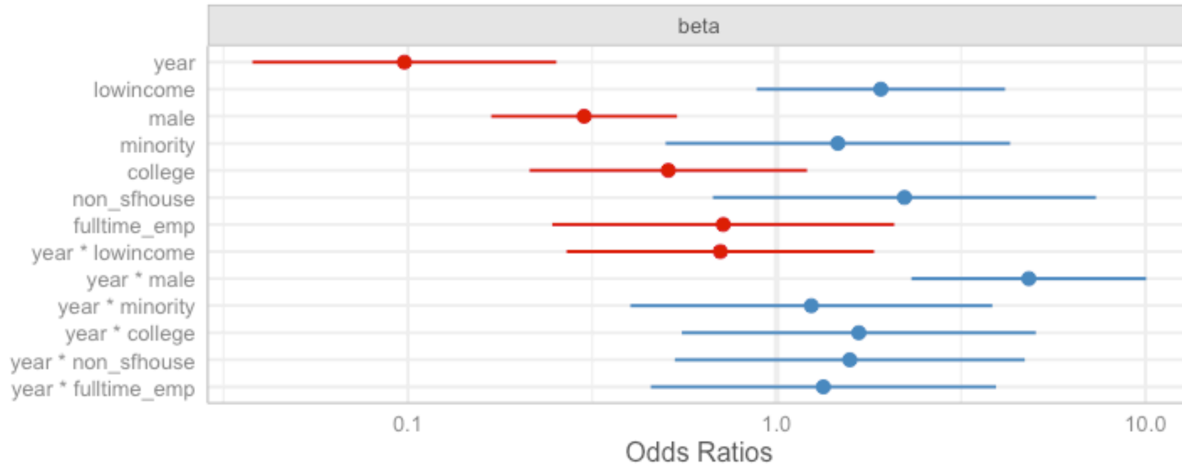

Figure 7. Visualizing the Result for the Ordered Logistic Regression with Time-Modifying Effects, Public Charging Incentive

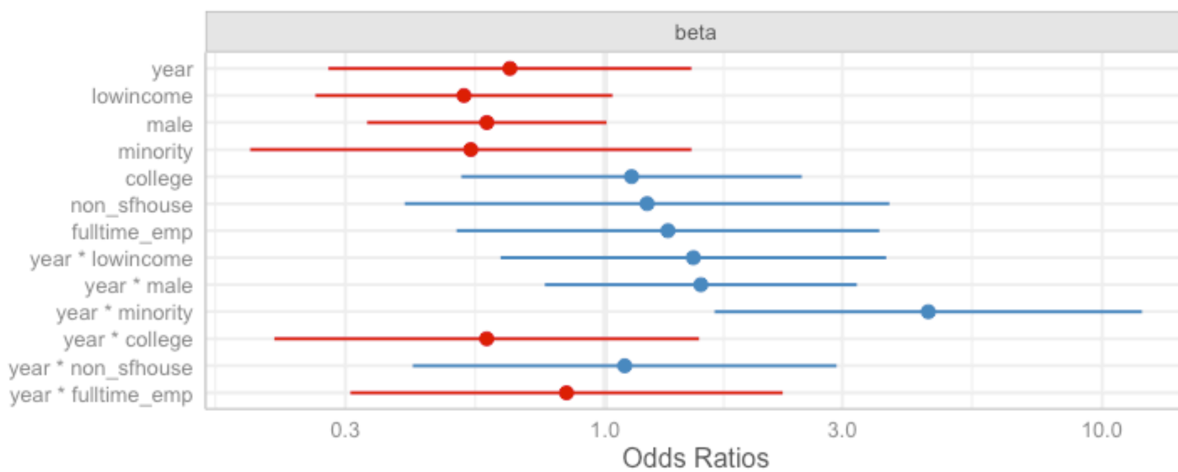

Figure 8. Visualizing the Result for the Ordered Logistic Regression with Time-Modifying Effects, Free Parking Incentive

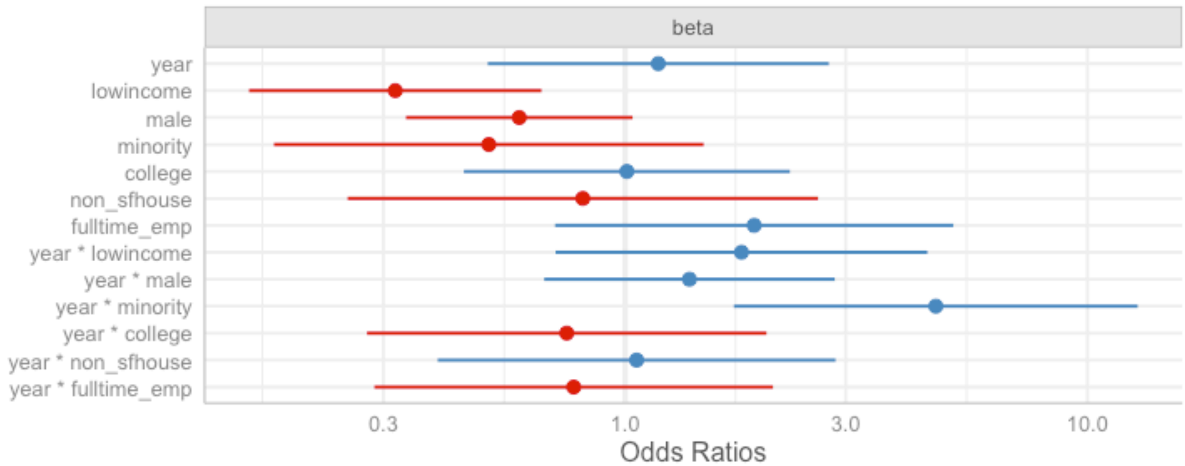

Figure 9. Visualizing the Result for the Ordered Logistic Regression with Time-Modifying Effects, HOV Lane Incentive

The results of the ordered logit model indicate that amongst all three non-financial, planning-related EV incentives, both the lower-income group and the non-single-family-homeowner group consider public charging availability the most important factor for their EV purchase decision-making. Meanwhile, surveyed HOV lane access importance is negatively correlated with low-income status. The only group finds HOV lane access very important for the purchase decision-making is the population with full-time employment status. There is no conclusive conclusion for different groups' attitudes towards free parking incentives.

With the added time-modifying effect, self-reported importance of public charging availability and free parking have declined between 2017 and 2019, but such trend is not found in the marginalized study groups. The results show that public charging infrastructure availability is considered by the less advantaged and minority groups the most important factor in their EV purchase decision-making process, while free parking and HOV lanes are not as important as the other incentive, i.e., charging infrastructure, in terms of affecting the purchase decision for EV for the less-advantaged groups, which are the targeted communities from an equity and justice perspective. Under the circumstances of utilizing Rawlsian-enlightened equity as the theoretical guidance for making EV policies, the most disadvantaged groups should benefit the most from EV incentives and policies, while the California analysis result indicates that different social groups react differently to these three incentives. The moderate-income group with single family housing is more sensitive to the HOV lane access incentive, while the lower income group and the population who lives in multifamily housing consider charging infrastructure the most valuable when making the EV purchase decision. Informed by the results, we could argue that it is important to ask whether analyses using different time thresholds could lead to different results that would be sufficient to propose policy adjustments, but the study is restrained by limitation of data source with survey results of only two years. Future research on equity implications of these incentives should incorporate more data points from different years, pay more attention to the adjustable spatial and temporal components as parameters in the statistical analysis, and include sensitivity analyses that look more thoroughly at the distributional effects in different areas among various stages of EV adoption.

4.6 Conclusion

This study utilizes an ordered logistic regression model and provides a demographic profile of EV buyers who have different perspectives towards three different planning-related non-financial EV incentives. Informed from the results, HOV incentives are not the policies that is received as a preferable policy by the less-advantaged social groups, indicating that these incentives have not been able to prioritize equity perspective comparing to building EV charging infrastructure. This finding matches the results found from existing literature on transportation policy in urban areas, especially those with congestion problems in the city center and on freeways[204]. As a common way of providing disincentives for taking trips in single-occupancy vehicles, the HOV lane is built to encourage people to share the vehicle, carpool, or take the public transit more often. Although HOV lane access could be important to middle- or upper-income households, less advantaged groups usually are more sensitive to the cost of transportation services and thus have fewer travel mode options[205]. As urbanization and suburbanization accelerate, the less advantaged are exposed to longer travel distance and travel time. Compared to public transportation, single-occupancy vehicles are providing less mobility with occupying more social resources and road space, and at the same time take much more travel cost than public transit. HOV and transit lane incentives for EV undermine these lanes' purpose, which is reducing single occupancy driving that lead to encouraging more travel using public transit[206]. Meanwhile, a transition to EV could accelerate fast in the near future, and this policy could create congestion, or slow down the speed on HOV lanes. In return, it could be worse off in the long term, that it will encourage EV's single occupancy trips and slow HOV travel speeds due to increased traffic volume. Therefore, incentives that allow driving EVs in HOV lanes are less progressive, less equitable measures among the incentives discussed in this study and challenge the unremitting efforts of promoting public transit by transportation planning policies.

Similar to the HOV lane access incentives, free parking has long been considered undesirable in transportation planning scholarship as free parking increases the cost and supply

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[204] Jenn, Springel, and Gopal, "Effectiveness of Electric Vehicle Incentives in the United States"; Wee, Coffman, and La Croix, "Do Electric Vehicle Incentives Matter?"; Hardman, "Understanding the Impact of Reoccurring and Non-Financial Incentives on Plug-in Electric Vehicle Adoption – A Review."
[205] Martens, "Justice in Transport as Justice in Accessibility."
[206] Lawrence D. Frank and Gary Pivo, "IMPACTS OF MIXED USE AND DENSITY ON UTILIZATION OF THREE MODES OF TRAVEL: SINGLE-OCCUPANT VEHICLE, TRANSIT, WALKING," *Transportation Research Record*, no. 1466 (1994), https://trid.trb.org/view/425321.

of housing and commercial buildings, and the public sector is subsidizing car drivers by providing free parking[207]. Free parking has led to dependence on the automobile, perpetuate sprawl processes, overconsumption of energy and resources, and transformed cities in the U.S. to a form more suitable for cars, not people. A free parking benefit for EV patently deters the long-lasting endeavor to prioritize public transit, reduce car ownership, and improve street designs. Another factor to take into consideration is paid parking. Like road pricing, paid parking revenues could be redistributed purposefully to target the less advantaged groups to put the transportation policies in the position of the Rawlsian equity principles.

Informed by the result, EV buyers who are from the lower-income, minority, and renter groups consider EVSE infrastructure to be more important during their decision-making process of the EV purchase. This preference is potentially correlated to the lower home ownership, which is an obstacle of installing charging equipment at residential places. In addition, utility providers that are given public funding to deliver subsidies on EVSE cover a different area of a state, and different utility providers may have different rebate or tax credit programs. This may create confusion and indirectly lead to a degradation of spatial and inter-jurisdictional equity. The findings of this result lead to a policy implication that governments should analyze the spatial location of public charging stations at the early stage of the infrastructure investment to ensure that drivers from all socioeconomic backgrounds receive equal opportunities of enjoying the advantage of EV and build the electrified transportation system more equitable and socially resilient.

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[207] Shoup, *The High Cost of Free Parking*.

Chapter 5. REDUCING CARBON EMISSION WITH SMARTER EV INCENTIVES: A REGRESSION TREE MODEL

5.1 INTRODUCTION

According to Highway Statistics, in the United States, there are 273 million motor vehicles registered in 2018, and that number could be concerted to 0.83 vehicles per capita[208]. However, the current EV market share in the U.S. is merely around 2%[209]. In the academic and professional fields of transportation, environment, public policy, and urban planning, people are reaching a consensus that EV, including the electrification of light-duty vehicles, heavy-duty vehicles, all types of public transportation, and even air freight, is critical to the attempt of reducing carbon-based greenhouse gas (GHG) emissions[210]. Governments around the world have enacted large scale public policy frameworks, with financial incentives and non-financial incentives, to subsidize the adoption of EV by distributing the funds to public sectors, private sectors, as well as individuals, whoever affiliated with a transition from conventional vehicles to EV. During this process, the most basic assumption is that the transportation system's full electrification is a necessary component of making the transportation system more environmentally sustainable and climate resilient. The major intention of promoting electric vehicles is to reduce transportation-related carbon footprint in the era of climate change, which has made the evaluation of carbon emission reduction as the most important research question regarding EV policies.

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[208] Federal Highway Administration, "Highway Statistics Series - Policy," 2019, https://www.fhwa.dot.gov/policyinformation/statistics.cfm.
[209] Bui et al., "Update on Electric Vehicle Adoption across U.S. Cities," 2020, https://theicct.org/publications/ev-update-us-cities-aug2020.
[210] U.S. Department of Energy, "Reducing Pollution with Electric Vehicles," Energy.gov, accessed December 5, 2020, https://www.energy.gov/eere/electricvehicles/reducing-pollution-electric-vehicles.

In addition to carbon reduction, the relationship between reducing carbon emission in transportation sector and social equity and justice has not been discussed in existing literature. Most attempts of reducing carbon emission are within the international or national level scale, but recent policies[211] implemented from local governments have extended the emphasis of carbon reduction work to smaller geographical scales in the society, including cities, neighborhoods, households, and even individuals. For consumers, there are multiple intentions for purchasing an EV instead of a conventional ICE vehicle, including environmental performance, total cost of ownership, and range confidence[213]. Although carbon reduction is not the sole factor of the decision-making process of EV purchase by consumers, switching to EV is an example of configuring carbon reduction responsibility to individuals. Such thoughts are reasonable from the perspective of climate change, as carbon emission comes from both the supply side that carbon emissions are generated during the production, and the demand side that carbon emissions are generated during the consumption.[214]. By linking emissions to transportation behavior, people can intuitively recognize their responsibility for climate change and, in the process, consider how they can change their behavior. Essentially, this assumes that each individual is morally motivated to take action to reduce emissions, and the responsibilities of taking such actions are based on how much carbon is generated during the daily activities.

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[211] European Environment Agency, "EEA Technical Report 8/2005 - Market-Based Instruments for Environmental Policy in Europe," Publication, accessed October 13, 2021, https://www.eea.europa.eu/publications/technical_report_2005_8; C40 Cities, "C40 Cities - A Global Network of Mayors Taking Urgent Action to Confront the Climate Crisis and Create a Future Where Everyone Can Thrive.," C40 Cities, 40, accessed February 20, 2022, https://www.c40.org/; Carbon Neutral Cities Alliance, "About Us – CNCA," accessed February 20, 2022, https://carbonneutralcities.org/about/.

[213] Kenan Degirmenci and Michael H. Breitner, "Consumer Purchase Intentions for Electric Vehicles: Is Green More Important than Price and Range?," *Transportation Research Part D: Transport and Environment* 51 (March 1, 2017): 250–60, https://doi.org/10.1016/j.trd.2017.01.001.

[214] Sara Fuller, "Configuring Climate Responsibility in the City: Carbon Footprints and Climate Justice in Hong Kong," *Area* 49, no. 4 (2017): 519–25, https://doi.org/10.1111/area.12341.

Therefore, the attempt to achieve a full electric transportation sector assumes that each individual has equal quantity of carbon reduction responsibilities without considering other socioeconomic characteristics of each. This raises questions about the equity and justice of requiring all individuals to reduce their carbon consumption. It is particularly important given the debate about energy consumption and the complex role that energy services play in promoting or generating the public well-being. Another related assumption is whether individuals really have the ability to afford a lifestyle changing to reduce carbon emission, i.e., make a complete switch to public transit or other non-motorized travel consumption, from the time and cost perspectives. Overlooking the legitimacy of these assumptions underscores the need to explore more closely the consumption behaviors associated with everyday life[215]. If not everyone in the society has the capability of changing their lifestyle for carbon reduction, an integration with non-linearity of carbon consumption is needed in every process of carbon calculation, evaluation, and policymaking[216].

Amongst the advocates of EV, California is regarded as the leader of providing incentives in the U.S., including equity measures, to consumers and automakers. Globally, countries are following California and adopting similar policies like the Zero Emission Vehicle (ZEV) program, which requires automakers to sell EVs in California, incrementally increase the proportion of EV production, and reach a particular target of producing the only EV in the future. In California, a governor executive order has required sales of all new passenger vehicles to be

[215] Rita Vasconcellos Oliveira, "A Methodological Framework for Developing More Just Footprints: The Contribution of Footprints to Environmental Policies and Justice," *Science and Engineering Ethics* 26, no. 1 (February 1, 2020): 405–29, https://doi.org/10.1007/s11948-019-00100-8.

[216] Simone Bastianoni, Federico Maria Pulselli, and Enzo Tiezzi, "The Problem of Assigning Responsibility for Greenhouse Gas Emissions," *Ecological Economics* 49, no. 3 (July 1, 2004): 253–57, https://doi.org/10.1016/j.ecolecon.2004.01.018.

zero-emission by 2035[217]. However, what are the costs associated with the transition and the expected carbon emission reductions from California's 2035 ZEV mandate?

This study will estimate the EV transition cost of residents in California and forecast the carbon reduction amount under the scenario of a complete transition to EV. During this process, an equity evaluation is provided.

There are three main targets of this study. (1) Evaluating current carbon footprint by travel for different socioeconomic groups and estimating how much carbon reduction could be achieved with the scenario of a complete transition to EV. (2) Estimating the cost of shifting to EV and calculating the one-time purchase cost of the transition for different social groups. (3) Creating an indicator of carbon mitigation cost that analyzes EV's carbon reduction through an equity perspective by combining the cost of switching to EV and the potential carbon saving with transition to EV. The study that applies a regression decision tree to the 2019 California Vehicle Survey will investigate the potential carbon mitigation cost and its socioeconomic contributing factor for all California drivers under the scenarios of non-existence vs. existence of current financial incentives and provide policy implications to ensure a more equitable EV adoption.

5.2 METHODS

Investigating the potential carbon mitigation cost consists of two components. Firstly, to estimate the importance of EV for reducing carbon emission in the near future, a framework of calculating the potential carbon emission reduction is needed. Secondly, an estimation of the financial cost

[217] "Governor Newsom Announces California Will Phase Out Gasoline-Powered Cars & Drastically Reduce Demand for Fossil Fuel in California's Fight Against Climate Change."

of a full transition to EV is required to illustrate the cost of the shift. The estimated cost f added to the driver could be calculated as:

$$f = \frac{EV\ price\ +\ EVSE\ price\ -\ Financial\ Incentives\ Received}{Annual\ Household\ Income} \tag{7}$$

The estimation of carbon emission is simplified as[234]:

$$Carbon = mileage \times \frac{energy}{mileage} \times \frac{carbon}{energy} \tag{8}$$

This framework could be further elaborated as:

$$C_{ICE} = \sum_i FE_i \times EF_i \times LD \tag{9}$$

$$C_{EV} = \sum_u FE \times EF_u \times LD \tag{10}$$

$$C_s = C_{ICE} - C_{EV} \tag{11}$$

Where C_{ICE} and C_{EV} denote the total carbon emission from ICE and EV; FE is the model's fuel economy, and FE_i is the fuel economy of a model using fuel *I*; EF_i is the emission factor for fuel *i*, and EF_u is the emission factor for utility provider *u*; LD is the driving distance, usually a product of vehicle ownership and driving demand. C_s is the difference of C_{ICE} and C_{EV}, indicating the carbon saving when switching to EV.

[234] John Heywood and Don MacKenzie, "On the Road toward 2050: Potential for Substantial Reductions in Light-Duty Vehicle Energy Use and Greenhouse Gas Emissions," *Massachusetts Institute of Technology*, 2015.

Based on the annual mileage and vehicular miles-per-gallon fuel economy information that the respondents voluntarily provided, an annual carbon emission amount could be estimated for gasoline-powered vehicles. For EV users, a carbon emission per mileage driven profile is built using the California Energy Emission's electricity consumption by county data and the renewable energy generation by county data in 2019, with the assumption of the non-renewable energy generated by natural gas (see Table 5)[238]. Note that this study assumes the omission of the usage of coal for energy generation for the convenience of calculation, as coal counts only less than 3% of the total California power mix. The carbon per kWh electricity profile for each county varies from 0 to 0.412 kgCO2 per kWh, due to their different adoption rate of renewable energy as well as the proximity to the nearest energy generation sites. The carbon profile can then be translated to kgCO2 per mileage driven with a constant conversion from miles-per-gallon to electricity consumption.

Table 5. Carbon Emission per kWh in Counties of California[239]

County	Total GWh Consumed	Renewable Energy Rate	kgCO2/kWh
Alameda	10684.1	9%	0.378
Amador	317.9	25%	0.309
Butte	1396.2	17%	0.341
Calaveras	330.6	62%	0.157
Colusa	285.5	66%	0.141
Contra Costa	9639.4	2%	0.404
El Dorado	1227.9	15%	0.349
Fresno	7387.3	30%	0.290
Glenn	394.1	5%	0.394
Humboldt	791.4	26%	0.306
Imperial	1415.8	100%	0.000
Inyo	208.6	100%	0.000
Kern	17105.1	89%	0.047
Kings	1583.1	69%	0.129
Lake	446.1	100%	0.000
Lassen	403.8	69%	0.129
Los Angeles	66118.7	6%	0.387

[238] California Energy Commission, "Renewable Electricity Generated by County," accessed September 28, 2021, https://cecgis-caenergy.opendata.arcgis.com/documents/renewable-electricity-generated-by-county/explore.
[239] California Energy Commission; California Energy Commission, "Electricity Consumption by County," accessed January 15, 2022, https://ecdms.energy.ca.gov/elecbycounty.aspx.

Madera	1568.0	23%	0.318
Marin	1355.3	2%	0.403
Mariposa	109.7	42%	0.240
Mendocino	562.3	8%	0.380
Merced	3698.6	11%	0.367
Mono	205.2	100%	0.000
Monterey	2470.7	17%	0.341
Napa	1043.0	0%	0.412
Nevada	712.5	43%	0.237
Orange	19459.5	3%	0.402
Placer	2914.9	22%	0.320
Plumas	210.5	79%	0.085
Riverside	15520.1	34%	0.272
Sacramento	10828.2	4%	0.396
San Benito	379.9	100%	0.000
San Bernardino	14987.2	22%	0.322
San Diego	19047.7	6%	0.389
San Francisco	5603.6	0%	0.411
San Joaquin	5583.3	10%	0.370
San Luis Obispo	1707.4	100%	0.000
San Mateo	4325.3	2%	0.404
Santa Barbara	2757.6	5%	0.392
Santa Clara	16664.5	0%	0.411
Santa Cruz	1200.7	3%	0.402
Shasta	1535.6	84%	0.064
Sierra	22.0	100%	0.000
Siskiyou	495.6	79%	0.087
Solano	3226.6	78%	0.092
Sonoma	2880.4	100%	0.000
Stanislaus	4750.1	7%	0.386
Sutter	632.1	1%	0.410
Tehama	507.7	11%	0.366
Trinity	135.0	17%	0.342
Tulare	4162.2	20%	0.330
Tuolumne	452.6	100%	0.000
Ventura	5344.0	0%	0.412
Yolo	1720.7	16%	0.348
Yuba	511.7	7%	0.385

The estimated financial cost f with the financial incentives and the carbon saving C_s will then be assigned to each survey respondent, and a potential carbon mitigation cost f/C_s is calculated and is the target variable of the model that explores what socioeconomic-based independent variables are associated to the target variable.

Multivariate regression tree models will be used to predict the contributing factor of socioeconomic variables to the potential carbon mitigation cost f/C_s , for both a Tesla Model 3 purchase and a Chevy Bolt purchase by learning decision rules inferred from the survey data, under the scenarios of applying the financial incentives and not applying the financial incentives. The four models constructed using multivariate regression tree models are:

- Tesla Model 3 purchase without financial incentives,
- Tesla Model 3 purchase with financial incentives,
- Chevy Bolt purchase without financial incentives, and
- Chevy Bolt purchase with financial incentives.

Decision tree algorithm is a supervised machine learning algorithm, which can be used for classification as well as solving regressions[240]. In general, a decision tree contains a root node, several internal nodes, and several leaf nodes. The leaf nodes correspond to decision outcomes, and each other node corresponds to an attribute test. The set of samples contained in each node is divided into sub-nodes based on the results of the attribute tests. The root node contains the full set of samples, and the path from the root node to each leaf node corresponds to a sequence of decision tests. During the decision tree model building, feature selection determines which features are used to make judgments. In the training dataset, there may be many attributes for each sample, and different attribute may be more or less useful. Thus, the role of feature selection is to filter out the features that have a higher correlation with the classification results, i.e., the features that have a higher classification power. The commonly

[240] S.R. Safavian and D. Landgrebe, "A Survey of Decision Tree Classifier Methodology," *IEEE Transactions on Systems, Man, and Cybernetics* 21, no. 3 (May 1991): 660–74, https://doi.org/10.1109/21.97458.

used criterion in feature selection is information gain[241]. Once the features are selected, they are triggered from the root node, and the information gain of all features is calculated for the nodes, and the feature with the largest information gain is selected as the node feature, and the child nodes are created according to the different values of the feature; new child nodes are generated using the same way for each child node until the information gain is ideally small or there are no features to select.

Let the data at node m be represented by Q_m with N_m sample. For each candidate split $\theta = (j, t_m)$ consisting of a feature j and threshold t_m, partition the data into $Q_m^{left}(\theta)$ and $Q_m^{right}(\theta)$ subsets:

$$Q_m^{left}(\theta) = \{(x, y) \mid x_j \leq t_m\}$$

(12)

$$Q_m^{right}(\theta) = Q_m \setminus Q_m^{left}(\theta)$$

(13)

The quality of the candidate split of node m is computed using an impurity function or loss function $H()$:

$$G(Q_m, \theta) = \frac{N_m^{left}}{N_m} H\left(Q_m^{left}(\theta)\right) + \frac{N_m^{right}}{N_m} H\left(Q_m^{right}(\theta)\right)$$

(14)

Select the parameters that minimizes the impurity:

$$\theta^* = argmin_\theta G(Q_m, \theta)$$

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[241] Laura Elena Raileanu and Kilian Stoffel, "Theoretical Comparison between the Gini Index and Information Gain Criteria," *Annals of Mathematics and Artificial Intelligence* 41, no. 1 (May 1, 2004): 77–93, https://doi.org/10.1023/B:AMAI.0000018580.96245.c6.

(15)

Recurse for subsets $Q_m^{left}(\theta)$ and $Q_m^{right}(\theta)$ until the maximum allowable depth is reached, $N_m < min(sample)$ or $N_m = 1$.

If a target is a classification outcome taking on values 0,1,…,K-1, for node m, let

$$p_{mk} = 1/N_m \sum_{y \in Q_m} I(y = k)$$

(16)

be the proportion of class k observations in node m.

This analysis uses a classification and regression tree, which has two branches at each node, and the test criterion of the CART algorithm is the maximum entropy reduction. Use entropy method to measure impurity of the model with:

$$H(Q_m) = -\sum_k p_{mk} \log(p_{mk})$$

(17)

The multivariate regression tree (MRT) is a relatively new classification technique based on decision-trees[242]. Like general regression models, MRT requires dependent variables (potential carbon mitigation cost in this study) and independent variables (socioeconomic variables in this study). The MRT does not require a regression relationship between the

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[242] "CLASSIFICATION AND REGRESSION TREES: A POWERFUL YET SIMPLE TECHNIQUE FOR ECOLOGICAL DATA ANALYSIS - De'ath - 2000 - Ecology - Wiley Online Library," accessed January 15, 2022, https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/0012-9658%282000%29081%5B3178%3ACARTAP%5D2.0.CO%3B2?casa_token=Pb4kfeaR3u4AAAAA%3AHLOgQliGanAbDJQOLcYvQGOYRZ4g7dFJ9oTDh5smqvdpPJvpgcvmbjs9zOfTw4cjc3h3cZmVNlmSQEM; Glenn De'ath, "Multivariate Regression Trees: A New Technique for Modeling Species–Environment Relationships," *Ecology* 83, no. 4 (2002): 1105–17, https://doi.org/10.1890/0012-9658(2002)083[1105:MRTANT]2.0.CO;2; Anantha M. Prasad, Louis R. Iverson, and Andy Liaw, "Newer Classification and Regression Tree Techniques: Bagging and Random Forests for Ecological Prediction," *Ecosystems* 9, no. 2 (March 1, 2006): 181–99, https://doi.org/10.1007/s10021-005-0054-1.

dependent variable and the independent variable, but rather uses the independent variable as the classification node, and divides the sample defined by the dependent variable into as homogeneous categories as possible by using the binary split method, and each division is done by an optimal division value of one of the independent variables. The optimal partitioning principle is to make the differences within the two nodes as small as possible and the differences between the nodes as large as possible and repeat the process until the portioning results satisfy some condition or can no longer be partitioned[243]. Because of the characteristics of dependent and independent variables, MRT can prune the classification result (nodes of the regression tree) using cross-validation to obtain a regression tree of appropriate size. The reason for pruning is that if the tree has too many nodes (too many categories), the results are not very meaningful even though the homogeneity of the samples belonging to the same category is high. However, if the tree has too few branches, the prediction error will be very large. To balance the size of the tree and the size of the error, *the cost complexity criterion* is usually used to limit the size of the tree, and the final goal is to make the error and the size of the tree as small as possible. The calculation of the error is based on cross-validation, i.e., a portion of the original data is taken to build the model, and the remaining portion is used to verify the magnitude of the prediction error of the model. In pruning theory, a well-known rule is the one standard deviation rule, which means that the prediction error (obtained by cross-validation) should be as small as possible, which is not necessarily the minimum value but allowed to be within the range of minimum error given or take one corresponding standard deviation. Hence, the smallest possible tree is selected within this range.

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[243] Marc P. Vayssières, Richard E. Plant, and Barbara H. Allen-Diaz, "Classification Trees: An Alternative Non-Parametric Approach for Predicting Species Distributions," *Journal of Vegetation Science* 11, no. 5 (2000): 679–94, https://doi.org/10.2307/3236575.

To illustrate the importance of each variable, a *boosted regression tree (BRT) model* is used to explore the contribution and marginal effects of the socioeconomic factors on the target variable. The BRT model is a self-learning method based on the categorical regression tree algorithm[244]. The algorithm uses recursive binary partitioning to eliminate interactions between predictors and builds a large set of small regression trees to represent the nonlinear associations between responses and their predictors. The BRT model is flexible when dealing with different data formats and can improve the stability and predictability of the model, and the contribution of the independent variables to the dependent variable are more intuitive and can reflect the degree of contribution of the relevant factors in different threshold intervals.

5.3 DATA

In this study, the 2019 California Vehicle Survey[245] will be used to build a framework to estimate the real-world scenario carbon footprint. The Survey collected demographic information and travel behavior of 7,159 drivers in California. In addition to economic and demographic data, the survey integrated light-duty vehicle holding and use information with vehicle choice data collected via the stated preferences survey's set of eight vehicle and fuel type choice exercises. EV owner survey participants also provided additional data on charging behavior, electricity rates, and their main motivations for purchasing EVs.

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[244] J. Elith, J. R. Leathwick, and T. Hastie, "A Working Guide to Boosted Regression Trees," *Journal of Animal Ecology* 77, no. 4 (2008): 802–13, https://doi.org/10.1111/j.1365-2656.2008.01390.x; Prasad, Iverson, and Liaw, "Newer Classification and Regression Tree Techniques."

[245] National Renewable Energy Laboratory, "2019 California Vehicle Survey."

Table 6. List of EV and EVSE Incentives Available in California

Program Name	**Target**	**EV Incentive**	**EVSE Incentive**
* Federal Plug-In Electric Drive Vehicle Tax Credit[246]	Federal		
California Clean Fuel Reward (CCFR)[247]	CA	$1,500	
Clean Vehicle Rebate Project (CVRP)[248]	CA	$2,000 ($4,500 for low income)	
SMUD Residential EV Incentive (Sacramento, Placer, Yolo)[249]	SMUD user	$1,500	
LADWP–- Charge up LA Electric Vehicle Charger Rebate Program[250]	Los Angeles		$750
LADWP–- Charge Up LA Used Electric Vehicle Program[251]	Los Angeles	$1,500 (used EV)	
Alameda Municipal Power EV Rebate Program[252]	Alameda	$1,000 (used EV)	$800
Anaheim Public Utilities Personal Use EV Charger Rebates[253]	Anaheim		$1,000
** Azusa Light and Water EV Charger Rebate[254]	Azusa	$150	
** Burbank Water and Power–- Electric Vehicle Charger Rebate[255]	Burbank	$500	
** Glendale Water and Power–- Electric Vehicle Charging Station Rebate Program[256]	Glendale		$500
** Pasadena Water and Power–- Residential EV and Charger Incentive Program[257]	Pasadena	$500 ($1500 for low income)	$600

*: Federal tax credit incentive is phasing out, so this analysis is not including the federal incentive.

**: These incentives are at local level and will not be included in the study, as the analysis is conducted on the county level.

[246] U.S. Department of Energy, "Federal Tax Credits for Electric and Plug-in Hybrid Cars."
[247] California Clean Fuel Reward, "EV Rebates and Incentives," accessed September 28, 2021, https://cleanfuelreward.com/.
[248] California Air Resources Board, "Clean Vehicle Rebate Project."
[249] Sacramento Municipal Utility District, "Residential Electric Vehicles," accessed September 28, 2021, https://www.smud.org/en/Going-Green/Electric-Vehicles/Residential.
[250] Alternative Fuels Data Center, "Electric Vehicle Supply Equipment (EVSE) Rebate - LADWP," accessed September 28, 2021, https://afdc.energy.gov/laws/9232.
[251] LADWP, "Electric Vehicles (EVs)," accessed September 28, 2021, https://www.ladwp.com/ladwp/faces/ladwp/residential/r-gogreen/r-gg-driveelectric?_adf.ctrl-state=1d4357epvd_4&_afrLoop=316102481217629&_afrWindowMode=0&_afrWindowId=null.
[252] Alameda Municipal Power, "Electric Vehicles," accessed September 28, 2021, https://www.alamedamp.com/349/Electric-Vehicles.
[253] City of Anaheim, "Personal Use EV Charger Rebates," accessed September 28, 2021, https://www.anaheim.net/593/Personal-EV-Charger-Rebate.
[254] City of Asuza, "Plug-In Electric Vehicles," accessed September 28, 2021, https://www.ci.azusa.ca.us/1625/Plug-In-Electric-Vehicles.
[255] Burbank Water and Power, "Electric Vehicles Rebate," Burbank Water & Power, accessed September 28, 2021, https://www.burbankwaterandpower.com/conservation/electric-vehicles-rebate.
[256] Glendale Water & Power, "Charging Station Rebate," accessed September 28, 2021, https://www.plugshare.com/widget2.html.
[257] City of Pasadena, "Residential Electric Vehicle and Charger Incentive Program," Pasadena Water and Power, accessed September 28, 2021, https://ww5.cityofpasadena.net/water-and-power/residentialevrebate/.

The table 5 provides, current EV and EVSE financial incentives to estimate the financial cost of a non-EV driver shifting to EV. State of California and a few county- and city-level governments, as well as certain utility companies, offer EV and EVSE incentives to customers who purchase an EV or EVSE. This list only includes the incentives for non-commercial vehicles. Note that although the federal government provides a substantial tax credit for new EV of up to $7,500, it only applies to car manufacturers who sell fewer than 200,000 EVs in total. Once the manufacturer's EV sales exceed 200,000, the tax credit will be cut in half in the next two quarters and cut in half again for another two quarters before it is phased out completely[258]. Tesla and Chevrolet as two predominant EV manufacturers have already passed the phase out period, and customers who purchase a Chevrolet or Tesla EV will no longer be eligible for receiving the federal tax credit incentive. Therefore, this analysis does not include the federal incentive as the federal tax credit incentive is phasing out for the vehicular models used in this analysis and will be completely phasing out for other models in the near future as more EV models become available.

In this study, two scenarios are presented to estimate the financial cost added to the consumers if they switch to EV immediately. The first scenario is they buy a new Tesla Model 3[259], and the second scenario is they buy a used Chevy Bolt[260]. Both models are among the most popular and best-selling EV models in the United States, and this study will use these two models as the baseline for the actions of buying a new EV and buying a used EV. lists the

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[258] Jianwei Xing, Benjamin Leard, and Shanjun Li, "What Does an Electric Vehicle Replace?," *Journal of Environmental Economics and Management* 107 (May 1, 2021): 102432, https://doi.org/10.1016/j.jeem.2021.102432.

[259] U.S. Department of Energy, "Fuel Economy of 2020 Tesla Model 3," 2020, https://www.fueleconomy.gov/feg/PowerSearch.do?action=noform&path=1&year1=2020&year2=2020&make=Tesla&baseModel=Model%203&srchtyp=ymm.

[260] U.S. Department of Energy, "2021 Chevrolet Bolt EV," accessed September 28, 2021, https://www.fueleconomy.gov/feg/Find.do?action=sbs&id=43663.

assumptions used for both EV models in this study. The price for used cars could be lower if the car has been used for more years, but this study assumed price of a used Chevy Bolt ($27,500) as an average of 1-year-old and 2-year-old used EV price, due to the concern of battery degradation by the general public towards EV. For the vehicle charging station at home, the cost will be different for different households, as the difficulty of installing a charger varies. This study assumes the equipment and installation fee adds up to $2,000, including $1,000 for the EVSE and $1,000 for installation by an electrician.

Table 7. A Comparison of the EV Models in this Analysis

	Chevy Bolt	**Tesla Model 3**
Price	$27,500	$49,999
Condition	Used	New
Range (miles)	259	353
Federal Tax Incentive	N/A	N/A
MPGe	118	134
EVSE Purchase and Installation	$3,000	$3,000

5.4 RESULTS

The carbon profile of different fuel type and of different socioeconomic groups in California, 2019 was demonstrated in the Table 8. The average carbon emission per survey respondent for African American (6,135 kg) and Hispanic/Latino (4,813 kg) drivers' vehicles are significantly higher than the white (3,568 kg) and Asian (3,559 kg) drivers' vehicles. For other socioeconomic variables, vehicles of drivers with no bachelor's degree (4,091 kg) emit slightly higher carbon emission than those who have a bachelor's degree (3,602 kg). Similar amount of difference can be found for vehicles of lower-income group that have a household income less than $50,000 (4,144 kg), whose carbon emission is higher than other groups, especially those who are from the higher-income households who earns more than $150,000 (3,607 and 3,740 kg). Vehicles with drivers who own a single-family housing (3,793 kg) emit slightly less carbon dioxide than those who own a condo, apartment, or rent housing (4,021 kg), potentially due to a higher number of vehicles per household for households with single-family housing. Not surprisingly, vehicles with drivers who have a full-time job (4,212 kg) generate more carbon emission than those who work part-time, work from home, do not have a job, or retired (3,554 kg).

Comparing the annual average carbon emission and carbon emission per mileage driven, it can be found that the vehicles of socioeconomically marginalized group members are emitting more transportation related carbon dioxide than vehicles of other groups, due to the reason that the less-advantaged groups usually have to share one vehicle within the household, while the non-marginalized groups may have the access to more than one vehicle at home. The excessive carbon amount brought by worse fuel economy, which can be interpreted by average carbon emission per mileage driven, is not as striking as the total carbon emission. For all the socioeconomic groups, the averaged carbon emission per mileage driven range from 0.39 to 0.41, which can be considered insignificant.

Table 8. Carbon Profile: Gasoline Drivers

Group	Subgroup	# Respondent	Avg kgCO2	Avg kgCO2/mi
Race				
	White	3512	3568	0.408
	Asian	836	3559	0.396
	Hispanic	648	4813	0.402
	Black	181	6135	0.399
Education				
	Bachelor	3199	3602	0.399
	No Bachelor	2408	4091	0.412
Income				
	<50k	981	4144	0.409
	50-100k	1756	3840	0.397
	100-150k	1239	3676	0.408
	150-200k	700	3740	0.406
	200-250k	426	3607	0.407
Housing				
	Single-family housing	4547	3793	0.408
	Non-Single-family housing	1025	4021	0.388
Employment				
	Full-time employed	2379	4212	0.398
	Not full-time employed	3194	3554	0.409

The result of the regression tree is presented using the boosted regression tree algorithm to demonstrate the contributing factor of seven socioeconomic independent variables, namely estimated annual household income ‘est_income’, a dummy variable ‘white’ for race, a dummy variable ‘fulltime’ for full-time employment, a dummy variable ‘college’ for education, a dummy variable ‘sfh’ for single-family housing, a dummy variable ‘kids’ indicating households with children, and the number of vehicles per person within the household ‘veh_pc’.

Case of No financial Incentives

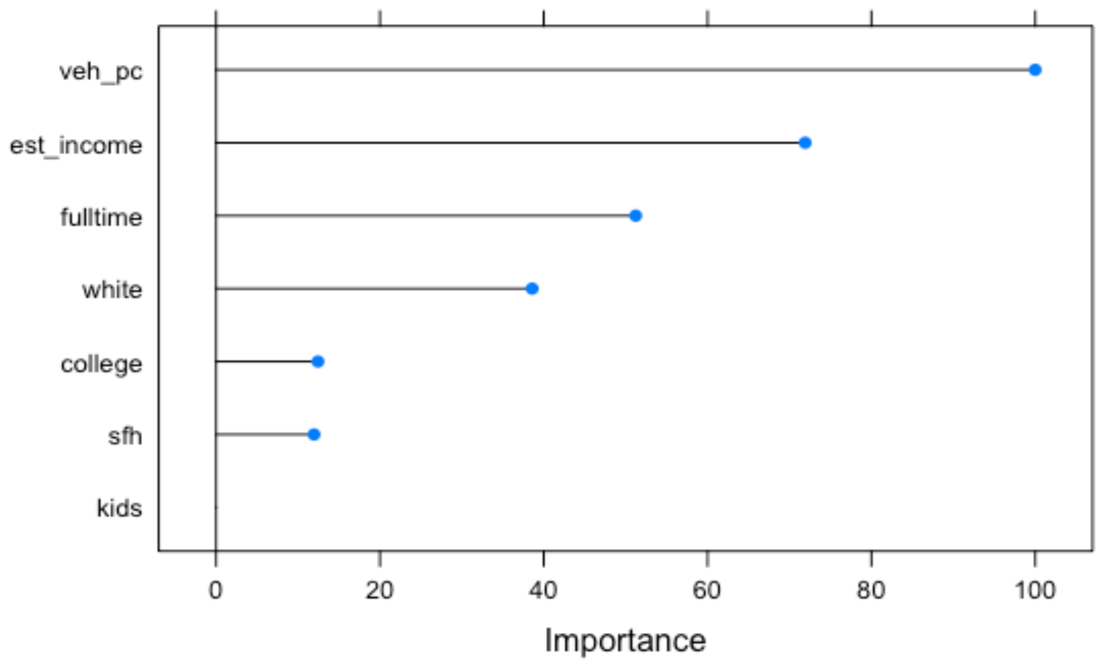

Figure 10. Importance of Each Variable Among Chevy Bolt Owners Without Financial Incentive

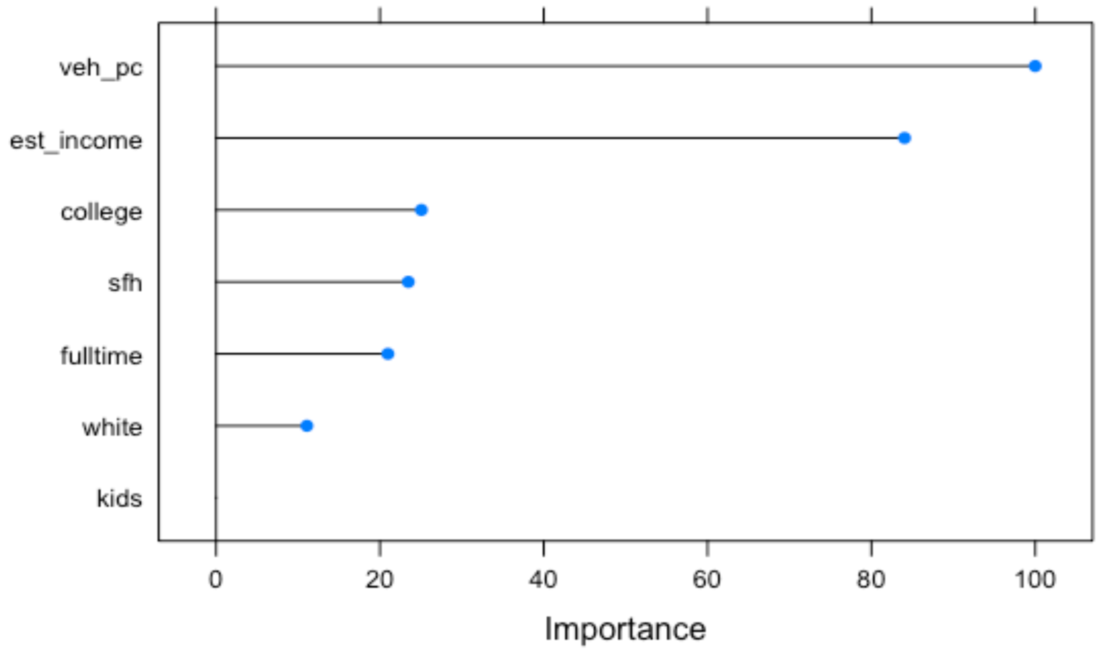

Figure 11. Importance of Each Variable Among Tesla Model 3 Owners Without Financial Incentive

Figure 10 and Figure 11 demonstrate the importance of each independent variable to influence the potential carbon mitigation cost. Under the circumstance that financial incentives are not included in the regression tree model, the number of vehicles per person within a household is the independent variable with the highest contributing factor (100%) for both Chevy Bolt (used) and Tesla Model 3 (new). For Chevy Bolt, estimated income (72%) and full-time employment (51%) are also contributing to the target variable with over 50% contributing factor. For Tesla Model 3, estimated income (84%) is the only independent variable with a contributing factor of over 50%. Variables with a contributing factor of lower than 50% include race, education, and single-family housing. The dummy variable indicating if the household has children does not contribute to the regression tree model at all for both cases.

Case of Financial Incentives

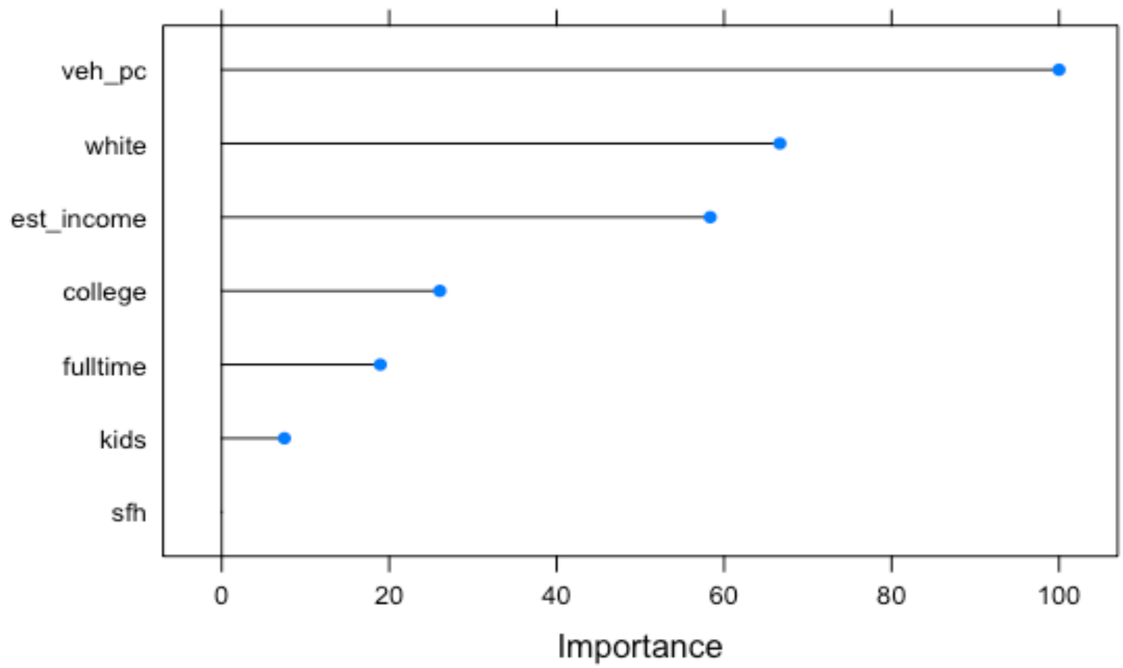

Figure 12. Importance of Each Variable Among Chevy Bolt Owners with Financial Incentive Included

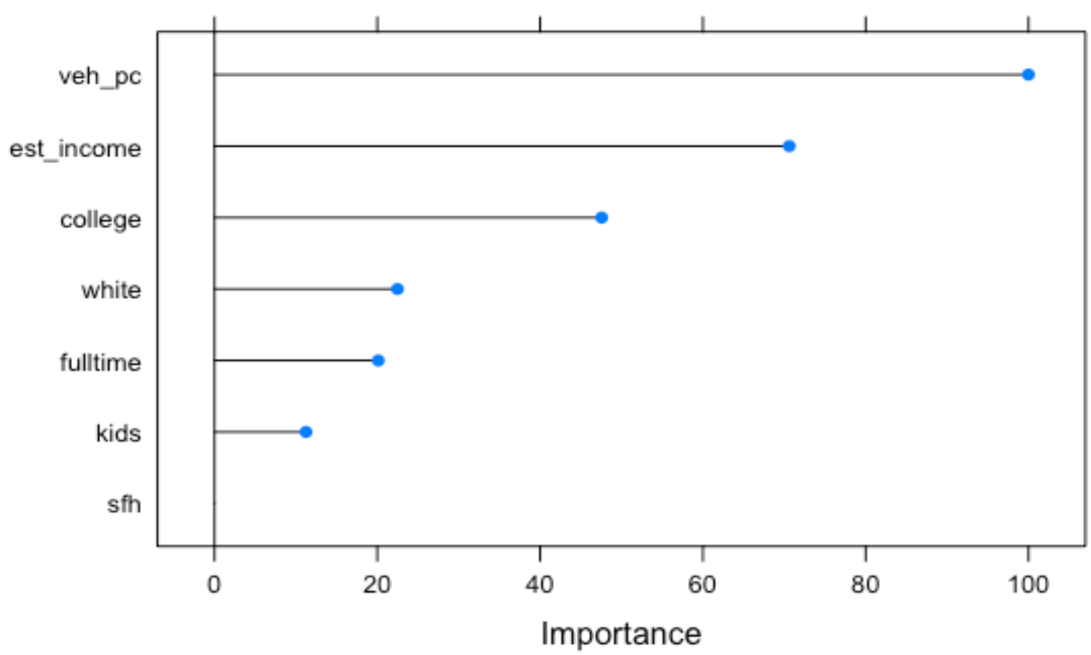

Figure 13. Importance of Each Variable Among Tesla Model 3 Owners with Financial Incentive Included

Figure 12 and Figure 13 visualize the contributing factor of each independent variable under the circumstance that financial incentives are included in the calculation of carbon mitigation cost. Similar with the models without the financial incentives, the highest contributing variable is the number of vehicles per person (veh_pc) within a household (100%) for both the Chevy Bolt (used) and the Tesla Model 3 (new). For Chevy Bolt, other important independent variables with a contributing factor higher than 50% include race (67%) and estimated income (58%). For Tesla Model 3, the only other important independent variable is estimated income (71%). The level of education influence differently for the Tesla 3 (48%) than Chevy Bolt (26%). Other variables with low contributing factor include full-time employment, and the dummy variable indicating if the household has children are similar between the two cases. Single-family housing is the only independent variable that does not contribute to either model at all.

Table 9. Contributing Factors of Each Independent Variable for Every Boosted Regression Tree Model

Variables (Sample Size: 5,607)	Chevy Bolt		Tesla Model 3	
	No incentive	With incentive	No incentive	With incentive
Number of vehicles per person	100%	100%	100%	100%
Estimated income	72%	58%	84%	71%
Race	39%	67%	11%	22%
Education	12%	26%	25%	48%
Full-time employment	51%	19%	21%	20%
Single-family housing	12%	0%	23%	0%
Children	0%	7%	0%	11%

Table 9 summarizes the difference of contributing factor of each independent variable to potential carbon mitigation cost per driver between Chevy Bolt and Tesla Model 3, as well as a comparison between the inclusion and non-inclusion of the financial incentives from various levels of governments. After the introduction of financial incentives, the importance of estimated income decreased from 72% to 58% for a used Chevy Bolt and from 84% to 71% for a new

Tesla Model 3. The importance of race (white vs. minorities) increased from 39% to 67% for Chevy Bolt with the financial incentives, and a smaller increase is observed for Tesla Model 3, from 11% to 22%. A similar effect can be found for education, whose importance increased from 12% to 26% for Chevy Bolt and from 25% to 48% for the Tesla Model 3. A significant decrease from 51% to 19% of full-time employment is found in the Chevy Bolt models after introducing the financial incentives, but similar effect is not found for Tesla Model 3. For both vehicle models, the importance of single-family housing drops to 0%. An opposite effect is seen for children presence within a household, whose importance increased from 0% to 7% for Chevy Bolt and 11% for Tesla Model 3.

5.5 DISCUSSION

This study provides a methodology to combine two key criteria of evaluating how and what EV adoption and policies achieve the objectives of promoting EV, i.e., to reduce transportation carbon emission, that are carbon emission saved and cost of transition to EV. Vehicle electrification is proven to be effective to reduce carbon emission, but it is crucial to calculate the cost of carbon reduction, including the cost of purchasing EV and EVSE, infrastructure maintenance cost, cost of government-provided subsidies and incentives, and other institutional costs like legislation, public education, and political controversies. With the vast adoption of EV expected in the 2020s, it is important to evaluate the priorities of allocating public funding to EV to ensure the merit of electrification is maximized and the public interest is well ensured. Existing policies and incentives from different government levels provide subsidies for EV and EVSE, but these incentives do not consider the carbon saving potential, which is directly affiliated with vehicle miles traveled (VMT). Hence, using EV adoption as a means of reducing carbon emission requires several hidden assumptions. First, EV's fuel economy, usually represented by miles per gallon of gasoline equivalent (MPGe), must be significantly better than the fuel economy of ICE, whose unit is conventional miles per gallon. Secondly, the emission factor of the electricity that the EV is using must be significantly lower than gasoline's emission factor. Thirdly, the distance of travel must stay the same, if not EV has lower vehicle miles traveled than ICE vehicles.

An immediate observation of the result of the regression tree is that number of vehicles per person within a household is the most important independent variable that contributes to the carbon mitigation cost. Based on the above discussion, this finding is not surprising, as families with more vehicles will emit less carbon dioxide per vehicle than those who own only one car. The high mitigation cost is induced by the high VMT for those households who have low per capita number of vehicles. This argument implies an underlying equity issue, as financially worse-off households oftentimes cannot afford multiple vehicles, which is also revealed in the regression tree result, which estimated annual household income becomes the second most important factor of contributing to carbon mitigation cost. Moreover, the descriptive statistics suggest that the less-advantaged social groups, such as the lower-income communities and Black and Hispanic communities, is borne with more responsibility of carbon emission even though the fuel economy of their vehicles are similar to other groups. It can be argued that the high mitigation cost is derived from both high denominators, i.e., the carbon emitted, and the low numerator, i.e., income. Given this result, policymakers should consider incorporating new methods of determining the priorities of EV subsidy programs that can be designed to favor the potential EV buyers with the highest carbon mitigation cost in order to have the two policy objectives of carbon reduction and social justice taken into account at the same time.

One updated incentive that incorporates both carbon accounting and social equity should be constructed around quantifying potential carbon mitigation cost per driver. There are multiple dimensions that the subsidies can be given. First, the incentives should be provided with different degrees to different socioeconomic groups. Some local governments already provide more subsidy for EV and EVSE purchase for the lower-income, or for those vehicle models that are under certain amount and not considered luxurious. From the comparison of with-incentive and no-incentive regression tree models, it can be observed that the importance of income as an independent variable has decreased, indicating that the financial incentives have some effects of promoting EV in a more equitable approach. However, household income is still the second more important independent variable to influence the financial cost of adopting EV, although the burden cannot be eliminated. Furthermore, the threshold amount is often established without the assistance from simulation modeling, or it is applied to too many cities and neighborhoods that an amount appropriate for one area does not necessarily represent that it is appropriate for all areas. The regression tree model suggested in this study provides the policymakers different thresholds of income that can be applied to different counties, cities, or marginalized communities. Second, incentives can be applied to only EV drivers who travel for more than certain VMT with non-ICE so that the public funding will prioritize its allocation to the drivers who will likely to decrease the most carbon dioxide emission by switching to EV. For instance, specific programs could be used to incentivize fleets used for public sectors and businesses that usually have more mileage per year than residential vehicles that are used mainly on commuting. For residential drivers, an evaluation of yearly mileage driven could be used to provide different amount of EV purchase rebate after several years of usage, i.e., if the newly acquired EV is not driven much, the financial incentive will be decreased. Although programs like these may raise concerns that they are encouraging more driving, policies can be made to target those who have fewer residential vehicles so that they can ensure the elasticity of driving demand is so small that the policy will not increase the driving demand substantially. Thirdly, the incentive should also target those who is currently driving a vehicle with poorer fuel economy, which combines with VMT also leads to a higher carbon emission. For example, as more electric truck models are revealed, governments should provide more financial incentives to the current pickup truck drivers, whose trips emit more carbon dioxide than other vehicles with the same mileage traveled.

5.6 CONCLUSION

This study presents a regression tree method that analyzes the profile of more than 7,000 drivers in California and simulated the potential carbon saving and carbon mitigation cost borne on each driver, indicate that households with fewer residential vehicles and with lower income are exposed to a higher EV switch cost and potential carbon mitigation cost. Policymakers should consider incorporating social equity, VMT and fuel economy to the subsidy program construction, so that carbon reduction and social equity and justice can both be ensured at one and the same time.

Chapter 6. EQUITY EVALULATION OF CHARGING STATION LOCATION SELECTION: THE CASE OF SIX U.S. CITIES

6.1 INTRODUCTION

Electric Vehicles (EV) have been widely regarded as a promising way to promote urban sustainable development. It can effectively reduce transportation-related carbon emissions and air pollution of urban road transportation and reduce dependence on fossil fuels[261]. To achieve the objectives of a transition to EV, governments around the world have taken steps to provide incentives for improving EV competitiveness or disincentives for abiding by the path dependence of using ICE vehicles[262]. Amongst the financial or non-financial incentives for adopting EV, those who target electric vehicle supply equipment (EVSE) infrastructure, also known as charging stations, aim to increase the attractiveness of EV by not only making the vehicle more affordable, but also to decrease the cost of owning an EV by reducing the cost of searching for charging with driving time saving and vehicle miles traveled (VMT) saving.

Adopting EV depends on developing charging infrastructure, and they can be charged from a standard power outlet or at a direct current fast-charging station. Infrastructure is not a direct way to motivate consumers to adopt EV. However, increasing the number of EV charging stations could incentivize consumers to adopt the technology. Existing literature demonstrates that charging infrastructure is positively correlated with the market share and the penetrate rate

[261] Coffman, Bernstein, and Wee, "Electric Vehicles Revisited"; U.S. Department of Energy, "Reducing Pollution with Electric Vehicles."

[262] Hardman, "Understanding the Impact of Reoccurring and Non-Financial Incentives on Plug-in Electric Vehicle Adoption – A Review"; Jenn, Springel, and Gopal, "Effectiveness of Electric Vehicle Incentives in the United States"; Wang, Tang, and Pan, "A Global Comparison and Assessment of Incentive Policy on Electric Vehicle Promotion."

of electric vehicles and obtaining public charging facilities is very important for the large-scale promotion of electric vehicles. Policymakers, workplaces, utility companies, and local agencies are promoting the introduction of such infrastructure in the hope of increasing EV market share. In some areas, charging is free, giving consumers an additional incentive. Some US states also proposed financial incentives for EVSE installations for homeowners and business owners with an income tax credit at the state level. In Georgia, businesses could purchase or lease qualified EVSEs and receive 10% of the cost of EVSE as a tax credit, up to $2,500[263]. The State of New York also offers an income tax credit for 50% of the cost of charging infrastructure for up to $5,000[264]. This incentive's equity implication is similar to the income tax credit when making new EV purchases that only the higher-income consumers could enjoy the benefit of the incentive to the maximum level, since the household income for the lower-income group does not reach the threshold to obtain 100% of the eligible federal tax incentive. For example, Liu et al[265] found that 62% of households in the surveyed Atlanta Metro area are not eligible for full federal EV credit ($7,500). In California, although no financial incentives for the private purchase of EVSEs, *the California Capital Access Program* and *the Electric Vehicle Charging Station Financing Program* provide loan guarantees to help finance the installation of EVSE at small businesses in the state[266]. Considering the fact that most large-city residents live in dense high-rise buildings, public charging infrastructure is essential when charging availability is limited for apartment- and condo-residents. In addition, adequate coverage of public charging

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[263] Stephens et al., "Incentivizing Adoption of Plug-in Electric Vehicles."
[264] The New York State Energy Research and Development Authority, "Drive Clean Rebate for Electric Cars."
[265] Liu, Guensler, and Rodgers, "Equity Assessment of Plug-In Electric Vehicle Purchase Incentives with a Focus on Atlanta, Georgia."
[266] California Air Resources Board, "Low Carbon Transportation Investments and AQIP Grant Solicitations."

stations can reduce the range anxiety of EV drivers, which is also critical to attracting potential buyers of electric vehicles.

The willingness to purchase EV is heavily associated with the density and readiness of regional charging network and the easiness of access to charging, but it is also challenging for public charging facilities to make profits in the early stage of EV deployment, as the initial investment is large while the charging demand is small. Inability of recovering infrastructure investment will undermine the market and slow the capital flow into the industry, and it is crucial for the public sector to consider strategic planning for the location of charging infrastructure. Government-provided or subsidized charging infrastructure is expected to help address the problem of limited EV range and the inability to charge at home for those who do not own a home with sufficient space to install charging equipment[267].

Charging infrastructure is strategically important for urban development in the next several decades also under the premise of transportation electrification being an important component of achieving carbon reduction goals. Furthermore, charging infrastructure has been recognized as an important instrument for smart city ambitions. As more EVs are driven in the city, EVSE can become distributed data centers that provide connection and data service for urban planning, namely energy management and traffic management. With the technology of energy storage systems, EVSE could further act as additional energy that can be transferred back to the grid. With this strategic importance, how chargers are spatially distributed can have a long-term impact on smart city initiatives and climate change policies in larger metropolitan areas, even a potential weakening effect when underlying equity issues are not resolved.

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[267] Simon Árpád Funke et al., "How Much Charging Infrastructure Do Electric Vehicles Need? A Review of the Evidence and International Comparison," *Transportation Research Part D: Transport and Environment* 77 (December 1, 2019): 224–42, https://doi.org/10.1016/j.trd.2019.10.024.

Yet, existing literature and professional reports do not evaluate the equity aspects of these policies and incentives. Moreover, the analysis conducted in Chapter 3 explored how different social groups react to the policy of investing more on public charging and encouraging more public charging availability. The result of the study shows that there is a pattern for the low-income communities, the minority group, and the renters who do not own single-family homes, they strongly lean to the direction that they consider public charging "extremely important" or "very important", while the moderate- or higher-income group do not value public charging as the above marginalized group. This study is intended to focus on spatially measuring equitability of current EVSE installation location selection, i.e., whether or not the marginalized group mentioned above has access to EVSE, identify if there is gap between the better-off social groups and the worse-off social groups in different areas and thus determine the comparative access differences between different socioeconomic groups and communities.

6.2 BACKGROUND

The core of the study of spatial equity of infrastructure is to explore the spatial rationality of public facilities, and the evaluation of the spatial accessibility and fairness of public facilities distribution are the critical components of it. Since the rapid urbanization process, the mismatch between urban public facilities and public needs has become more prominent. At the same time, the development of social equity theories and urban social science has led to a growing concern for the disadvantaged groups in the city. As an important social welfare resource, urban infrastructure has naturally become a hot spot for scholars to study. With the combined effects of these factors, the study of accessibility and spatial equity of urban public facilities and infrastructure has become an important area in the study of built environment and urban planning[268].

In urban planning and urban geography research, there are different definitions of spatial equity of public resources, such as equity in distribution measured by equality, equity in distribution with compensation based on public interest, equity in distribution based on user requirement, equity in in distribution based on market norms, and so on[269]. The main concern of the academic community is the second category, i.e., the degree of rationality in the layout of infrastructure based on different needs of the public through a perspective of public interest, more often described as a Rawlsian equity. The fundamental focus of this type of equity is to reduce the inequality in the provision of facilities and infrastructure due to socioeconomic differences, so that the spatial allocation of public resources can take into account the needs of the socially disadvantaged groups to the greatest extent possible, hence people of different background can utilize the urban infrastructure equally[270].

Some representative studies on the spatial equity of public facilities and infrastructure include Pinch's geographically based study on the inequity in the distribution of preschool resources and Ben-Elia and Benenson's study on the equity in the use of transit facilities among the lower-income neighborhoods[271]. As a special type of public facilities, the study of

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[268] Guijun Li, Tanxiaosi Luo, and Yanqiu Song, "Spatial Equity Analysis of Urban Public Services for Electric Vehicle Charging—Implications of Chinese Cities," *Sustainable Cities and Society* 76 (January 1, 2022): 103519, https://doi.org/10.1016/j.scs.2021.103519.
[269] Eran Ben-Elia and Itzhak Benenson, "A Spatially-Explicit Method for Analyzing the Equity of Transit Commuters' Accessibility," *Transportation Research Part A: Policy and Practice* 120 (February 1, 2019): 31–42, https://doi.org/10.1016/j.tra.2018.11.017.
[270] Keone Kelobonye et al., "Relative Accessibility Analysis for Key Land Uses: A Spatial Equity Perspective," *Journal of Transport Geography* 75 (February 1, 2019): 82–93, https://doi.org/10.1016/j.jtrangeo.2019.01.015; Shuocheng Guo and Eleftheria Kontou, "Disparities and Equity Issues in Electric Vehicles Rebate Allocation," *Energy Policy* 154 (July 1, 2021): 112291, https://doi.org/10.1016/j.enpol.2021.112291.
[271] Steven Pinch, "Inequality in Pre-School Provision: A Geographical Perspective," in *Public Service Provision and Urban Development* (Routledge, 1984); Ben-Elia and Benenson, "A Spatially-Explicit Method for Analyzing the Equity of Transit Commuters' Accessibility."

accessibility and spatial equity of open space is increasingly becoming a critical branch of spatial equity research. For instance, Talen uses data from Pueblo, CO and Macon, GA to compare the spatial distribution of park accessibility with the spatial distribution of selected demographic and socioeconomic factors and synthesizes the differences in park distribution between the two cities[272]. Talen's study found that the spatial pattern of low access for Macon "corresponds in certain areas to spatial clusters of high housing value and low percentages of non-White residents, while the reverse situation is true for Pueblo". Erkip, through a questionnaire survey, evaluated the accessibility and spatial equity of parks of Ankara, based on the number of parks, population distribution, travel time and accessibility, and found that the service has its limitation to service "equally" on a geographical basis[273]. Nicholls uses the park system of Bryan, TX as an example, and uses GIS as a platform to analyze the socioeconomic attributes of the population in the area based on the accessibility evaluation and used the Mann-Whitney U test to measure the level of accessibility and spatial equity provided by the local park system[274].

Throughout the existing literature, it is found that survey method and GIS-based spatial analysis methods are the most commonly used evaluation methods in the study of spatial equity of public facilities and infrastructure. GIS in particular has provided indispensable technical methods in many studies. Although the analysis methods and evaluation indexes chosen by researchers may differ due to different research purposes and focuses, the core idea of the research is that the spatial accessibility of public facilities and infrastructure is evaluated through

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[272] Emily Talen, "The Social Equity of Urban Service Distribution: An Exploration of Park Access in Pueblo, Colorado, and Macon, Georgia," *Urban Geography* 18, no. 6 (August 1, 1997): 521–41, https://doi.org/10.2747/0272-3638.18.6.521.

[273] Feyzan (Beler) Erkip, "The Distribution of Urban Public Services: The Case of Parks and Recreational Services in Ankara," *Cities* 14, no. 6 (December 1, 1997): 353–61, https://doi.org/10.1016/S0264-2751(97)00026-7.

[274] Sarah Nicholls, "Measuring the Accessibility and Equity of Public Parks: A Case Study Using GIS," *Managing Leisure* 6, no. 4 (January 1, 2001): 201–19, https://doi.org/10.1080/13606710110084651.

the spatial analysis function of GIS. On this basis, the spatial distribution characteristics of residents with different socioeconomic attributes are integrated with the results of the accessibility analysis to obtain a comprehensive analysis of the spatial equity of facilities and infrastructure. It can be seen that there are two main factors affecting the evaluation of spatial equity. First, the accessibility distribution characteristics of these facilities; and second, the spatial differentiation of people with different needs. Among them, the accessibility evaluation based on GIS is the core component of these studies, while the demographic variables to measure the equity include age, gender, race, and income level of the population. This study aims to achieve the said objectives by identifying the spatial relationship between the locations of existing charging stations and the demographic variables, thus evaluates the spatial equity of existing EVSE systems in the study regions.

6.3 METHODOLOGY

A series of spatial analyses were employed including *Global Moran's I, Cluster and Outlier Analysis* (Anselin Local Moran's I), *Ordinary Least Squares (OLS)*, and *Geographically Weighted Regression (GWR)* via QGIS and R applications.

6.3.1 *Global Moran's I*

The spatial analysis starts with Global Moran's I analysis to discover if there is spatial autocorrelation based on feature locations and feature values simultaneously[277]. Moran's I spatial autocorrelation is one of the most commonly used coefficients to measure the similarity between samples for a given variable as a function of spatial distance[278]. It evaluates the presence of

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[277] Luc Anselin, "Local Indicators of Spatial Association—LISA," *Geographical Analysis* 27, no. 2 (1995): 93–115, https://doi.org/10.1111/j.1538-4632.1995.tb00338.x; J. K. Ord and Arthur Getis, "Local Spatial Autocorrelation Statistics: Distributional Issues and an Application," *Geographical Analysis* 27, no. 4 (1995): 286–306, https://doi.org/10.1111/j.1538-4632.1995.tb00912.x.
[278] Anselin, "Local Indicators of Spatial Association—LISA."

spatial autocorrelation with existing type of pattern: clustered, dispersed, or random. The Moran's I statistic for spatial autocorrelation is given as:

$$I = \frac{n}{S_0} \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j} z_i z_j}{\sum_{i=1}^{n} z_i^2}$$

(18)

where z_i is the deviation of an attribute for feature,

i from its mean (x_i-$\bar{X}$),

$w_{i,j}$ is the spatial weight between feature i and j,

n is equal to the total number of features, and

S_0 is the aggregate of all the spatial weights:

$$S_0 = \sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j}$$

(19)

The z_i-score for the statistics is computed as:

$$Z_I = \frac{I - E[I]}{\sqrt{V[I]}}$$

(20)

where:

$$E[I] = -\frac{1}{n-1}$$

(21)

$$V[I] = E[I^2] - E[I]^2$$

(22)

For the Global Moran's I statistic, the null hypothesis states that the attribute being analyzed is randomly distributed among the features in the study area, i.e., the spatial process promoting the observed pattern of values is random chance[279].

6.3.2 *Cluster and Outlier Analysis*

In addition, a Cluster and Outlier Analysis (Anselin Local Moran's I) was performed to identify statistically significant hot spots, cold spots, and spatial outliers of the desired to-be-explored[280]. The Local Moran's I statistic of spatial association is given as:

$$I_i = \frac{x_i - \bar{X}}{S_i^2} \sum_{j=1, j \neq i}^{n} w_{i,j} (x_j - \bar{X})$$

(23)

Where x_i is an attribute for feature *i*,

$\bar{X}$ is the mean of the corresponding attribute,

$w_{i,j}$ is the spatial weight between feature *i* and *j*, and:

S_i^2 is ……

$$S_i^2 = \frac{\sum_{j=1, j \neq i}^{n} (x_j - \bar{X})^2}{n-1} - \bar{X}^2$$

(24)

with *n* equating to the total number of features.

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[279] Daniel A. Griffith, "Spatial Autocorrelation" (A Primer (Washington, DC, Association of American Geographers), 1997).
[280] Griffith.

The z_{I_i}-score for the statistics is computed as:

$$z_{I_i} = \frac{I_i - E[I_i]}{\sqrt{V[I_i]}}$$

(25)

where:

$$E[I_i] = -\frac{\sum_{j=1, j \neq i}^{n} w_{i,j}}{n - 1}$$

(26)

$$V[I_i] = E[I_i^2] - E[I_i]^2$$

(27)

6.3.3 *Global Ordinary Least Squares (OLS) Linear Regression and Geographically Weighted Regression (GWR) Models*

If the explanatory variable has spatial autocorrelation tested by Global Moran's I, a further spatial econometric model should be built to perform spatial regression. A global Ordinary Least Squares (OLS) linear regression is performed to generate predictions or to model a dependent variable in terms of its relationships with a number of explanatory variables.

While OLS is a traditional approach, the underlying independent and homoscedastic assumptions associated with the use of spatial data may not hold, and alternative estimation strategies may be required, including strategies based on local and global specifications. Geographically Weighted Regression (GWR) extends OLS by taking spatial structure into account, estimates local rather than global model parameters, and provides a local model of the variable of process by fitting a regression equation to every feature in the dataset. It constructs the separate equations by incorporating the dependent and explanatory variables of features falling within the bandwidth of each target feature. Each GWR equation may be expressed as:

$$\hat{y}_i = \beta_0(u_i, v_i) + \sum_k \beta_k(u_i, v_i)x_{ik} + \varepsilon_i$$

(28)

where $\hat{y}_i$ is the estimated value of the dependent variable for observation *i*, (u_i, v_i) captures the coordinate location of *i*,

β_0 is the intercept,

β_k is the parameter estimate for variable *k*,

x_{ik} is the value of the *k*-th variable for *i*, and

ε_i is the error term.

The weighted observation changes as *i* changes, as follows:

$$\hat{\beta}_{(u_i, v_i)} = (X^T W_{(u_i, v_i)} X)^{-1} X^T W_{(u_i, v_i)} Y$$

(29)

where $W_{(u_i, v_i)}$ is the distance weighted matrix:

$$X = \begin{bmatrix} 1 & x_{11} & \cdots & x_{1k} \\ 1 & x_{21} & \cdots & x_{2k} \\ \cdots & \cdots & \cdots & \cdots \\ 1 & x_{n1} & \cdots & x_{nk} \end{bmatrix}, W_{(u_i, v_i)} = W_i = \begin{bmatrix} W_{i1} & 0 & \cdots & 0 \\ 0 & W_{i2} & \cdots & 0 \\ \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & \cdots & W_{in} \end{bmatrix}$$

(30)

$$\beta = \begin{bmatrix} \beta_0(u_1, v_1) & \beta_1(u_1, v_1) & \cdots & \beta_k(u_1, v_1) \\ \beta_0(u_2, v_2) & \beta_1(u_2, v_2) & \cdots & \beta_k(u_1, v_1) \\ \cdots & \cdots & \cdots & \cdots \\ \beta_0(u_n, v_n) & \beta_1(u_n, v_n) & \cdots & \beta_k(u_n, v_n) \end{bmatrix}$$

(31)

The distance decay function is modified by a bandwidth setting, at which distance the weight rapidly approaches zero. The bandwidth in this research is chosen by minimizing the Akaike Information Criteria (AIC) score. The AIC is given as:

$$AIC_c = 2n \log_e(\hat{\sigma}) + n \log_e(2\pi) + n \left\{ \frac{n + tr(S)}{n - 2 - tr(S)} \right\}$$

(32)

where *tr(S)* is the tract of the hat matrix.

In the regression models, the following variables are specified. The dependent variable is the charging infrastructure density, which is the number of EV chargers per 1,000 population. The independent variables are median household income, poverty rate whose thresholds are collected from the Current Population Survey Annual Social and Economic Supplements conducted by eh U.S. Census Bureau, population whose race is identified as "white-only", population with a bachelor's degree or higher, housing density, which is calculated with housing units per acre, renter rates, , the percentage of age 25-64 population who are employed, and the average commute time in minute. The level of geography of all independent variables is census tracts. below lists the dependent variable and all the independent variables, and the median values in each study area.

Table 10. List of Variables and their Median Values in each Study Area

Variable	Definition	Data Source	Median values in each study area					
			LA	SF	SEA	PDX	ATL	DTW
evse	Number of chargers per 1,000 population	AFDC (DOE)	21.45	35.27	18.1	12.88	14.78	1.46
medincome	Median of household income	ACS 2019	77450	113898	93121	79275	73094	62834
poverty	Rate of population who live under the poverty line	ACS 2019	0.143	0.094	0.093	0.109	0.136	0.172
whiteonly	Rate of population whose race is identified as "white-only"	Census 2020	0.319	0.435	0.68	0.764	0.486	0.624
college	Rate of population who has a bachelor's degree or higher	Census 2020	0.331	0.505	0.419	0.403	0.39	0.285
hden	Housing density, calculated by (housing units / acre)	Census 2020	6.575	8.298	3.48	3.193	1.66	2.365
renterrate	Rate of population who are renting instead of owning housing	ACS 2019	0.511	0.448	0.378	0.374	0.383	0.329
emprate	Rate of age 25-64 population who are employed	ACS 2019	0.738	0.776	0.765	0.77	0.796	0.753
commute	Average commute time in minutes	ACS 2019	30	32.6	29.5	25.5	31.8	26.6

LA: Los Angeles; SF: San Francisco; SEA: Seattle; PDX: Portland; ATL: Atlanta; DTW: Detroit

6.4 DATA

To evaluate current EVSE spatial distribution, the location of all non-residential charging stations in the United States and Canada was collected and identified if a spatial relationship between the distribution of charging facilities and the less-advantaged communities can be found using the metrics provided by the U.S. Census.

The study area will be limited to six main metropolitan areas in the United States: Los Angeles-Long Beach-Anaheim Metropolitan Statistical Area, San Francisco-Oakland-Berkeley Metropolitan Statistical Area, Portland-Vancouver-Hillsboro Metropolitan Statistical Area, Seattle-Tacoma-Bellevue Metropolitan Statistical Area, Detroit-Warren-Dearborn Metropolitan Statistical Area, and Atlanta-Sandy Springs-Alpharetta Metropolitan Statistical Area. These cities are selected as a sample of cities that have high EV market penetration rate and considered as more “EV-friendly”. These cities are selected also based on different policy coverage of transportation electrification planning. The metropolitan areas of Seattle, Portland, and San Francisco have established comprehensive vision of achieving carbon neutrality in the transportation sector by introducing roadmaps of EV policies from the regional, county, local, or utility service level. Among these three cities, the policy documents of Seattle and San Francisco both provide extensive discussion of ensuring equity[281]. On the state level, the state governments of all study areas but Atlanta have enacted a document guiding the legislation and executive policies to achieve a complete transportation electrification[282]. Moreover, the document written by the State of Oregon[283] includes their guidance that incorporating the discussion of racial and economic disparities associated with EV adoption.

Table 11 lists the presence of EV planning documents either on the state level or on the regional, county, or local level, and whether or not the planning document includes a dedicated equity section or mentioning of equity consideration in the roadmap of transportation electrification.

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[281] Seattle City Light, “Transportation Electrification,” accessed January 15, 2022, https://www.seattle.gov/city-light/energy-and-environment/future-of-energy/transportation-electrification; City of San Francisco, “Electric Vehicle Roadmap: San Francisco’s Electric Mobility Strategy,” sfenvironment.org - Our Home. Our City. Our Planet, June 25, 2019, https://sfenvironment.org/electricmobilitysf; City of Portland, “Electric Vehicles: The Portland Way,” n.d., https://www.portlandoregon.gov/shared/cfm/image.cfm?id=309915.
[282] State of California, “Zero-Emission Vehicles in California: Community Readiness Guidebook,” n.d.; State of Oregon, “Oregon 2021 Zero Emission Vehicle Interagency Action Plan,” accessed January 15, 2022, https://www.oregon.gov/energy/Get-Involved/Pages/ZEVIWG.aspx; Washington State Department of Transportation, “Washington State Electric Vehicle Action Plan 2015-2020,” 2015, 48; State of Michigan, “Michigan’s Response to Electrify America’s Zero Emission Vehicle (ZEV) Investment Plan,” n.d.
[283] State of Oregon, “Oregon 2021 Zero Emission Vehicle Interagency Action Plan.”

Table 11. Presence of EV Planning Documents and Equity Mentioning in Six Metropolitan Areas

	State Level	Regional/County/Local Level
Atlanta, GA	No	No
Detroit, MI	Yes	No
Portland, OR	Yes *	Yes
Seattle, WA	Yes	Yes *
San Francisco, CA	Yes	Yes *
Los Angeles, CA	Yes	No

*: Equity is brought up or dedicated in a separate section

In order to explore the spatial relationship between socioeconomically marginalized groups and EVSE locations, the research uses the dataset of locations of charging stations provided by the Alternative Fuels Data Center at the U.S. Department of Energy[284]. The other data used includes the information needed to the model's other variables besides the charging equipment locations, including population, employment, income, race, education, and housing. All the above data are obtained from the Census Bureau, including the Census 2020 data and five-year estimate American Community Survey 2019 data.

[284] Alternative Fuels Data Center, the U.S. Department of Energy, "Alternative Fuels Data Center: Electric Vehicle Charging Station Locations," accessed February 19, 2022, https://afdc.energy.gov/fuels/electricity_locations.html#/find/nearest?fuel=ELEC.

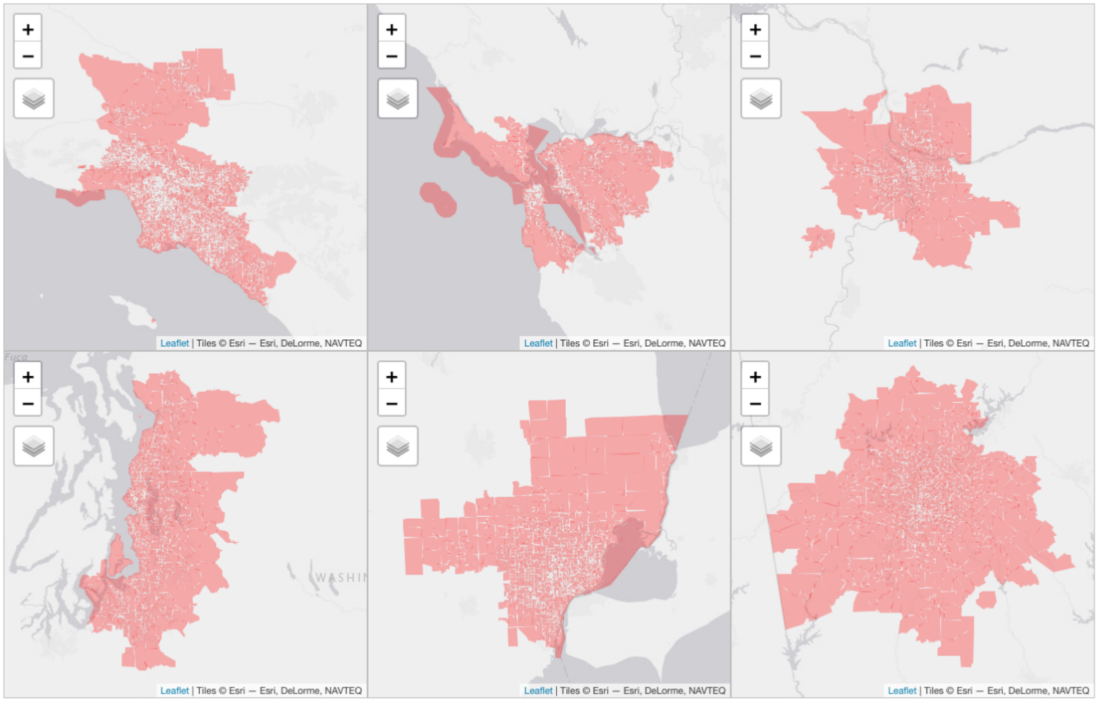

Figure 14. Maps of the Six Metropolitan Areas. Clockwise from the Top Left: Los Angeles, San Francisco, Portland, Atlanta, Detroit, Seattle. Shaded Areas are Waters.

6.5 RESULTS

Figure 15 and Figure 16 illustrate the number of EV chargers within the six metropolitan areas, in which Figure 15 shows the number of chargers in each census tract, and Figure 16 shows the charging infrastructure density based on a per-capita-like metric, where the number of chargers per 1,000 population is used.

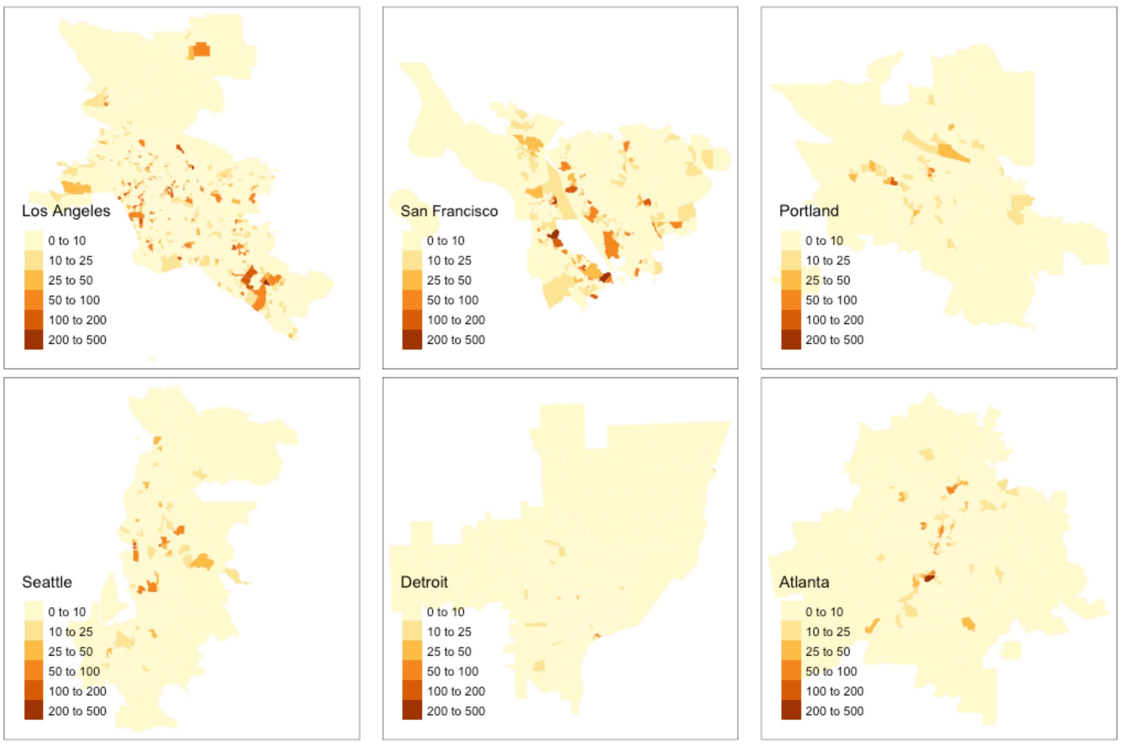

Figure 15. Number of EVSE in Each Tract for Each Metropolitan Area

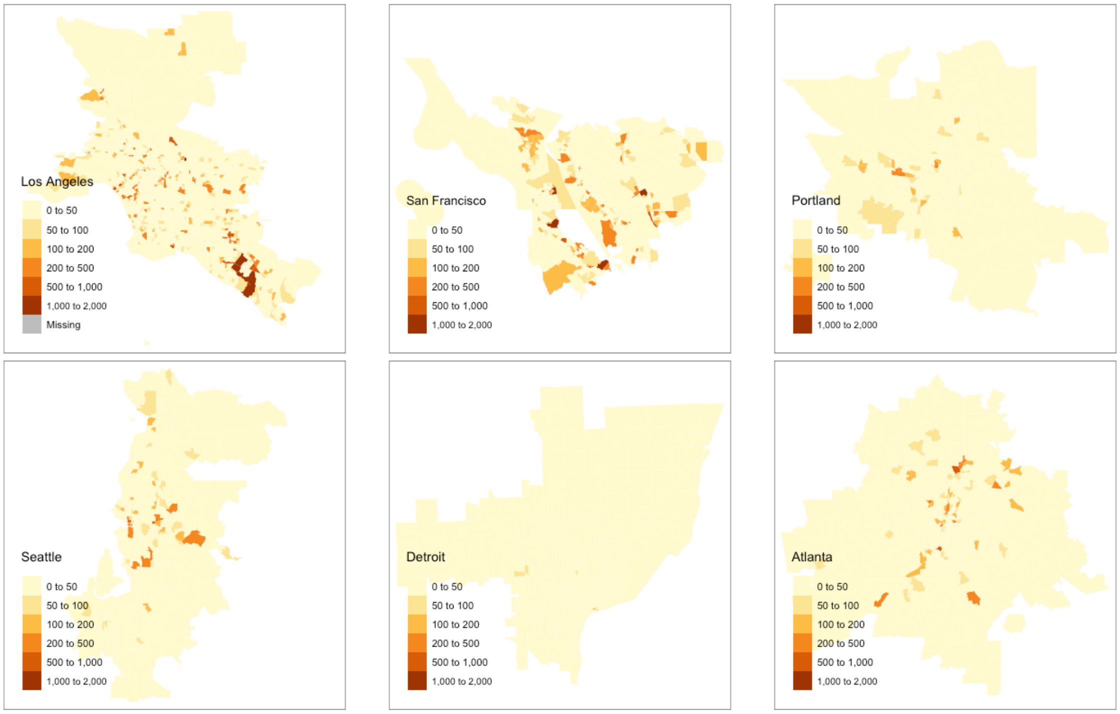

Figure 16. Number of EVSE per 1,000 Population in the Tract for Each Metropolitan Area

Table 12 illustrates the result of the global OLS with the statistically insignificant variables omitted. Detailed summary of the OLS models is presented in Appendix II. All independent variables have at least one metropolitan area that shows statistically significance. The variables *housingden*, *rentrate*, *emprate*, *commute* returns significant coefficient estimates in more than 3 metropolitan areas. Variable *housingden* is significant in Los Angeles, San Francisco, Atlanta, Seattle, and Portland metropolitan areas. Variable *rentrate* is significant in Los Angeles, San Francisco, Detroit, Seattle, and Portland metropolitan areas. Variable *emprate* is significant in Los Angeles, Atlanta, and Portland metropolitan areas. Moreover, the Moran's I of the residuals of the global OLS model are also estimated. It is showing that there is significant spatial autocorrelation in all six metropolitan areas, with Moran's I being positive and p-value < 0.05. The assumption of global OLS estimation is therefore violated since there are dependent residuals. Therefore, the GWR model is used to show the geographical variations of the associations with different factors. The detailed summary of the GWR model for the local parameter estimates is also presented in Table 14 through Table 19 in the Appendix.

Table 12. Global OLS of Six MAs: Statistical Significance of Each Variable

Variable/City	LA	SF	Atlanta	Detroit	Seattle	Portland
commute	-0.043 **	-0.096 ***	-0.104 **			
college				0.203 ***		
emprate	-0.055 **		-0.077 *			-0.118 **
rentrate	0.188 ***	0.106 *		0.258 ***	0.374 ***	0.474 ***
medincome					0.209 **	
poverty			-0.146 **			
whiteonly	-0.147 ***					
housingden	-0.196 ***	-0.117 ***	-0.099 *		0.120 ***	-0.149 *
R2	0.079	0.021	0.125	0.068	0.14	0.155
Sample Size	3,113	1,103	1,442	1,320	864	569

*p<0.1; **p<0.05; ***p<0.01

The performance of OLS and GWR models in terms of R-squared and AICc are also provided in Table 13. For most metropolitan areas except for Atlanta, the global model explains on average 9.3% of the variance of EVSE density which is increased to an average of 34% if the model is calibrated as GWR by taking into account the local impact of the explanatory variables. Comparing the models in terms of AICc, it is demonstrated that the model fit is greatly enhanced by reducing the value of AICc significantly.

Table 13. Performance Comparisons of OLS and GWR Models: AICc and Global R-squared

Metropolitan Areas	AICc		R_2	
	OLS	GWR	OLS	GWR
Los Angeles	7862.2	7371.5	0.079	0.446
San Francisco	2704.4	2627.7	0.021	0.331
Seattle	1890.3	1834.3	0.140	0.270
Detroit	3471.2	3453.2	0.068	0.123
Atlanta	2473.0	2476.0	0.125	0.128
Portland	1240.3	1189.4	0.155	0.530

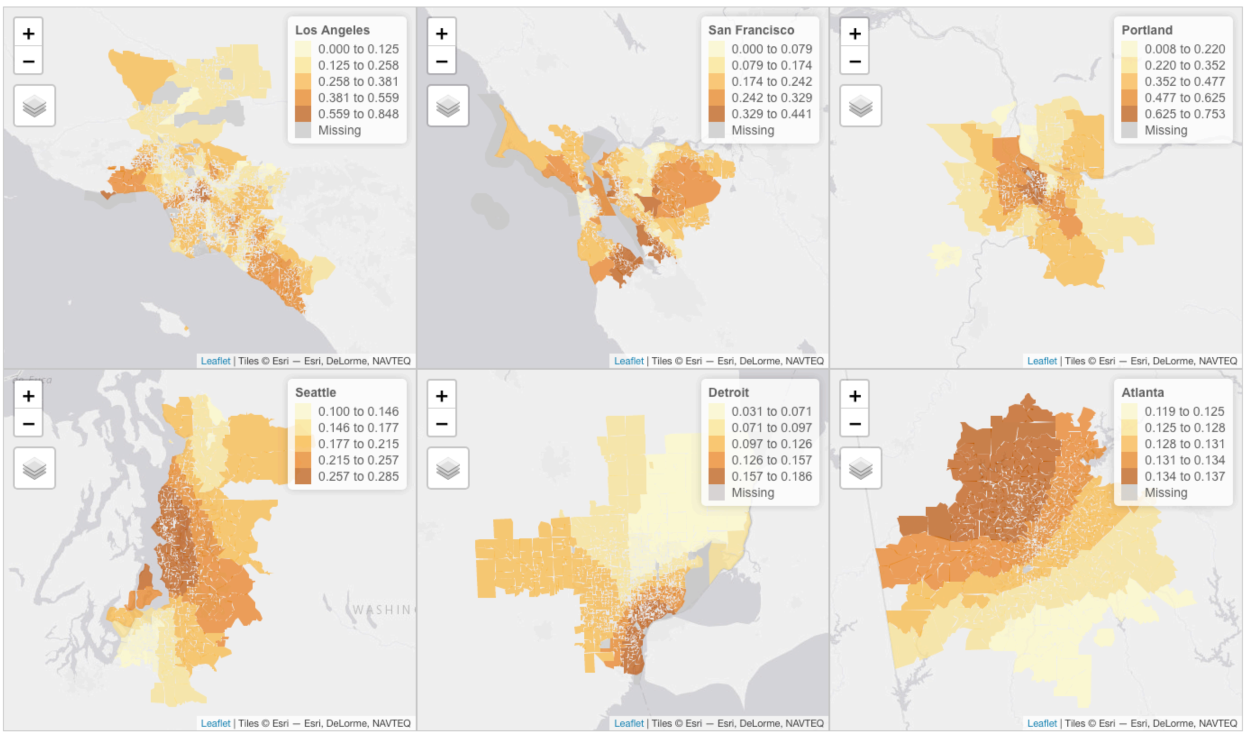

Figure 17. Geographical Distribution of Local R-squared Values for GWR Model

The geographical distribution of local r-squared values (Figure 17) shows the performance of the model varies from different metropolitan areas, as well as from different neighborhoods in each metropolitan area. Local r-squared values are helpful to see where GWR predicts well and where it predicts poorly. It can be observed here that the GWR model yields high local r-squared value for most of the high-density census tracts. In the Los Angeles

Metropolitan Area, r-squared is high in most of the city center of Los Angeles as well as the southern part of Orange County. In Seattle, Detroit, and Portland, local r-squared are the highest in downtown areas. In Atlanta, r-squared in the northern part of the city is higher than the southern part, where Northern Atlanta is a wealthier and more developed area than the southern part of the city. In Bay Ara, the pattern above is not observed, that downtown San Francisco does not necessarily have a higher r-squared value, but the highest value can be found in South Bay, such as Palo Alto, Redwood City and City of Fremont, potentially due to the presence of high-tech sectors as well as educated young and affluent population.

In the GWR analysis, census tracts with insignificant statistical relationships are omitted. The result indicated different EVSE accessibility in communities with different characteristics in different cities. For housing density, the global models suggest that there is a significant negative association between *EVSE density and housing density (housingden)*, but from the maps it differs for different neighborhoods. The most negative association happen in the suburbs and usually away from the center of the metropolitan area for five cases. In Bay Area, there is no clear association between EVSE and housing density in San Francisco and Oakland, but the most negative association is in South Bay. In Los Angeles, the negative relationship can be found in Orange County, namely Anaheim and Irvine. In Portland, the negative association is found in Hillsboro and Beaverton, outside of central Portland. In Atlanta, the whole metropolitan area is showing similar negative relationship. In Detroit, the negative association can only be found in the less-advantaged northern part of the city, and there is no significant relationship found in central Detroit. In terms of *rental rate (rentrate)*, the most positive association can be found in the center of the metropolitan area in the Atlanta, Detroit, Portland, Seattle, and Los Angeles metropolitan areas. Note that the correlation is the greatest in central cities, but the same pattern is not found for housing density.

Observed from the maps of the relationship between *EVSE density and median household income (medinc)*, positive correlations can be found in the most urbanized city centers, such as Downtown Seattle, Downtown San Francisco, Downtown Detroit, Downtown Los Angeles, and Santa Monica. A negative correlation exists in Orange County and East Bay Area. Other census tracts, especially in Portland, Detroit, and Atlanta metropolitan areas, do not show a significant relationship. Similarly, a negative relationship between *EVSE density and poverty rate (povertyrate)* can be found in the city centers of Detroit, Portland, Seattle, and all over the metropolitan area of Atlanta.

The relationship between *EVSE density and white-only population share (whiteonly)* is in general not significant. The areas showing the most significant negative correlation are suburbs of Detroit, South Bay Area, City of San Francisco, and Orange County. The negative correlation may be due to the high Asian population in Bay Area and Orange County, as well as the high African American population in the suburb of Detroit. The only area with a positive correlation is in part of the downtown area of Los Angeles, Beverly Hills, and Santa Monica, which are all considered the wealthier neighborhoods in the Greater Los Angeles Metropolitan Area.

The model results show conflicted relationship *between EVSE density and employment rate (emprate)* in different metropolitan areas. Negative correlations between *EVSE density and employment rate* are mostly located in the city centers in Seattle, Portland, Atlanta, Los Angeles, and Santa Monica, indicating that EVSE density in these metropolitan areas is not sufficient to support employees who drive an EV to commute. The peripheral suburbs outside of these city centers show an opposite pattern, that, not surprisingly, EVSE density tend to be higher when the employment rate is higher. In Portland, a negative correlation is found in the city center of Portland, and a positive correlation is found in the suburbs of Portland, namely Hillsboro and Beaverton. In Los Angeles, a negative correlation is found in part of Downtown Los Angeles and Santa Monica, while a positive correlation is found in Orange County. In Seattle, the negative correlation can be found only in the west part of the city that are close to the Puget Sound. In most of the Atlanta Metropolitan Area, there is a negative pattern. In contrary, a positive correlation is found in the northwest part of the Detroit Metropolitan Area. For average commuting time, the negative correlation can be found in all of Atlanta Metropolitan Area and most area of City of Seattle. A positive correlation is located in Orange County and a few suburb Portland census tracts. This may be due to the reason that the metropolitan areas of Orange County and Portland have higher deployment of EVSE along key commuting corridors than the metropolitan areas of Atlanta and Seattle.

6.6 DISCUSSIONS

We investigate the geographical distribution of EVSE to better understand how different socioeconomic and built-environment factors may influence the overall EVSE spatial distribution, The results find that there are no homogeneous associations between current EVSE spatial distribution and socioeconomic indicators such as median income, education, poverty rate and race. Instead, a more universal discovery from the OLS result is that EVSE distribution is correlated with built-environment and transportation variables such as housing density, ratio of rental housing, and time of commute. It is also associated with rate of employment (*emprate*) within an area. This study reveals how the benefits of EV charging infrastructure is currently unequally distributed across different regions.

From the illustrations of geographical distribution of number of EVSE in each tract and number of EVSE per 1,000 population in each tract from Figure 15 and Figure 16, it is found that higher density of EVSE and per capita EVSE does not cluster geographically in big cities. Instead, in the large metropolitan areas like Los Angeles, San Francisco, EVSE distribution is found spatially spread out throughout the metropolitan area in both city centers as well as suburbs in different regions of the six metropolitan areas. Under the circumstance that employment destinations are mostly located in city centers other than the San Francisco metropolitan areas, the chargers in downtown areas must tolerate more competitions during the day when the daily commuters drive to work and park their vehicles in the city center. In contrary, neighborhoods in the suburbs may have more access to chargers during the day due to less competition from commuters. The OLS results support these arguments, that higher per capita number of chargers is found in lower housing density tracts with high renters' rate, low employment rate and lower commute time, which indicates the busier neighborhoods with a proximity from the city center, such as main arterials, suburbs along the highway, and suburbs with shopping facilities. This distribution indicates a potential lack of chargers at the workplace in city centers, which is as important as EVSE at residences. Failure to provide sufficient chargers at workplaces will discourage those with longer commutes to drive EVs and may further discourage EV adoption by those for whom residential charging is difficult, expensive, or unavailable, especially those who live in older multi-family dwellings or housings without a garage. In the meantime, in a private market-based housing system, unless there is extensive subsidy and market intervention from the government, the cost of installing charging station in multi-family housing properties will likely to be passed on to renters and raise the cost of housing, which put a policy recommendation of charging infrastructure installation mandate on multi-family housing equitably questionable.

More specifically, the result of the GWR method successfully found the geographically varying relationship of EVSE density with said social equity and built-environment factors. We found that the predictive efficiency and model accuracy are enhanced by utilizing the method. Moreover, it can detect the spatial relationship between EVSE density and independent variables of interest that are found of no association in the OLS result. For instance, EVSE density is correlated with poverty rate, race, and income in only limited neighborhoods in all metropolitan areas. The key advantage of this method is its capability of visualization of the geographically varying heterogeneous relationships between the independent variables and the dependent variable in different areas, even if it is found no statistically significant association in conventional statistical models. This tool could enable the policymakers for a better understanding of the relationship between EVSE infrastructure and social equity and justice based on spatial contexts and certain metropolitan area's known features.

Based on the result of this study, charging infrastructure in all metropolitan areas are found spatial unequal to varying degrees. Current spatial inequities can partly be attributed to an absence of equity assessment in current EVSE location analyses. Therefore, spatial equity should be regarded as one of the basic evaluation indicators for EVSE siting, and different spatial assessment methods should be adopted to provide policymaking directions. Although all metropolitan areas have state level transportation electrification roadmap except the State of Georgia, and three out of six (Portland, Seattle, San Francisco) have similar plans at the regional, county, or local level, only a few among these documents consist of sections that discuss equity.

Furthermore, no existing planning document in all these municipalities discuss the equity aspect of EV development through a spatial equity perspective.

The methodologies in this study could serve as a starting point of implementing these equity assessments, as they are uncomplicated to perform, whose repeatability allows the public sector to evaluate the spatial equity of charging infrastructure with empirical evidence and thus improve accessibility of EV charging. With the information provided by this toolbox, policymakers and planners are capable of identifying local hot spots of EVSE and their relationship with socioeconomic and built-environmental indicators, and therefore adjust planning and siting strategies by increasing deployment in low-access zones or less-advantaged neighborhoods and decreasing deployment in high-access zones or more-marginalized neighborhoods, depending on the equity targets proposed by the city's comprehensive plan. Legislators and policymakers could then incorporate the information of spatial equity assessment and accessibility analysis to the financial or planning incentives of promoting EV and EVSE.

This research work could accede to certain shortcomings and potential future research directions that should not be overlooked if adopted by other planning scholars or practitioners. Firstly, future studies could further develop this method to incorporate with detailed features within a specific metropolitan area to simulate a smaller-scale scenario, in which the spatial equity assessment is more comprehensively conducted. Secondly, different preferences in EV usage and charging as well as the different travel behavior within a metropolitan area will inform different charging habits. These heterogeneities will significantly impact the usage of charging stations, and future research could simulate these preferences to better predict charging accessibility. Thirdly, future research could distinguish Level 1/2 slow charging and Level 3 DC fast charging. Also, future studies could use time-varying data instead of cross-sectional data from one year to evaluate existing EV regulations, incentives, and policies, and compare them by simulating the ex-ante and ex-post relationships between EVSE location and social equity.

6.7 CONCLUSIONS

EVSE is escalated to a higher level in the last decade with more roadmap plan documents and incentives, but it has rarely been studied for its equitable spatial distribution. To better understand the relationship between EVSE and equity, this study has proposed a toolbox consist of different statistical methods to identify potential inequities in charging availability and accessibility in addition to conventional methods of spatial distribution of charging stations. The results suggest that there are associations between social equity indicators and current EVSE infrastructure density within all studied metropolitan areas, although the significance and effect are not completely homogeneous for all variables. The GWR model further demonstrates the utilization of spatial equity assessment, indicating where the higher densities of associations are located. This set of methodology could fill the missing part in existing EV planning, and it can serve as a policy tool for EV policymakers to evaluate spatial equity of charging station locations and enhance convenience and accessibility of charging infrastructure.

Chapter 7. CONCLUSION

This dissertation has discussed the relationship between vehicle electrification and social equity from different perspective by conducting three research topics. The first research selected three planning-related incentives, i.e., providing better EVSE infrastructure, free parking incentive, and HOV lane access. Using an ordered logistic regression, this study analyzed how important these incentives were to influence the purchase decision-making process for existing EV owners in California, and how different socioeconomic groups react to these incentives differently. Results suggest that the marginalized communities, including the lower-income households or drivers who do not reside in single-family housing dwellings, consider the charging infrastructure availability and accessibility the most important incentive to encourage their purchase. On the other hand, the better-off group of drivers consider HOV lane access the most important incentive for their EV purchase. The second research discussed the potential carbon mitigation cost under the scenario of a complete switch to EV, and it estimated the cost under different scenarios of including the existing financial incentives and not including the existing financial incentives. Using a combination of multivariate regression tree methodology and a boosted regression tree methodology, the study was able to create a profile of those who have a high carbon mitigation cost, i.e., those who have higher potential carbon reduction per percentage of their annual household income, and those who are exposed to a low carbon mitigation cost. The result of the simulation demonstrated that the number of vehicles per household and annual household income are the two most important variables to impact the potential carbon mitigation cost. However, the determining factor of income has decreased with the introduction of current financial incentives, including some local measures that provide specific subsidies for marginalized communities. The third research topic explores the relationship between current EVSE availability and the socioeconomic status of six cities in the United States, and it conducted a Geographically Weighted Regression model to detect if there is spatial correlation between the two. Results are presented to show heterogeneity among different metropolitan areas with different features, and it is found that current EVSE allocations are spatially correlated with certain socioeconomic variables in various cities, and the availability and accessibility of EVSE in marginalized communities need to improve.

The above research shed light on how to advance equity agenda in facing major vehicle electrification processes in urban and transportation planning field. There are policies, regulations, or incentives that governments can propose regarding the trend of vehicle electrification that could have a better impact on addressing the injustice and inequity issue than the existing policies. To reduce carbon emissions from travels, planners and policymakers should still focus on distributing public funding to subsidies that could either reduce driving or introduce more renewable energy. For instance, a guaranteed carbon reduction and pollution reduction through transportation policies could be achieved with road pricing, encouraging active transpiration and public transit, and developing land-use planning policies that transform the cities to have higher density. Reducing driving should still be the top priority for transportation planners. A 50% reduction of VMT will be effective in reducing air pollution and carbon emissions as a full adoption of EV in most areas in the world. A similar effect could be realized with continuing strict regulations on improving the fuel economy of on-road ICEs. Researchers could also explore different variations of pricing driving. Congestion pricing should be considered as a priority, as it decreases the demand of driving during congested peak hours if done correctly, and thus manage the travel demand to limit travel amount and density in the urban area in the location and during the period that vehicles contribute the most emissions, since pollutant emissions and carbon emissions are greater when the vehicle is idling or at a slow speed in the traffic[285]. Other pricing schemes, including pricing driving based on mileage or pricing driving based on well-to-wheel carbon emissions, should also be explored, in which policymakers are informed of the carbon and environmental equity and justice impact with each of these pricing schemes[286].

Switching from conventional ICE to EV is still necessary, and it will bring a positive impact of the equitable and just outcome if the correct measures are proposed. First, equity evaluations should be brought into policymaking for EV promotion, including the financial incentives, non-financial incentives, and infrastructure building. For non-financial incentives, governments should find the incentives that benefit the marginalized groups and have the greatest carbon reduction potential, instead of establishing policies that encourage more driving and thus greater VMT. For infrastructure, planners should ensure that drivers from all communities could benefit from electrification, especially the disadvantaged, low-income, non-white communities who are more likely to be overlooked by the market. For financial incentives, more EV subsidies should be provided under the principle of justice, which enables more public funding to be allocated to the less-advantaged communities. Secondly, governments can use the methods provided in this dissertation to prepare more accurate thresholds of issuing benefits, such as amount of rebates to different socioeconomic groups, density of EVSE in different neighborhoods, VMT to prioritize public funding, and even thresholds of future carbon tax measures. Thirdly, the priorities of switching to EV should be focusing on vehicles with more driving mileage than vehicles whose main task is the single-occupancy daily commute[287]. Instead

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[285] Sean D. Beevers and David C. Carslaw, "The Impact of Congestion Charging on Vehicle Emissions in London," *Atmospheric Environment* 39, no. 1 (January 1, 2005): 1–5, https://doi.org/10.1016/j.atmosenv.2004.10.001.
[286] Heywood and MacKenzie, "On the Road toward 2050."
[287] Heywood and MacKenzie.

of providing subsidies to everyone who purchases an EV, public funding should be distributed on subsidizing electric freight vehicles and public transit vehicles. For residential vehicles, more subsidies could be provided to those who have more carbon emission reduction potential, or those who have face higher carbon mitigation cost. In addition, a use-based road pricing should be implemented to diminish the negative equity impact that adopting EV could potentially induce and remedy the loss of fuel tax as EVs become more available.

There are several directions of future research on EV and equity needs that can be derived from this dissertation. First, studies are needed to analyze the costs of production, distribution, and usage of electrified transportation systems, especially the social and environmental externalities of emissions from electricity generation for EVs should be studied to explore the impacts of the policies on public health and community resilience in disadvantaged communities. Second, this dissertation discusses the potential cost of fast transitions to EV, but more uncertainties could be discussed in future studies. For instance, the lack of standardization of chargers and exclusive charging stations could substantially increase of cost of charging, especially for those who purchase from a less-popular automaker. Third, a series of new financial and non-financial incentives could be researched and adopted to accelerate EV adoption while avoiding the risk of raising more equity issues. For instance, future research could explore the ideal incentive to be given to electrified micro-transit, ridesharing, and active transportation like electric bicycles. Fourth, this dissertation only focuses on the cost of adopting EV on the individual level. Future research topics could explore how the public sector should balance the minimization of social cost while ensuring social equity and justice.

To sum up, future planning policy research and practice on clean transportation should evaluate the real impact of EV adoption, their equity implications, and their limitations so that a more comprehensive inventory of planning toolboxes that target mobility, accessibility, sustainability, resilience, and equity could be built.

APPENDIX I. REGRESSION TREE RESULT FOR RESEARCH 2

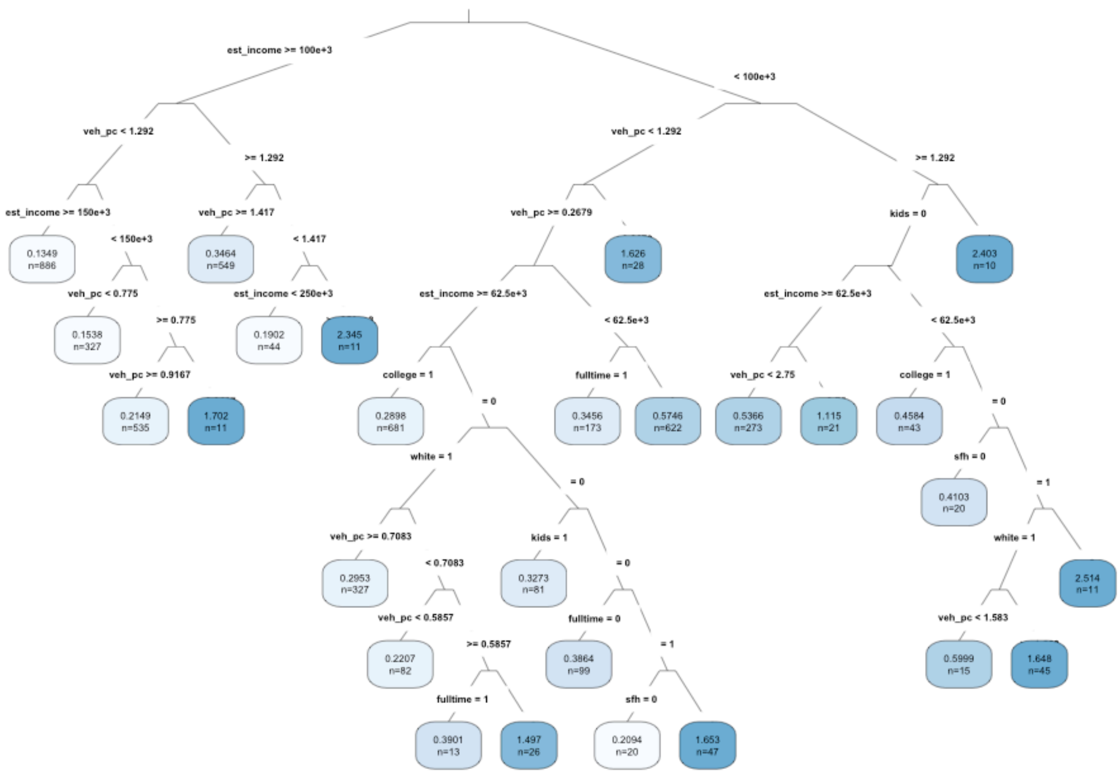

Figure 18. Regression Tree Result among Chevy Bolt Owners with no Financial Incentive, Pre-pruning

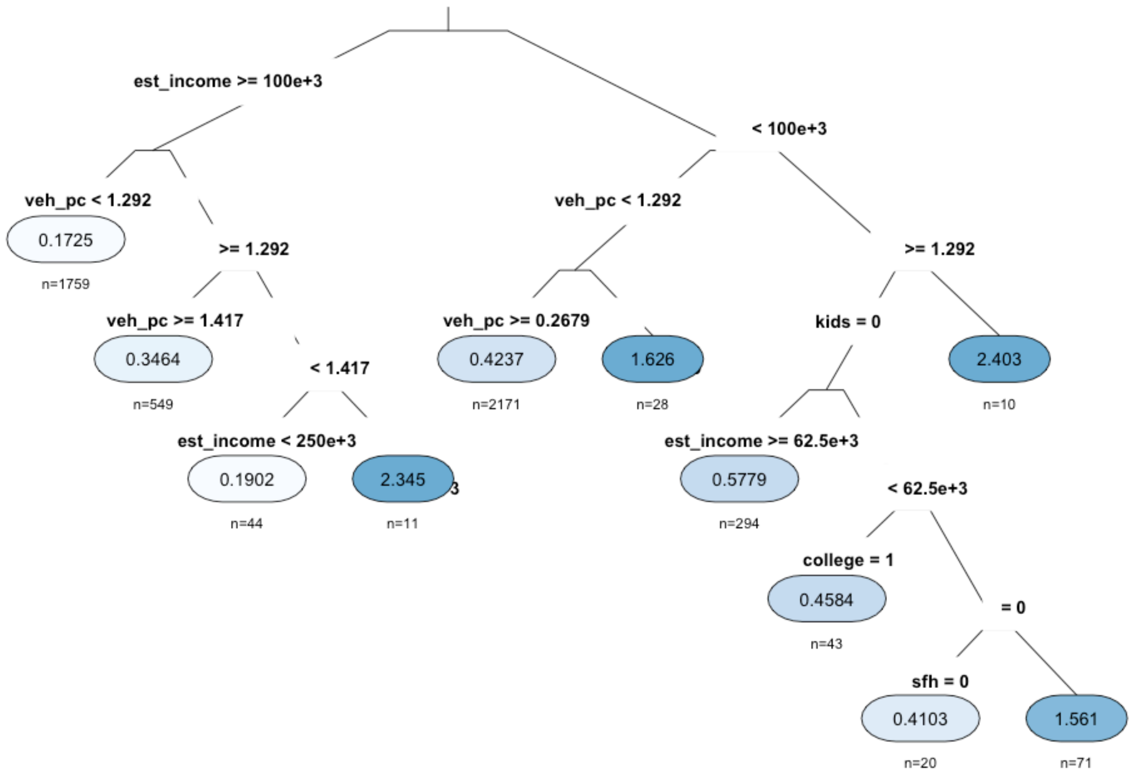

Figure 19. Regression Tree Result among Chevy Bolt Owners with no Financial Incentive, After-pruning

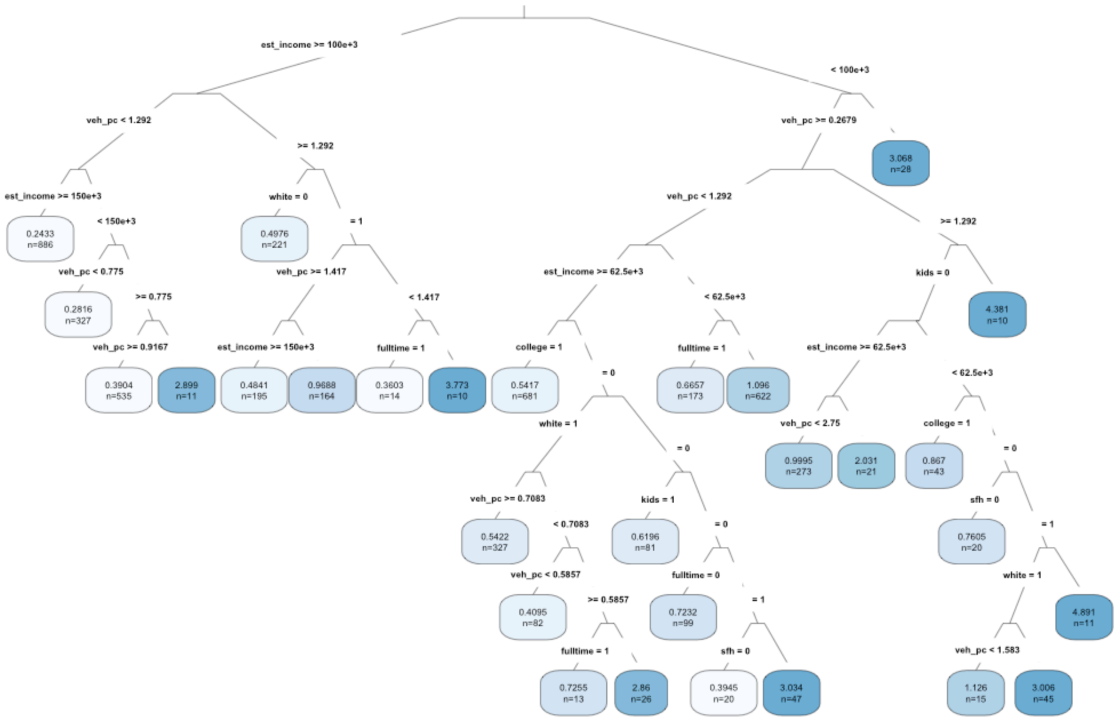

Figure 20. Regression Tree Result among Tesla Model 3 Owners with No Financial Incentive, Pre-pruning

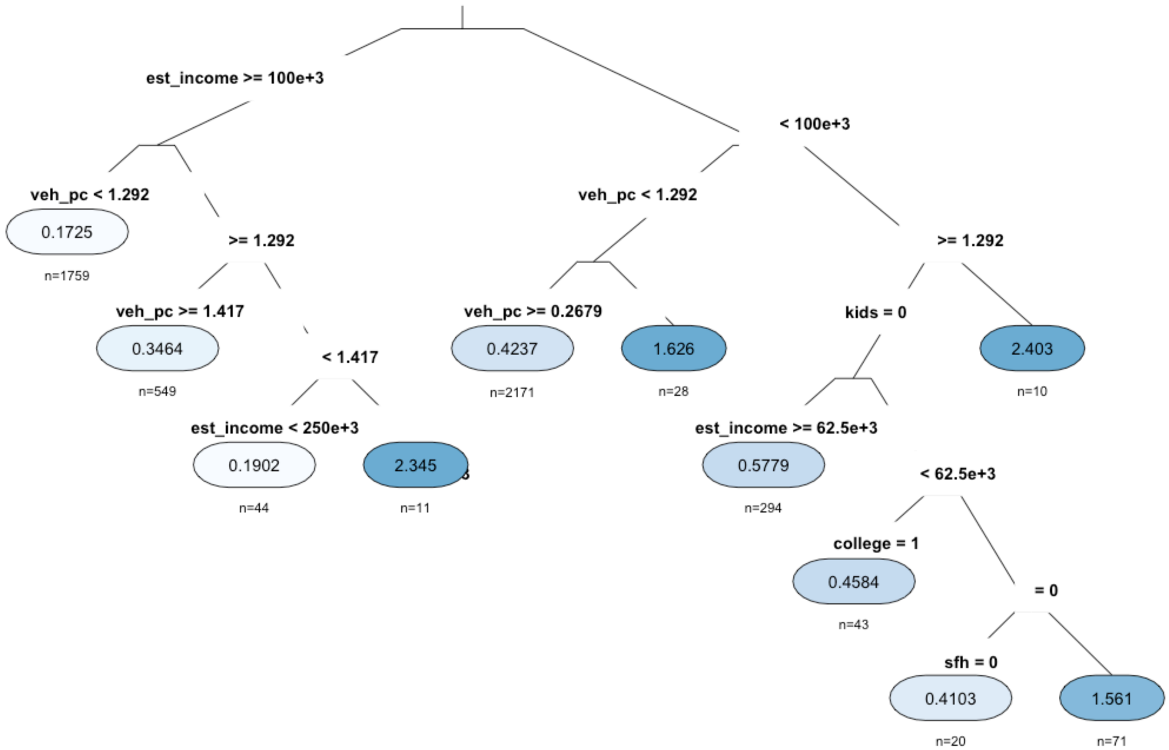

Figure 21. Regression Tree Result among Tesla Model 3 Owners with No Financial Incentive, After-pruning

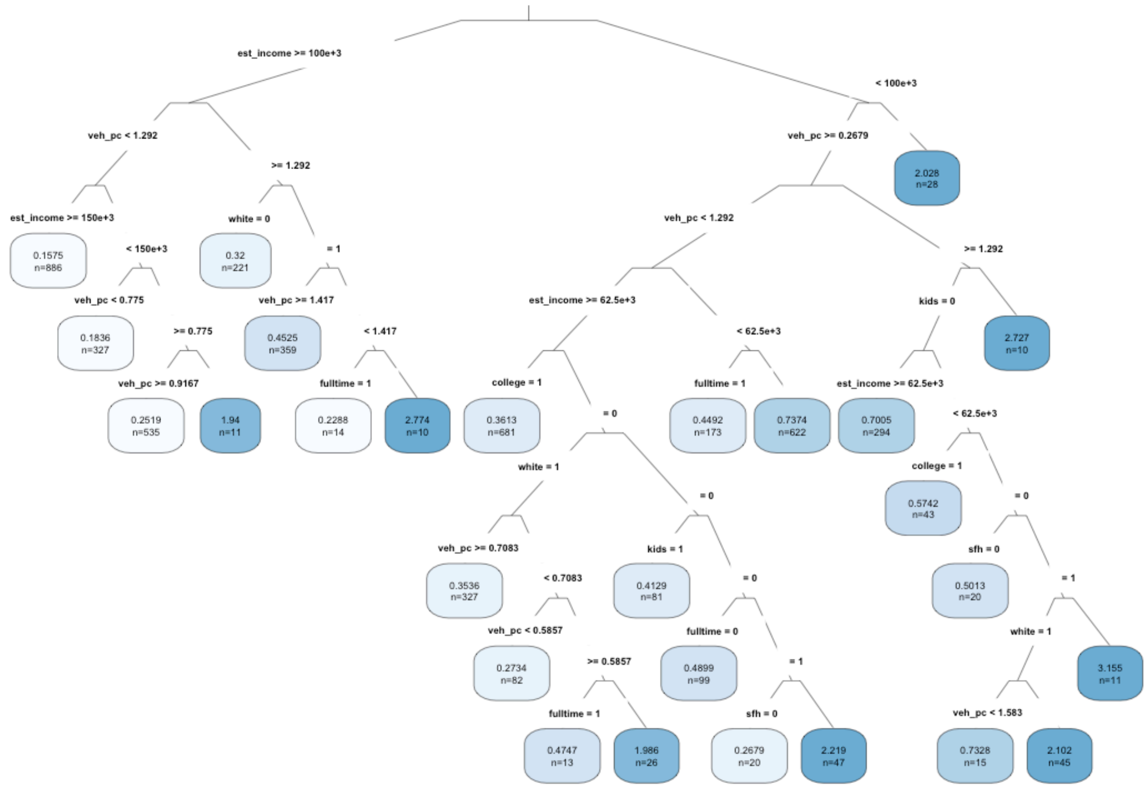

Figure 22. Regression Tree Result among Chevy Bolt Owners with Financial Incentives, Pre-pruning

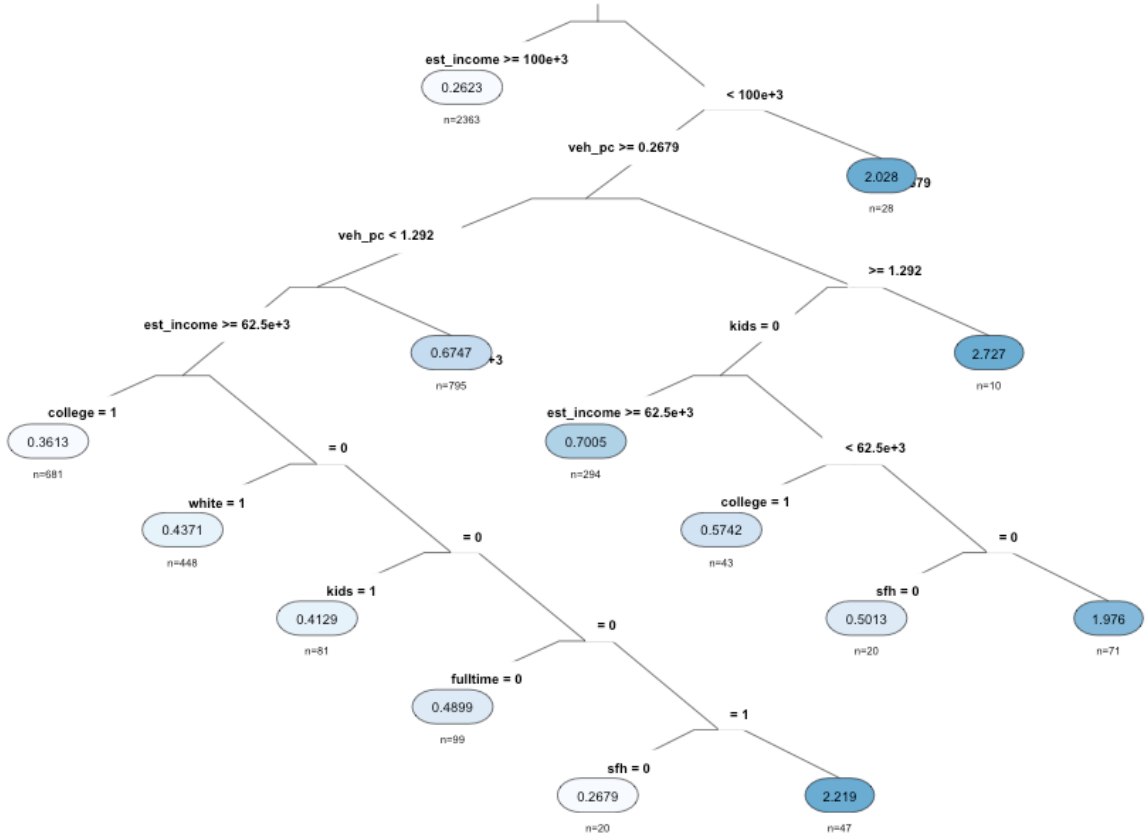

Figure 23. Regression Tree Result among Chevy Bolt Owners with Financial Incentives, After-pruning

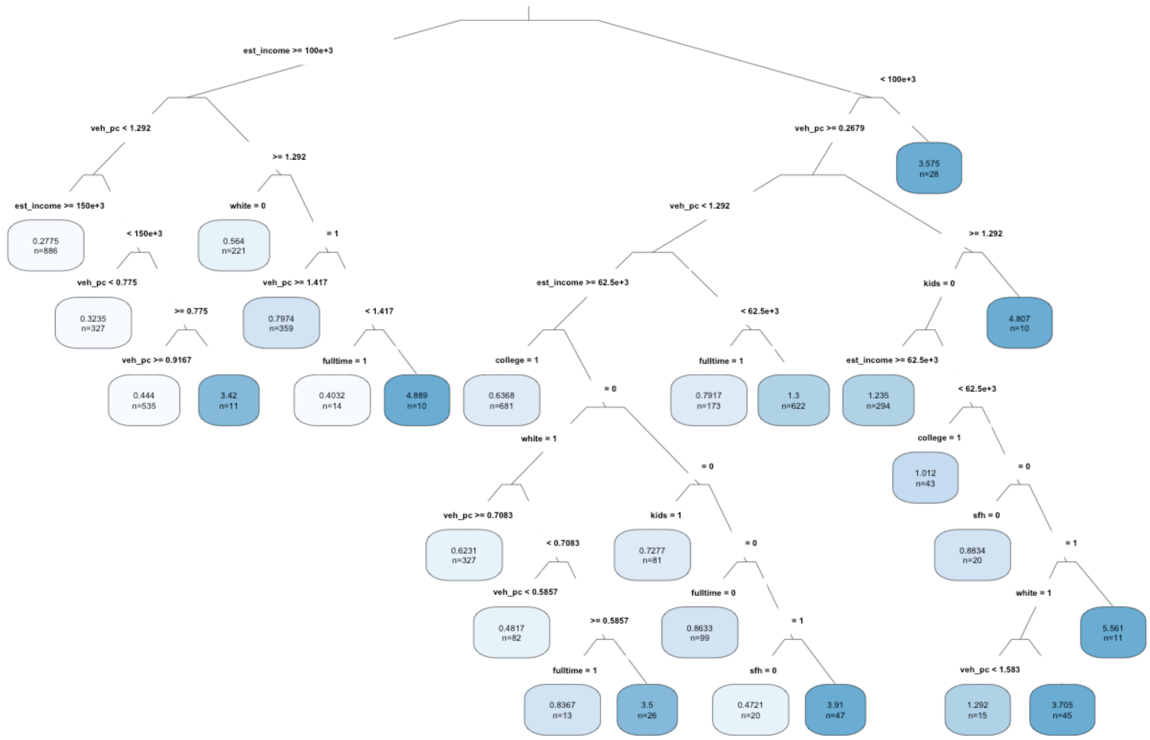

Figure 24. Regression Tree Result among Tesla Model 3 Owners with Financial Incentives, Pre-pruning

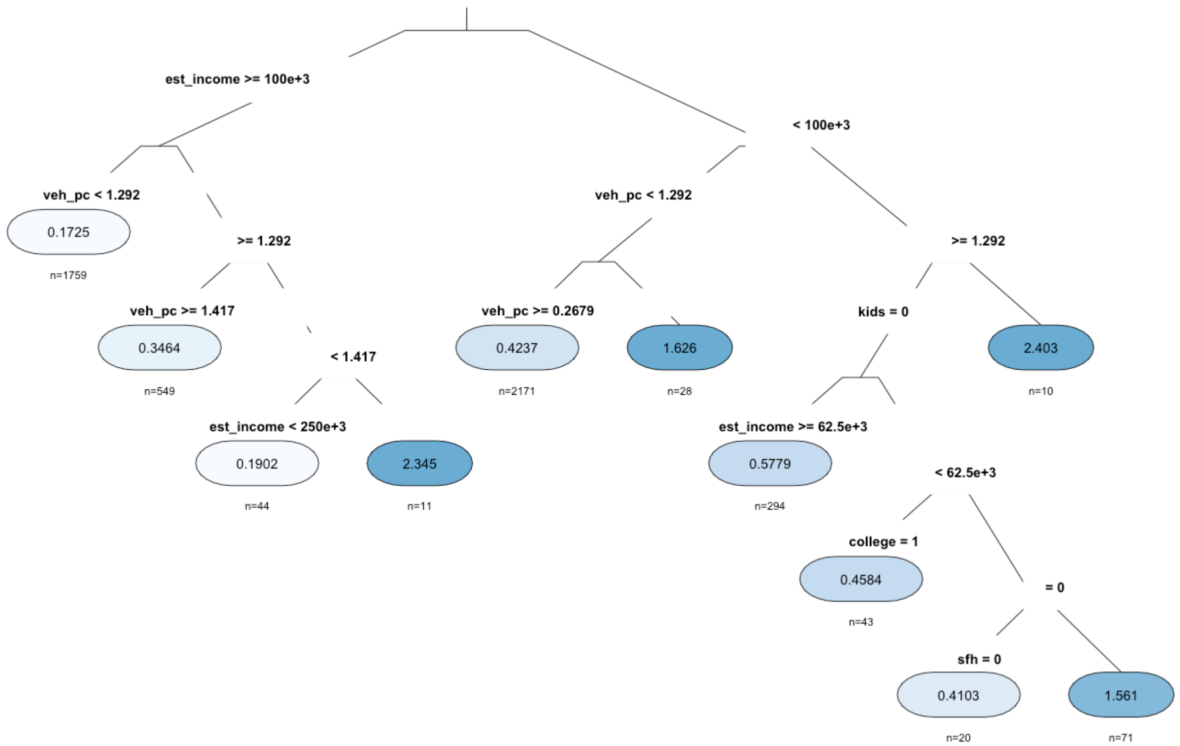

Figure 25. Regression Tree Result among Tesla Model 3 Owners with Financial Incentives, After-pruning

APPENDIX II. REGRESSION MODEL RESULT TABLES AND MAPS FOR RESEARCH 3

Table 14. Study 3: Results of OLS and GWR, San Francisco

	OLS			GWR				
Variable	Est.	SE	p-value	Mean	STD	Min	Median	Max
Intercept	0	0.032	1	-0.229	0.22	-1.857	-0.196	0.594
commute	-0.096	0.033	**0.004**	-0.058	0.084	-0.357	-0.024	0.07
college	0.031	0.063	0.618	0.234	0.308	-0.785	0.168	1.565
emprate	0.018	0.042	0.679	-0.005	0.125	-0.457	-0.004	0.8
rentrate	0.106	0.054	**0.05**	0.124	0.133	-0.214	0.08	0.759
medincome	0.054	0.066	0.409	-0.037	0.322	-0.737	-0.079	1.257
poverty	0.009	0.056	0.872	0.067	0.152	-0.184	0.027	1.151
whiteonly	-0.073	0.05	0.147	-0.236	0.402	-2.313	-0.103	0.269
housingden	-0.117	0.039	**0.002**	-0.729	1.205	-8.594	-0.29	0.224
	AICc:	2704		AICc:	2627.658			
	R2:	0.021		R2:	0.331			

***Bold**: significant with p-value < 0.1*

Table 15. Study 3: Results of OLS and GWR, Los Angeles

	OLS			GWR				
Variable	Est.	SE	p-value	Mean	STD	Min	Median	Max
Intercept	0	0.018	1	-0.01	0.468	-1.865	-0.092	4.527
commute	-0.043	0.019	**0.019**	0.024	0.141	-0.32	0.007	1.153
college	0.402	0.036	**0**	0.319	0.585	-0.578	0.16	3.676
emprate	-0.055	0.023	**0.02**	0.001	0.178	-0.428	-0.01	1.642
rentrate	0.188	0.034	**0**	0.239	0.278	-0.302	0.142	1.449
medincome	-0.068	0.04	**0.094**	-0.003	0.34	-1.292	-0.038	1.41
poverty	0.039	0.032	0.229	0.03	0.233	-0.658	0.005	1.512
whiteonly	-0.147	0.032	**0**	-0.12	0.552	-2.946	-0.042	4.103
housingden	-0.196	0.024	**0**	-0.417	0.664	-6.389	-0.231	0.159
	AICc:	7862		AICc:	7371.525			
	R2:	0.079		R2:	0.446			

***Bold**: significant with p-value < 0.1*

Table 16. Study 3: Results of OLS and GWR in Seattle

	OLS			GWR				
Variable	Est.	SE	p-value	Mean	STD	Min	Median	Max
Intercept	0	0.035	1	-0.05	0.108	-0.244	-0.016	0.166
commute	-0.058	0.041	0.155	-0.116	0.118	-0.326	-0.091	0.083
college	-0.015	0.071	0.838	0.004	0.131	-0.231	0.042	0.358
emprate	-0.03	0.045	0.505	-0.107	0.146	-0.367	-0.097	0.141
rentrate	0.374	0.069	**0**	0.468	0.295	0.092	0.414	0.992
medincome	0.209	0.083	**0.012**	0.158	0.206	-0.171	0.096	0.565
poverty	-0.08	0.056	0.15	-0.153	0.126	-0.346	-0.145	0.021
whiteonly	-0.012	0.045	0.788	-0.056	0.061	-0.197	-0.05	0.123
housingden	0.12	0.046	**0.009**	-0.07	0.209	-0.646	0.039	0.156
	AICc:	1890		AICc:	1834.276			
	R2:	0.14		R2:	0.27			

***Bold**: significant with p-value < 0.1*

Table 17. Study 3: Result of OLS and GWR in Portland

	OLS			GWR				
Variable	Est.	SE	p-value	Mean	STD	Min	Median	Max
Intercept	0	0.043	1	0.026	0.384	-0.517	-0.087	1.657
commute	0.014	0.047	0.763	0.047	0.139	-0.193	0.021	0.504
college	0.143	0.079	**0.072**	0.056	0.257	-0.927	0.07	0.572
emprate	-0.118	0.052	**0.024**	-0.09	0.503	-1.439	-0.056	0.992
rentrate	0.474	0.08	**0**	0.517	0.293	0.02	0.445	1.424
medincome	-0.013	0.098	0.897	-0.029	0.228	-0.827	-0.006	0.438
poverty	-0.087	0.078	0.27	-0.179	0.332	-1.172	-0.161	0.824
whiteonly	-0.029	0.053	0.588	-0.081	0.145	-0.69	-0.048	0.232
housingden	-0.149	0.059	**0.012**	-0.276	0.435	-1.646	-0.109	0.239
	AICc:	1240		AICc:	1189.404			
	R2:	0.155		R2:	0.53			

***Bold**: significant with p-value < 0.1*

Table 18. Study 3: Results of OLS and GWR in Atlanta

	OLS			GWR				
Variable	Est.	SE	p-value	Mean	STD	Min	Median	Max
Intercept	0	0.031	1	-0.004	0.002	-0.008	-0.005	0.001
commute	-0.104	0.04	**0.009**	-0.117	0.005	-0.127	-0.117	-0.1
college	0.291	0.067	**0**	0.287	0.008	0.272	0.287	0.308
emprate	-0.077	0.038	**0.046**	-0.09	0.005	-0.096	-0.091	-0.07
rentrate	0.317	0.065	**0**	0.32	0.02	0.264	0.32	0.362
medincome	-0.114	0.077	0.138	-0.116	0.008	-0.133	-0.117	-0.1
poverty	-0.146	0.056	**0.009**	-0.143	0.008	-0.162	-0.144	-0.12
whiteonly	0.043	0.048	0.366	0.054	0.008	0.029	0.055	0.065
housingden	-0.099	0.04	**0.013**	-0.097	0.005	-0.108	-0.097	-0.09
	AICc:	2473		AICc:	2476.028			
	R2:	0.125		R2:	0.128			

Bold*: significant with p-value < 0.1*

Table 19. Study 3: Results of OLS and GWR in Detroit

	OLS			GWR				
Variable	Est.	SE	p-value	Mean	STD	Min	Median	Max
Intercept	0	0.027	1	-0.028	0.034	-0.108	-0.023	0.072
commute	-0.037	0.03	0.217	-0.047	0.034	-0.146	-0.05	0.043
college	0.203	0.057	**0**	0.212	0.073	0.075	0.187	0.337
emprate	0.008	0.044	0.864	0.041	0.109	-0.112	0.014	0.282
rentrate	0.258	0.047	**0**	0.248	0.125	0.056	0.219	0.54
medincome	-0.038	0.075	**0.615**	-0.019	0.159	-0.23	-0.07	0.493
poverty	-0.1	0.059	**0.087**	-0.074	0.06	-0.227	-0.069	0.064
whiteonly	0.008	0.044	0.857	-0.026	0.1	-0.323	0.011	0.111
housingden	-0.054	0.033	**0.099**	-0.099	0.135	-0.353	-0.054	0.053
	AICc:	3471		AICc:	3453.207			
	R2:	0.068		R2:	0.123			

Bold*: significant with p-value < 0.1*

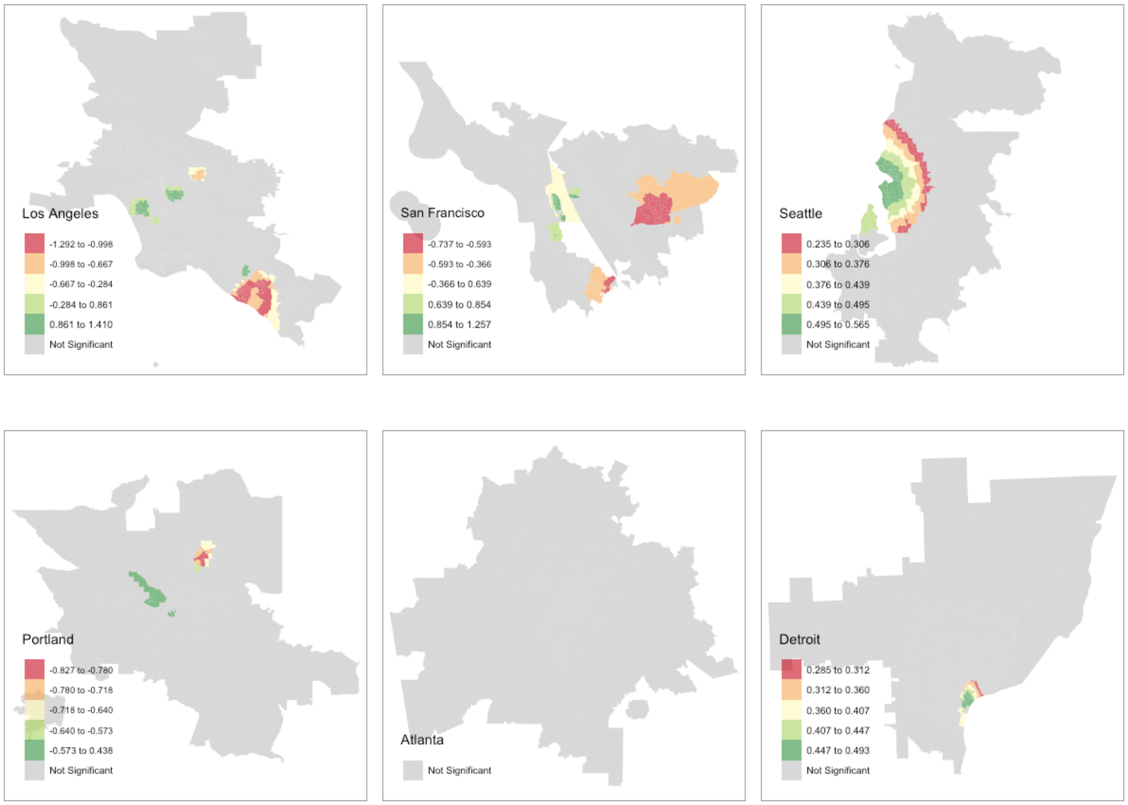

Figure 26. GWR Result, EVSE Density vs. Median Household Income

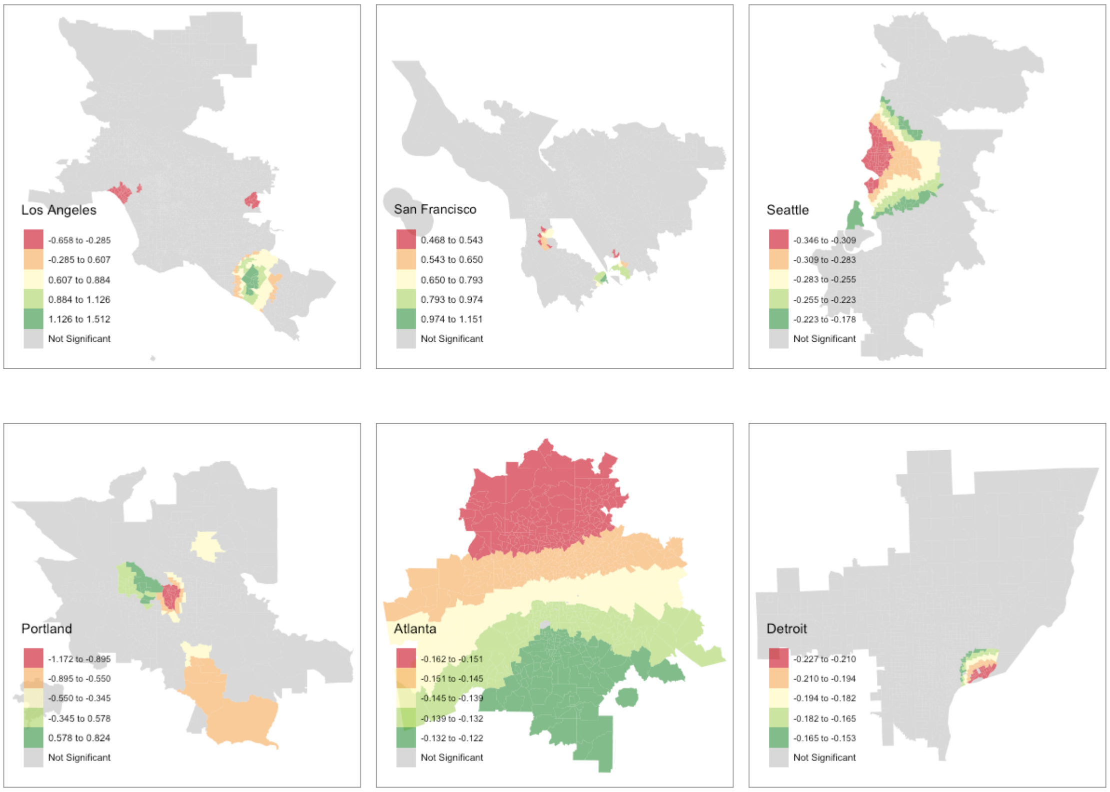

Figure 27. GWR Result, EVSE Density vs. Poverty Rate

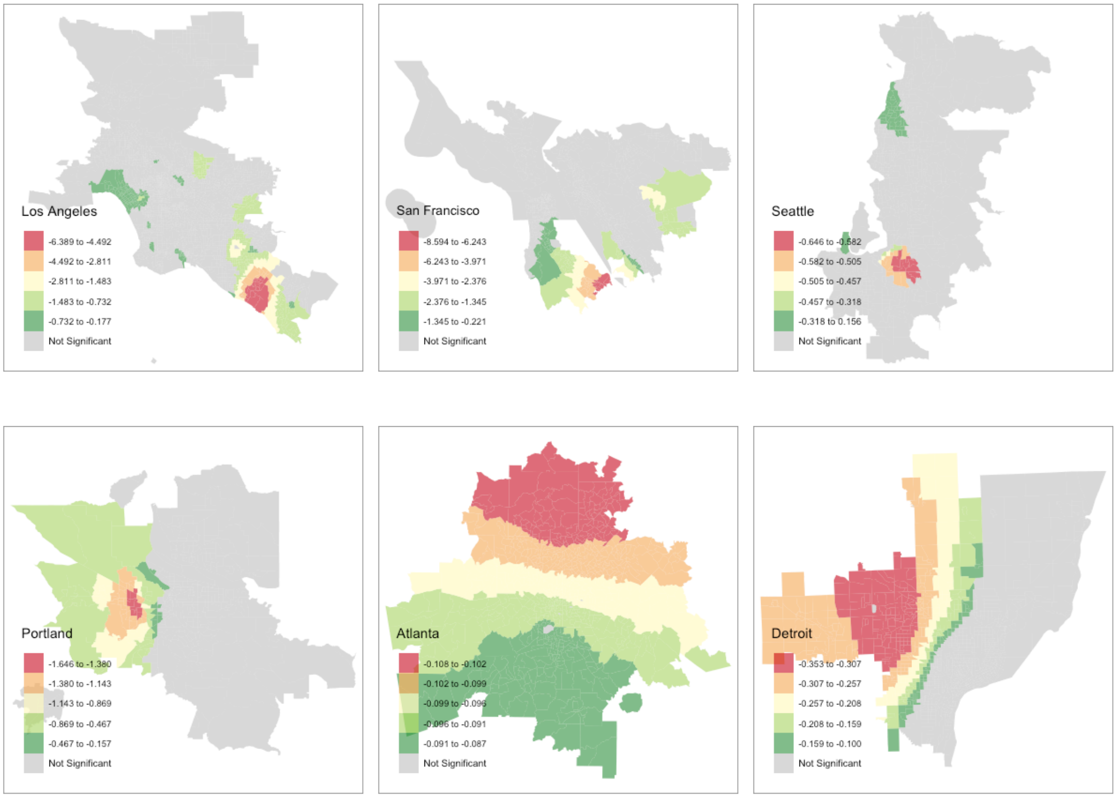

Figure 28. GWR Result, EVSE Density vs. Housing Density

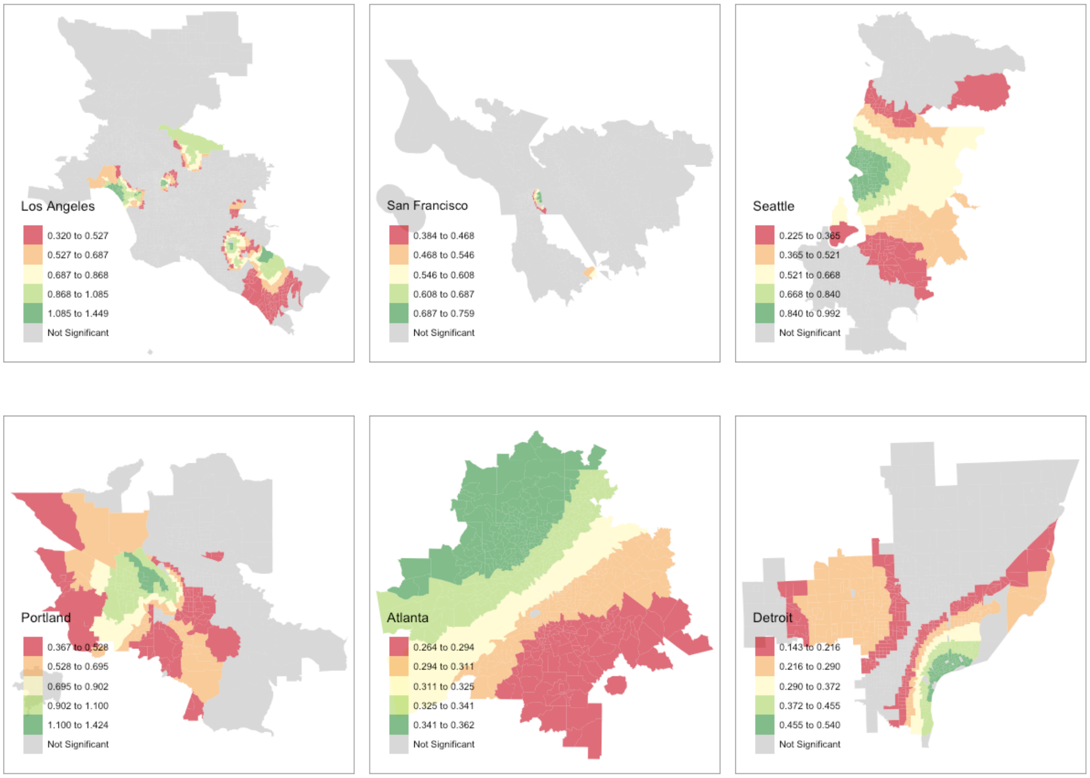

Figure 29. GWR Result, EVSE Density vs. Renter Rate

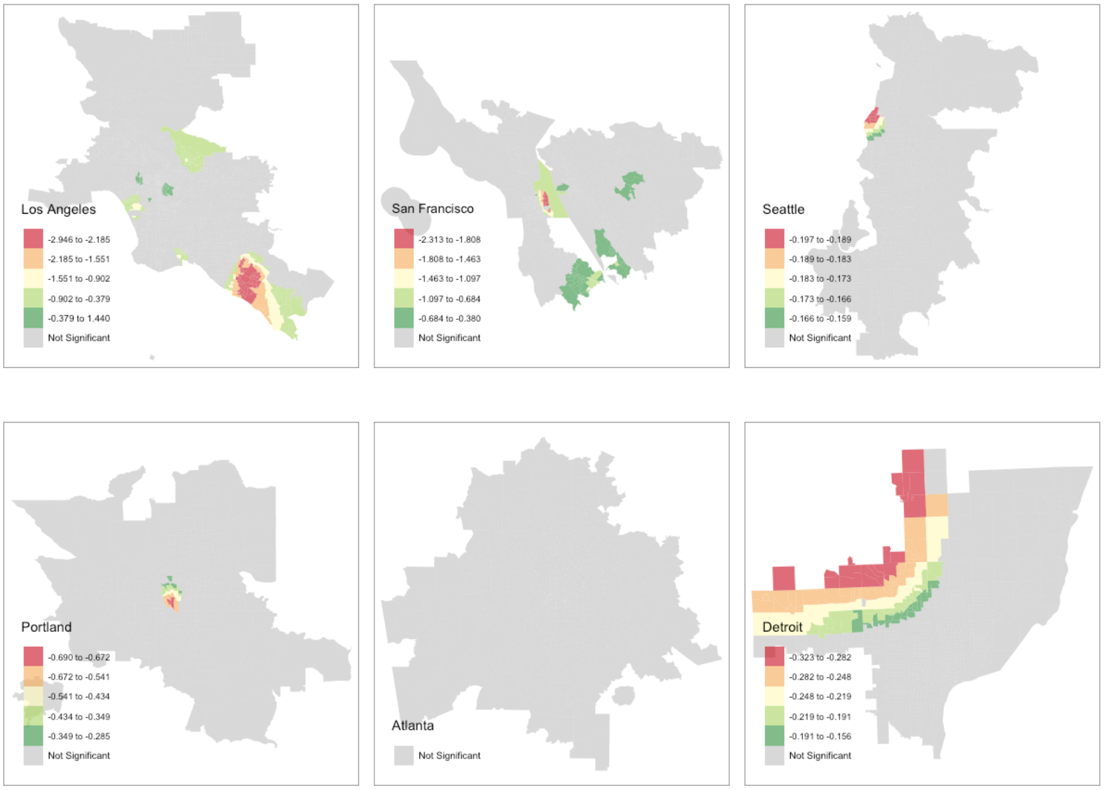

Figure 30. GWR Result, EVSE Density vs. White-Only Rate

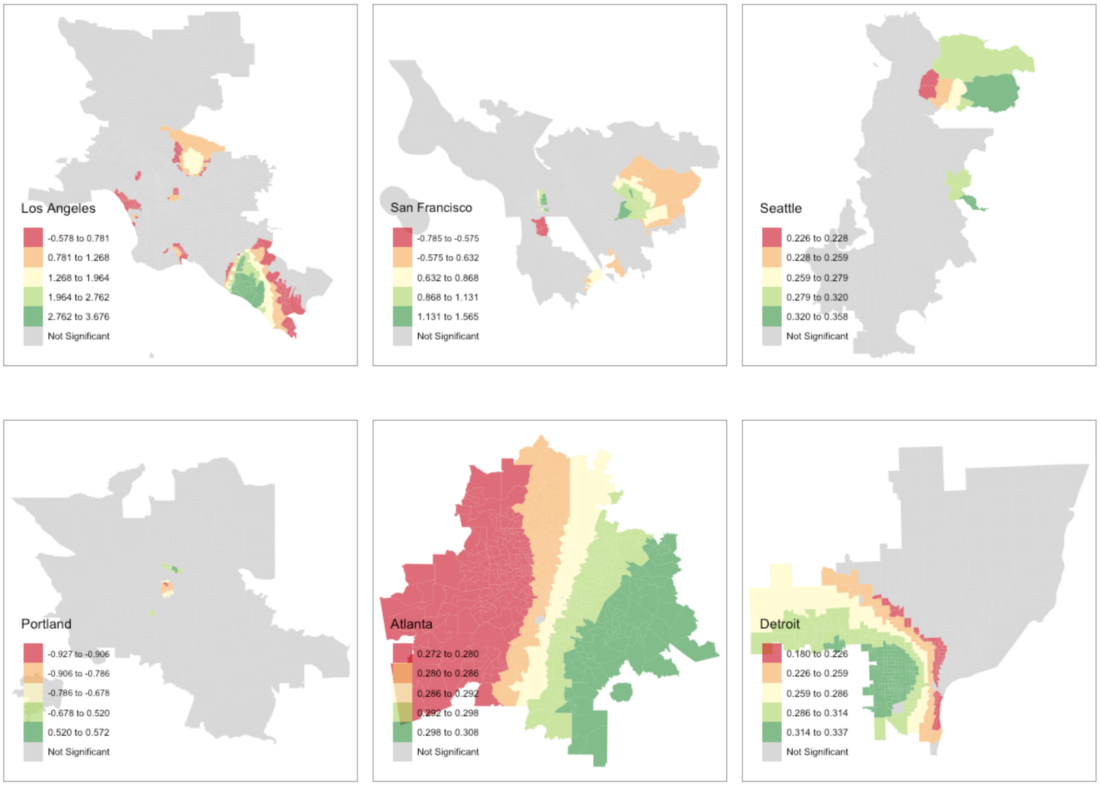

Figure 31. GWR Result, EVSE Density vs. College Degree or Higher

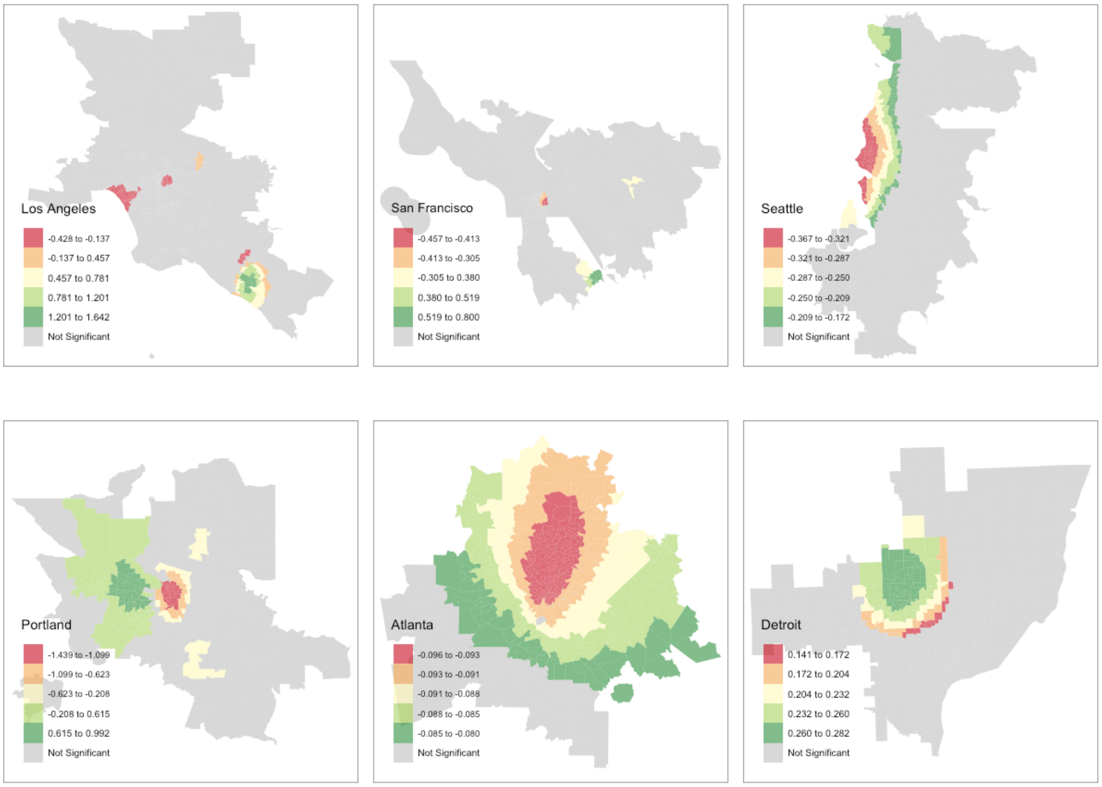

Figure 32. GWR Result, EVSE Density vs. Employment Rate

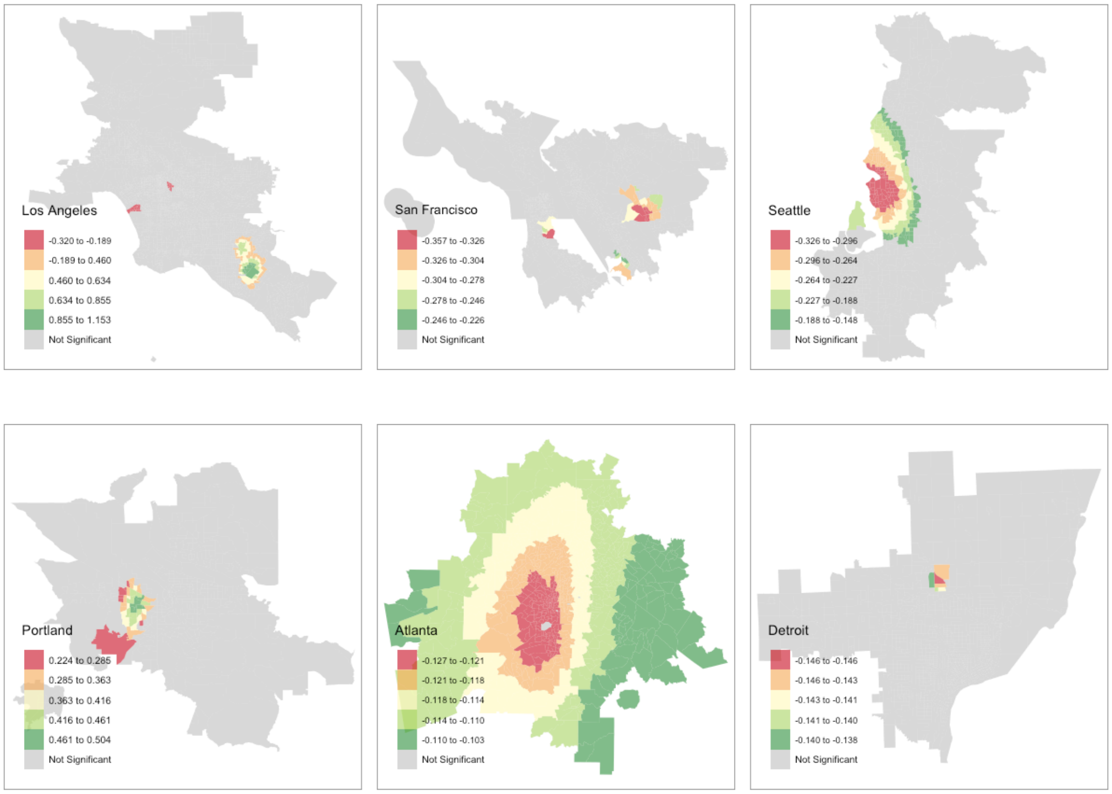

Figure 33. GWR Result, EVSE Density vs. Average Commute Time

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EDUCATION

Ph.D. Urban Design and Planning, University of Washington, 2022

Dissertation: Driving Electric with Equity: A Transportation Equity and Climate Justice Survey of Current Electric Vehicle Infrastructure, Policies and Planning

M.R.P. City and Regional Planning, Cornell University, 2015

Thesis: Evaluation of Job Access and Reverse Commute Program in Seattle Using Geographically Weight Regression

B.A. Geography, University of Washington, 2013

REFEREED JOURNAL ARTICLES

Young, Meg, Luke Rodriguez, Emily Keller, Feiyang Sun, Boyang Sa, Jan Whittington, and Bill Howe. "Beyond Open vs. Closed: Balancing Individual Privacy and Public Accountability in Data Sharing." In *Proceedings of the Conference on Fairness, Accountability, and Transparency*, pp. 191-200. ACM, 2019.

REPORTS

Tech Policy Lab. 2017. Driverless Seattle: How the City Can Plan for Autonomous Vehicles.

CONFERENCE PAPERS (selected)

Sa, Boyang and Christine Bae. “Driving Electric with Equity: An Evaluation of Current Electric Vehicle Charging Infrastructure.” *National Conference of Association of Collegiate Schools of Planning*, 2021.

Bae, Christine, Boyang Sa, Eric Guida, Haoyu Yue. *“It Takes a Village to Make Urban Villages Work: Effects of Zoning and Land Use Policies on Land Value and Densification* *in the City of Seattle"*. National Conference of Association of Collegiate Schools of Planning, 2021.

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COURSES TAUGHT

Introduction to Infrastructure Systems (IPM 502) ~ Autumn 2019
Introduces infrastructures; systems thinking; the history, basic concepts, legal frameworks, politics, processes, and techniques used in infrastructure systems courses; and climate change as emerging yet lasting phenomenon. Includes overview of IPM online learning environment.

Introduction to Geographic Information Systems ~ Autumn 2018
Provides students with introductory practical knowledge of Geographical Information Systems and Science for current and future coursework in urban planning.

TEACHING APPOINTMENTS

Theories and Methodologies of Planning (UrbDP 510) ~ Winter 2018, 2019, 2020, 2021
Survey of the philosophy, methods, and analytical techniques used in planning public actions and policies, with emphasis on the logic and assumptions upon which these are based. Various planning surveys and methods. Open to graduate students in urban design and planning and to graduate students seeking the urban design certificate.

Survey of Urban Planning (UrbDP 500) ~ Autumn 2020, 2021
Concepts and logic of planning as a professional activity. Evolution of guiding ideas in relation to changing social, economic, and environmental conditions within the American political framework. Major procedures used by planners. Critical appraisal. Open to graduate students in urban design and planning and to graduate students in architecture seeking the urban design certificate.

Introduction to Urban Planning (UrbDP 300) ~ Spring 2020
Principles and theories of urban structure and institutions. Concepts and logic of planning as a community process and a professional activity. Evolution of planning

ideas in response to changing social, economic, and environmental conditions within the American political framework. Complementary nature of public and private responsibilities. Major procedures used by planners.

Infrastructure Finance (IPM 503) ~ Summer 2019

Covers how to pay for infrastructure, including planning, budgeting, and public/private partnerships. Examines the relationships between infrastructure finance, urban form, and sustainability; local government finance, budget accountability, and equity issues; and infrastructure investments in changing economic climates, forms of finance available for infrastructure, collective decision-making, and alternative forms of project delivery.