EV Friendly Cities: A Comparison of Policy and Infrastructure in Sixteen Global Cities

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Abstract

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Electric vehicles, one of the emerging modes of transportation, are at the forefront of sustainable mobility. In the past years, there has been a rapid rise in EVs, both as private and public transportation modes. Private users are influenced by multiple factors while choosing electric cars as their travel modes. Among them, policy and infrastructure are deemed to be the main influencers globally. These policies and infrastructures vary in different cities. However, there is a lack of research dealing with what parts of the policy and infrastructure are actually most effective in EV adoption. This research presents a descriptive and quantitative evaluation as well as statistical analysis to identify the most effective policies and infrastructure components in electric car adoption as a personal transportation mode in sixteen selected cities; Seattle, Los Angeles, San Francisco, San Jose, New York, Oslo, Bergen, London, Amsterdam, Stockholm, Berlin, Munich, Paris, Shenzhen, Beijing and Tokyo. The cities are evaluated based on total electric vehicles on road, EVs on household level and electrification ratio of the registered cars in conjunction with household median income. Policy level incentives like electrification target, parking, toll, and lane access benefits along with tax rebates, subsidies and other monetary incentives as part of the total cost of ownership are also observed. Total number of public and residential charging points as well as the EV supply equipment program are analyzed as part of EV infrastructure preparedness on city level. Among the sample cities, Norway is the pioneer in the electric car integration into their passenger car market. All the sample cities have active Zero Energy Vehicle mandates and incentives for electric vehicles. Through secondary data collection via various online resources and statistical observation with help of the existing literature, this study found high correlation between EV ownership and incentives. Multilinear Regression Analysis model predicted 0.53% increase in passenger electrification with every $100 incentive increase. The environmental conditions of the sample cities are also evaluated to observe the impact of mass EV adoption in the overall improvement in CO_2 emission reduction. At the end of this paper, this research proposes some policies to improve the EV adoption challenges present in the sample cities as well as the cities aiming to turn towards this sustainable mode in the future.

University of Washington

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Two years, that’s the length of my journey in the University of Washington’s Master of Urban Planning program. Half of it was disrupted by COVID. But throughout this tough journey, I received help from many people. And I would like to thank all of them for their continuous support and help to make my grad school experience interesting and fruitful.

My academic supervisor, Professor Christine Bae, who was more than just the person to help me in my academic performance; always inspired me to challenge myself, to try new things and to break the boundaries. My thesis is a brainchild of Christine and my idea, which started as a small class project and turned into a full-fledged thesis work. She was the mentor and my continuous support throughout this journey, which was at times stressful due to the unprecedented situation all of us faced due to the pandemic. Professor Ed McCormack relentlessly helped me understand the thesis process and mentored me to do a better job at data analysis. The back-to-back revisions developed my work to the way it is now. This thesis would not be complete without their continuous guidance and support.

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GLOSSARY:

BEV: Battery Electric Vehicle
GHG: Greenhouse Gas
GREET Model: The Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies Model by Argonne National Laboratory.
HEV: Hybrid Electric Vehicle
EVSE: Electric Vehicle Support Equipment
ICCT: International Council on Clean Transportation
ICE: Internal Combustion Engine
LCA: Life Cycle Analysis
NEV: New Energy Vehicle
NOAA: National Oceanic and Atmospheric Administration
PHEV: Plug-in Hybrid Vehicle
WTP: Well to Pump
WTW: Well to Wheel
ZEV: Zero Energy Vehicle

Chapter 1: INTRODUCTION

Over the past century, human mobility and transportation systems have developed rapidly. With the growth of the transportation system, the rising pollution has also become a concern for the world. GHG emissions from all the developing sectors are imploring concerned entities to look for a solution to stop the avalanche, called global warming and environmental pollution. Sustainable transportation is at the forefront of the solution to this ongoing concern. The transportation sector itself is responsible for 29% GHG gas emission in the United States in 2019 (EPA, 2020) and approximately 24% globally (Center for Climate and Energy Solution, 2019). Reducing the pollution in transportation operation, production and recycling; as well as the energy sector is presented as the best method to reduce the greenhouse gas emission. Also, the dwindling non-renewable energy source dependence has made transportation authorities look for alternative fuel sources. Electric vehicles came to the forefront as a solution as a sustainable transportation mode (Rougei et al., 2018).

Many cities have stepped up to take the mantle of electrifying their public transportation fleet as well as the passenger cars and freight careers. To achieve this dream, various policies and infrastructural initiatives are adopted in those cities to promote EVs as both personal and public transportation modes. The majority of automobile companies and city authorities have taken up the challenge to electrify the transportation sector (Sierzchula et al., 2012). Along with all this development comes the question, what is making the consumers interested in adopting the electric vehicles?

Different studies have proven that the consumers chose the electric mode as personal transportation choice considering the vehicle price, fuel cost and safety issues as well as environmental benefit (Caulfield et al., 2010; Lane and Potter, 2007). The existing studies have looked at the issue from mainly one lens, or in one particular geographic location. The cities observed were all EV friendly. How do we define EV friendliness? Different sources measured EV friendliness based on different criteria. The ICCT (2017) report used the number of EVs (cumulative electric vehicles sales through the year the data is observed, electric vehicle sales in the target year, and 5% electric share of new light-duty vehicles sales) in the global cities to identify the EV friendly ones. On the other hand, ChargePoint, an individual charging infrastructure provider, scored the US cities based on the number of EVs on the road and the number of charging stations available. This can show how the term ‘ EV friendliness’ can be defined from different perspective. In general, EV friendly cities can be identified through the total electric vehicle share, which reflects effective policies and infrastructure availability in the cities. The important question is, are all these policy interventions and infrastructure having the similar effect on EV adoption globally, or are they locally concentrated, with different ranges of impacts? This paper will investigate this issue through the multiple lenses of policy intervention, infrastructural development and environmental impact. In urban and transportation planning, it is of great significance to track and analyze the impact of policies and infrastructure decisions on the target population and environment.

To observe the situation holistically, three lenses should be adopted. And the lenses can be manifested through the questions presented below-

a. What are the global cities already identified as EV friendly with a high EV adoption rate?
b. How is consumer behavior in different cities getting affected by different components, like policy and infrastructure, in case of EV adoption?
c. What is the environmental cost of the EV adoption in cities, are they all positive?
d. Can this impact of policy and infrastructure be analyzed?

The answers to these questions can be multifold. But this can be a good starting point to understand the effectiveness of the policies, incentives as well as the positive aspects of EVs in the cities.

In order to find the answers to these questions step by step, the chapters are arranged in a sequence to introduce the readers to the topic and its importance in the planning profession in the current chapter, followed by exploring the existing literature on relevant topics that influence EV adoption decisions in Chapter 2. In the next part, this research will explain the Methodology in Chapter 3. Chapter 4 will present the study design as well as data collection and framing process. The Analysis process and results will be part of the next section of the paper in Chapter 5 and Chapter 6 will reiterate the findings and what they imply for the future planning decision makers. Like all studies, this research also has limitations, which will be addressed in Chapter 7. This paper will conclude with the suggestions on how this study can be used moving forward with some policy suggestions in Chapter 8 based on the findings from the study.

Chapter 2 : LITERATURE REVIEW

The greenhouse gas emission rate all over the world has been a concern for a long time. The continuous emission from different sectors has increased the concentration of GHG in 2018, to almost 46% higher than the year 1750 according to NOAA (2018). Recent reports from the World Meteorological Organization (2019) warned about the current CO2 emission situation. Energy sector, industry, and transportation (at approximately 24%) are liable for most of these emissions globally (Center for Climate and Energy Solution, 2019). To control the unprecedented CO_2 concentration, policy makers introduced electric cars as a sustainable solution through low energy travel mode. As a response to this initiative, increased number of electric vehicle manufacturing by the car companies (Sierzchula et al., 2012) is making the air and noise pollution reduction possible in the urban environment (Brady and O'Mahony, 2011, Hawkins et al., 2013). But this is not a one-way solution, rather part of an array of possible answers to the ongoing crisis.

Chapter 2.1 : Electric Vehicles Around the World

Electric vehicles are at the forefront of sustainable transportation technology. The environmental impact of EVs is undeniable. Over a year, just one electric car on the roads can save an average of 1.5 million grams of CO_2 (Moses, 2020). Due to this reason, not only the USA, but many countries all over the world are seeing a rise in EVs, especially plug-in ones. Electric cars, which accounted for 2.6% of global car sales and about 1% of global car stock in 2019, registered a 40% year-on-year increase (IEA, 2020). Currently, 2.2% of vehicles registered globally are electric. The global market for electric vehicles (EVs) will see substantial growth (32% of new vehicle sales within the decade) (Forbes, 2021). A McKinsey report from 2019 says worldwide sales of EVs reached 2.1 million in 2018, with a growth rate of about 60% year-over-year. The International Energy Agency (IEA) has said the global EV fleet will reach about 130 million by 2030, a sharp rise from just more than 5.1 million in 2018.

Forty percent of all the EV capita is concentrated in twenty of the cities, according to a 2017 report by ICCT. The cities are-

- Shanghai, Beijing, Shenzhen, Qingdao, Hangzhou, Tianjin, Taiyuan in China
- Oslo, Bergen,

- Amsterdam, Utrecht, Rotterdam, Hague
- Paris,
- London,
- Stockholm,
- Tokyo,
- Los Angeles, San Francisco, San Jose and New York.

Among the countries at the forefront of EV adoption globally, China is leading with the highest number of new EV additions to their automobile population till 2019. With North America and Europe following behind. Multiple factors are helping in this massive EV adoption and the impact on infrastructure and environment is also versatile. This paper will introduce them in the relevant chapters.

Chapter 2.2 : EV Adoption and User Behavior

In EV adoption as a personal vehicle on mass level, customer attitude towards the low emission cars is a critical issue. Ajzen's Planned Behavior Theory (TPB) (1991) explains consumer behavior as a combination of values, beliefs, intentions, and attitudes. According to the TPB, an individual will consider the alternatives and evaluate their outcomes based on their beliefs relating to the actions and their effects when given a choice. The behavior in this case is the indicator of the belief. Using this TPB theory, findings of different relevant studies can be connected to the economic benefits and regulations present for the car buyers. Choo et al. (2004) found that the customers are influenced by the 'economic and regulatory environments, vehicle performance and application and the existing fuel/road infrastructure'. On the other hand, this behavior can be complex and dependent on multiple other factors. And different social–psychological models can be able to explain them to some extent, if not completely (Lane and Potter, 2007).

Electric vehicles on the other hand are still a new research topic in customer behavior analysis. The novelty and uncertainty in EV life cycle cost analysis is one of the main deciding factors in mass level adoption. Available literature found that the potential EV customers consider different aspects like fuel costs, Vehicle Registration Tax and Carbon dioxide emissions decrease while selecting electric cars as personal travel mode (Caulfield et al., 2010 ; Lane and Potter, 2007).

Bakker et al. (2012) found safety as well as the above-mentioned factors as the most observed reasons for people choosing electric cars. Technology, money, tax and other benefits, social environment as well as environmental improvement and employers providing extra benefits to the EV owners, came to the forefront in a study conducted on the European electric car buyers recently (New Motion Survey, 2020).

Though the monetary and environmental aspects were identified as influencing factors in electric car buying, the issue is not always entirely clear to the consumers. In some cases, many of them assumed that the alternative fuel vehicles were less dangerous than their fossil fuel counterparts (Shell, 2004). Tesla, one of the leading electric car manufacturers, published data about one vehicle fire for every 205 million miles traveled for their models in the USA for the period of 2012 to 2020. This number is low compared to at least one vehicle fire for every 19 million miles traveled by conventional vehicles for the same time period as per the data provided by the National Fire Protection Association & U.S. Department of Transportation (InsideEVs, 2021). Though it might be the case for this one company, in the recent years there have been several reports of fire incidents in electric cars (CNN, 2020). There is also the issue of range anxiety, where consumers think that hybrids have limited range and special power points to charge them. A more recent survey has identified consumers prefer the electric cars when they do not have to be concerned about running out of power mid journey along with the low cost of EV operation and the driving satisfaction of these powerful cars (J.D. Power, 2021). All these factors will keep on influencing car purchasing behavior for EV customers in the future as they are doing now. This observation is still an ongoing process and various new issues are coming forward with new studies.

Chapter 2.3 : Policy, Subsidies and Other Benefits

The relationship between policy incentives and EV adoption rate is still a topic of ongoing research. There are multiple other variables in play while evaluating the impact. Different groups of people might have different reactions to the policy. Most of the existing literature has tried to understand the impact of EV friendly policies from only one particular policy or incentive. Zhang et al. (2011) found a positive impact of policies on EV adoption overall. Bakker and Trip (2013) identified some EV friendly policies which will help effective promotion of EVs in the urban environment. Some of the key points of their findings are direct subsidies to the consumer, or local business and car sharing; solving charging infrastructure and free parking dilemma; accessibility to toll-roads, congestion charge exemption, and, if applicable, on ferries; regulatory measure is the obligation to property developers to introduce charging facilities on their property; raising awareness by govt initiative and test drive; cooperation between different levels of government and public – private partnership to promote electric vehicles. EV policies can be purchased-based, or use-based (Langbroek et al, 2016).

Langbroek et al. (2016) also investigated the effect of policy incentives on EV adoption. Their study speculated that policy incentives overall have a positive influence on electric vehicle adoption. And advanced stages-of-change to EV-adoption increases likelihood to adopt EVs as consumers become less price sensitive. Consumers' intentions to be more environmentally responsible can also vastly influence the EV adoption. Along with these positive impacts, the policies might have some side effects too. Whitehead et al. (2015) identified the probability of congestion due to a convenient clean vehicle purchase and unchanged travel pattern. In many cities, incentives, for example easy license plate adoption as well as parking fee and toll exemption, have been criticized due to their impact on the economics of the cities. Easy charging point availability might also increase VMT (Klöckner, 2013).

Chapter 2.4 : EV-friendly Infrastructure

Electric vehicles, both BEVs and PHEVs, need a certain amount of charging to operate. Different electric vehicles have different charging demand, which influences charging behaviors. And the range of electric vehicles plays a very important role in the VMT of the car (Nicholas et al., 2017b). Due to the range restriction of BEVs, low range battery charging demand occurs mostly within the region and metro areas, whereas long range BEVs would need to charge on long distance travel corridors, and fast chargers can be most useful for range extension in these cases. (Ji et al., 2015, Neaimeh et al., 2017). Easily available chargers can increase VMT and reduce range anxiety (Axsen and Kurani, 2013, . Dong et al., 2014, He et al., 2016).

The chargers used for EVs can be classified as Level 1: the slowest charger found at residential buildings; Level 2 : 208–240 V, medium charger with multiple range of charging and can be found at home or public locations and DC fast chargers : the fastest charger found at the fast-charging facilities with high power demand (Idaho National Laboratory, 2015). Charger availability and charging behavior depend on geographic location, driver awareness, and driver willingness to use the chargers (Tal et al., 2013)

Despite EV adoption, many consumers are not well aware of the charging system. (Axsen et al., 2017). But there is a pattern observed among the consumers. While most charging occurs at home, some of them occur at work, followed by DC fast and public locations. (California Air Resources Board, 2017). Some studies found that the 3.4 ~ 8.3% of PEV journeys need the public chargers, covering 30% to 40% of the VMT (Figenbaum and Kolbenstvedt, 2016).

The cost component of the charging also influences the charging behavior. Level 1 infrastructure has lower cost, making them most affordable and most available among the chargers (Dong et al., 2014). On the other hand, costly DC chargers attract more customers when free to use them rather than their counterpart home chargers. (Nicholas et al., 2017). Consumers with BEVs will feel more comfortable charging at home and install the relevant facilities at their residences, PHEV users might avoid doing so and charge at public chargers as they have the alternative fuel mode. (Tal et al., 2013) But there are some drawbacks of uncontrolled charging. It can increase load at the peak hour if not given the lower off-peak charging rate to the EV users (Azadfar et al., 2015) Smart charging should also be implemented to avoid straining the grid (Garcia-Villalobos et al., 2014). Overall, more infrastructure will increase the EV purchase as there will be more charging facilities (Graham-Rowe et al., 2012). But this has to be done in a strategic way to avoid the negative impact.

Chapter 2.5 : Environmental Cost of EV Adoption

Energy efficiency and positive environmental impacts are the most prominent selling points of EVs. EVs can reduce fossil fuel consumption, which are one of the most degrading elements for the environment. An EV is more energy efficient in the lifecycle analysis and the energy consumption is approximately 44% less than the conventional vehicles (Xiao et al., 2019). Electric vehicles can reduce the air and noise pollution in the cities (Brady and O’Mahony, 2011, Hawkins et al., 2013).

While EVs do not emit harmful gases, there is a hidden cost for them which can offset the positive impact. They can be identified as the battery production emission (Bater 2018) [Chapter 2.5.1], and battery-end life pollution [Chapter 4.2.7]. The cost of energy production can also be taken as a hidden cost for Electric Vehicles. Kawamoto et al. (2019) suggested that the emission reduction by EVs depends on the regions, power mix and battery production system. Understanding these issues simultaneously is necessary in EV planning.

2.5.1. Battery Life

The lithium-ion battery introduction to the vehicles is a progress towards sustainable transportation (Casals et al., 2017). The battery is efficient, and there is no tailpipe emission, but is the life cycle considerably emission free? Many researchers have asked the same question. The energy production source used to power the whole process during the well-to-tank, (Figure 1) can be a major source of large carbon footprint (Bradley and Frank 2009). The production phase of the electric car also has a 50% more carbon footprint, and the battery part is responsible for almost 80% of it (Helms et al. 2010; Campanari et al. 2009).

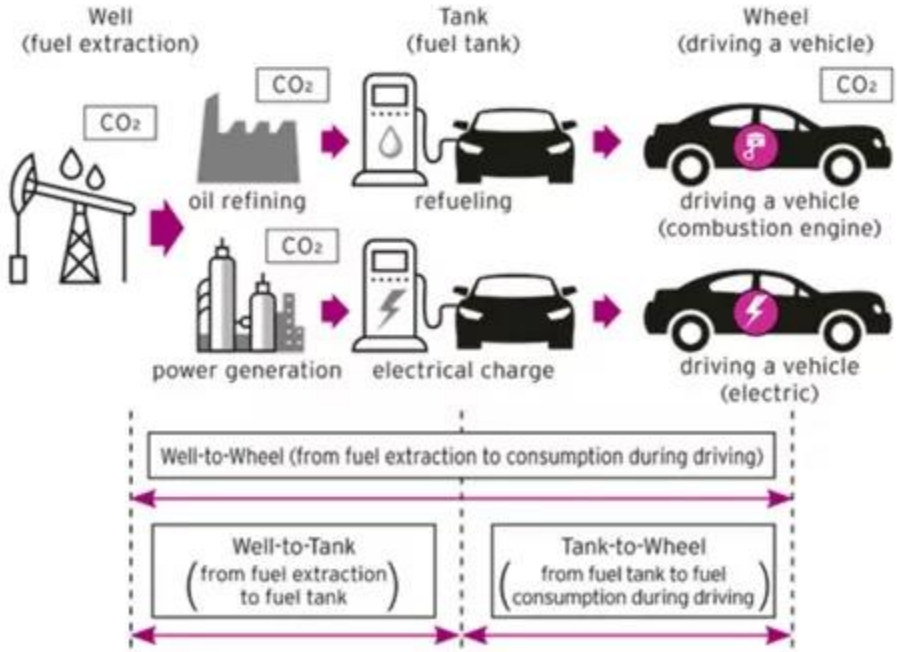

Figure 1: Conceptual illustration of Well-to-Wheel analyses for efficiency and CO_2 emissions (Kleebinder, 2019)

The end life pollution is another environmental concern for EV batteries. By the end of 2030, there will be 145 million batteries on the street. These batteries will need to be recycled at their end of life. There is a challenge in implementing the mass level battery recycling: the lack of a common recycling process for all types of the batteries, and recycling is costlier than freshly producing the battery from scratch. It is also hard to handle the batteries without proper expertise and improper processing can release toxic gases and materials into the environment (Morse 2021). Damaged batteries can also release toxic fumes (ERA). The negative impact of lithium-ion batteries is not only possible at the end of life. The raw material for lithium-ion batteries creates additional environmental cost for the developing countries due to the demand of the material (UNCTAD, 2020). A more recent publication by the Central Research Institute of Electric Power Industry in Japan has identified that the lithium-ion batteries add 3.2 kg/kWh to landfill at the end of life, which can be 191 kg on average and upto 640 kg based on the EV models and battery capacity[1] (EV database). On the other hand, almost 25% of every conventional vehicle gets added to the landfill (Ben Hewitt, 2009), which can be approximately 325 kg for a 1300 kg car, in

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[1] calculated based on the useable battery capacity

turn contributing to landfill GHG emission. The recycling of the battery will use 2.8 to 11.2 kg-CO2/ kWh depending on the material recovery option (Ishihara et al. 2020). Another study by Aichberger et al. (2020) found that recycling can reduce 20 kg CO2-eq/kWh in the total lifecycle of EV batteries. Therefore, the battery recycling and disposal leads to a waste management problem and a source of sustainable material extraction opportunity.

Chapter 3: METHODOLOGY

Electric vehicles, though have been a consideration for sustainable transportation mode and mass produced since the mid nineteen nineties (Quiroga, 2009), still lack some comprehensive analysis on the key factors. In the existing research on electric vehicles (specifically electric passenger cars) adoption, the interrelationship between infrastructure, environment and policy and public interest in EV adoption have not been observed holistically so far. Multiple research have been conducted by several organizations, both academic and business entities, on these issues. But most of them have concentrated on one or two of the aspects like consumer behavior, policy components, infrastructure or environmental impacts of electric vehicles due to the comparative novelty of the sector and lack of enough data. The geographic extent of the observation also focused on certain countries or one or two cities, except for some sporadic publications from organizations like the International Council on Clean Transportation.

This research is designed to have a comprehensive look at the current global scenario, concentrating mostly on the American and European cities, in the EV adoption. The main aim of the research is to investigate how different infrastructure and incentive policies influence the EV adoption rate and resulting positive environmental impacts in the 16 cities. Different cities have taken different measures and this research is an effort to observe them through a comprehensive lens rather than analyzing them separately.

To achieve the goal of this study, a mixed method for research was adopted. As the topic is still evolving, following a method that can provide the flexibility of analysis is most suitable for this research. In general, the research followed a modified exploratory sequential method, Creswell et al. (2018) explained the process as "*three-phase exploratory sequential mixed methods is a design in which the researcher first begins by exploring with qualitative data and analysis, then builds a feature to be tested (e.g., a new survey instrument, experimental procedures, a website,* *or new variables) and tests this feature in a quantitative third phase*." An initial qualitative phase of data collection and analysis used case studies on the selected cities, followed by a quantitative data collection and analysis phase. In the final phase, the two strands of data were integrated to observe the correlation between the two parts. For understanding the topic of electric vehicle adoption and the relationship between policy and infrastructure, the first step in this study was to identify the cities, who have adopted EVs on a large scale along with a growing market share of the new electric vehicles. The next step is conducting case study-based observation in those 16 global cities[2] to comprehend the EV ready policies and scenarios [Chapter 4] and observing them through both descriptive and statistical lens with the help of the cost of ownership and environmental impact analysis. The second part is built on the information collected in step one and worked on understanding the interrelationship among the selected variables (which will be introduced in Chapter 4.1) quantitatively through statistical analysis. The process of analysis and literature base will be explained in the relevant parts of the paper. The rationale behind choosing the sixteen locations is their rapidly rising electric vehicle ownership. The main data sheet in Excel was built based on the characteristics represented through the case studies and ideal EV policies and Infrastructure scenarios observed in different countries as well as the literature reviewed throughout the process.

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[2] USA = Seattle, San Francisco, Los Angeles, San Jose, New York ;
Norway = Oslo, Bergen ; UK = London; Germany = Berlin, Munich; Sweden = Stockholm; Netherlands = Amsterdam ; France = Paris ;
China = Shenzhen, Beijing; Japan = Tokyo.

Chapter 4: STUDY DESIGN:

Different elements of EV adoption need to be observed as a whole. To connect the dots in explaining the current scenario, the following research questions are addressed.

a. *Which EV friendly cities are chosen globally; those are known for their high EV adoption rate?*

Specifically, cities which have already adopted Electric vehicles on a large scale. These cities are spread all over the world, but concentrated mostly in Europe and some American states, like California and New York. If the EV market share doubles every two years, it will have 16% market share in 2025, and 64% in 2029. Even if the growth is half that rate, plug-in vehicles will become 32% of new vehicle sales within the decade.(IHS Markit, 2021) For the convenience of selecting the target cities, the International Council on Clean Transportation (ICCT) 2019 ranking for EV market share was followed as a starter. The ranking was conducted based on the new vehicle share; not total EV adopted in the city. But this is a good indicator which cities will have a large share of electric vehicles in a decade. In addition, among the Chinese cities, only Beijing and Shenzhen were taken for evaluation due to lack of transparent and available data on other Chinese cities. From the American context, Seattle, with local vehicle share of 12% inside the US and global share of 0.9% (ICCT 2020, SeattlePI 2020), Washington was added from outside the list as an emerging EV friendly city in North America.

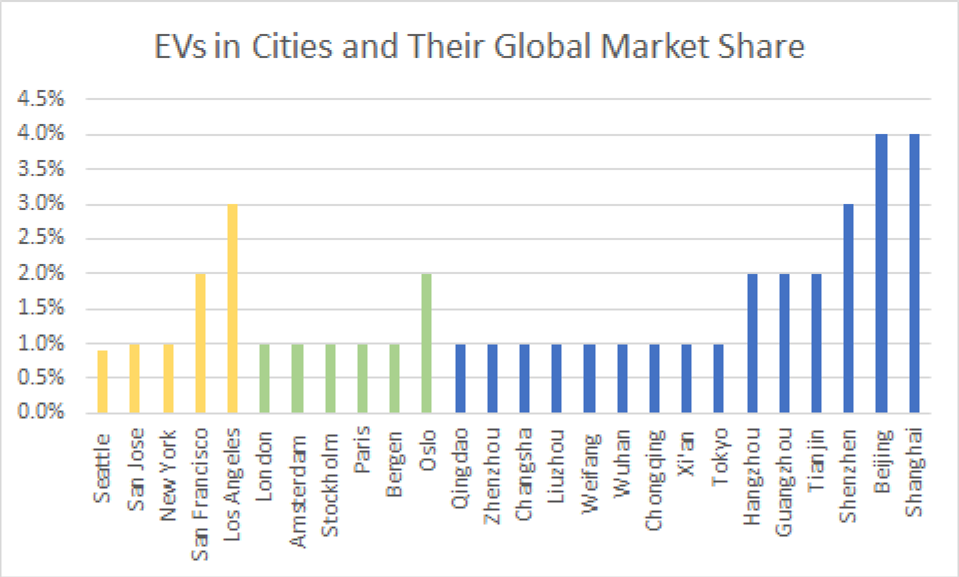

Figure 2 : EV market share in 14 selected cities (excluding Berlin and Munich) (ICCT, 2019; Seattle PI, 2020)

The German cities, Berlin, and Munich were selected based on the report by CleanTechnica (2020) on the global EV share in different countries, where Germany showed a substantial volume of BEVs and PHEVs (approx. 6% and 13%) among the EV friendly countries. The cities selected for the final analysis are,

- The USA: Los Angeles, San Francisco, San Jose, New York, and Seattle.
- Europe: Oslo and Bergen in Norway, Berlin and Munich in Germany, London from the UK, Paris in France, Stockholm from Sweden and Amsterdam in the Netherlands.
- Asia: Shenzhen and Beijing in China, and Tokyo in Japan.

b. *How is consumer behavior in different cities getting affected by different components, like policy and infrastructure, in case of EV adoption ?*

The relationship between policy incentives, infrastructure and EV adoption rate is still a topic of ongoing research. There are multiple other variables in play while understanding the impact. Different groups of people might have different reactions to policy and infrastructure initiatives. The cost of ownership is a good indicator why people buy electric cars. Various reports have identified it as a major catalyst in car purchasing decisions (New motion, 2020). And the cost of ownership is influenced by the tax incentives and subsidies. Langbroek et al. (2016) investigated the effect of policy incentives on EV adoption. And found a significant relationship between policy and EV Infrastructure is also an important part of the EV penetration in the car market. Charging facility and electricity availability is important for reducing range anxiety among the potential EV buyers (Funke et. al. 2016). For evaluating this relationship different variables are identified for the next step, which is data collection.

c. *What is the environmental cost of the EV adoption in cities, are they all positive?*

While EVs do not emit harmful gases through tailpipes unlike their diesel or gasoline counterparts, there is a hidden cost for EVs which can offset the positive impact. They can be identified as the Battery production emission and Battery end-life pollution. The cost of energy production can also be taken as a hidden cost for Electric Vehicles. Understanding these issues simultaneously is necessary in EV planning. To study these impacts, this paper has identified environmental cost as a significant element in EV impact analysis.

d. *Can this impact of policy and infrastructure be analyzed statistically*?

Though there are not enough literature on statistical evidence of the interrelationship between all the policies and infrastructure on EV adoption yet, which can be attributed to the newness of the issue and the lack of data availability, On the very last stage, this paper aims to conduct a statistical analysis with the significant variables to identify which components have the most significant relationship the growth of Electric cars and users in the selected cities. The hypothesis for the statistical analysis is, ‘Electric vehicle adoption has a statistically significant relationship with cost of ownership (TCO), policy and charging facilities.

To answer all the questions above, the study identified four observational dimensions, which are

- the cost of ownership
    - influenced by policy and incentives in different cities,
- infrastructure: evaluated through the availability of public charging station or points available,
- the environmental cost of the EV passenger car usage through the carbon footprint analysis. (See Table 1)

Table 1 : Observation Elements in EV Friendly Cities

Observation Criteria	***Observation Elements***
Cost of Ownership	Purchase price
	Depreciation of purchase price
	Maintenance and Repair Cost
	Insurance Cost
	Fuel Cost
	Incentives
Policy	Tax/ Rebate
	Subsidies
	Parking facilities
	Access to HOV/ bus lanes
	Other facilities (license plate)
	Charging infrastructure subsidies
Infrastructure	Public Charging Stations/ points
	Residential charging facilities or related programs
Environmental cost	Carbon footprint in the Energy production phase
	CO2 emission in the EV operation phase
	CO2 emission in the battery disposal phase

Based on the criteria stated above, we collected data and analyzed the interrelationship between the related variables descriptively and statistically, appropriate variables and calculation process will be introduced in relevant chapters.

Chapter 4.1: Data Collection

The data collection stage of this research depended on the myriad of publicly available information on the internet and already published printed sources. All the data used here are secondary data, extracted from the internet and printed sources. The sources are mostly government or regional databases, with some exceptions of third-party sources due to the unavailability or accessibility in some cases. Data modified or customized will be explained in the appropriate sections and in the relevant Appendices along with the sources throughout the paper. The target dataset was searched based on the table presented below.

Table 2: Database Creation

Attribute	***Data***
Socio-demographic attribute	
Demographic data	Population (City)
	Median household numbers
	Median household income
Vehicle data	Total registered passenger cars (city)
	Total registered electric passenger cars (city)
	Vehicle miles traveled
Electric Vehicle data	Most popular EV model
	Average fuel economy (kWh / 100 miles)
Non-Electric vehicle data	Most popular gasoline car model
	Average fuel economy (gallons / 100 miles)
Total Cost of Ownership (TCO)	
Electric Vehicle	Median purchase price (based on most popular model)
	Resale price (based on most popular model)
	Depreciation (for 3 years based on car model and annual 10,000 miles of driving mileage),
	Maintenance cost (average for the model selected)
	Total fuel cost (charging cost)
	Tax
	Subsidies
	Insurance cost
Non-Electric vehicle	Median purchase price (based on most popular model)
	Resale price (based on most popular model)
	Depreciation
	Maintenance cost (average for the model selected)
	Total fuel cost (gallons)
	Tax
	Insurance cost
infrastructure	Total Public Charging Stations/ points in the city
	Residential charging facilities availability and type
Energy	Total energy usage in the city

	Total energy usage in the EV charging
Environmental cost	Energy sources in the selected sixteen cities
	CO2 emission from energy sources
	CO2 emission by EVs (BEV and PHEV)
	Battery disposal facility
Policies	Existing programs
	Target year and target level of electrification
	National, state and city-based subsidies
	Tax cuts, rebates, and credits, both the monetary amount and existence of the provision in the EV initiatives in the cities.
	Parking fees, tolls, and congestion fees exemption
	Access to HOV/ bus lanes
	Incentives for the residential chargers
	Other facilities (license plate etc.)

Chapter 4.2: DATA ANALYSIS APPROACH:

Based on the data extracted in the Data Collection phase, this research followed the analysis process derived from multiple literature sources. In some places, the analysis was customized to accommodate the updated data due to the constantly changing nature of the information available in different platforms. The most common modification is conducted to adjust the regional and metropolitan data to city-based calculation. Some information on two Chinese cities, Beijing and Shenzhen, needed the customization due to data asymmetry observed there. For example, in China, the household level income for the cities is not publicly available. While inputting data in the data sheet, we considered the median income for individuals in the city and calculated the median household income based on total household size. The lack of vehicle miles travelled data was also observed during data collection for China. This research used 2008 country based VMT data for all the cities to ensure data similarity. In some European cities, like Oslo, Bergen, London and Stockholm, the charger availability data was found to be different in different sources. In those cities, we assumed the data on chargers per million population in the ICCT report to be acceptable and the total charger number was calculated based on that value and total EVs in the city. The other adjustments are explained in the relevant Appendices.

The formula and data analysis process followed throughout the paper is introduced in the subsections here. Final analysis and findings will be presented in Chapter 5.

4.2.1. City Demographic and Economic Profile:

The demographic and economic profile of the selected cities are very important in understanding the vehicle electrification process in the urban context. Transportation is the second largest cost incurring component in a household level after housing. In the USA, the cost is almost 50% of the total household expenditure for families earning less than $25,000 annually. The percentage gradually decreases with the rise in income, with median income households spending 16% of their income and higher income households spending less than 10%. (ICCT, 2021; U.S. Bureau of Labor Statistics, 2020). Understanding the correlation between the household median income and total cost of EV ownership in the selected cities is important for unbiased evaluation of the scenario.

4.2.2. EV ownership Profile of the Cities:

The percentage of EV by household is an important indicator for evaluating electric car penetration as a private mode of transportation in the urban households and future demand of the other relevant facilities this will create (Farkas et al., 2018). The per capita electric car ownership depends on the growing market share of EVs in different regions and also on charger density and energy demand (Wang et al. 2019).

For better understanding of the process, this paper created the two variables for EV availability on household level and EV concentration in registered cars. The city-based EV ownership data compilation was done using the table presented below.

Table 3: City based EV density data collection sheet format (*detail data in Appendix 1)

City based EV ownership profile

Total Population	Number of Household	Median Annual Household Income	Total Registered passenger cars	Total Registered EVs	EV per HH	EVs per registered passenger cars
2019 data	2019 data	2019 data	City Based data (till 2020)	City based data till 2020		

4.2.3. Policy Based Ranking

To evaluate the city performance in promoting EV friendliness, this study developed a binary scoring system for policies present in the 16 selected cities. For determining the policies to observe, this paper followed the modified variables from the Melton et al. (2020) study on Canadian cities. The eight selected criteria were the presence of carbon tax, subsidies/ grants, tax break, access to HOV/bus or other lanes, reduced parking charge, reduction in tolls, Zero Energy Vehicle mandate, EV charging incentives (both public and residential). The scoring was done in a binary method, present = 1 and absent = 0. The total possible score is 8 for each city. This score does not reflect the level of EV penetration in the sample cities. This scoring will also be used in observing the performance of the city through the lens of EV density, TCO and policy implications.

4.2.4. Total Cost of Ownership:

The real cost of owning a car depends on the factors like purchase price, depreciation, interest rate, fuel cost, maintenance expenditure, tax and for electric vehicles, and subsidies pay a major price in evaluating the long-time cost of ownership. Insurance cost is also a major defining part of electric vehicle ownership. For the calculation of TCO in this paper, the modified version of the formula from Hangman et al. (2016) is followed. For this analysis, we are assuming that the car is bought with a one-time cash payment, without any loan, removing the necessity of interest rate calculation. The modified formula is as mentioned below-

$TCO = (PP-RP) + FC(TMD)+IC+ MR + T - S$

Where, TCO is Total cost of ownership for 3 years, PP and RP are purchasing and resale price accordingly, making (PP-RP) the depreciation component (after 3 years of ownership) of the equation. FC is fuel cost for VMT (per capita annual vehicle miles driven for 3 years), IC, MR, T and S are annual insurance cost, maintenance and repair cost, tax and subsidies accordingly. In the case of non-electric cars , the subsidy is zero. All the costs of ownership are calculated for 3 years, except for subsidies, as most of the subsidies are one time offers, which are issued when the car is first bought. The timeline is set as 3 years due to the presence of Tesla or more recent EV models in the cities (as most registered models); and data, (specifically on depreciation rate, which is a major component of TCO calculation) older than 3 years is not available yet.

The calculation process is explained below. (See Appendix 2 for purchase price and depreciation comparison between EV and non-EV, and Appendix 7 for TCO, financial return and benefit comparison between EV and non-EV)

Table 4 : TCO calculation process

	Variables	***Electric Car TCO***	***Conventional Car TCO***
Depreciation Calculation	Popular car model	Most purchased EV models in the city	Most purchased CV models in the city
	Purchase price, PP	Local Price of the most popular EV, converted to $	Local Price of the most popular CV, converted to $
	Resale value, RP (Car Edge)	Calculated for new car, with 3 years of ownership, annual 10,000 miles drive.	
	Depreciation rate, (PP-RP)/PP	Calculated for 3 years. In some instances, used to calculate the resale price due to data unavailability for resale price	
Fuel Cost Calculation	Annual VMT per Capita	Country based 2008 data for consistency	
	Average Fuel Economy	3 mile/kWh =30 kWh/100 miles (INL, n.d.)	4.18 gallons/ 100 miles (AFDC, 2020)
	Fuel Cost per unit	City based public and residential charging rate per kWh	State / country-based rate per gallons
	Energy Consumption *[Sec. 4.2.4]*	Annual VMT/ Capita*percentage of usage (residential or public)*Average Fuel Economy/100	Annual VMT per Capita*Average Fuel Economy/100
	Total Fuel Cost, FC	Total energy consumption * electricity cost per unit	Total fuel consumption * fuel cost per unit
	Annual Maintenance and Repair Cost, MR	Model based repair cost	Model based repair cost
	Annual Insurance Cost, IC	Median for the EVs in the city	Median for the CVs in the city
Total Incentives Calculation *[Table 5, Sec 4.2.6]*	Annual Tax, T	Total tax rate on sales, road or others (emission tax, usage tax)	Total tax rate on sales, road or others (emission tax, usage tax)
	Total subsidies (not annual), S	Federal, state and local subsidies	N/A
	Total Incentives (T-S)	3*Tax - S	3*T
Total Cost of Ownership for 3 years		(PP-RP)+3*(IC+MR+FC)-(3T-S)	(PP-RP)+3*(IC+MR+FC)- 3T

4.2.4.a. Depreciation Calculation:

Depreciation is a major part of total ownership cost calculation. For a typical new vehicle bought, the depreciation rate is almost 48% in five years (Hagman, 2016). This cost depends on the purchase price and resale price over a certain period of time. For this study, the depreciation period is taken as three years and based on the purchase price and average annual mileage of 10,000[3] miles, the depreciation is calculated.

4.2.4.b Fuel Cost Calculation:

Fuel cost comprises almost one-fourth of the total cost of ownership (Hagman, 2016). For EVs, the fuel cost is calculated both for residential and public chargers. Most of the charging (80%) are done at home (Office of Energy Efficiency & Renewable Energy, n.d.). The average fuel economy is considered as 30 kWh/ 100 miles (Idaho National Laboratory). The average fuel economy is considered for standardized results in all cities, only with the VMT and per unit cost as the variable. .

*Annual charging cost at home = 80% * Residential energy cost per unit (per kWh) * Average fuel economy (30 kWh/ 100 mile) * VMT*

*Annual charging cost at public station = 20% * Public energy cost per unit (per kWh) * Average fuel economy (30 kWh/ 100 mile) * VMT*

Total cost of annual charging = Annual charging cost at home + Annual charging cost at public station

For non-EVs, the fuel cost is calculated based on the average fuel economy of 4.13 gallons/ 100 miles (US Department of Energy, 2020). The fuel costs per gallon are city

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[3] The highest average VMT in all three regions is 9,555 miles (Asia) annually. The closest rounded mileage is considered. See Appendix 3

based for the US, but some of the European and Asian fuel costs are collected on a country level due to the data availability publicly.

*Total fuel cost = Gasoline cost per unit (per gallons) * Average fuel economy (4.13 gallons / 100 mile) * VMT*

4.2.4.c. Insurance cost and maintenance and repair cost:

Insurance is another major component of TCO after fuel cost. Insurance depends on location and personal factors, in the USA, a credit score can significantly affect the insurance rate (Bank rate, 2020). For this research, the average cost of insurance is calculated for the countries. Insurance for electric cars is typically higher than the non-electric counterpart, except in some cases. Taking this into consideration, the insurance cost for electric and non-electric versions of the cars are calculated separately for three years. In some countries, like Japan, insurance can be both the liability (mandatory) ones along with optional insurance (Supermelf, n.d.). For the consistency of the analysis, only liability/ mandatory insurances are considered in most cases. For maintenance and repair cost, an average cost for the car model is used for calculation.

4.2.4.d. Tax and subsidies:

In car ownership cost, tax continues to have a larger impact over the years. And in the case of electric cars, the introduction of tax rebates, credit and subsidies (grant or benefits) can substantially offset the total cost of car operation over the years. For tax calculation in different cities in the USA, the state tax rate and relevant fixed taxes like road tax, user tax etc. are considered. In the case of other cities, country-based tax rates are taken into consideration. For electric vehicles, the total reduced tax along with subsidies are counted towards the final tax calculation. The table below is a list of taxes to be paid as well as available rebates, subsidies, and incentives on passenger EVs in the sample cities. For the calculation process, only car purchase is considered, leasing or used car scrapping is not included.

Table 5: Tax and Subsidies available in the sample cities

City	*Electric Cars*				*Conventional Cars*
	Tax	Federal / National Subsidy/ Incentives	State Subsidy/ Incentive	City Subsidy/ Incentive	Tax
Seattle	$150 road tax	$7500 tax credit	N/A	N/A	10.1% local tax + $54 registration fee
Los Angeles	$100 road tax	$7500 tax credit	California Clean Fuel Reward (CCFR) = $1,500 Clean Vehicle Assistance Program (CVA Program) = $ 2500 California Clean Vehicle Rebate Project (CVRP) = $800	$450	9.5% local tax
San Francisco	$100 road tax	$7500 tax credit		Clean Cars for All (for low-income residents[4]) = $9500	8.5% local tax
San Jose	$100 road tax	$7500 tax credit		San Jose Rebate = $3000	9.25% local tax
New York	$61 registration fee	$7500 tax credit	The Drive Clean Rebate = $2000	N/A	4.5% sales tax + $25 license plate fee + $50 certificate fee + annual fees ($140 weight-based registration fee + use tax $15 + $25 MCTD fee)
Oslo	100 % use tax sales and	N/A	N/A	N/A	25% Vat+ Carbon Emission Tax

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[4] Income based incentives are not included in the final calculator due to the inconsistency with the other cities.

Bergen	emission tax exemptions				Calculated from The Norwegian Tax Administration
London	100% emission tax exemption	"Purchase grant: up to 35% purchase price (£3,500 max.)	N/A	N/A	20% Vat+ £140 + CO2 emission tax Calculated from Vehicle Certification Agency
Amsterdam	100% tax Exemption Calculated from Transport Styrelsen	Purchase/ Lease Grant : 1. New EV = 4,000 euro 2. used EV = 2,000 euro	N/A	N/A	Weight tax+ CO2 emission tax + Diesel surcharge. Calculated from Transport Styrelsen
Stockholm	Bonus Malus scheme: 60,000 SEK (€6,000) for up to 25% of the car's purchase price (new)	Supermiljöbilspremie: •SEK 20,000: Vehicles with CO2 emissions between 1-50g/km (plug-in hybrids) •SEK 40,000: Vehicles with zero CO2 emissions (electric vehicles)	N/A	N/A	25% Vat + $236 annual tax
Berlin Munich	Kfz-Steuer (motor vehicle tax) 10-year exemption	Umweltbonus: For vehicles priced up to €40,000: BEV: €9,000 PHEV: €6,750 For up to €65,000: BEV: €7,500 PHEV: €5,625	N/A	N/A	19% Vat + Annual Carbon Tax + Weight Tax Calculated from kfz-steuer.wiki

Paris	Carte-Grise €43	Purchase Grant : €7,000 based on CO2 emission rate Conversion bonus : Up to €5,000	N/A	N/A	car registration fees €300 + regional tax €46 + €818
Tokyo	Exemption of Shaken or mandatory tax	Subsidy of ¥850,000	N/A	additional subsidy of approx. ¥330,000	Annual vehicle tax ¥30,000 ~ ¥80,000 + Weight Tax ¥10,000 ~ ¥80,000
Shenzhen	100% tax exemption	RMB 10,000 (approximately $1,500) to RMB 25,000 (approximately $3600)	N/A	N/A	10% purchase cost + $13000 license plate cost
Beijing	100% tax exemption		N/A	N/A	

*Appendix 6 has details of the whole process. Relevant sources in Table 5 are added to the reference section and in the appendix 6.

4.2.5. Parking and Toll cost:

Parking charges control travel mode choice to a significant extent, and higher parking charges can reduce the demand for car travel (Ding and Yung, 2020). Parking cost has a significant impact on EV adoption. INRIX, an international transportation consultation organization, found parking charges as a major cost incurring sector in car ownership using the two-hour parking cost analysis within one mile of the city centers. They conducted an analysis on the parking cost in three countries globally. The summary result indicated that, on average, drivers pay $1304 annually only for parking.

As there is a wide variance in the parking cost analysis process and the scope is limited in this study for observing the scenario in detail and accurately, a simple descriptive analysis is conducted for this part. The basis for this analysis is to observe the variance in annual parking cost for both EVs and non EVs in comparison with the global average.

For the annual parking cost calculation process, we considered only the on-street parking. For this, we assumed that the on-street parking for the vehicles, both EV and non-EV, would be available for two hours based on the parking regulation in most sample cities and both the EV and non-EV driver will use the parking space at the same time and day. This time limit can vary as long as four to five hours in some cases but based on the regulations in the majority of the cities considered, it is counted as two hours on average for two hundred sixty-one weekdays annually.

*Annual Parking Cost = Hourly street parking rate on average * 2 hours * 261 workdays*

Tolls are also a major cost for car drivers annually. The reduction in toll price or access to HOV or bus lanes inspire potential EV buyers to select electric cars as their travel mode (2020). As toll rates vary greatly in different cities, for the consistency of the evaluation process, this study will use a binary method for indicating the presence or absence of toll exemption in the 16 cities. Not all the cities have tolled highways. Germany and Amsterdam do not have any toll roads anymore, except for some tolled bridges and tunnels. Exemption on these bridges will be considered for evaluation in this study as those bridges are part of the transportation network the EV users have to traverse for travel purposes.

4.2.6. Charging facility:

Charging infrastructure is a major part of the EV scheme. Easy and available charging points are the key to reducing the range anxiety of the EV drivers. The chargers are classified as Level 1: the slowest charger found at residential buildings; Level 2: 208–240 V, medium charger with multiple range of charging and can be found at home or public locations and DC fast chargers : the fastest charger found at the fast-charging facilities with high power demand (Idaho National Laboratory, 2015).

In the data collection phase, this research looked into the public charging points available in the target cities. But in most cities the data on the number of Level 2 and DC fast chargers are not publicly available. In those cases, the information from the ICCT report from 2020[5] is used to find electric vehicles per charging point in the cities. Based on those numbers, households per charging point and chargers per million people is calculated (Chapter 5.6 for Infrastructure and the Public Charging points, Table 18 for EV Charger Availability in the Selected City and Appendix 13 for sources).

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[5] Assumed from the graph presented on the report

4.2.7 Environmental cost:

In EV operation, the emission is mostly from the energy generation, which can be calculated through the well-to-wheels (WTW) analysis (Liu. 2020, Xinyu. 2021) and the non-electric miles driven by the PHEV and conventional vehicles. For BEV, the per mile CO2 emission through the tailpipe is calculated to be zero, and 0.29 lb/ mile for non - electric miles of PHEV. For non-electric miles of conventional vehicles is 0.48 lb/mile (National Renewable Energy Laboratory, 2016). The emission from energy production (Well-to-pump) is calculated using the coefficient from the GREET model. The list below shows the coefficients used in this paper.

Table 6: CO2 emission coefficient from GREET model

Fuel Type	Co2 Emissions (lb. per kWh)
Coal	2.23
Natural Gas	0.97
China Mix	1.59
CA mix	0.44
Japan mix	1.28
Nuclear	0
Wind	0
Solar	0
Water (Reservoir Hydropower)	0

For estimating a total annual carbon footprint of electric cars, the calculation is divided into two parts: energy related emission and tailpipe emission.

*Emission from energy sources = total energy used by the electric cars * {(percentage of coal * 2.226 lb/ kWh) + (percentage of natural gas * 0.97 lb/ kWh) + (percentage of zero emission of fuel * 0 lb/ kWh)}*

For California, Japan and China, the respective Well-to-Tank emission rates are used for calculation. The power mix varies greatly in different cities. For example, San Jose Clean Energy and Pacific Gas & Electric both supply electricity in San Jose. But they have different renewable and non-renewable sources, and it is not possible to identify which EV charger is using which power source. To adjust the difference, the standardized value of 0.44 lb CO2 emission per kWh electricity production is used for calculation rather than calculating it from the power mix documented in Table 20 [Chapter 5.9]. Well-to-Tank CO2 emissions for Japan and China are also derived in the similar process from the GREET model value.

*Emission from energy sources = total energy used by the electric cars * CA mix*

*Tailpipe emission = VMT * {(number of BEV * 0 lb/ kWh) + (number of PHEV * 0.29 lb/ kWh*300/326 miles)}*

The mileage is divided by 326 as it was assumed that the electric range of the PHEV will be 26 miles, and the non-electric mile is 300.

Dead Batteries:

For the end-of-life emission from dead batteries or cradle-to-grave carbon footprint evaluation, this study tried to indicate if there is a recycling facility available in the city. Due to the ongoing research on EV battery recycling and difference in carbon intensity of different batteries, the CO2 emission is not calculated in the similar way as the WTW. For example, the most recent study found that the disposed lithium-ion battery can add 3.2 kg/kWh to landfill without material recovery. On the other hand, the recycling can produce 2.8 kg-CO2/ kWh, which is equivalent to 2.1 kg-CO_2 reduction per kWh if they were produced from raw material (Ishihara et al., 2020). Another study by Aichberger et al. (2020) found that recycling can reduce 20 kg CO2-eq/kWh in the total lifecycle.

This study did not use any standardized comparison for CO2 emission from dead batteries in the cities due to the difference of CO_2 emission of various types of disposed batteries . To avoid inconsistency in data analysis, this emission or landfill addition by dead batteries are separately evaluated based on the availability of proper recycling facilities in the sample cities and what can be implied from the available data following the table below.

Table 7: Battery End of Life Possible Situation

Types of facilities available	Landfill or CO2 Emission
Collection and Landfill	7.05 lb-landfill/kWh*60.5 kWh*number of EVs
Proper Recycling	6.17 lb-CO2/kWh* 60.5 kWh*number of EV

*60.5 kWh is used as an average usable battery capacity for this calculation (Electric Battery Database)

Chapter 4.3: STATISTICAL ANALYSIS DESIGN

For the statistical analysis, the predictors will be selected during the observation phase in Chapter 5 based on the simple correlation test. Variables with moderate values ($r > 0.3$) [6], will be used to run the multiple regression analysis.

For example, if electric vehicles per 100 vehicles and EV per 100 households both had the potential to become the dependent variable in checking the impact of policy on EV adoption through TCO analysis, a correlation check would be conducted to find which has the highest chance of creating a better model. Based on the rationale, the dependent and independent variables will be chosen in the observation phase.

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[6] Considering $r = 0.7$ for significant value for sample size = 16 in social science and 0.3 to 0.7 as moderate.

Chapter 5: ANALYSIS AND RESULT

5.1. City Demographic and Economic Profile:

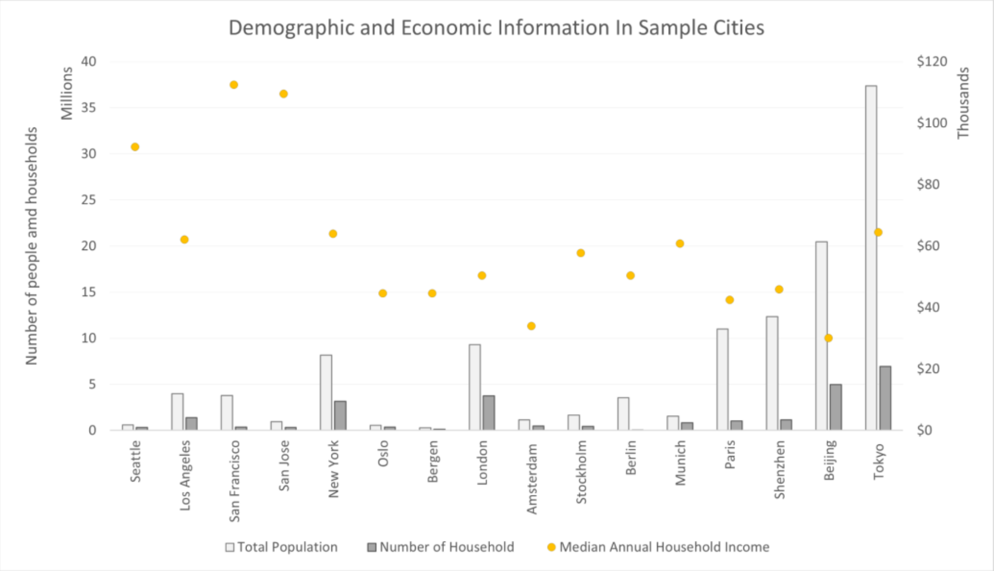

Figure 3 : Demographic and economic information of the 16 selected cities, 2019

The primary observation based on the collected data shows that the range of the median household income of the 16 sample cities is approximately $40,000 to $110,000. The five cities in the USA have the highest median household income ($88,000) followed by Europe ($48,000) and Asia ($46,000). Among all the sample cities and also in Asia, Japan has the highest population and number of households. Their median income is also the highest among the three cities in Asia ($64,000). New York, on the other hand, has the highest population as well as the number of households among US cities selected for observation. In Europe, London is closer to New York both in total population and households. Paris and Shenzhen have almost similar population and household profiles.

Among the other US cities, San Francisco ($112,000) and San Jose ($109,000) have the highest per household income. On the other hand, Oslo and Bergen, two of the high personal income ($88,000 and $84,940) cities have considerably low median household income ($77,000) based on available data calculation (Appendix 1). The small household size in Norway (2.1) can be responsible for this low median household income.(OECD, 2011) The population and households will work as a base information in extracting the variables in the calculation. The interrelationship between the median income and EV density in the cities will be explored in the later parts.

5.2. EV Profile of the cities:

Based on the analyzed data, the cities can be ranked according to the EV density in every 100 households and in every 100 registered passenger cars. While Berlin ranks highest in EV density on household level, Oslo leads in the passenger car electrification sector. In the next section, this will be explained in conjunction with median income.

Table 8: EV ownership rank of the sample cities

City	*Electric Cars per 100 HH*	*EVs per 100 registered passenger cars*
Oslo	18	**87**
Bergen	26	34
Paris	6	19
San Jose	33	17
Stockholm	13	16
Tokyo	7	16
Shenzhen	23	9
Amsterdam	4	8
Beijing	8	7
Munich	3	3
Seattle	4	3
Berlin	**70**	2
London	1	2
San Francisco	13	1
New York	<1	<1
Los Angeles	8	1

Among the European cities, Berlin has the highest EVs per 100 households. But Oslo has 87% of their cars electrified (Table 8). Berlin also has the highest passenger car ownership, 2873 cars per hundred 100 households (Appendix 1 explains EV ownership and city profiles in detail), but the EV percentage among passenger cars is quite low, only 2% of total passenger cars are electric. Most of the American cities observed in this study have similar ownership percentages (Seattle 3%; LA, San Francisco and NY both have 1%). San Jose, with the second highest median income in the USA, has 17% of the total car battery electrified. San Francisco has the highest median household income, but their electrification rate is low. Seattle on the other hand, has high EV concentration in the automobile population along with high income at the household level. What is the relationship among the EV density and median income observed here?

5.2.1. EV Adoption and Median Income:

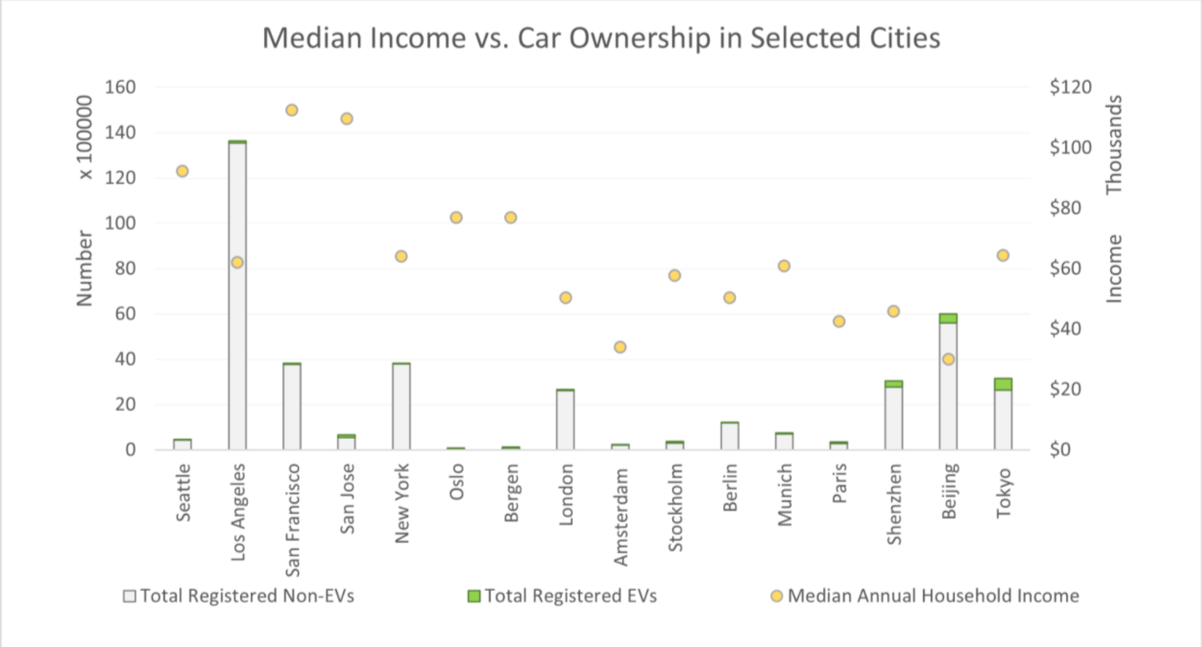

Figure 4: Median income and car ownership comparison in sample cities

With similar median income as Berlin, London has lower car ownership overall (71 cars per hundred households). Contrary to that, 34 cars in every hundred registered passenger cars are electric in the Greater London region. The other cities in Europe have almost similar total car ownership as London (Bergen 77, Amsterdam 50, Stockholm 77, and Munich 89 cars per 100 households), except Paris (34) and Oslo (21). Not so surprisingly, Oslo, the EV capital of the world, has 87% of their passenger cars electrified. This scenario will be discussed in relation to the convenient policies available in those cities in the coming chapters.

In the case of Asia, Tokyo has the highest median household income, but lowest car ownership (45 cars per hundred households) compared to the selected Chinese cities (Shenzhen 261 and Beijing 121). The ratio of passenger car electrification is also higher in Tokyo at 16%, followed by Shenzhen (9%) with the second highest median income and Beijing standing last in median income with 7% car electrification.

The irregular relationship between the total number of EVs and median income presented above, while observed through a simple correlation check, (Appendix 12: TCO, Policy Component and EV Density Linear Correlation Check) shows weak relation (r = 0.20). According to this value, in the sample cities, median household income was not significant in electric car purchase decisions.

5.2.2. BEV and PHEV breakdown in the sample cities:

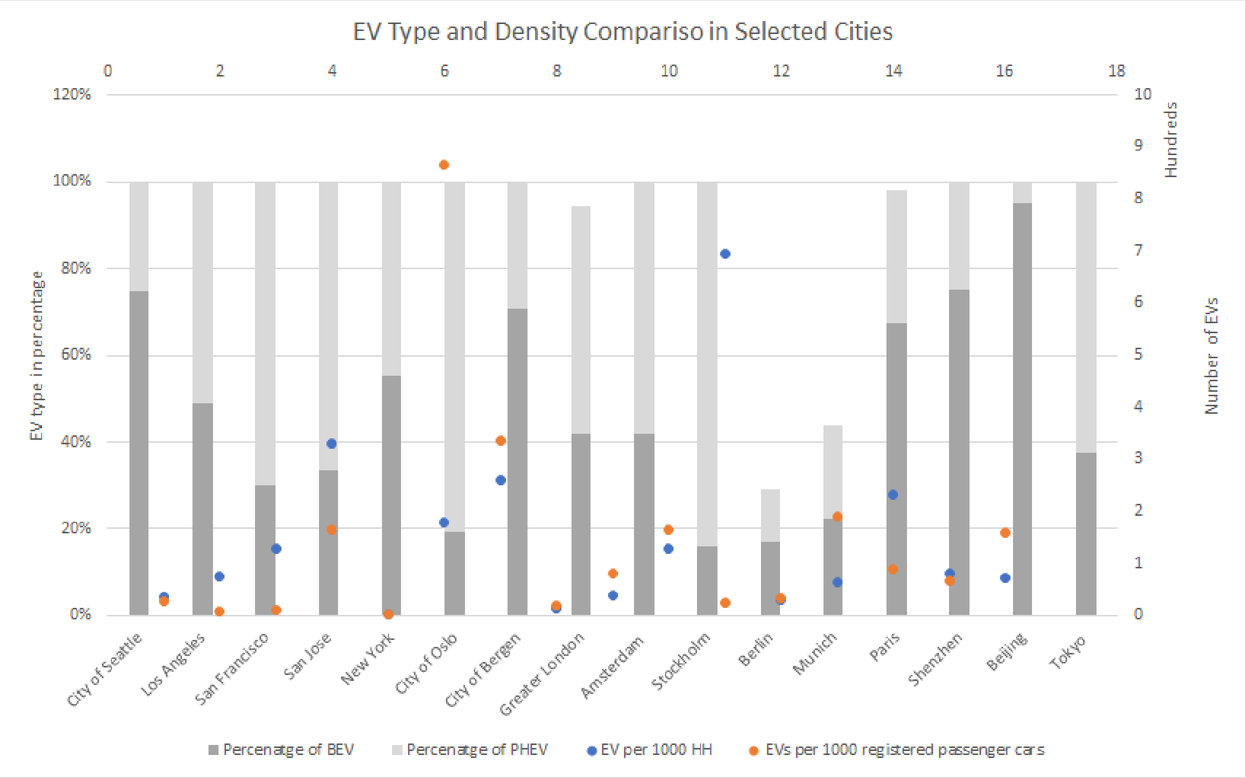

Figure 5: EV type and density comparison

In the sample cities, (Table 9) on average 55% EVs are BEVs, and the rest are PHEVs. A region wise breakdown shows Asia, with the sample 3 cities having the highest percentage of BEVs (69%) followed by the USA (48%) and Europe (37%). The highest concentration of BEVs is in Beijing (95%), followed by Shenzhen and Seattle (75%). The concentration of BEVs in China is partially due to the localized market and expertise the country has with auto production (McKinsey, 2021). China's tech city, Shenzhen, is the home to BYD, the electric vehicle company. Along with attractive incentive packages like multiple EV registration facilities (Clean Technica, 2020) as well as aggressive electrification programs (Electrek, 2020) has led to a high percentage of BEVs in the Chinese cities. In these cities, policies and infrastructures are also major players. In the policy analysis result section (Chapter 5.4), this correlation will be explored in detail.

The high concentration of PHEVs in European cities is mostly due to the EU regulation to promote low emission vehicles and their early transition to EVs. But this might change in the near future as most European cities will stop labelling PHEVs as green vehicles (Elective, 2021). Table 10 in Chapter 5.4.1 has listed the vehicle electrification policy initiation dates and target the cities have for their phase out from the ICE to ZEV[7] The information shows that Norway is one of the earliest adopters of EV policies and China is one of the late adopters. The summary of the findings globally and in the three different regions are presented in Table 9.

Table 9: EV Ownership Summary in the selected EV friendly cities

Average	*Sample Average (16)*	*USA (5)*	*Europe(8)*	*Asia(3)*
Total Registered EVs	1,13,422	56,108	44630	392388
Median Annual HH Income	60371	88089	48139	46791
EV per 100 HH	11	11	11	8
EVs per 100 registered passenger cars	14	4	21	11
Battery Electric Vehicle share	55%	48%	37%	69%
Plug-in Hybrid Electric Vehicle share	45%	52%	63%	31%

5.3. TCO Components Analysis:

5.3.1. Purchase Price and EV Adoption Rate Analysis Result

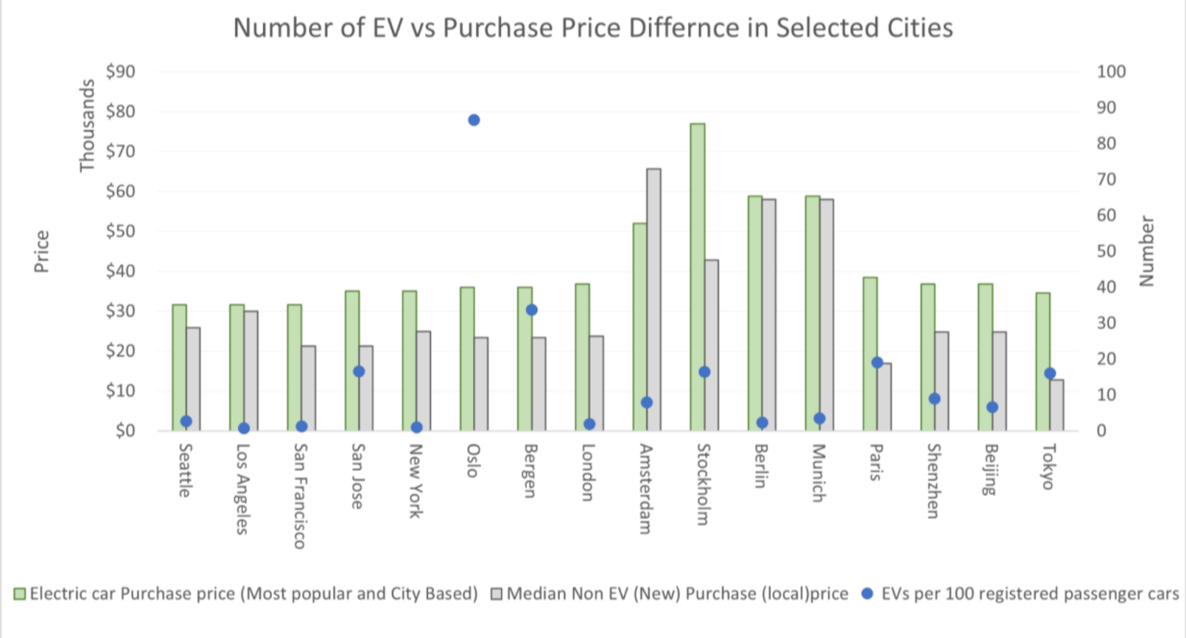

Figure 6: EV vs Non-EV Purchase Price (for most purchased model) comparison in sample cities (Appendix 2)

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[7] ICE = Internal Combustion Engine, ZEV = Zero Energy Vehicle

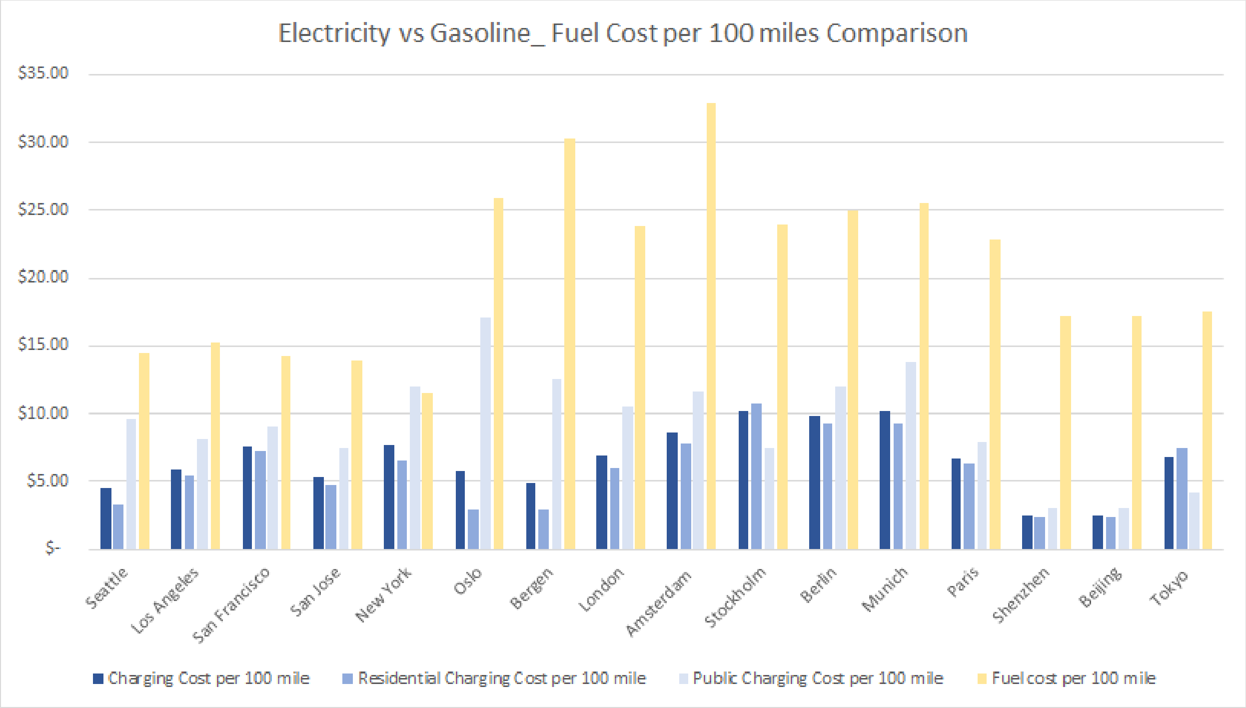
The purchase price for the most popular conventional vehicle models is lower than most popular EV models in all sample cities, except for Amsterdam (-21%), where the CV model selected has a higher price than the most popular EV model. But the rate of EV adoption is comparatively low in that Dutch city. Among all the cities observed, Japan showed the highest difference in purchase price (170%) between the two types of cars, followed by Paris (127%), Stockholm (80%) and San Jose (65%). On the other hand, in cities (Oslo 84 and Bergen 34) with the highest EV concentration in passenger cars, the EV purchase price is 54% higher than that of the non-EV model.

From the observation, no clear relationship between EV adoption and purchase price is found. In an effort to evaluate the situation statistically, a simple correlation check was conducted which produced weak inverse correlation between the independent variable, purchase price and dependent variables, total EVs in the city ($r = -0.25$), EV in 100 households ($r = -0.18$), and in 100 cars in all sample cities ($r = 0.08$). These values indicate that rising EV price did not significantly influence auto users' behavior negatively in the sample cities but decreased the total electric cars on the city and household level. Consumer behavior can be responsible for this, where the increasing car price means increased expense for the urban households. And so, with the high EV price, families' decision to buy a new car, which might be an EV, was reflected in this value. On the other hand, for auto users, there is a lower chance to adopt a new EV as the personal travel mode.

In another correlation analysis, the price difference between two types of cars, EV and non-EVs, showed a different correlation with total EVs in the city ($r = 0.31$) and EV density in 100 registered vehicles ($r = 0.23$). Based on the values, it can be assumed that the purchase price itself did not affect the potential EV buyers significantly. But the impact, if observed on larger sample size or in detail on different car models of wider price range, might show significant change among consumers' choice of EVs and the purchase price difference among different EV models. This difference can influence consumers' preference for a lower priced EV model than a higher priced one.

The impact of purchase price difference between EV and non-EV models, on the other hand, is moderate. The increasing gap increased users. This can be better explained through policy analysis. Some possible reasons might be the exemption of sales tax and other incentive schemes. Due to the possibility of more benefits in the future as people are aware of the EV friendly policies and incentives available to them, the initial purchase price gap had a positive impact despite the common idea, a price gap increase will reduce consumers. Import tax on the non-EV models or by reducing the vat and tax on EVs. but greater than the change of EV use after the price decrease of EV models. The policy analysis step along with the regression analysis will be used to better understand the scenario in the later chapters.

5.3.2. Fuel Cost Analysis Result



*Charging cost per 100 miles is the average of 80% home charge and 20% public charging

Figure 7: Fuel Cost Comparison in EV friendly cities (Appendix 3: Annual Fuel Cost and Appendix 4: Fuel Cost Comparison for 100-mile Drive)

Fuel cost is a very important factor in EV purchasing decisions as discussed in Chapter 2.2 and 4.2.4.b. In all the 16 cities, the charging cost for a 100-mile drive for EVs is substantially lower than the conventional cars (Table 10), except for New York. On average the gasoline cost is $14 (245%) higher than electricity in all the selected cities. In European cities, the monetary amount is the highest ($18; 263%)[8], followed by the three Asian cities ($13; 277%) and the five cities in the USA ($8; 256%).

Bergen ($25; 517%), Oslo ($20; 345%) and Amsterdam ($24; 284%) have the highest difference in fuel costs in Europe. Norway and Netherlands, both countries are at the forefront of EV friendly policies, which will be discussed in the policy analysis section. The high gasoline cost can be an indicator of their inclination towards fossil fuel ban (Ausick, 2019). The cost difference is lowest in Sweden ($14, 136%) and the two German cities ($15, approx. 152%). In Sweden, the public charging cost is low, but home charging can be costly. On the other hand, in Germany, electricity is the costliest (Statistica, 2021). Along with moderate gasoline price, the difference remains lower in those two German cities.

In Asia, gasoline cost is 577% higher than electricity for a 100-mile drive in the two Chinese cities. China, as one of the highest electricity users, has the lowest electricity price in Shenzhen and Beijing. Gasoline prices are higher there than in the USA. The high gasoline price and low electricity cost have an impact on the low EV fuel cost in these cities. On the other hand, Tokyo has a similar gasoline price as China, but higher charging cost, making the cost difference ($11, 156%) lower than China, and closer to the German cities.

The USA, on the other hand, has the lowest cost difference among the three regions considered. New York has the lowest fuel cost difference ($4, 50%). The low density of EVs in New York (less than 1 car per 100 registered cars) might be an indication towards that. Due to the high public charging cost from the distributor in New York (Utility Dive, 2020), and comparatively lower gasoline price, it would become more convenient for the EV users to charge at home. Among the other American cities, Seattle has the highest cost difference ($10; 217%), followed by San Jose ($9; 161%) and Los Angeles ($9; 157%) and lastly, San Francisco ($7; 89%).

A correlation check (Appendix 12: TCO, Policy Component and EV Density Correlation Check) on the number of electric cars in these 16 cities showed a low (r = -0.26), moderate (r = -0.48) and strong (r = -0.74) inverse correlation respectively with residential, average (considering 80% residential and 20% public charge) and public charging cost per 100-mile drive; and a positive relation with percentage difference between gasoline and fuel cost (r = 0.38). According to these values, the number of EVs in these cities were more influenced by the public charging cost than

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[8] x; y = Cost difference between charging and gasoline, Percentage difference of fuel cost with charging cost.

the fuel cost difference particularly. With increasing public charging cost, the number of EVs decreased. In the multiple regression analysis, the cost of public charging will be used to observe the impact on EV density in the cities.

Table 10: Fuel Cost for EVs and Non-EVs in the selected cities

City	Charging Cost for100 mile	Gasoline cost for100 mile	Difference in fuel cost for EV and non-EV	Cost difference in percentage (compared to charging cost)
Seattle	5	14	10	217%
Los Angeles	6	15	9	157%
San Francisco	8	14	7	89%
San Jose	5	14	9	161%
New York	8	12	4	50%
Oslo	6	26	20	345%
Bergen	5	30	25	517%
London	7	24	17	247%
Amsterdam	9	33	24	284%
Stockholm	10	24	14	136%
Berlin	10	25	15	154%
Munich	10	26	15	151%
Paris	7	23	16	245%
Shenzhen	3	17	15	577%
Beijing	3	17	15	577%
Tokyo	7	18	11	156%

5.3.3. Insurance Cost Analysis result:

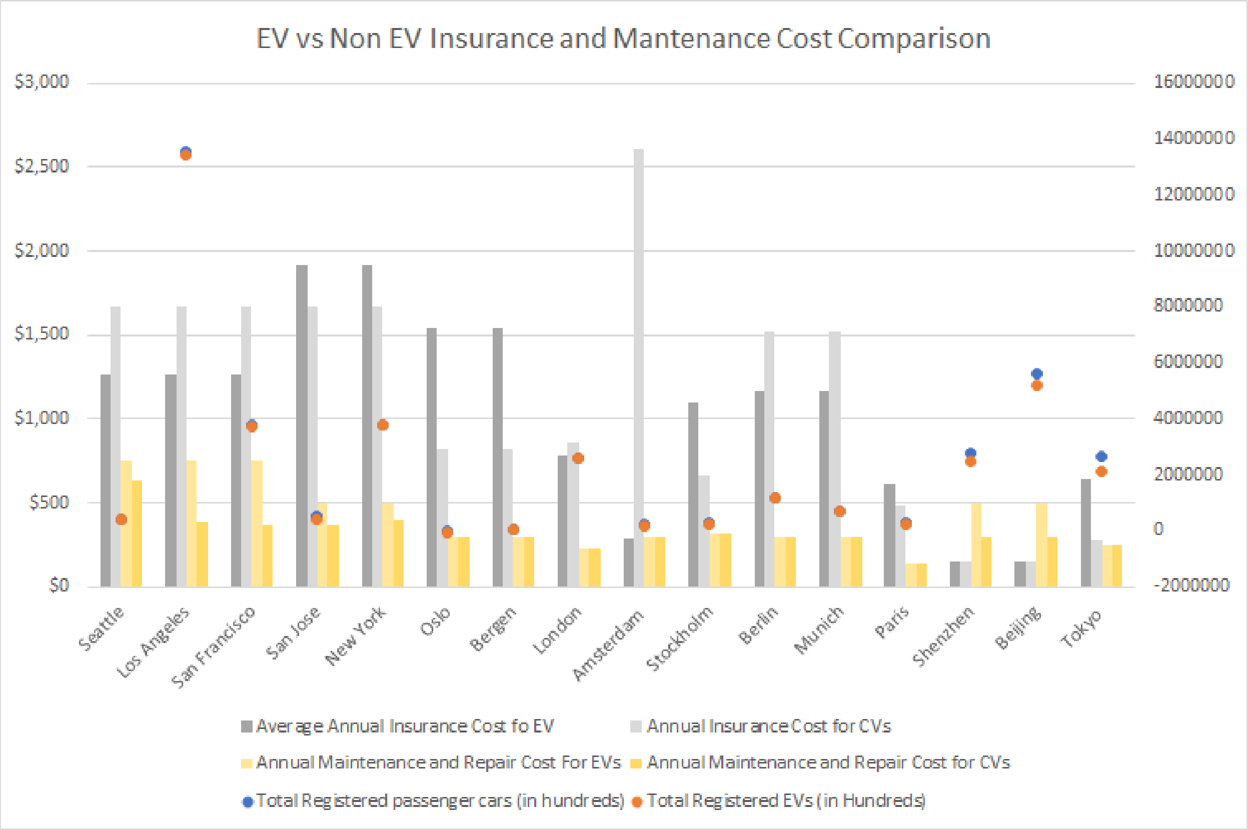


Figure 8: Insurance and maintenance Cost Comparison in the selected Cities

The average insurance cost for EVs in the 16 cities is $1048, with the USA having the highest annual rate ($1,523), followed by Europe ($1,026) and Asia ($313). EV annual insurance cost is lower than conventional vehicles on average (by $92). (Appendix 5 explains annual insurance and maintenance & repair cost comparison in EV friendly cities in details)

Among the selected American cities, Seattle, Los Angeles and San Francisco have a higher (by $411) insurance cost for conventional vehicles. Whereas in San Jose and New York, the rate is higher than conventional vehicles by $239. On average, for the 5 cities, this rate is $151 lower for EVs.

Table 11: Insurance Cost for EVs and Non-EVs in the selected cities

City	*EV*	*Non-EV*	*Cost Difference non-EV vs EV*	*% Difference non-EV vs EV*
Amsterdam	292	$2,609	-2317	-89%
Seattle	1263	$1,674	-411	-25%
Los Angeles	1263	$1,674	-411	-25%
San Francisco	1263	$1,674	-411	-25%
Berlin	1170	$1,522	-351	-23%
Munich	1170	$1,522	-351	-23%
London	784	$859	-75	-9%
Shenzhen	148	$148	0	0%
Beijing	148	$148	0	0%
New York	1913	$1,674	239	14%
San Jose	1913	$1,674	239	14%
Paris	612	$486	126	26%
Stockholm	1096	$660	436	66%
Oslo	1541	$820	721	88%
Bergen	1541	$820	721	88%
Tokyo	643	$274	368	134%

In Europe, surprisingly, EV insurance is higher in Norway than non EVs, (by 88%) despite high concentration (87%) of electric cars in their automobile population. Stockholm (66%) and Paris (23%) also have higher insurance rates for conventional vehicles than EVs. On the other hand, Amsterdam offers 89% less insurance rate for EVs than conventional vehicles.

The correlation analysis found a moderate inverse relationship (r = -0.53) between insurance cost and total number of EVs in the selected cities. This can be interpreted as, in the sample cities, insurance cost negatively impacted EV adoption, both on the city level and in the households (r = -0.43). In the multilinear regression analysis, this correlation will be observed in relation with other cost components.

5.4. Policy and EV growth:

This part is divided into two sections, a point-based evaluation of existing EV friendly policies in the sample cities and a qualitative analysis. As policy impact is not directly quantifiable, for this research, we chose the Total Cost of Ownership (TCO) as a way to quantify the impact of policy on electric vehicle ownership as it depends on incentives like subsidies and tax rebates. The point allocation system is presented in the table below. This scoring system followed the criteria presented in the Canadian EV policy study by Melton et al. (2020). As table 5 has already listed the incentives, table 11 will only show the presence and absence of the facilities.

5.4.1 Active Policies in the Cities

Most of the cities (13) have at least 6 of the policies present, ZEV mandate is the most common one among all, indicating all the selected cities are ready to move forward with the transportation electrification (Table 13). Though the target year and level of electrification are different for different countries and states, all of the selected cities have started actively implementing the ZEV mandate they have set. The country, state and city-based target achievement are also different (Table 12). Among the cities, Norway and California are the forerunners, having adopted the targets in the beginning of the 1990s. The newest members are the Netherlands and Sweden. Despite that, their EV adoption rate is considerably high. City wise, they both already have 1% of global EV share as shown in figure 1. [Chapter 4].

The country and city-based electrification target is set according to the availability of the resources and based on local policies. Some of the earliest EV policy adopter countries, like Japan, have a lower electrification rate than the German cities, who are considerably the newest members in this process. Japan is one of the largest suppliers of cars in the world market. This slow electric vehicle penetration in Japanese auto market is happening due to the policymakers' decision, who want to secure the auto industry against rapid electrification (Dooley and Ueno, 2021). On the other hand, vehicle electrification rate shows regional differences in the same country. For example, Norway has 17.2% electric cars in their total car share, whereas Oslo (87%), the capital of Norway and Bergen (34%), the western coastal city have different percentages, showing more concentration of EVs in the capital city than the regional one. Similar pattern can be observed in Sweden, which has 4% electric vehicles overall, and Stockholm, the capital, has achieved 16% vehicle electrification, indicating that urban areas have more concentrated EVs. One other example can be how China has achieved only 1.6% electric vehicles overall, whereas the two selected cities, Shenzhen (9%) and Beijing (6.5%) have more concentrated EV share. China's region wise EV policies and mandates are responsible for that. In the subsequent sections of this research, they will be explored in detail.

In the policy checklist presented in Table 13, following the mandate, is the charger installation facility, both in public places and private houses. Tax exemption and rebate along with subsidies are also prominent in these samples. Among all the cities, San Jose has the highest number of policies active, and Seattle and Beijing have the lowest active policies (Table 13). In the next part, this study will try to observe the impact of some of these policies in combination with TCO and EV adoption.

Table 12: ICE to ZEV phase out target and current stage in the sample cities / countries

City	*% of EVs in Vehicle Market*	*Target Year*	*Initiation Year*	*Remaining Years to Target Completion*	*Name of the current initiative*	*Target*
WASHINGTON	4.1%	2030	2009	9	Clean Car 2030	100% ZEV sales after the target year
Seattle	2.7%	2030	2009	9	Drive Clean Seattle	30% electrification of light duty vehicles
CALIFORNIA	5.37%	2030	1990	9	Transportation Electrification Framework	5 million ZEVs and 250,000 charging stations
Los Angeles	0.77%	2028	N/A	7	N/A	80% of all vehicle sales to be ZEV
San Francisco	1.22%	2030	N/A	9	N/A	Banning non-ZEV car sales
San Jose	16.57%	2030	N/A	9	N/A	Banning non-ZEV car sales
NEW YORK	2.6%	2035	2010	14	Drive Change, Drive Electric	100% new ZEV sale after the target date
NYC	0.24%	2035	2010	14	Drive Change, Drive Electric	100% new ZEV sale after the target date
NORWAY	17.2%	2025	1990	4	N/A	100% electrification of new vehicles
Oslo	87%	N/A	N/A	N/A	N/A	N/A
Bergen	34%	N/A	N/A	N/A	N/A	N/A
UK	1.38%	2030	2009	9	Road to Zero Strategy	100% new ZEV sale after the target date

London	1.90%	N/A	N/A	N/A	N/A	N/A
NETHERLANDS	3%	2030	2013	9	Mission Zero	100% new ZEV sale after the target date
Amsterdam	8%	N/A	N/A	N/A	N/A	N/A
SWEDEN	4%	2045	2011	24	Super Green Car Premium	Becoming carbon neutral by the target date
Stockholm	16.45%	N/A	N/A	N/A	N/A	N/A
GERMANY	1.2%	2050	2010	29	Government Program for Electric Mobility	100% electrification by target date
Berlin	2.37%	N/A	N/A	N/A	N/A	N/A
Munich	3.47%	N/A	N/A	N/A	N/A	N/A
FRANCE	1.29%	2040	2008	19	Bonus Malus Scheme	100% electric cars on road
Paris	19.08%	N/A	N/A	N/A	N/A	N/A
CHINA	1.75%	2035	2009	14	NEV subsidy program	All new vehicles should be eco-friendly
Shenzhen	9%	N/A	N/A	N/A	N/A	N/A
Beijing	6.7%	N/A	N/A	N/A	N/A	N/A
JAPAN	0.9%	N/A	N/A	N/A	N/A	N/A
Tokyo	16%	2035	1996	14	Tokyo ZEV Promotion Strategy	100% new ZEV sale after target date

Table 13 : Presence of EV friendly Policies in the Sample Cities

	Carbon tax	Subsidy/ Rebate	Tax Cut/Rebate	Access to HOV/ Bus/ Other lanes	Reduced Parking charges	Reduced Toll	EVSE Program	ZEV mandate	Total Active Policies
Seattle		X	X				X	X	4
Los Angeles	X	X	X	X	X		X	X	7
San Francisco	X	X	X	X		X	X	X	7
San Jose	X	X	X	X	X	X	X	X	8
New York		X		X		X	X	X	5
Oslo	X		X	X	X	X	X	X	7
Bergen	X		X	X	X	X	X	X	7
London	X	X	X	X	X		X	X	7
Amsterdam	X	X	X		X	X	X	X	7
Stockholm	X	X	X	X			X	X	6
Berlin	X	X	X		X	X	X	X	7
Munich	X	X	X		X	X	X	X	7
Paris	X	X	X		X		X	X	6
Shenzhen		X	X	X	X	X		X	6
Beijing		X	X	X				X	4
Tokyo	X	X	X		X		X	X	6

5.4.2. Tax and Subsidy in the EV Friendly Cities:

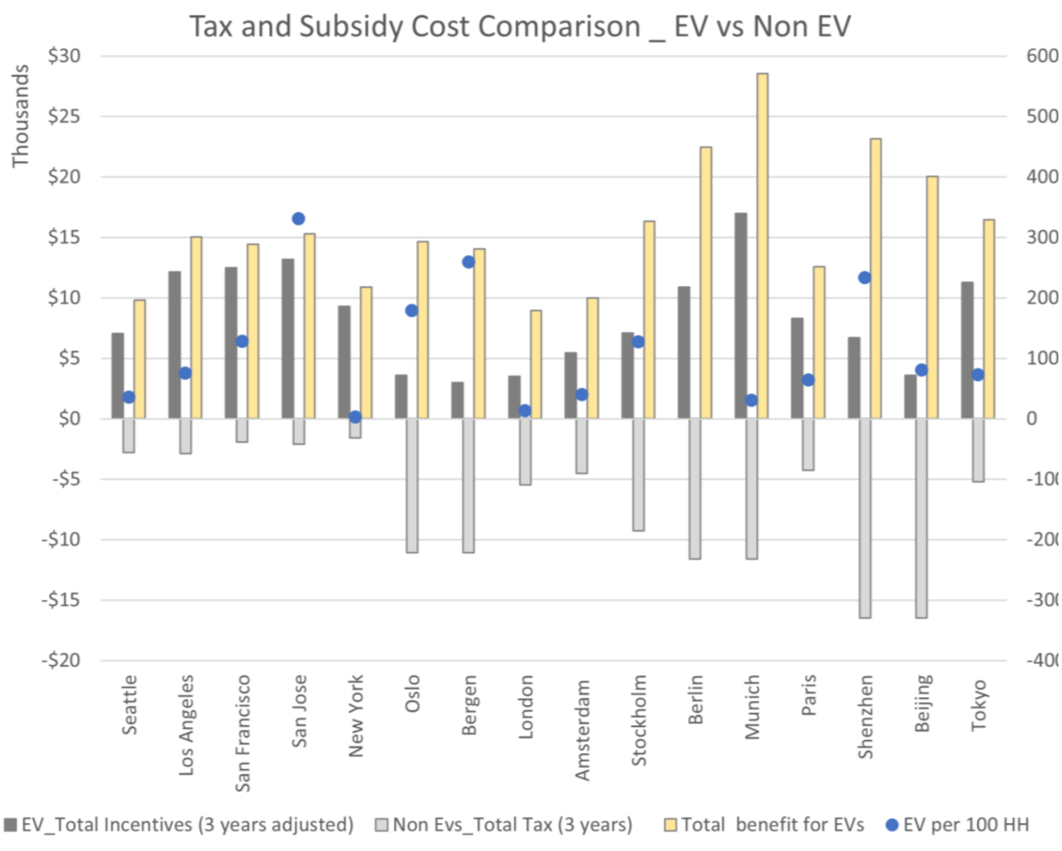


Figure 9: Tax and subsidy benefit for EVs and non EVs (Appendix 6)

In all of the sample cities, EVs have high tax and incentives benefits. On average EV owners receive $15,803 in subsidy and tax rebate in three years in the sample cities. The highest benefit is observed among the three Asian cities ($19,900), followed by Europe ($15,950) and the five cities in the USA grant the least benefit for three years on average. Non-EV models pay 324% higher tax than the EV owners in 3 years on average. On the city level, the three Californian cities and New York have the highest benefit percentage (671% on average) compared to non-EV drivers. Table 14 shows the EV and no-EV tax and subsidy benefit difference in the sample cities. The percentage shows a greater difference than the monetary amount due to the tax imposed on non EVs as explained in Table 5 [Chapter 4.2.4.d]. In California, the cars sales tax is 9.25% of the purchase cost, which increases with local tax. Also, the road tax adds to the annual cost. All these taxes add up to raise the TCO of a non-EV user in the selected time frame. This cost might decrease over time with the reduced subsidy and tax rebate.

In China on the other hand, the tax benefit comes from a reduction of 10% purchase cost and one time $13000 equivalent license plate cost. Japan, on the other hand, benefits from the exemption of Shaken or annual vehicle tax, leading to an almost 324% benefit for the EV user. All the European cities let the electric car users have an exemption from the carbon tax, which varies in different countries. Sweden among them has the highest carbon tax at $126 (Jonsson et al. 2020) per metric ton. Also, two German cities provide the highest subsidies in Europe. The impact of that can be observed in the total benefit (Stockholm 221%, Munich 247%).

Table 14 : EV vs Non-EV_ Tax and Subsidies Comparison in Sample Cities

City	*Total Incentives for EVs for 3 years*	*Total tax for non EVs for 3 years*	*Benefit percentage Compared to non-EV*	*% EV Incentives of Median Income*
Seattle	$7,050	$2,772	354%	3%
Los Angeles	$12,150	$2,889	521%	7%
San Francisco	$12,500	$1,944	743%	4%
San Jose	$14,700	$2,103	799%	5%
New York	$9,319	$1,569	694%	5%
Oslo	$3,600	$11,070	133%	3%
Bergen	$3,000	$11,070	127%	2%
London	$3,500	$5,445	164%	2%
Amsterdam	$5,466	$4,507	221%	5%
Stockholm	$4,646	$9,276	150%	3%
Berlin	$10,904	$11,577	194%	7%
Munich	$16,977	$11,577	247%	9%
Paris	$8,309	$4,254	295%	7%
Shenzhen	$6,691	$16,473	141%	5%
Beijing	$3,600	$16,473	122%	4%
Tokyo	643	$5,190	318%	6%

The correlation check between the EV per 100 households and total incentives (r = 0.30) and comparative benefit for EV owners (0.38) showed moderate positive relation. In the electric car purchasing decision, the incentives helped in increasing the numbers of EVs on the household level as they reduced the car ownership cost for the urban households. In the sample cities, conventional vehicle owners pay almost 5% of their median household income in three years for car related taxes. Analysis of the sample cities' data showed that the EV incentives help the consumers save 10% of their three years median income which would have been part of car tax paying otherwise. In the next chapter, this study will evaluate how tax and incentive related benefits act in combination with TCO and median income.

5.4.3. Policy, TCO and EV Density Analysis Result

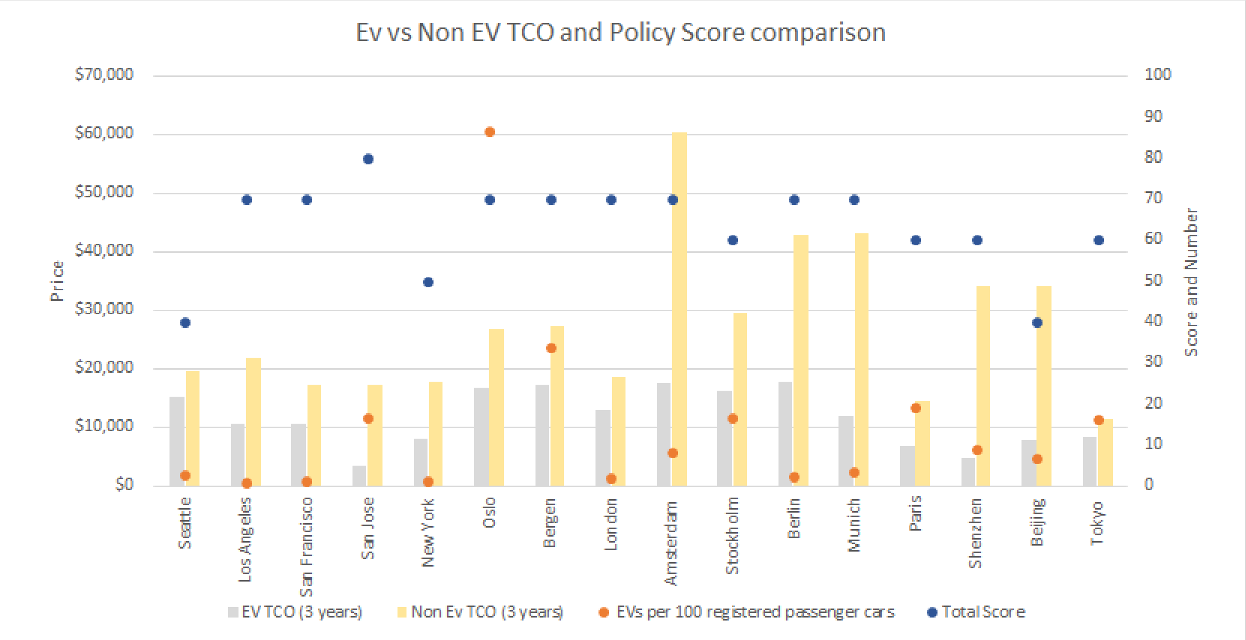
As the second part of the policy and EV growth observation, this paper calculated the TCO for both CVs and EVs in the selected cities. The summary statistics of the findings can be presented as -

Table 15: Total Cost of Ownership and Policy Component Summary in the EV friendly cities

Average	*Sample Average (16)*	*USA (5)*	*Europe(8)*	*Asia(3)*
Electric car Purchase Price	41706	33002	49261	36067
Annual Insurance Cost	1048	1523	1026	313
Total Annual Fuel Cost	384	541	325	278
Annual Maintenance and Repair Cost	14416	647	273	413
Total incentives (tax + subsidy)	8416	10844	7355	7197
Total Cost of Ownership: EVs (3 years)	11552	9502	14572	6919
Total Cost of Ownership: non-EVs (3 years)	27261	18691	32864	26611
EV TCO savings compared to non-EV	15710	9189	18293	19692

**The number against the heading indicates sample size.*

The average EV ownership cost for 3 years is lower than conventional vehicle models in all sample cities on average despite having a higher purchase price overall. The difference is highest in Asia, and lowest in the USA. The city based quantitative analysis shows that Amsterdam has the highest financial return (approx. $43 thousand) from EVs over the three years compared to the non-electric counterparts. Their policy score (7) is high, but the EV density in the automobile population is still low. In case of percentage-based comparison, San Jose has the most financial return for their EV users, compared to the CV owners. The financial return for three years is 80% higher for EV than CV. In the previous scoring San Jose also achieved perfect scores. Other high scoring cities, Berlin (7), and Munich (7) also have high TCO for non-electric cars than the electric ones, higher by $25,000 and 31,000 respectively. Oslo and Bergen have almost 50% higher cost for non EVs, making them one of the EV friendly cities. In the USA, Californian cities are also ahead in convenient EV policies, but still behind Chinese cities of Shenzhen and Beijing.



** The calculation is based on the most popular EV and non-EV models in the cities.*

Figure 10: TCO of electric and non-electric vehicles in the EV friendly cities

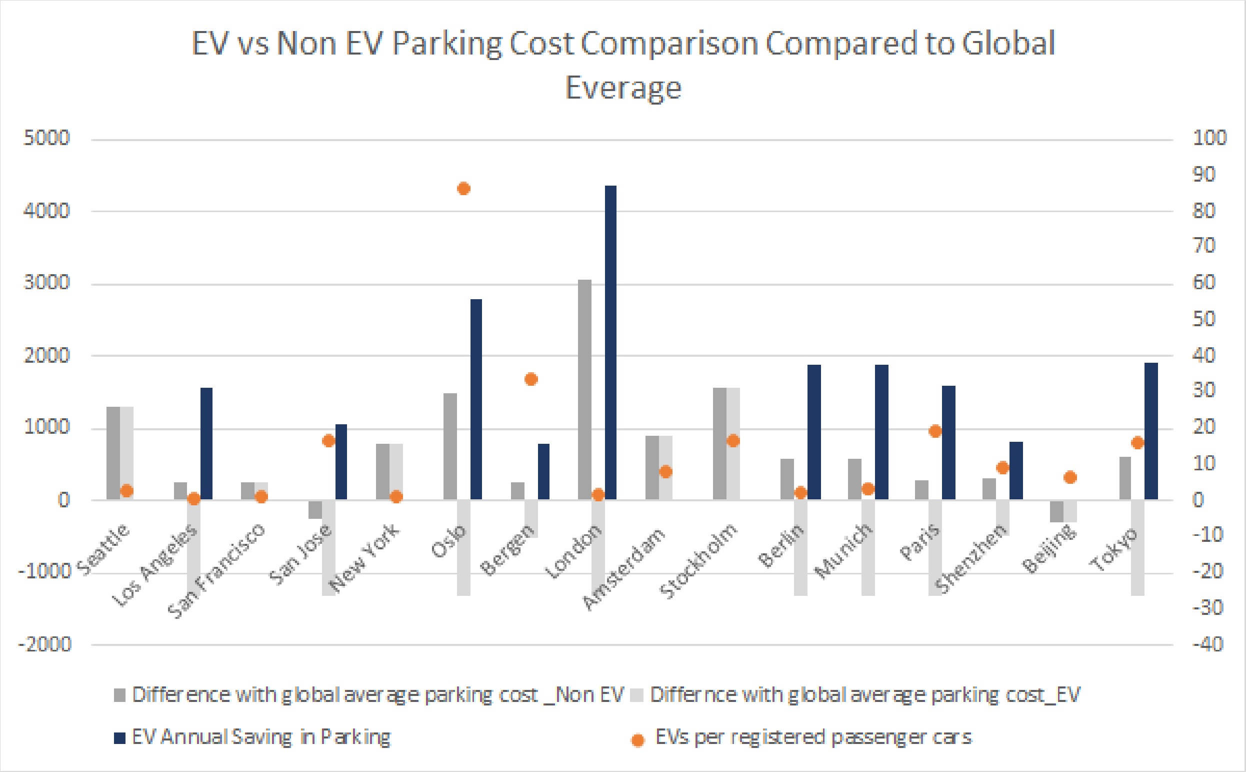
A correlation check (Table 16) established moderate (r = -0.47) inverse correlation between total number of the EVs and the TCO for 3 years, but an insignificant correlation (r = 0.01) with the TCO difference for EVs and Non EVs was observed in another correlation check, indicating that with decreasing TCO for EVs, the total number of EVs in a city will increase. And the TCO is influenced by various components as we have analyzed already. In the multiple regression analysis part, this paper will try to understand which part of the ownership cost impacts the EV adoption the most.

Table 16: TCO, Policy Component and EV Density Linear Correlation Check

Variables	*Total EVs*	*EV per 100 HH*	*EV per 100 cars*
Median Annual Household Income	-0.18	0.20	-0.23
Electric car Purchase price	-0.25	-0.18	-0.08
EV and Non-EV Purchase Price Diff.	0.31	0.07	0.23
Annual Insurance Cost	-0.53	-0.43	-0.23
Average charging cost for 100 miles	-0.48	0.10	-0.16
Residential Charging Cost per 100 miles	-0.26	0.07	-0.34
Public Charging Cost per 100 miles	-0.74	0.09	0.45
Total Annual Fuel Cost	-0.40	-0.23	-0.49
Difference in fuel and charging cost	-0.12	0.12	0.45
Annual Maintenance and Repair Cost	-0.05	-0.03	-0.34
Total Incentives	0.17	0.30	0.14
Total comparative benefit for EVs	0.29	0.38	0.08
Total Cost Of Ownership for 3 years	-0.47	0.15	0.43
New TCO percentage of Purchase price	-0.34	0.28	0.50
Difference in Cost _EV vs non EVs	0.01	-0.26	-0.26
Financial Return %of Purchase Price	0.34	-0.28	-0.50
Electric Car TCO % of median income	-0.31	-0.23	-0.42
EV incentives comparative benefits % of median income	0.43	0.24	0.06

5.5. Parking and Toll Exemption:

Parking and toll cost analysis showed that a typical EV owner in these cities benefited from the reduced parking cost and toll exemption. This cost is calculated as a separate indirect incentive to understand the implication of reduced charges on EV owners' finances, which in turn will impact the consumers' behavior.



**The annual parking cost is calculated for two hours on street parking for 261 workdays.*

Figure 11: Annual parking cost comparison in sample cities (Appendix 11)

In the sample cities, most EV drivers pay less than the global average of 2 hours on street parking cost ($1,304) annually (INRIX, 2020). The total annual savings on street parking in London ($4,359), Oslo ($2,793) and Tokyo ($1,911) are higher than the other EV friendly cities. London has a considerably high ($8.35 per hour) on street parking rate among all cities (City of London). Berlin, Munich and Paris also help their EV owners to have less annual payment than the non EVs. On the other hand, in Amsterdam, Stockholm, New York, San Francisco and Seattle, the parking rate is the same for EVs and non EVs, making the EV drivers have no savings in parking. In the correlation check, the saving in parking doesn't show any direct relationship (r =

0.00006) with total EV numbers in the city. But a low positive correlation (r = 0.28) was observed in relation to the EV density in the automobile population in the city. Indicating that in the sample cities, with increasing savings on parking, the electric car owner's ratio among total auto ownership increased.

Among all the cities, only three do not offer a toll break to the EV drivers. Seattle, Los Angeles and Shenzhen are the ones who still don't offer these facilities. In Seattle, EVs are not eligible for toll exemption or HOV lane use as the Washington State DOT is concerned about the congestion this might cause with rapidly increasing electric cars in the state (SeattlePI, 2011). In Los Angeles, the toll exemption is no longer applicable for the electric vehicle owners. But they can still use the SOV in the HOV lane with 15% exemption of the toll (Los Angeles Times, 2018). In Beijing, EVs don't have to pay tolls, but Shenzhen doesn't offer the same facility yet (ECNS.CN, 2015). On the other hand, while cities like Wuhan (Beggin, 2021) let EVs use HOV lanes, the two cities considered here don't provide the same flexibility. The variation in facilities in combination with other policies and incentives develop multiple different scenarios in these 16 cities. Due to the limited scope in this research, this study will not explore this variability.

Table 17 : Toll and other facilities for EVs

City	***Reduced Toll***	***Access to HOV/ Bus/ Other Lanes***
Seattle		
Los Angeles		X
San Francisco	X	X
San Jose	X	X
New York	X	X
Oslo	X	X
Bergen	X	X
London	X	X
Amsterdam	X	
Stockholm	X	X

Berlin	X	
Munich	X	
Paris	X	
Shenzhen		X
Beijing	X	X
Tokyo	X	

5.6. Infrastructure and the Public Charging points:

Number of public charging points varies among the 16 cities: Los Angeles (11,000), Beijing (41,000), and Shenzhen (34,000) have the highest number of chargers, whereas Tokyo (42) has the lowest number of public charging stations. In Beijing and Shenzhen, the Chinese government has introduced new charging stations to facilitate electric cars, both private vehicles and public transportation. The generous subsidies for charging equipment are making this high concentration of charging points possible. (Nikkei Asia, 2020). Some of the charging points in Shenzhen are exclusively dedicated to taxis. London also has reached the milestone with 500 rapid chargers and 5,500 on street chargers (City of London). On the other hand, Tokyo is planning to add more chargers as per their EVSE program initiated in 2020. Up to September 2019, the program supported the installation of 57 charging facilities (IEA, 2019), which is still lower than their charger demand.

Total charging points cannot accurately explain the charging demand and supply situation in a city. Though there are no standard number of electric vehicles per charging point requirement yet, according to the ICCT report on emerging best practices for EV charging infrastructure (2020), one public chargers per 25 to 30 electric vehicles is typical. In our analysis, New York so far has the lowest number (3) of electric vehicles per charging points. Followed by Berlin (5), Stockholm (6), Amsterdam (9) and Shenzhen (9). Tokyo on the other hand has the highest load on each public charger with almost 12,000 EVs per charging point, which could be related to scarcity of public charging points in Tokyo (only 42) . On the other hand, Bergen (0.21), Oslo (1) and Amsterdam (1), have the lowest number of households per charging point, indicating that the cities are almost fulfilling their goal of optimum number of chargers for their customers. Tokyo (165,000) is still behind in this criterion. Another calculation of charger per million population showed that the cities like Bergen(4,000), Oslo (2,500) and Stockholm (1,100) are still at the forefront in this case. And Tokyo has the lowest number.

*The table below is the full list of charging points data explained above. A more detailed table with data sources is available in the Appendix 8 and 9.

Table 18: EV Charger Availability in the Selected City

City	***Total Public Chargers***	***Household per charging station***	***Public chargers per million people***	***EVs per public charge point***
Seattle	650	511	107	18
Los Angeles	11,045	125	276	10
San Francisco	893	406	24	52
San Jose	1,027	317	109	105
New York	3,351	945	41	3
Oslo	1,450	1	2500	20
Bergen	1,121	0.22	4000	25
Greater London	6,000	22	750	9
Amsterdam	575	1	500	10
Stockholm	1,822	8	1100	6
Berlin	1,425	2	400	5
Munich	1,310	635	85	20
Paris	4,453	230	400	15
Shenzhen	33,937	34	275	9
Beijing	41,130	121	201	11
Tokyo	42	165,381	0.11	12028

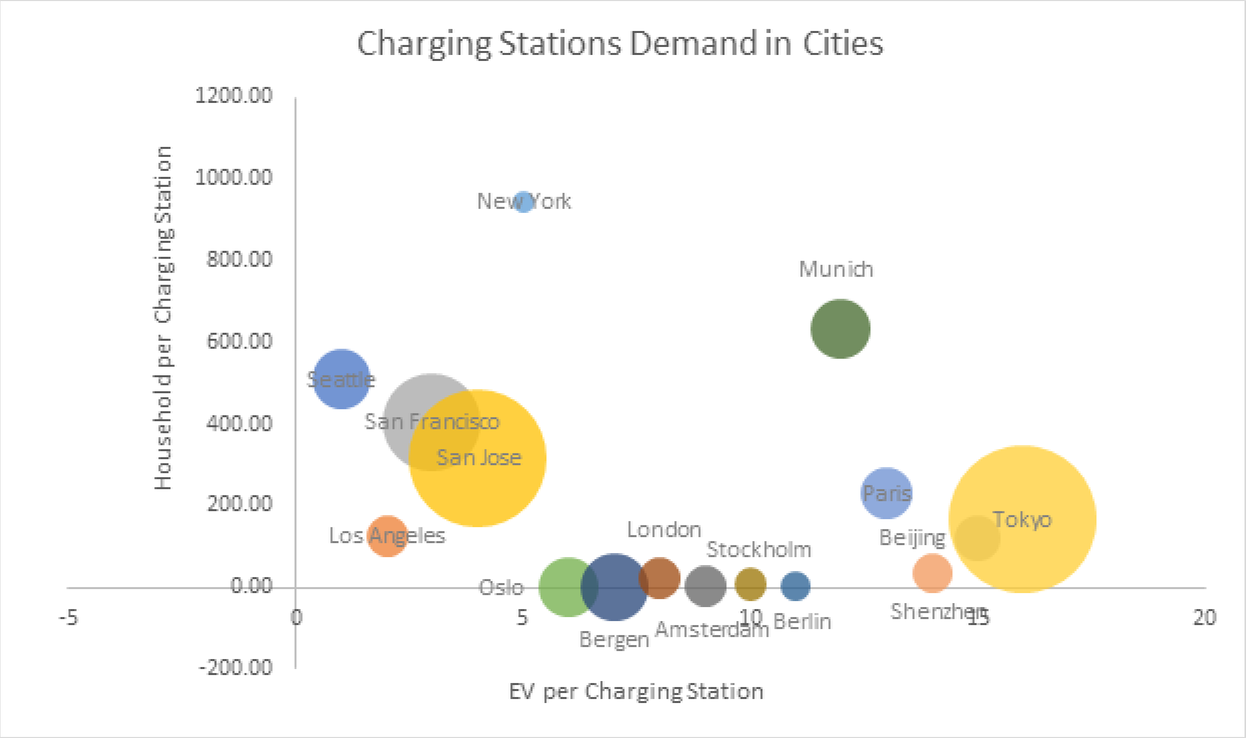


Figure 12: Charging infrastructure supply and demand in the sample cities

Overall, Tokyo and San Jose have the most charging infrastructure development demand. Tokyo is at the lowest rank both from individual EV charging demand and household level demand. New York and Amsterdam, along with Berlin, Stockholm and London are performing better than the other cities public-charging-infrastructure wise. Shenzhen and Beijing are also moving forward fast. All of these cities have the charging infrastructure development plan in place already as indicated in Table 12 [Chapter 5.4.3].

The charging point availability can be a potential reason for EV adoption. Though there is a lack of statistical proof of electric vehicles adoption and the charging point availability. For this study, this paper tried to observe that correlation. The simple linear regression analysis showed a stronger correlation between the EV per 100 households and the other charging availability variables shown in Appendix 13.

Among these variables, chargers per million population and EV per 100 registered cars show the most significant (r = 0.66) relationship overall. The correlation between EV per 100 cars and total public charger (r = 0.38) as well as charger per 100 households (r = 0.34) shows moderate correlation. These coefficients indicate that the EV adoption is mostly influenced by the charger availability per million population. Charger placement depends on multiple factors. The dependence of EV density on charger per million population might be due to the complex factor of locational decisions of chargers in urban areas. This will be explained in detail in the limitations section. Overall EV adoption depends mostly on total charging facilities. The multiple regression analysis conducted in the next chapter will use all these variables.

5.7. Multiple Regression Analysis Result

The multilinear regression model with seven predictors from the policy components (R2 = 0.76, adjusted R = 0.49) found significance (P = 0.05) in the relationship (r = 0.0053) between EV per 100 passenger cars and total incentives with a variance of 76% and 95% confidence interval. The other predictors, median household income, purchase price, insurance and maintenance cost and fuel cost do not show any statistically significant (p >> 0.05) correlation. With this, we can assume that, with every unit (in this case US dollars as all calculations are done in dollar amount) increase of the incentive, the EV density in every 100 registered cars will increase by 0.0053. This will amount to 53 cars in every 1,000,000 cars in the urban area. Which can also be explained as, with every 100-dollar incentive increase, there will be 53 electric cars in every 10,000 cars.

Table 19: TCO and Multiple Regression Analysis Result

Multiple Regression	*Multiple R*	*R Square*	*Adjusted R Square*	*Standard Error*	*Observations*
Regression Summary	0.87	0.76	0.49	15.27	16

Predictor Variables	*Coefficients*	*Standard Error*	*P-value*
Intercept	10.56	24.45	0.68
Median Annual Household Income	0.0002	0.0003	0.60
Electric car Purchase price	0.0003	0.0005	0.57
Annual Insurance Cost	-0.0011	0.0151	0.94
Total Annual Fuel Cost	-0.0175	0.0603	0.78
Annual Maintenance and Repair Cost	-0.0084	0.0412	0.84

Total Incentives	0.0053	0.0023	0.05
Total Cost of Ownership	-0.0010	0.0013	0.47

5.8. EV Infrastructure and Energy Consumption:

The number of chargers put extra demand on the electricity grid. A simple calculation on the energy demand for charging in the sixteen cities indicates that the energy used in charging is considerably low in all of the cities. The calculation is conducted considering 80% charging (Office of Energy Efficiency & Renewable Energy) is done at home and the rest at public charging stations or workplaces. Some of the cities use the Time of Use (ToU) or peak and off-peak hour charging.

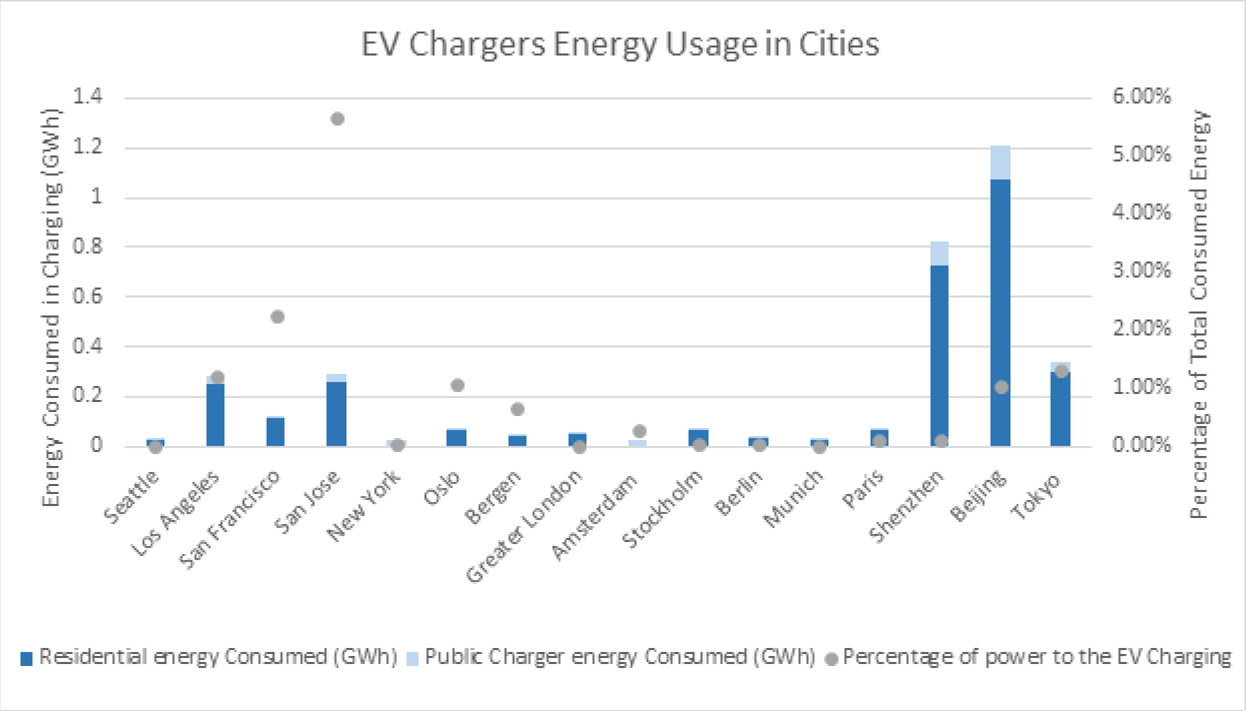


Figure 13: Current energy demand vs load and BEV vs PHEV proportion in sample cities (Appendix 8)

Among the cities, San Jose is estimated to be consuming the highest percentage of electricity (5.66%) for charging based on current demand and BEV and PHEV proportion, San Francisco (2.24%), Tokyo (1.31%) and Los Angeles (1.20%) are following behind (Table19). This usage is mostly influenced by the VMT, number of EVs and what is the overall power usage in a city. Most of the cities use 1% ~ 0.01% energy for charging according to this estimation. For example, Munich (0.01%) and London (0.02%) are estimated to use only a meager portion of their total energy for EV charging. A study by McKinsey (2018) implied that 25% passenger vehicle electrification will increase the demand in residential areas by 30% during peak hours. As most of the EV friendly cities are already prepared to incorporate necessary electricity demand into their grid, the challenge of power shortage might not be a problem in the future (US Drive, 2019).

Table 20 : Power Demand for Charging in the Selected Cities

City	*Annual VMT per Capita (2008)*	*Total Registered passenger cars (2020)*	*Total Annual Power Usage in City (TWh) (2020)*	*Total Annual Energy consumed in Charging (TWh)*	*Percentage of power to the EV Charging*
Seattle	8699	432014	9	0.03	0.33%
Los Angeles	8699	13541827	23	0.28	1.20%
San Francisco	8699	3783300	6	0.12	2.16%
San Jose	8699	542490	5	0.29	5.71%
New York	8699	3791431	54	0.03	0.06%
Oslo	4039	10428	7	0.07	1.03%
Bergen	4039	77117	6	0.04	0.62%
Greater London	3884	2622169	269	0.05	0.02%
Amsterdam	3821	218479	7	0.02	0.27%
Stockholm	4350	301297	138	0.07	0.05%
Berlin	4350	1192546	65	0.03	0.05%
Munich	4350	714574	400	0.03	0.01%
Paris	3884	321787	65	0.07	0.11%
Shenzhen	13090	2768000	670	0.82	0.12%
Beijing	13090	5600000	117	1.21	1.04%
Tokyo	2485	2652113	26	0.34	1.32%

5.9. EVs and Environmental Cost:

The carbon footprint of the electric vehicle is lower than conventional vehicles. A Well-to-Wheel analysis showed that the emission in the Well-to-Pump step (energy supply) of the EV has the most CO2 emission. As the BEVs do not have any tailpipe emission, the only emission happens in the PHEVs non-electric mile, which in this case is considered to be 300 miles on average.

Table 21 : Power generation mix in the selected cities

City	*Renewable Sources*	*Natural Gas*	*Coal*
Seattle	84%	3%	3%
Los Angeles	52%	27%	21%
San Francisco	100%	0%	0%
San Jose	100%	0%	0%
New York	28%	71%	1%
Oslo	97.60%	0%	2.40%
Bergen	97.60%	0%	2.40%
London	56%	45%	9%
Amsterdam	97%	3%	0%
Stockholm	50%	46%	4%
Berlin	10%	50%	40%
Munich	82%	14%	4%
Paris	51%	46%	3%
Shenzhen	15%	28%	58%
Beijing	15%	28%	58%
Tokyo	29%	0%	71%

The power generation mix in the table above shows different energy sources in different cities. The cities in California (San Francisco and San Jose), Norway (Oslo and Bergen) and Netherlands (Amsterdam) have the cleanest energy sources. And the Asian cities, Shenzhen, Beijing and Tokyo has the most carbon emitting energy sources among the sixteen cities. There is a regional difference in renewable and non-renewable power sources. For example, in California, San Francisco and San Jose have almost 100% renewable energy sources, but Los Angeles almost equal percentage of renewable and non-renewable sources. In Germany, Munich has 82% renewable source supplying their electricity, demonstrating their target to achieve 100% clean energy by 2025 (CNBC, 2014). But Berlin does not show the same percentage despite Germany's greenhouse gas emission reduction (Clean Energy Wire, 2021).

Using the carbon emission calculation process mentioned in Chapter 4.2.7 , the carbon footprint of the existing EVs in the selected cities are calculated. The graph below is the summary of the total carbon footprint and the emission offset possible by the electrification of vehicles.

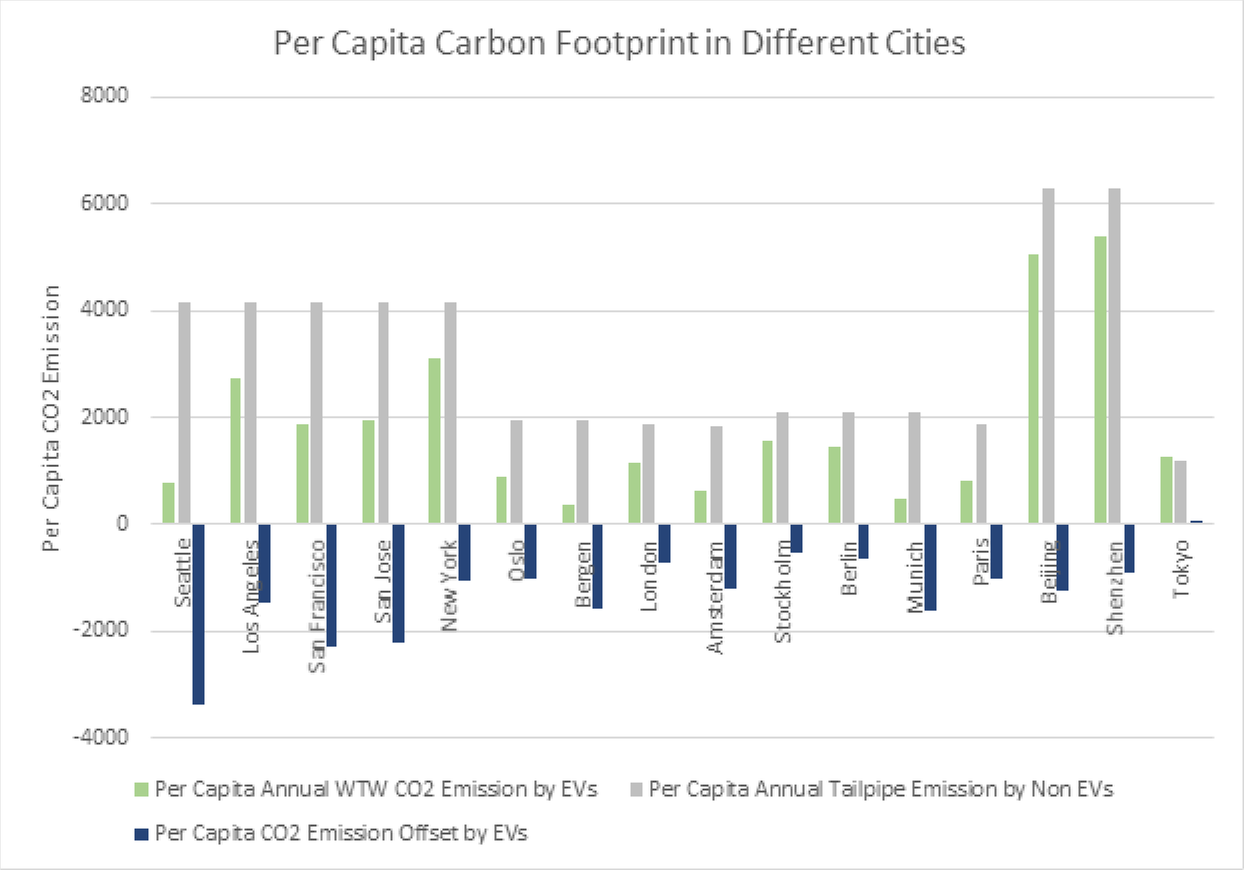


Figure 14: Carbon Footprint from EVs and Non EVs in EV friendly cities

The carbon footprint summary of the cities in figure 15 reflects the high carbon intense energy production method observed in Table 20. In Asia, the carbon footprint is highest for the two Chinese cities, Beijing and Shenzhen. On average, China is the consumer of 24% of total global energy in 2018 (BP, 2019). The carbon footprint is also higher in the Chinese cities due to the use of a higher percentage of coal (58%) as their energy source. On the other hand, Europe's energy is much greener as most of the cities use renewable sources (67% on average). The impact of this can be observed in the per capita carbon emission in European cities which are much lower than the other two regions as well as the sample average. The carbon emission is offset by the EVs to a considerable level. These results are also based on the assumptions made on average fuel economy of the EV and non-EV models and charging scenario on household and public charger level during the research. The outcome might be different in the real-life scenario.

In the case of 100% electrification, carbon emission decreases for all the countries. But the change in percentage will be highest in the USA, followed by Europe. Asian cities on the other hand will not have the same level of environmental benefit, specifically due to their energy production system and the CO2 emission from the coal and gas-based energy production.

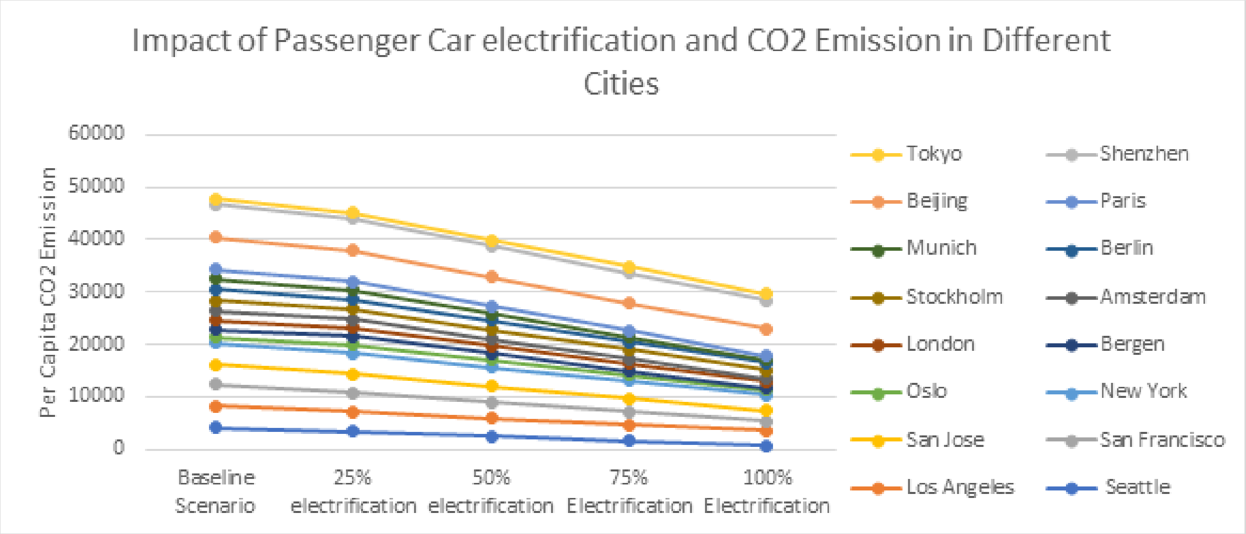


Figure 15: Impact of electrification on CO2 emission in EV cities (Appendix 10b)

Table 22: Environmental cost of the EV adoption

Average	*Sample Average (16)*	*USA (5)*	*Europe(8)*	*Asia(3)*
Current electrification of passenger cars	14%	4%	21%	11%
Total annual power usage in Charging (GWh)	220	150	49	789
Approx. WTP[9] CO2 emission (million lb)	260	74	19	1218
Tailpipe emission (million lb)	61	50	25	172
Approx. WTW[10] CO2 emission	321	124	44	1390
Per Capita emission by EVs (lb)[11]	1818	2093	924	3903
Per Capita tailpipe emission by non EVs (lb)[12]	3,146	4,176	1,963	4,587
Per Capita CO2 Emission Offset by EVs (lbs)	1,298	2,082	1,039	683
Per Capita CO2 emission change in case of 100% electrification[13]	40%	49%	46%	9%

As shown in the table above, the simple observation shows that the carbon emission decreases about 40% from the baseline carbon footprint due to electric vehicles. As mentioned above, cleaning the energy sources can produce better results overall.

Next, battery recycling and reuse facilities are also observed in those cities. Most of them lack proper facilities to handle dead batteries. Due to the lack of battery recycling, the dead batteries will end up in the landfill, adding more landfill volume overall and will also emit toxic fumes (See Chapter 4 for more) . But in the case of recycling, it will reduce 20% emission compared to what might have emitted while producing the battery from scratch (Aichberger, 2020). Many cities are planning to add the facility to their scheme in the near future. Los Angeles, Germany (early 2021) as well as Sweden (Northvolt's recycling program by 2022) and Norway (by late 2021) are looking forward to initiating their own battery recycling facility in the next two years. Many other cities observed are planning to have their own recycling facilities by the next decade (Energy Storage, 2021).

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[9] WTP = Well to Pump

[10] WTW = Well to Wheel

[11] Considering 0.29 lb/mile CO2 emission for PHEV non-electric miles, in this case 300 mile on average

[12] Considering 0.48 lb/mile CO2 emission for Conventional vehicles

[13] Considering the current number of vehicles without any increase.

Table 23: Dead EV battery handling facility in EV friendly cities and the environmental impact

Cities	*Types of Facilities available*	*Total Landfill increase*	*Unit*
Seattle	Collection by the city and probable Landfill	1150	Metric Ton
Los Angeles	Collection by the city and probable Landfill	10090	Metric Ton
San Jose	Collection by the city and probable Landfill	10336	Metric Ton
Oslo	Collection by the city and probable Landfill	6502	Metric Ton
Bergen	Collection by the city and probable Landfill	3764	Metric Ton
London	Collection by the city and probable Landfill	4591	Metric Ton
Amsterdam	Collection by the city and probable Landfill	1823	Metric Ton
Stockholm	Collection by the city and probable Landfill	5692	Metric Ton
Berlin	Collection by the city and probable Landfill	808	Metric Ton
Munich	Collection by the city and probable Landfill	1082	Metric Ton
Paris	Collection by the city and probable Landfill	6236	Metric Ton
		CO2 emission reduction	
San Francisco	Collection by the startup and battery swapped	3917	Metric Ton -CO2
New York	Collection by the manufacturer and proper disposal and recycle	756	Metric Ton -CO2
Beijing	Collection by the manufacturer and proper disposal and recycle	33583	Metric Ton -CO2
Shenzhen	Collection by the manufacturer and proper disposal and recycle	22837	Metric Ton -CO2
Tokyo	Collection by the manufacturer and proper disposal and recycle	42413	Metric Ton -CO2

**Cities with proper recycling were evaluated based on total CO2 emission in recycling, and the cities with no recycling facilities are evaluated by increased landfill size.*

In table 22, the potential impact of dead batteries, either in landfill volume increase for per kWh battery capacity or the emission of CO2 per kWh battery capacity during recycling, is listed along with the current facilities available. The data indicate, increasing EVs and lack of proper recycling, cities will keep on adding the dead batteries to their landfills. The two cities in California, Los Angeles, and San Jose, will have the highest increase in landfill volume in a decade. Unlike San Francisco, these two cities still lack proper battery recycling facilities, which will add more dead batteries to their landfill after a decade as they have rapidly increasing number of EVs on their roads. On the other hand, Asian cities like Shenzhen, Beijing and Tokyo, have different types of battery recycling and handling facilities. In China, the battery swapping is already available along with recycling facility. Japan has started recycling their dead batteries. Among the US cities, New York has the mandate for the EV sellers and producers to provide recycling facilities. Many of these facilities are still provided by private suppliers, without proper government supported program. It is advisable for all the cities to adopt proper recycling facilities to get the best outcome of vehicle electrification.

Chapter 6: FINDINGS SUMMARY

- The 16 sample cities have approximately 21% of the global share of 8.5 million (Statista, 2021) total EVs on road in 2020.
- In the sample cities, the median annual income is $60,000 on average, which is above global median income (Washington Post, 2018).
- Berlin has the highest number of electric vehicles per capita, but Oslo has the highest level of vehicle electrification at 87% of all vehicles.
- EV density in the sample cities does not show significant correlation with median income in this study.
- BEV percentage in total electric passenger cars is higher than the PHEVs in the selected cities. The increasing inclination towards battery electric vehicles can increase the demand for more charging infrastructures at residences and public places (Tal et al. 2013).
- EV purchase price is higher for the selected models than the conventional vehicle models in most of the sample cities. Despite that, the total cost of ownership for three years is less for the EV users than the conventional vehicle owners due to the tax breaks and incentives.
- Among the TCO components, public charging cost and insurance cost have moderate influence on EV percentage in the automobile population of the cities based on the correlation check.
- Purchase price differences of different EV models can influence the users more than the price gap between the EV and non-EVs in the sample cities as explained in Chapter 5.3.1.
- There is a moderate correlation among the policy component, namely incentives, and the electric vehicle adoption in the sample cities. But these incentives also have different impacts in different regions.
- Parking charge is found to be weakly correlated to electric vehicle adoption.
- From the EV friendly infrastructure analysis, Tokyo and San Jose were found to be in need of more public charging infrastructure. Both of them have a high percentage of EVs per

charger (>>30 EV per charger as mentioned in Chapter 5.3) indicating a lack of enough infrastructure. San Francisco also needs infrastructure development.

- A multilinear regression model with seven predictors from policy components found total incentives to have statistically significant coefficient ($r = 0.0053$, $p = 0.5$) for the estimation of electric vehicle increase in the total auto population. The coefficient indicates small increase with per unit ($) incentive change for the current model.
- The environmental cost of the electrification of the cars in the sample cities is not null. Though the per capita WTW carbon emission is still lower than the conventional diesel or gasoline fueled vehicles. Due to the lack of green energy production in some of the cities, the carbon footprint of electric cars is still large enough to be concerned. In case of cities like China, who have high coal dependency, the carbon emission in a BEVs lifecycle can still cause environmental damage.
- More vehicle electrification can reduce carbon emission in the long run.
- In most of the cities, the battery recycle facility is still not developed enough to recycle the dead batteries on mass level. The disposed electric batteries will be liable for the increase of landfill after their useful lifespan. As the situation is still new, most of the EVs have not crossed their lifespan of 17 years (Cagatay, n.d.), this study could not use any real-life example for comparison.

Chapter 7: LIMITATIONS OF THE STUDY:

The electrification of passenger cars in global cities aiming for sustainable transportation is still evolving. The information and relevant studies or case studies are still relatively less available than other features of sustainable transportation. This research tried to cover most aspects of the EV policies and infrastructure, but there were still some limitations that we faced during the process.

- The sample cities are only a part of the vast global EV friendly cities. The primary selection was based on the market share of electric vehicles in those cities. Per capita EV percentage can produce a different ranking.

- Data availability was one of the major challenges faced during the analysis. As different cities present their data differently (city or regional level) to the public, many data were extracted or calculated from regional data sources, as well as third party sources and finally standardized for city level analysis.
- The policy varies in different cities and changes continuously. Also, the incentives are largely different for different car models. The simplification of the data was not able to cover most aspects of the pricing and subsidy scheme. A more extensive and thorough analysis will be able to observe the range of variability in the policy and pricing front.
- The infrastructure preparedness for EV adoption might be influenced by the budget and economic ability of the city. Energy production capacity as well as land use or public perception and value can also be deciding factors in this case. Many national and local initiatives are also being adopted to improve the charging infrastructure. This needs extensive study. Due to the scope limitation and lack of enough evidence, this was not considered in this study. We can evaluate the cities based on their existing EV infrastructure. But the standardization of what is necessary in different cities might not be the perfect solution.
- The allocation of charging points follows different methods like land use-based demand model, future demand-based model or user pattern-based model. All these might be controlling factors for the location and availability of charging stations. Extensive study will be able to capture the complexity of this location pattern and their impact on electric car penetration in the cities. This study did not have the scope to observe different methods followed in different cities.
- The environmental cost analysis in this research used the GREET model emission rate to calculate the Well-to-Pump emission in different energy sectors. The emission rate depends on the time of use greatly. This study did not use the timing of charging in energy usage calculation. Also, the emission for battery production is also not considered in this analysis as the main aim of the environmental impact analysis was to observe the emission from the energy sources and tailpipe.
- The emission from battery disposal is still an ongoing research. This study used the availability of recycling and reusing facilities as a marker to observe the city's

preparation for sustainable electrification of the transportation. Due to the lack of enough information, this study did not include the carbon footprint from the Life Cycle Analysis.

- The policy incentives can have both advantageous and disadvantageous effects on the EV adoption, making it difficult to define and measure them. For example, the use of HOV lanes can create congestion when the city reaches a certain threshold of EV ownership. So, the current incentives in many cities might not be a long lasting one, but a good start for the promotion of EVs for the initial stage. This study didn't address them.
- China, with the most polluted power generation mix among the cities observed, has started integrating Demand Response based power integration to their grid. In this process, the EVs will depend on availability of clean energy in the grid and charge with energy from renewable sources (Finamore, 2020). China is hoping to clean up their power grid through this process. The Chinese government aims to reduce the share of carbon-heavy fuel in national energy consumption to 20% by 2025 (CNBC, 2021). If this is successful, China will be able to reduce their carbon footprint by 2030 and the current carbon footprint will change greatly in the coming decades.
- The environmental cost also needs to address the life cycle analysis of the EV itself to understand the real cost of the mass adoption. As observed in many analyses, the EV in the long run might not be a completely sustainable transportation mode. But based on the current available information, this study tried to address the factors which might not change in the near future and will be essential for environmental sustainability in EV adoption.

Chapter 8: CONCLUSION

Electric vehicles will be dominating the auto market scenario in the coming decades. This research is an exploratory work to analyze the global scenario of vehicle electrification to prepare for the mass adoption of EVs. The main takeaway from this research can be summarized as, the availability of proper infrastructure, convenient policy incentives as well as positive environmental impact, are the main focus of the EV friendly cities while supporting and planning for EV integration in their auto market. From the analysis, it is observed that the sample cities successfully implemented the public policy and charging infrastructure as the leaders in EV adoption. All the sixteen cities have ongoing and future policies to accommodate more electric cars and going all electric in the transportation sector. Cities in Europe have convenient incentive schemes as well as sustainable energy sources, which are playing in favor of their GHG emission reduction through vehicle electrification. On the other hand, Shenzhen, and Beijing, the two sample cities in China, are representations of the country's aggressive EV policies. Along with policy interventions, ensuring sustainable energy production should be on the agenda for cities looking towards reducing their emission through vehicle electrification. Dead battery handling facilities should also be focused on in the cities aiming to achieve a better environmental return though EV adoption.

Vehicle electrification is a long process. The novelty of the situation adds challenges for proper analysis of the situation, but at the same time creates opportunities for the improvements of the developing parts. Based on the analysis conducted in this paper, the main policy related suggestion would be to increase incentives, both in the cities with mass EV adoption rate or the ones looking forward to electrifying their vehicles in the future. The parking charge and toll exemption can encourage the regular car drivers to switch to EVs in the long run. Improving the charging infrastructure through strategically placing more chargers as well as smart charging facilities can solve the range anxiety, and also can make sure that the electricity grid is not overburdened. Based on the findings in this study, publicly available (both city and private supplier operated) chargers would be given priority. To achieve the maximum environmental benefit, along with mass vehicle electrification, cities should improve their battery handling capacity.

The aim of this study was to understand the policies and initiatives quantitatively. The data analyzed here are also used to conduct statistical analysis to get a better grasp of the performance of different cities. On the last note, this analysis is not a complete one, but an initial effort to encompass all the major factors contributing to EV adoption on planning level and connect the dots through statistical analysis holistically. This can be expanded, modified, and reconstructed to make use in a more standard situation.

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Appendix 1: EV ownership and City Profile

		Total Population	Number of Household	Median Annual Household Income	Total Registered passenger cars	Total Registered EVs	EV per 100 HH	EVs per 100 registered passenger cars
		2020	2019	2019 data	Till 2020	Till 2020	2020	2020
USA	Seattle	608,660	331,836	$92,263	444000	11,986	36	27
	LA	3,998,280	1,383,869	$62,142	13647010	105,183	76	8
	SF	3,792,621	362,354	$112,449	3829928	46,628	129	12
	San Jose	945,942	325,114	$109,593	650228	107,738	331	166
	New York	8,175,133	3,167,034	$63,998	3800436	9,005	2.84	2.37
Norway	Oslo	580,000	378,017	$77,900	78210	67,782	179	867
	Bergen	280,216	151,008	$77,900	116358	39,241	260	337
UK	London	9,304,016	3,740,000	$50,422	2672927	50,758	1	2
Netherlands	Amsterdam	1,149,000	475,368	$73,392	237479	19,000	4	8
Sweden	Stockholm	1,656,571	465,949	$57,786	360635	59,338	13	16
Germany	Berlin	3,562,038	41,507	$50,400	1221433	28,887	1	2
	Munich	1,538,302	832,310	$60,824	740244	25,670	3	3
France	Paris	11,017,230	1,025,721	$42,509	348745	66,365	6	19

China	Shenzhen	12,356,820	1,166,400	$45,885	3040000	272,000	7	9
	Beijing	20,462,610	4,973,562	$30,039	6000000	400,000	8	7
Japan	Tokyo	37,393,128	6,946,000	$64,450	3157277	505,164	7	16

Appendix 2: EV vs Non-EV Purchase Price and Depreciation in Different Cities

		Electric Car				Non Electric Car				EV Vs Non-EV	
		Purchase Price		Depreciation		Purchase Price		Depreciation		Price Difference	
		PP	Popular EV model	Resale value, RP	Depreciation	PP	Most Popular Model	Resale value, RP	Depreciation	Difference in PP	Percentage
		Model based Local Data	city based data on most registered model_2019	Source : Car Edge (after 3 years)	(PP-RP)/PP	New Model Local Data	*Cars above 6000 lbs are not considered	Source : Car Edge (after 3 years)	(PP-RP)/PP	EV -Non EV	Diff. Vs. Non-EV price
USA	Seattle	$31,670	Nissan Leaf	$16,682	39%	$25,845	Subaru Forester	$19,684	24%	5,825	23%
	LA	$31,670	Nissan Leaf	$16,682	39%	$29,945	Toyota Camry	$21,282	29%	1,725	6%
	SF	$31,670	Nissan Leaf	$16,682	39%	$21,250	Honda Civic	$15,861	25%	10,420	49%
	San Jose	$35,000	Tesla Model3	$26,950	23%	$21,250	Honda Civic	$15,861	25%	13,750	65%
	New York	$35,000	Tesla Model 3	$26,950	23%	$24,970	Honda Accord	$18,113	27%	10,030	40%
Norway	Oslo	$36,000	Volkswagen ID.3	$21,960	39%	$23,438	Volkswagen Golf	$14,276	39%	12,562	54%
	Bergen	$36,000	Volkswagen ID.3	$21,960	39%	$23,438	Volkswagen Golf	$14,276	39%	12,562	54%
UK	London	$36,804	Nissan Leaf	$24,305	34%	$23,693	Ford Fiesta	$16,680	30%	13,111	55%
Netherlands	Amsterdam	$52,018	Volkswagen ID.3	$31,731	39%	$65,747	Volkswagen Polo	$22,354	67%	-13,729	-21%
Sweden	Stockholm	$77,000	Tesla Model 3	$59,290	23%	$42,848	Volvo s/v60	$28,601	33%	34,152	80%

Germany	Berlin	$58,896	Volkswagen ID.3	$35,927	39%	$57,994	Volkswagen Golf	$35,324	39%	902	2%
	Munich	$58,896	Volkswagen ID.3	$35,927	39%	$57,994	Volkswagen Golf	$35,324	39%	902	2%
France	Paris	$38,472	Renault Zoe	$26,546	31%	$16,952	Renault Clio	$11,329	50%	21,520	127%
China	Shenzhen	$36,800	Tesla 3	$28,336	23%	$24,856	Volkswagen Lavida sedan	$15,140	39%	11,944	48%
	Beijing	$36,800	Tesla 3	$28,336	23%	$24,856	Volkswagen Lavida sedan	$15,140	39%	11,944	48%
Japan	Tokyo	$34,602	Nissan Leaf	$18,215	47%	$12,839	Honda N Box (K-Car)	$9,583	25%	21,763	170%

** Local Price of Nissan Leaf in London is £26,000*

For non EV prices in Amsterdam, the average diesel car €53,976 price is considered. And for the depreciation rate, a fixed depreciation table is used. Source is provided in the relevant cells in the table.

Appendix 3: Annual Fuel Cost: EV Charging Cost in EV friendly Cities

	EV FUEL COST CALCULATION								NON-EV FUEL COST CALCULATION		
	Annual VMT per Capita	Average Fuel Economy (kWh/ 100 mile)	Annual Energy consumed per EV (residence) 80%	Annual Energy consumed (public charger) 20%	Total Energy Consumption (kWh)	Residential Electricity Cost per kWh ($)	Public Charging Electricity Cost per kWh ($)	Total Annual Fuel Cost	Average Fuel Economy	Fuel cost per gallon	Total Fuel Cost
	(country based 2008 data for consistency)	3 mile / kWh = 0.3 kWh/ mile = 30 kWh/100 mile	Annual VMT per Capita*percentage of usage (residential or public)*Average Fuel Economy/100			Level 1 Charger at domestic rate	Level 2 Charger at peak hour	FC	Gallons/ 100 miles	Local Rate	FC
Seattle	8699	30	2088	522	2,610	$0.11	$0.32	$397	4.13	$3.50	$1,257
Los Angeles	8699	30	2088	522	2,610	$0.18	$0.27	$517	4.13	$3.70	$1,329
San Francisco	8699	30	2088	522	2,610	$0.24	$0.30	$658	4.13	$3.46	$1,243
San Jose	8699	30	2088	522	2,610	$0.16	$0.25	$465	4.13	$3.38	$1,214
New York	8699	30	2088	522	2,610	$0.22	$0.40	$668	4.13	$2.79	$1,002
Oslo	4039	30	969	242	1,212	$0.10	$0.57	$235	4.13	$6.27	$1,046
Bergen	4039	30	969	242	1,212	$0.10	$0.42	$199	4.13	$7.35	$1,226
London	3884	30	932	233	1,165	$0.20	$0.35	$268	4.13	$5.79	$929

Amsterdam	3821	30	917	229	1,146	$0.26	$0.39	$328	4.13	$7.97	$1,258
Stockholm	4350	30	1044	261	1,305	$0.36	$0.25	$441	4.13	$5.80	$1,042
Berlin	4350	30	1044	261	1,305	$0.31	$0.40	$428	4.13	$6.04	$1,085
Munich	4350	30	1044	261	1,305	$0.31	$0.46	$444	4.13	$6.19	$1,112
Paris	3884	30	932	233	1,165	$0.21	$0.27	$257	4.13	$5.54	$889
Shenzhen	13090	30	3142	785	3,927	$0.08	$0.10	$331	4.13	$4.15	$2,244
Beijing	13090	30	3142	785	3,927	$0.08	$0.10	$331	4.13	$4.15	$2,244
Tokyo	2485	30	597	149	746	$0.25	$0.14	$170	4.13	$4.24	$435

Appendix 4: Fuel Cost Comparison for 100-mile Drive

		Total Registered EVs	Electric Cars per 100 HH	Electric Cars per registered passenger cars	Residential Charging Cost per 100 miles	Public Charging Cost per 100 miles	Charging Cost per 100 miles	Gasoline cost per 100 miles	Difference in cost	Cost difference in percentage (compared to charging cost)
USA	Seattle	11986	4	3	3	10	5	14	10	217%
	Los Angeles	105183	8	1	5	8	6	15	9	157%
	San Francisco	46628	13	1	7	9	8	14	7	89%
	San Jose	107738	33	17	5	8	5	14	9	161%
	New York	9005	1	1	7	12	8	12	4	50%
Norway	Oslo	67782	18	87	3	17	6	26	20	345%
	Bergen	39241	26	34	3	13	5	30	25	517%
UK	London	50758	1	2	6	11	7	24	17	247%
Netherland	Amsterdam	19000	4	8	8	12	9	33	24	284%
Sweden	Stockholm	59338	13	16	11	8	10	24	14	136%
Germany	Berlin	28887	70	2	9	12	10	25	15	154%
	Munich	25670	3	3	9	14	10	26	15	151%
France	Paris	66365	6	19	6	8	7	23	16	245%
China	Shenzhen	272000	23	9	2	3	3	17	15	577%
	Beijing	400000	8	7	2	3	3	17	15	577%
Japan	Tokyo	505164	7	16	8	4	7	18	11	156%

Appendix 5: Annual Insurance and Maintenance & Repair Cost Comparison in EV Friendly Cities

	Total EVs	Median Annual Household Income	Annual Insurance Cost_EV		Difference	Annual Maintenance and Repair Cost		Difference
	City based data	2019 data	EV	Non-EV	EV vs Non-EV	EV	Non EV	EV vs non-EV
Seattle	11,986	$92,263	$1,263	$1,674	-$411	$748	$632	$116
Los Angeles	105,183	$62,142	$1,263	$1,674	-$411	$748	$388	$360
San Francisco	46,628	$112,449	$1,263	$1,674	-$411	$748	$368	$380
San Jose	107,738	$109,593	$1,913	$1,674	$239	$496	$368	$128
New York	9,005	$63,998	$1,913	$1,674	$239	$496	$400	$96
Oslo	67,782	$44,586	$1,541	$820	$721	$300	$300	$0
Bergen	39,241	$44,586	$1,541	$820	$721	$300	$300	$0
London	50,758	$50,422	$784	$859	-$75	$230	$230	$0
Amsterdam	19,000	$34,000	$292	$2,609	-$2,317	$300	$300	$0
Stockholm	59,338	$57,786	$1,096	$660	$436	$313	$313	$0
Berlin	28,887	$50,400	$1,170	$1,522	-$351	$300	$300	$0
Munich	25,670	$60,824	$1,170	$1,522	-$351	$300	$300	$0

Paris	66,365	$42,509	$612	$486	$126	$141	$141	$0
Shenzhen	272,000	$45,885	$148	$148	$0	$496	$298	$198
Beijing	400,000	$30,039	$148	$148	$0	$496	$298	$198
Tokyo	505,164	$64,450	$643	$274	$368	$248	$248	$0

Appendix 6: EV vs Non-EV_ Tax and Subsidies Comparison in Sample Cities

	Median Income	EV_Tax (Annual)	EV_Subsidies, S (One time)				EV Total (3T-S)	Non EV _Tax	Total Tax	EV Benefit	Benefit percentage	% of Median Income	
	HH, 2019	**Annual T**	National	State	City	Total **S**	For 3 years	**Annual T**	For 3 years	EV Vs Non EV	Compared to non EV	EV Incentives	EV benefits
Seattle	$92,263	$150	$7,500	$0	$0	$7,500	-$7,050	$924	$2,772	$9,822	354%	3%	4%
Los Angeles	$62,142	$100	$7,500	$4,500	$450	$12,450	-$12,150	$963	$2,889	$15,039	521%	7%	8%
San Francisco	$112,449	$100	$7,500	$4,500	$800	$12,800	-$12,500	$648	$1,944	$14,444	743%	4%	4%
San Jose	$109,593	$100	$7,500	$4,500	$3,000	$15,000	-$14,700	$701	$2,103	$16,803	799%	5%	5%
New York	$63,998	$61	$7,500	$2,000	$0	$9,500	-$9,319	$523	$1,569	$10,888	694%	5%	6%
Oslo	$44,586	$0	$3,600	$0	$0	$3,600	-$3,600	$3,690	$11,070	$14,670	133%	3%	11%
Bergen	$44,586	$0	$3,000	$0	$0	$3,000	-$3,000	$3,690	$11,070	$14,070	127%	2%	11%
London	$50,422	$0	$3,500	$0	$0	$3,500	-$3,500	$1,815	$5,445	$8,945	164%	2%	6%
Amsterdam	$34,000	$0	$4,858	$607	$0	$5,466	-$5,466	$1,502	$4,507	$9,973	221%	5%	10%
Stockholm	$57,786	$43.33	$4,776	$0	$0	$4,776	-$4,646	$3,092	$9,276	$13,922	150%	3%	8%
Berlin	$50,400	$0	$10,904	$0	$0	$10,904	-$10,904	$3,859	$11,577	$22,481	194%	7%	15%

Munich	$60,824	$0	$10,904	0	$6,073	$16,977	-$16,977	$3,859	$11,577	$28,554	247%	9%	16%
Paris	$42,509	$53	$8,470	$0	$0	$8,470	-$8,309	$1,418	$4,254	$12,563	295%	7%	10%
Shenzhen	$45,885	$0	$3,600	$3,091		$6,691	-$6,691	$5,491	$16,473	$23,164	141%	5%	17%
Beijing	$30,039	$0	$3,600	$0	$0	$3,600	-$3,600	$5,491	$16,473	$20,073	122%	4%	22%
Tokyo	$64,450	$0	$7,726	$0	$3,600	$11,326	-$11,326	$1,730	$5,190	$16,517	318%	6%	9

**The negative sign in EV Total indicates the benefit the EV users accumulate over the three year period. As tax is low or null for them in the cities selected, subsidies increase financial benefit rather than decreasing them.*

Appendix 7: EV vs Non-EV_ TCO, Financial Return & Benefit Comparison

	EV TCO	IC % of TCO	MR % of TCO	FC % of TCO	Return of PP	Return % PP	Non-EV TCO	IC % of TCO	MR % of TCO	FC % of TCO	TCO Diff.	EV TCO	Non EV TCO	EV Benefit	Non EV tax
		In case of EV after 3 years						In case of EV after 3 years			EV -non EV		% of median income		
Seattle	$15,161	24.99%	14.80%	7.85%	$16,509	52.13%	$19,623	25.59%	9.66%	19.22%	$4,462	30%	39%	4%	1%
LA	$10,421	36.36%	21.53%	14.88%	$21,249	67.09%	$21,726	23.12%	5.36%	18.36%	$11,305	21%	43%	8%	2%
SF	$10,494	36.11%	21.38%	18.80%	$21,176	66.86%	$17,188	29.22%	6.42%	21.70%	$6,694	21%	34%	4%	1%
San Jose	$3,471	72.07%	42.87%	40.15%	$31,529	90.08%	$17,261	29.09%	6.40%	21.11%	$13,790	4%	21%	5%	1%
New York	$7,963	72.07%	18.69%	25.17%	$27,037	77.25%	$17,655	28.44%	6.80%	17.03%	$9,692	10%	22%	6%	1%
Oslo	$16,668	27.74%	5.40%	4.23%	$19,332	53.70%	$26,729	9.20%	3.37%	11.74%	$10,061	25%	41%	11%	8%
Bergen	$17,159	26.94%	5.25%	3.47%	$18,841	52.34%	$27,269	9.02%	3.30%	13.49%	$10,110	26%	41%	11%	8%
London	$12,845	18.31%	5.37%	6.26%	$23,959	65.10%	$18,511	13.92%	3.73%	15.05%	$5,666	18%	25%	6%	4%
Amsterdam	$17,582	4.99%	5.12%	5.59%	$34,436	66.20%	$60,401	12.96%	1.49%	6.25%	$42,819	18%	63%	10%	4%
Stockholm	$16,177	20.33%	5.80%	8.18%	$60,823	78.99%	$29,566	6.70%	3.17%	10.57%	$13,390	9%	17%	8%	5.4%
Berlin	$17,761	19.77%	5.07%	7.23%	$41,135	69.84%	$42,967	10.63%	2.09%	7.58%	$25,207	16%	40%	15%	7.7%

Munich	$11,735	29.92%	7.67%	11.34%	$47,161	80.08%	$43,048	10.61%	2.09%	7.75%	$31,314	11%	40%	16%	6.3%
Paris	$6,647	27.62%	6.34%	11.62%	$31,825	82.72%	$14,422	10.11%	2.92%	18.48%	$7,774	8%	18%	10%	3%
Shenzhen	$4,698	9.42%	31.67%	21.17%	$32,102	87.23%	$34,256	1.29%	2.61%	19.65%	$29,559	6%	40%	17%	12%
Beijing	$7,789	5.68%	19.10%	12.77%	$29,011	78.83%	$34,256	1.29%	2.61%	19.65%	$26,467	9%	40%	22%	18%
Tokyo	$8,269	23.31%	9.00%	6.17%	$26,333	76.10%	$11,319	7.27%	6.57%	11.54%	$3,050	15%	21%	9%	3%

Appendix 8: EV Types and Charging Infrastructure in the Sample Cities

	EV TYPE AVAILABILITY IN CITIES			CHARGING POINT DATA			
	Total EVs	% of BEV	% of PHEV	Total Public Chargers	Household per charging station	Public charger per million people	EVs per public charge point
Seattle	11,986	75%	25%	650	511	107	18
Los Angeles	105,183	49%	51%	11,045	125	276	10
San Francisco	46,628	30%	70%	893	406	24	52
San Jose	107,738	34%	66%	1,027	317	109	105
New York	9,005	55%	45%	3,351	945	41	3
Oslo	67,782	19%	81%	1,450	1	3800	20
Bergen	39,241	71%	29%	1,121	0.22	4000	25
Greater London	50,758	42%	52%	6,000	22	650	9
Amsterdam	19,000	42%	58%	575	1	3900	10
Stockholm	59,338	16%	84%	1,822	8	1100	6
Berlin	28,887	17%	12%	1,425	2	400	5
Munich	25,670	22%	22%	1,310	635	85	20
Paris	66,365	67%	31%	4,453	230	400	15

Shenzhen	272,000	75%	25%	33,937	34	275	9
Beijing	400,000	95%	5%	41,130	121	201	11
Tokyo	505,164	38%	62%	42	165381	0.11	12028

**In some cities, charger availability was calculated by using either EV per public chargers or Public chargers per million people. The cells are linked to the proper source.*

Appendix 9: EV Infrastructure and Energy Use in the Sample Cities

	ENERGY AND INFRASTRUCTURE					IN CASE OF 100% ELECTRIFICATION				
	Annual Energy consumed (residence) 80%	Annual Energy consumed (public charger) 10%	Total Annual Energy consumed in Charging(kW)	Total Power Usage in City (GW)	Percentage of power to the EV Charging	Annual Energy consumed (residence) 80%	Annual Energy consumed (public charger) 10%	Total Annual Energy consumed in Charging	Total Power Usage in Charging (GW)	Total Power Demand Increase for Charging
Seattle	28,421,203	3,552,650	31,973,854	9	0.35%	926986400	231746600	1158733000	10	12%
LA	249,409,930	31,176,241	280,586,171	23	1.20%	28492325846	7123081461	35615407307	59	152%
SF	110,564,314	13,820,539	124,384,853	6	2.24%	7996151285	1999037821	9995189106	15	178%
San Jose	255,468,346	31,933,543	287,401,889	5	5.66%	1357550705	339387676	1696938382	6	28%
New York	2,669,082	24,021,738	26,690,820	54	0.05%	7934577674	1983644419	9918222093	64	18%
Oslo	65,703,744	8,212,968	73,916,712	7	1.09%	75812013	18953003	94765016	7	0%
Bergen	38,037,836	4,754,730	42,792,566	6	0.66%	112790361	28197590	140987952	7	2%
London	47,309,339	5,913,667	53,223,006	269	0.02%	2491319786	622829947	3114149733	272	1%
Amsterdam	2,178,217	19,603,951	21,782,168	7	0.30%	217802421	54450605	272253026	8	3%
Stockholm	61,943,147	7,742,893	69,686,040	138	0.05%	376468146	94117036	470585182	138	0%
Berlin	30,155,241	3,769,405	33,924,646	65	0.05%	1275058208	318764552	1593822760	67	2%
Munich	26,797,003	3,349,625	30,146,629	400	0.01%	772743317	193185829	965929147	401	0%

Paris	61,855,950	7,731,994	69,587,943	65	0.11%	325050149	81262537	406312686	65	1%
Shenzhen	730,135,976	91,266,997	821,402,973	670	0.12%	9550624355	2387656089	11938280444	681	2%
Beijing	1,073,729,376	134,216,172	1,207,945,548	117	1.04%	18849916491	4712479123	23562395613	139	19%
Tokyo	301,338,802	37,667,350	339,006,152	26	1.31%	1883367510	470841877	2354209387	28	8%

Appendix 10a: EV Well to Wheel Carbon Emission in the Sample Cities

	Power generation Mix and Carbon Footprint			CO2 Emission from the vehicle					Emission by Non EVs	
	Total (estimated) power usage in Charging (kWh) annually	Total CO2 Emission (per kWh)	Total Carbon footprint from energy sector	For non electric range		Total CO2 Emission by EVs (lb)	Total CO2 Emission by Energy Sector + EV	Per Capita Annual WTW CO2 Emission by EVs	Tailpipe emission by non electric cars	Per Capita Annual Tailpipe Emission by Non EVs
	Public and Residential Chargers		WTP (Well to pump) = total annual charging demand * per kWh CO2 emission	Non electric = 300 mile Total emission = VMT * number of PHEV*300/326	Emission rate = 0.29 lb/mile	Emission by BEV + PHEV	Emission by EV + (total energy used in charging * per kWh CO2 emission)	Total CO2 emission/ number of electric cars	0.48 lb CO2/mile	lb
Seattle	31,973,854	0.077	2453062	24216322	7022733	7022733	9475795	791	1803923886	4176
Los Angeles	280,586,171	0.595	167018370	410932974	119170562	119170562	286188933	2721	56545448040	4176
San Francisco	124,384,853	0.441	54844391	111982678	32474977	32474977	87319368	1873	15797602020	4176
San Jose	287,401,889	0.441	126722678	289851363	84056895	84056895	210779573	1956	2265229065	4176
New York	26,690,820	0.705	18806282	32221718	9344298	9344298	28150580	3126	15831553941	4176
Oslo	73,916,712	0.038	2815922	203449711	59000416	59000416	61816338	912	20216537	1939
Bergen	42,792,566	0.038	1630220	42527524	12332982	12332982	13963202	356	149505050	1939
London	53,223,006	0.579	30836069	95031911	27559254	27559254	58395323	1150	4888020894	1864

Amsterdam	21,782,168	0.029	633883	38753551	11238530	11238530	11872413	625	400753373	1834
Stockholm	69,686,040	0.508	35415782	199398381	57825530	57825530	93241313	1571	629049998	2088
Berlin	33,924,646	1.119	37973419	14161544	4106848	4106848	42080267	1457	2489805934	2088
Munich	30,146,629	0.200	6028947	22367074	6486451	6486451	12515398	488	1491892628	2088
Paris	69,587,943	0.495	34426499	72577490	21047472	21047472	55473971	836	599847523	1864
Beijing	821,402,973	1.587	1303835938	240924291	69868044	69868044	1373703982	5050	17392189615	6283
Shenzhen	1,207,945,548	1.587	1917405791	819142588	237551350	237551350	2154957141	5387	35186510783	6283
Tokyo	339,006,152	1.279	433480766	722150119	209423534	209423534	642904301	1273	3164057798	1193

* In this table, only the carbon emitting segment is shown. The BEV and PHEV electric miles emission, which is zero, is not shown in the table.

Appendix 10b: Electrification and Carbon Footprint Reduction

	Baseline Scenario		25% electrification		50% electrification		75% electrification		100 % electrification	
	Total CO2 emission by all registered passenger cars	Per Capita Emission	Total CO2 emission by all registered passenger cars	Per Capita Emission	Total CO2 emission by all registered passenger cars	Per Capita Emission	Total CO2 emission by all registered passenger cars	Per Capita Emission	Per Capita CO2 Emission Offset by EVs	Per Capita CO2 Emission Offset by EVs in %
	In Metric Ton									
Seattle	822544	1.85	670515	1.51	500082	1.13	329650	0.74	1.54	83%
Los Angeles	25778376	1.89	23596497	1.73	21345211	1.56	19093926	1.40	0.66	35%
SF	7205273	1.88	6253802	1.63	5253624	1.37	4253446	1.11	1.04	56%
San Jose	1123098	1.73	1067916	1.64	904284	1.39	740652	1.14	1.01	58%
New York	7193835	1.89	6745824	1.78	6293525	1.66	5841227	1.54	0.48	25%
Oslo	37209	0.48	59670	0.76	50564	0.65	41459	0.53	0.47	98%
Bergen	74148	0.64	81436	0.70	60551	0.52	39666	0.34	0.72	113%
London	2243655	0.84	2043775	0.76	1827465	0.68	1611155	0.60	0.32	39%
Amsterdam	187164	0.79	165018	0.69	132448	0.56	99879	0.42	0.55	70%
Stockholm	327626	0.91	320406	0.89	299285	0.83	278165	0.77	0.23	26%
Berlin	1148443	0.94	1069302	0.88	981891	0.80	894480	0.73	0.29	30%

Munich	682387	0.92	566691	0.77	432362	0.58	298033	0.40	0.73	79%
Paris	297249	0.77	282943	0.73	237685	0.61	192427	0.50	0.47	61%
Beijing	8512059	2.80	8239148	2.71	7814123	2.57	7389097	2.43	0.56	20%
Shenzhen	16937791	2.82	16490774	2.75	15881206	2.65	15271638	2.55	0.41	14%
Tokyo	1726808	0.55	1737071	0.55	1765582	0.56	1794092	0.57	-0.04	-7%

Appendix 11: EV vs Non-EV Parking and Toll Cost Saving

	Average On Street Parking rate in central city (per hour)	Total Annual Parking cost	Difference with global average parking cost	Average On Street Parking rate in central city (per hour)	Total Annual Parking cost	Difference with global average parking cost	Parking
Seattle	$5.00	$2,610	$1,306.00	$5.00	$2,610.00	$1,306.00	$0
Los Angeles	$3.00	$1,566	$262.00	$0.00	$0.00	-$1,304.00	$1,566
San Francisco	$3.00	$1,566	$262.00	$3.00	$1,566.00	$262.00	$0
San Jose	$2.00	$1,044	-$260.00	$0.00	$0.00	-$1,304.00	$1,044
New York	$4.00	$2,088	$784.00	$4.00	$2,088.00	$784.00	$0
Oslo	$5.35	$2,793	$1,488.70	$0.00	$0.00	-$1,304.00	$2,793
Bergen	$3.00	$1,566	$262.00	$1.50	$783.00	-$521.00	$783
London	$8.35	$4,359	$3,054.70	$0.00	$0.00	-$1,304.00	$4,359
Amsterdam	$4.23	$2,208	$904.06	$4.23	$2,208.06	$904.06	$0
Stockholm	$5.47	$2,855	$1,551.34	$5.47	$2,855.34	$1,551.34	$0
Berlin	$3.62	$1,890	$585.64	$0.00	$0.00	-$1,304.00	$1,890
Munich	$3.62	$1,890	$585.64	$0.00	$0.00	-$1,304.00	$1,890

Paris	$3.04	$1,587	$282.88	$0.00	$0.00	-$1,304.00	$1,587
Shenzhen	$3.11	$1,623	$319.42	$1.55	$809.10	-$494.90	$814
Beijing	$1.94	$1,013	-$291.32	$1.94	$1,012.68	-$291.32	$0
Tokyo	$3.66	$1,911	$606.52	$0.00	$0.00	-$1,304.00	$1,911

Appendix 12: TCO, Policy Component and EV Density Linear Correlation Check

variables	*Total EVs*	*EV per 100 HH*	*EV per 100 cars*
Median Annual Household Income	-0.18	0.20	-0.23
Electric car Purchase price	-0.25	-0.18	-0.08
EV and Non EV Purchase Price Diff.	0.31	0.07	0.23
Annual Insurance Cost	-0.53	-0.43	-0.23
Average charging cost for 100 miles	-0.48	0.10	-0.16
Residential Charging Cost per 100 mile	-0.26	0.07	-0.34
Public Charging Cost per 100 mile	-0.74	0.09	0.45
Total Annual Fuel Cost	-0.40	-0.23	-0.49
Difference in fuel and charging cost	-0.12	0.12	0.45
Annual Maintenance and Repair Cost	-0.05	-0.03	-0.34
Total Incentives	0.17	0.30	0.14
Total comparative benefit for EVs	0.29	0.38	0.08
Total Cost Of Ownership for 3 years	-0.47	0.15	0.43
New TCO percentage of Purchase price	-0.34	0.28	0.50
Difference in Cost _EV vs non EVs	0.01	-0.26	-0.26
Financial Return %of Purchase Price	0.34	-0.28	-0.50
Electric Car TCO % of median income	-0.31	-0.23	-0.42
EV incentives comparative benefits % of median income	0.43	0.24	0.06

Appendix 13: Charger availability and EV density correlation

Variables	*Total EVs*	*EV per 100 HH*	*EV per 100 cars*
Total public charging point	0.0214655	-0.3121354	0.3832617
Charger per 100 household	0.2383757	-0.2732281	0.3390607
Public chargers per million people	0.0509553	-0.3647519	0.6584101
Charger per 100 EV	-0.0560834	-0.2832962	0.1480695

Appendix 14: TCO and Multiple Regression Analysis Result

Multiple Regression	*Multiple R*	*R Square*	*Adjusted R Square*	*Standard Error*	*Observations*
Regression Summary	0.87	0.76	0.49	15.27	16

	Coefficients	*Standard Error*	*P-value*
Intercept	10.56	24.45	0.68
Median Annual Household Income	0.0002	0.0003	0.60
Electric car Purchase price	0.0003	0.0005	0.57
Annual Insurance Cost	-0.0011	0.0151	0.94
Total Annual Fuel Cost	-0.0175	0.0603	0.78
Annual Maintenance and Repair Cost	-0.0084	0.0412	0.84
Total Incentives	0.0053	0.0023	0.05
Total Cost of Ownership	-0.0010	0.0013	0.47