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CAR-SHARING WITH ELECTRICAL VEHICLES: A LITERATURE REVIEW AND A PROPOSED AGENDA

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Orientador: Lino Guimarães Marujo

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.

"Então, tomou Samuel uma pedra, e a pôs entre Mispa e Sem, e chamou o seu nome Ebenézer, e disse: ***Até aqui nos ajudou o SENHOR****."*

1 Samuel 7:12

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COMPARTILHAMENTO DE CARROS COM VEÍCULOS ELÉTRICOS: UMA REVISÃO DA LITERATURA E PROPOSTA DE AGENDA

Frederico do Nascimento Barroso

Março / 2021

Orientador: Lino Guimarães Marujo

Programa: Engenharia de Produção

Muitas metrópoles vivem uma situação de mobilidade desafiadora com altos índices de poluição e trânsito. Em muitos casos, má distribuição dos transportes públicos, engarrafamentos e muitos carros movidos a combustíveis fósseis contribuem para o adoecimento da população e incrementando as emissões dos gases de efeito estufa (GEE). Este estudo tem por objetivo estabelecer uma ferramenta para implementação de compartilhamento de carros elétricos. A proposta é verificar através da revisão da literatura se este serviço irá contribuir com a popularização dos carros elétricos e com a redução dos GEE. Em seguida, é realizado um estudo de caso, que produz um modelo para implementar o serviço de compartilhamento de veículos elétricos. Ao final este modelo é aplicado na cidade do Beijing, China. Resultados confirmam que o compartilhamento de carros elétricos é uma estratégia para a popularização dos veículos elétricos e também de redução dos gases de efeito estufa. É identificado na literatura os principais indicadores e criado um modelo para implementar o serviço. Ao aplicar o modelo em Beijing, China, confirmamos que a cidade é um bom lugar para o serviço de compartilhamento de carros. O modelo proposto para implementação de compartilhamento de veículos elétricos é confirmado como uma ferramenta útil para contribuir com uma avaliação inicial de uma região para a implementação do serviço.

Abstract of Dissertation presented to COPPE/UFRJ as a partial fulfillment of the requirements for the degree of Master of Science (M.Sc.)

CAR-SHARING WITH ELECTRICAL VEHICLES: A LITERATURE REVIEW AND A PROPOSED AGENDA

Frederico do Nascimento Barroso

March /2021

Advisor: Lino Guimarães Marujo

Department: Production Engineering

Many metropolises are experiencing a challenging mobility situation with high levels of pollution and traffic. In many cases, poor distribution of public transport, traffic jams and many cars powered by fossil fuels contribute to the population's illness and increase greenhouse gases (GHG) emissions. This study aims to establish a tool for implementing electric car-sharing. The proposal is to verify through the literature review if this service will contribute to the popularization of electric cars and the reduction of GHG. Then, a case study is carried out, which produces a model to implement the service of car-sharing with electric vehicles. In the end this model is applied in the city of Beijing, China. Results confirm that car-sharing with electric vehicles is a strategy for popularizing electric vehicles and for reducing greenhouse gases. The main indicators are identified in the literature and a model to implement the service is created. By applying the model in Beijing, China, it confirms that the city is a good place for car-sharing service. The proposed model for implementing car-sharing with electric vehicles is a useful tool to contribute to an initial assessment of a region.

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1. INTRODUCTION

This section approaches the overview of the subject research, contextualizing, describing the problem, hypotheses, objectives, and expected results.

1.1 Contextualization of the research subject

Greenhouse gases provoke several environmental and health effects. The whole planet is warming up, the global average temperature is higher than at the beginning of the twentieth century. This effect yields many consequences such as melting glaciers and sea ice, shifting precipitation patterns, extreme weather events, forcing wildlife populations and habitats to move. Other effects expected to become more common are hurricanes, floods, and diseases. The greenhouse gases represent a key role in this climate change. These gases create a heat-trapping in the atmosphere, causing global warming. The main greenhouse gas is Carbon dioxide, and a relevant portion comes from the transportation sector due to burning fossil fuels (NALAU, VERRALL, 2021, OWEN, 2020, PAL, DEY, *et al.*, 2021).

According to PNME (2021), air pollution and greenhouse gases contribute to respiratory diseases. Deaths associated with exposure to fine particulate matters ($PM_{2,5}$) and other local atmospheric contaminants correspond to one of the main risks factor for premature deaths in the world. Seven million people dead per year due to these risks above mentioned. Fine particulate matters ($PM_{2,5}$), corresponds to particles with a diameter less than 2,5 micromillimeter, which penetrate lungs and blood system, increasing the risk of developing respiratory and cardiovascular diseases. These particulates also come from burning fossil fuels. The top ten causes of death in the world, two are related to respiratory diseases: Chronic Obstructive Pulmonary Disease in third place; and lower respiratory infections in fourth place. In large urban centers the problem is more predominant. Majority world's urban population is exposed to air pollution at least 2,5 times greater than the safety standards recommended by World Health Organization. In Brazil, there was an increase of 14% in deaths attributed to air pollution in ten years. As well as the number of preventable deaths from respiratory diseases, the population's exposure to O_3 (ozone) and $PM_{2,5}$ also increased especially in large urban centers. This represents a debt more than R$ 1.3 billion for hospital care related to respiratory problems in the year 2018 and the cost estimated between 2008 and 2019 of this expenditure was around R$ 14 billion. If pollution related to $PM_{2,5}$ remains at the same level of 2018, during the period of 2018 through 2025, 51.367 deaths in São Paulo metropolitan region are expected. In addition, 31.812 patient admissions in public hospitals would be registered in the same period, at an estimated cost of R$ 58.7 million for the Brazilian Unified Health System (SUS). This problem would be directly related to respiratory and cardiovascular diseases and lung cancer, and they can exceed the mortality levels in Brazil due to traffic accidents, for example PNME (2021). Some measures need to be taken to reverse this scenario. Sustainable mobility emerges as an option.

Sustainable Mobility involves a broad concept that seeks to value the individual in the space of cities, implying actions that allow a healthier and more harmonious coexistence with the environment. Promoting the transition to sustainable mobility implies thinking about integrated public planning with actions that allow advancing this proposal (BANISTER, 2008). Countries also discuss together how to tackles this issue.

The Paris Agreement is an international commitment discussed with 195 countries, signed in 2015 (COP 21 / UNFCCC). The Agreement rules measures to reduce GHG emissions to contain global warming. It reinforces the need for a global response to global warming by maintaining the world temperature below 2° C above pre-industrial levels and ensuring efforts to limit warming to 1,5° C.

Brazil is one of the signatories to the Paris Agreement and has committed itself in its Nationally Determined Contribution (NDC) to cut, by 2025, 37% of its emissions concerning the levels of 2005 and to reach the neutrality of emissions in 2060. This commitment implies accelerating transformations to guarantee the targets will be achieved.

There is an intense focus on reducing fossil fuel cars worldwide. In Norway, the deadline for all new Light Passenger and Commercial Vehicles to be zero-emissions is 2025; in the United Kingdom, this target is 2035; and France wants to eliminate the sale of vehicles powered by internal combustion by 2040. Transport has a major impact on climate change and GHG emissions. Electromobility can contribute to mitigating these impacts and promote environmental improvement for citizens (PNME, 2021). Another approach is car-sharing. This service offers benefits to its user. Owning a car carries responsibilities with issues of environmental pollution, high-energy costs, and limitations to park. Alternatively, car-sharing is presented and the user utilizes a car from a fleet based on their need, for a rental period, in addition to the ease of giving up the responsibilities of having a car. This market is expanding: the growth of this service is aligned with the implementation of intelligent transport system technologies (DEGIRMENCI; BREITNER, 2014).

Another trend is the use of electric cars although they have limited battery range (few kilometers autonomy), causing so-called “range anxiety". Vehicle high purchase costs strongly limit their popularity, as well. The deployment of electric vehicles in the car-sharing fleet needs an investigation if it is an effective strategy to overcome these initial disadvantages to make it competitive with traditional private mobility.

Having such importance, the subject of deploying car-sharing with electric vehicles aims to carry out a framework to implement the service in a region offering an option of electric vehicles. The hypotheses are the popularization support of electric cars, reduction of tailpipe gases, and identify the main operational indicators.

1.2 Description of the research problem and hypotheses

Urban mobility has been presenting issues mainly in the most populous cities over the years. In many big cities, the most used transport modal is the road and there is an excess of vehicles causing traffic jams and gridlocks in most of the roads. In addition, due to the increase in travel time, the tailpipe gases also follow the same trend. Thus, electric cars would be an important tool for combating vehicle combustion gases.

The two hypotheses are the popularization of electric vehicles (EV) due to car-sharing, and the reduction of gases generated from the cars' emissions. This study also seeks to identify the main operational indicators.

1.3 General and specific objective

The general objective of this work is to carry out a framework for the deployment of car-sharing using electric vehicles. For this objective, a literature review is made, observing the main techniques and parameters. Next, a multiple case study supports the development of a framework for implement car-sharing with electrical vehicles (CSEV). To test the framework, it will be applied in a region, and results discussed.

Thus, PICOS methodology is used to define the research question: Population, Intervention, Comparison, Outcome, and Study Design. Population to be considered are urban citizens, visitors, commuters receiving the intervention of car-sharing with electric vehicles, comparing with cases of other cities and studies. Thus, it evaluates if the region is a good place for this service and if it will reduce emissions and popularize electric vehicles. A multiple study case is conducted to build the framework and then applied in Beijing, China.

In the end, the intention is to answer the following questions:

i. What techniques have been applied by the authors in the literature to implement car-sharing?

ii. What aspects of car-sharing have been addressed?

iii. What are the untapped gaps?

iv. What are the main metrics and indicators that can be used in Electric vehicles for Car-sharing?

1.4 Justificative

In addition to presenting another option for urban mobility, car-sharing meet the 4.0 industry trends. Servitization is an aspect of the 4.0 industry and the focus shifts from product to service (PINTO, MORALES, *et al.*, 2019). For example, instead of purchasing a car, the biggest interest is in the transportation service and for this, one does not need to have a car. Thus, arises the search and construction for new economic models from network society. One of its characteristics is to have only the benefit of the product rather than its possession. Other examples already occur with room sharing (Airbnb), sharing tools, and even in a way with pets (DogHero). This market has been gaining more adherents mainly from the younger population. This economic model is increasingly powerful and will present several opportunities for society.

There are also public policies around the world with a date for banning the use of fossil fuel vehicles to meet the global environmental and sustainable appeal. Looking this way, the opportunity arises for the use of an electric vehicle. Currently, its prices are considered high compared to the internal combustion engine. One hypothesis to popularize the electric car is its use in car-sharing services. Thus, an opportunity emerges for companies to offer a larger number of products, at values much more accessible for the population.

1.5 Expected results

The expected result of this research is to present a framework to deploy car-sharing with electric cars for a region, impacting on lowering emission, improving health quality, and life quality due to this service option.

In this chapter, the context of car-sharing and electrical vehicles presented the relevance of the subject and the research gap, i.e., a tool to support car-sharing with electrical vehicles in a metropolitan region, which is the main goal of this study. The next chapter, Methodology, explains the process of the literature review and a study case. The ambition of Chapter 2 is to elucidate methods that a reader can recreate the study. Following, Chapter 3, literature review, provides previous researches and relevant debates concerning this topic. Moreover, this chapter results in the confirmation of this current study's hypotheses. Chapter 4 conducts a study case and creates a framework to support the implementation of car-sharing with electrical vehicles. In the same chapter, the framework application is performed in Beijing, China. Chapter 5, the last one, summarizes the study informing the main conclusion, limitations, and future studies.

2. METHODOLOGY

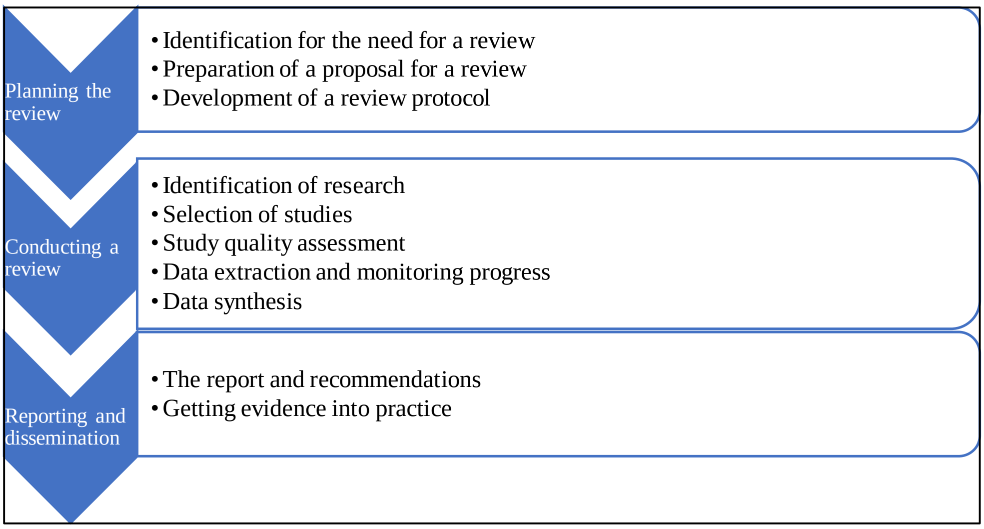
This section addresses the research methodology including study design, finality, objectives, approach, and procedures. The strategy to answer the research question and check the hypotheses is presented in this chapter. This section aims to present how the research is conducted. Thus, research can be replicated. This research utilizes a literature review and a study case to reach expected results.

According to RAGAB, ARISHA (2018) the research philosophy of this study is aligned to the scientific school of thought. Considering epistemology, this is a positivist paradigm, focusing to create generalized findings from structured observations of reality and objectivism ontology. The research approach is both deductive and inductive. Deduction regards the literature review to confirm hypotheses. In the literature review, the research starts from theory, designs a research method, and then creates a theory. This option is possible to generalize findings. The inductive approach is in the study case section. The study case starts from observation, then a study design, and by the end create a theory. The research purpose is exploratory, searching “what is happening” and “seeking new insights”, without investigating reasons for the phenomenon. This research aims to explore the main aspects of the researched problem. The research method is qualitative nature. Analyzing methods are thematic analysis and content analysis to uncover patterns and themes that emerge from within the data. Qualitative research is useful for studying a limited number of cases in-depth and describing complex phenomena. This is an applied study regards to the research finality. The intention is to develop a framework able to support the deployment of car-sharing with electrical vehicles. This developed technique intends to be useful for service providers to implement CSEV.

2.1 Methodology literature review

The literature review is conducted to confirm the hypothesis and identify the most recent publications on the subject. This is an applied and exploratory research, with a qualitative approach, utilizing the hypothetical-deductive method. Figure 1 summarizes the three steps of the literature review, i.e. planning the review, conducting the review, and reporting and dissemination The studies of DURACH, KEMBRO, *et al.* (2017), TRANFIELD, DENYER, *et al.* (2003), PAUL, CRIADO (2020), SILVA (2013) and PAGE, MOHER, *et al.*, (2021) were the guide to develop the literature review.

Figure 1: Stages of a systematic review.



Source: Modified of Tranfield, Denyer, *et al.*, (2003, p. 214).

In the step of planning the review, previous literature reviews are retrieved from Scopus, Web of Science, and Google Academic databases. After analyzing them, the researcher can confirm the need for this literature review. The preparation of a proposal for a review consists to set the research question utilizing question PICO (population, intervention, comparator, outcome) framework and FINER (feasible, interesting, novel, ethical, relevant) criteria (YACOUBIAN, OXFORD, *et al.*, 2017). Following, databases have to be at least two, with relevant publications to justify their selection. The databases chosen were Scopus, the largest database of literature review, and the Web of Science, which is not as large as the previous one, although have more years working with scientific articles. The keyword selection has to be consistent with the research question. A guide to improving terms choice is to check keywords of two expert papers and two seminal articles. The search will be based without time restriction in English. The scope of the research is global, as it aims to analyze the best practices of the subject in the most diverse approaches and localities.

The protocol used for publications selection considers the paper type, language, and publication quality. The paper selection workflow is presented according to Prisma 2020 chart (PAGE, MOHER, *et al.*, 2021). It demonstrates the filter performance, such as duplicates removal; quality parameters (A1 and A2); publications by the framework, and PICO. The quality parameter considered in this research is Qualis-Periódicos, available at Sucupira. The classification is as follows for a better understanding:

a) A1 and A2: includes journals of international excellence;

b) B1 and B2: covers journals of national excellence;

c) B3, B4, and B5: considers medium-sized journals;

d) C: includes journals of low relevance that is considered unscientific and inaccessible for evaluation.

After creating the protocol, the research moves to the stage of conducting the review. This means the proper conduction and follows the literature review research protocol previously stated. This section also exposes bibliometric pieces of information such as main authors, yearly publications, and journals. Next, literature synthesizing, creating codification, and categorizing selected publications. Each code is described and analyzed.

Reporting and dissemination stage is the last stage of the literature review. Each code is briefly commented, offering an overview of the research. Implications are highlighted and future studies recommended.

The meta-analysis is not conducted in this research. It aims to gather studies and measure how literature is more approachable for the subject and its solution. This study covers many aspects of car-sharing and heterogeneity of studies. Considering this context, meta-analysis would induce mislead and it is not appropriate for this research.

2.2 Study case Methodology

In this section, the framework LUKOSEVICIUS, ALBERTO, *et al.* (2018) is utilized and recommendations (MIGUEL, 2007), (YIN, Robert K., 2001) to guide the development of the research to attend the requirement of a study case and provide it a higher quality. This section offers a design study case analysis of the research subject, and if a study case is a recommended approach.

2.2.1 Research question

The research question is ‘How and why to implement car-sharing with electric vehicles?’ and these question types beginning with ‘how’ and ‘why’ are appropriate to a study case. The question is clear, simple, up-to-date, important to the community, and feasible regards time and costs to develop the research.

2.2.2 Check if the case study method is suitable

Car-sharing is a phenomenon that has been growing around the world and electrical vehicles follow the same direction. There are some studies relating Car-sharing and electrical vehicles although a framework to implement car-sharing, is unprecedented according to the author's knowledge. This study case aims to understand how the phenomenon works to best design a strategy of deployment of this service. This study considers a holistic view of understanding how other CS services operate and if it will help citizen’s mobility.

The boundaries between the phenomenon and its context are partially evident, and developing research is needed. Will this system improve mobility? Will it contribute to lower emissions? These answers are not clear before the development of this research.

The phenomenon’s behavior does not need to be controlled, and this with other characteristics mentioned in this section address to a study case be appropriated to the current research. This research aims to answer why a set of decisions is taken to implement car-sharing with electrical vehicles (YIN, Robert K., 2001).

2.2.3 Define the study case purpose

The study is exploratory to generate a framework and descriptive, to describe its characteristics and how it behaves in its context. The intention is smaller than the phenomenon knowledge. Although it would develop the knowledge of how to deploy this service. New theories should not be expected from this study case: a proposition of a framework is expected as it supports future studies.

2.2.4 Calculate case’s quantity

Multiple cases between 4 to 10. Thus, literature informs this range is enough to saturate knowledge of new inputs. It considers simulation experiences from other places around the world. The sampling technique is purposive when using judgment to select particularly informative individuals will enable the researcher to meet research objectives. The method for case selection is Maximum variation cases, indicated for exploratory studies. This method utilizes multiple heterogeneous cases to obtain data under varied circumstances (RAGAB, ARISHA, 2018).

2.2.5 Choosing case

This study case has the objective to understand the car-sharing service and then better understand their indicators. The access to other researches and its main data will be performed through retrieved indexed publications in WoS and Scopus databases. Other big cities can give an overview of how it works and compare them. Many studies that involve car-sharing with electrical vehicles with detailed parameters will be selected.

2.2.6 Unit of analysis quantity

Single and holistic unit regards to social and geography subjects to implement Car-sharing.

2.2.7 Validate unit analysis

The unit analysis is related to question research, sufficiently specific, in a circumscribed system based on literature.

2.2.8 Identify case type

This is a multiple and holistic case because the car-sharing system interacts with other transport modals addressing a holistic view. This study considers many cases and how it works in other cities.

2.2.9 Identify the theoretical support framework

Constructs are specified and related to the hypothesis of this research. Will this system improve mobility? Will it contribute to lower emissions? Reference theory is not applied, since a clear theory is missing to represent this study case (GIL, 2002).

2.2.10 Validating construct

The construct has the operation defined according to the literature review and concepts presented. Multiple sources of evidence are considered as triangulation and evidence is linked in a proper manner building the knowledge. The goal is to study the car-sharing phenomenon data from other cases and then build up the case explaining how to be implemented in a region, expecting to find similar results.

Fossil fuel cars contribute to emissions. An electric vehicle does not produce emissions at the tailpipe. Although, is relevant to investigate the measure of emissions from the energy that charges the batteries of an electric vehicle. The Brazilian energy matrix is considered clean, although this analysis is not a target of the current study. On the other hand, the popularity of electric vehicles supported by car-sharing will be reviewed.

2.2.11 Reliability

The study case protocol follows the study case protocol from (MIGUEL, 2007) and (LUKOSEVICIUS, ALBERTO, *et al.*, 2018). The expected results are to create a protocol, report, and data consistent with each other. A broad variety of journals, papers, thesis, dissertations, documents from governments are available for research. The research will be conducted remotely accessing databases. The access will be through CAFE by CAPES. The data will be collected during the literature review.

2.2.12 Defining collection procedure

Types of study to be included are original, short survey, comments, viewpoint, newer techniques, letter, dissertation, thesis, reports from government agencies, and direct observation. Both data types, qualitative and quantitative are important to implement a program such as car-sharing. Cases mainly in big cities, over million citizens, high-quality papers will be preferred.

2.2.13 Defining collection techniques

The criteria are according to Prisma protocol informed on literature review and map tables can be considered. Direct observation and documents are the sources and the evidence for the study case.

2.2.14 Case protocol

Quality tests are according to Table 1, following, from MIGUEL (2007) based on YIN, Robert K. (2001).

Table 1: Quality test.

Test	Operational activity	Research stage
Construct validity	Use of multiple sources of evidence. Linking evidence.	Data collect
Internal validity	Develop a pattern of convergence and construction of the explanation.	Data analysis
External validity	Utilize replication logic in multiple case studies.	Research planning (cases)
Reliability	Use research protocol in the study case. Develop a database for the study case.	Data collect

Source: (MIGUEL, 2007) based on (YIN, Robert K., 2001).

The techniques to collect data are direct observation and literature database review. The literature review protocol is to pick up some cases and direct observation supported with real-time observation and to understand the context of the phenomenon (YIN, Robert K., 2001). New cases can be incorporated, just in case, to contribute to the study case.

The method aims to analyze, explaining and building knowledge (YIN, Robert K., 2001). First, the case is described to promote a general narrative of the case, and the following steps are to reduce data (excluding no essential data), build a panel, and identify causalities (MIGUEL, 2007).

2.3 Analyzing Study Case Evidence

A debate between data and proposed theory is performed evaluating car-sharing data with information from car-sharing implementation from MILLARD-BALL, MURRAY, *et al.* (2005).

First, a brief description of the data collected from the set of cases with multiple evidence sources is written. After this, data is evaluated to reduce them to the essential, i.e. connecting to the objectives and hypothesis of the research. This phase is called data reduction. A codification is advised to reduce data and it means picking parts of the description of the case made on the phase before and associate them with codes, previously established, related to the objectives, research question, and hypothesis. Following, a display (or panel) with the data selected and sorted by code is constructed to visually support extracting conclusions. This display can be represented by a chart with one axis with the codes and the other with the evidence sources. In the next phase, a conclusion, insights, and new variables (causal network) can arise and an overview description, and then a detailed analysis to investigates evidence that can be generalized. This evidence chain leads us to the conclusion based on converging data sources.

2.3.1 Data reduction

Codification to reduced data is set according to research premises. Data from the display will be sorted by its similarity due to yield a conclusion. The parameters will be presented on a chart, supporting the analysis.

2.4 Study case writing

The research will be linear analytical, following the sequence of topics with the subject, problem, literature review, methods, findings, analysis, and final considerations, and will be submitted to other professors to approve this study case. The text seeks to seduce the reader to have a pleasant and clear reading.

3. LITERATURE REVIEW

The literature review is conducted according to papers of DURACH, KEMBRO, *et al.* (2017), TRANFIELD, DENYER, *et al.* (2003), PAUL, CRIADO (2020), SILVA (2013), and PAGE, MOHER, *et al.*, (2021). These studies support gathering publications, create selection protocol, analyze and report. This chapter is divided into three stages: Planning the review, Conducting the review, and Reporting and dissemination. The focus of the first stage is to identify previous studies and inform what this review seeks to bring new. Moreover, it brings the research objective and the research protocol. The second stage is the conduct of the research and is carried out avoiding bias in the study following criteria stated in the first stage. The third stage deals with how the report will be presented, seeking pieces of evidence and proposing future studies.

3.1 Planning the review

This stage aims to identify previous studies and identify the relevance of this current one. Also, investigate where studies have been published and comment on what this search brings new. Following, a proposal for the review, with review objective and research question is presented. By the end of this stage, the reasons for databases are informed why they were selected, and the paper selection is defined with a protocol.

3.1.1 Identification for the need for a review

First, this section presents concepts of electrical vehicles and car-sharing, including the main topics addressed in the literature. Also, it offers more details about electrical vehicles, emissions, and car-sharing. Electric vehicles history, development in Brazil and worldwide. Following the section shows previous literature reviews from databases (Scopus, Web of Science, and Google Scholar), checking year publication and discussing findings.

3.1.2 Electric vehicle

The first electric vehicle known is dated around 1830. This technology had kept dormant, and in the 1960s interests have been increasing to avoid pollution from conventional cars and oil prices instability and threats of shortage.

MELTON, GOLDBERG, *et al.*, (2017) defines vehicles with no pollutants and greenhouse gas (GHG) emissions at the tailpipe as Zero-emission vehicles (ZEVs). It includes vehicles powered by electricity called plug-in electric vehicles (PEV), battery-electric vehicles (BEV), and plug-in hybrid vehicles (PHEV) and powered by hydrogen, hydrogen fuel cell vehicles (HFCV).

The conventional internal engine vehicle (ICEV) has a significant technological difference comparing to an EV. Electrical vehicles offer powertrain efficiency range from 85% to 95%. For ICEVs the efficiency for diesel engines is among 35 to 40%, and even lower in gasoline engines reaching 18 up to 25%. ICEVs much of their energy is lost in heat (DE ALMEIDA, FERREIRA, *et al.*, 2008). Thus, implies emission reductions of around 4 to 8 tons for a 10-year vehicle lifetime. Emission reductions due to electromobility are estimated between 3,6 to 4,9 times the current internal combustion engine fleet. Moreover, this carbon cost also may convert into savings for the electric vehicle life-cycle (ZHAO, DOERING, *et al.*, 2015).

BEVs and PHEVs are manufactured in Norway, Netherlands, Iceland, Japan, France, Estonia, Sweden, United States, Switzerland, and Denmark attending to the social needs of energy security and environmental protection. PEVs integrated into smart grid provides the energy security that when the grid has a high load demand PEVs may provide power to it (RAMALINGAM, INDULKAR, 2015).

Brazil still is a country with opportunities for automakers to grow sales, different from EUA and Europe. These two countries have a consolidated car population and now search for sales opportunities and consider new technologies as PEVs (Plug-in electric vehicles), being an alternative. Brazil has additional characteristics as ethanol fuel used in hybrid vehicles (singular case around the world). Brazil's government supported for many years the internal combustion engines market, and nowadays face a limited infrastructure for electromobility. Additional barriers to EV penetration in Brazil are biofuels, as ethanol fuel, pre-salt oil (which receives lots of investment), EV lithium-ion batteries are under Asian country's control (COSTA, 2019). Unlike Europe and the USA have emission controls, infrastructure, and public transportation supporting this option. The involvement of stakeholders, such as automakers, car-sharing operators, and government (city, state, and federal) are elementary to develop electromobility (DE LARA, MARX, 2018).

There are four attempts from EV market penetration. The first phase (1801-1896) marked to change from animal power to mechanical transport. The second phase (1897-1965) reached 40% of automobility production in the United States of America (USA), considered the most successful one. The third phase (1966-2000) followed the same deployment reasons of the second phase: oil market instability and energy security. Leading countries pushing this technology were the USA and Europe, and the next phase (4th phase) vanguard countries are China and Japan. The fourth phase (2001-present) was considered disruptive since the conception of the car as a private asset changed to the car as a service (CaaS) being polyvalent to be used as Vehicle-to-Home (V2H), Vehicle-to-grid (V2G), Vehicle-to-everything (V2X). Other vehicle technology options in this phase are autonomous, shared, and connected. This last attempt has an additional reason than previous ones: emissions (GHG). EV adoption creates new business based on a circular economy and provides energy stability to the grid when renewable sources do not attend. EV sales are increasing since 2011 and should be predominant in 2040 in Europe and China. Automakers perceived this potential, PEV models in 2011 were 9 and nowadays around 170 (COSTA, 2019).

The policy is a relevant tool for long-term transition to zero-emissions mobility. Countries in the vanguard of this subject create manners to reduce the price gap between ICEV (internal combustion engine vehicles) and PEVs (Plug-in electric vehicles), deploy charging infrastructure, and have special actions on the battery supply chain. Technologies are advancing and key enablers to cut costs are battery chemistry, production capacity, smart vehicle design, and application of data science to correct battery size (TILL BUNSEN, CAZZOLA, *et al.*, 2019).

A deployment strategy suggested by PECORELLI PERES, PESSANHA, *et al.*, (2012) is installing a recharging network in a high-income area. It is the place where the population can afford PEVs lives. Other target areas are shopping malls, garages, airports, and others with a high concentration of people. PEVs market penetration is rising each year. To keep the reliability of the electricity distribution systems avoiding overloaded the system, keeping batteries controlled and monitored is recommended. Charging control mechanisms and business models have to be implemented beforehand supporting the network with a higher asset utilization and avoiding overload of feeders and transformers. The scenarios with low charging infrastructure and low battery capacity, options such as battery swapping become a feasible solution (ZHANG, Dong, LIU, *et al.*, 2019a). By 2030, AZADFAR (2015) forecast homes with a power supply beyond the grid, these new sources will offer more energy reliably to residents.

The SHUKLA, DHAR, *et al.*(2014) findings are that battery costs will reduce due to transport demand is expected to increase, production on a bigger scale, technology enhance imply increasing energy density. BEVs nowadays have a competitive autonomy with a conventional car, although charging time and costs are still a constraint. Large-scale penetration of BEVs will require, a relevant role to the government to support tax incentives, facilitating public-private partnerships, improve charging infrastructures and regulations, investments into grids, support research on innovative battery models and recycling and reuse, and priority for EVs in parking and traffic. Citizens and technologies have a strategic role in this scenario. Benefits expected beyond the air quality, energy security that BEV can operate as a distributed storage energy conjugating better to intermittent renewables energies such as solar and wind and mitigating fossil fuel sources. Electro mobility does not expect a reordering of the current electricity supply despite an increase in electricity demand.

EV deployed in car-sharing services may be a modal integration connecting to ferries, subway, scooters, Bus Rapid Transit (BRT), and others (DE LARA, MARX, 2018). To plan the car-sharing demand some factors are relevant as technical developments, users' knowledge and behavior, priority areas, charging stations, and paths that the society will follow (HARDINGHAUS, SEIDEL, *et al.*, 2019).

3.1.3 Car-sharing

Car-sharing dates from 1948 when is known the first car-sharing program called "Sefage" located in a housing cooperative in Zurich, Switzerland. In the 1970s emerged other programs as "Procotip" in Montpelier, France (1971); Witkar, Amsterdam in the Netherlands (1973); "Green Cars" in various places in Britain by the end of the mentioned decade (MILLARD-BALL, MURRAY, *et al.*, 2005). In Brazil, car-sharing has a fleet of around 8.000 units to 230 thousand users. The majority of ICE vehicles and the biggest adhesion is in São Paulo city (COSTA, 2019).

Authorities consider car-sharing as a tool to achieve their transportation and land use goals (KENT, DOWLING, 2013). Car-sharing is followed by many benefits such as reducing impacts on vehicle manufacturing; lower transportation cost for households; urban design benefits and costs savings; less parking need; impact local shops and services; less traffic congestion; impact on transit ridership, walking, and cycling; reduce emissions; decrease vehicle ownership and travel, and improved mobility. Also, car-sharing reduces fuel consumption, emissions and vehicle kilometers traveled (FELLOWS, PITFIELD, 2000). Private cars are parked 92% of the time (EM, 2015) and car-sharing can result in a significant reduction of parking lots.

Car-sharing is a niche product and needs a specific setting guided by local priorities and elements to well succeed. Some common barriers to its deployment are funding, divulgation, regulations, insurance, and interoperability. The most challenging barrier to expansion is the lack of knowledge of potential users and partners. Car-sharing association at a national level may support the business tailoring partnerships with automakers, workshops, promote greater understanding through the national media. In the USA, federal funding requests demonstrate how it reduces vehicle travel, and sometimes this information is challenging to gather (MILLARD-BALL, MURRAY, *et al.*, 2005).

Many papers searched the profile of a car-sharing user. Consensus establishes that people who live in a dense area with two or one households; innovators and environmental awareness; highly educated; cost-sensitive; few miles travelers; roughly among 30 to 40-year-old. These variables have explanatory power in some locations, although they are not associated with car-sharing success. MILLARD-BALL, MURRAY, *et al.* (2005) suggest the best way is to evaluate local characteristics to check if car-sharing fits instead of finding the user profile match. Multiple-regression analysis indicates to target neighborhoods with commute mode split; singles and childless households; users able to walk half a mile to get to work from where drop the car-sharing vehicle; a car is not needed every day. Although other car-sharing programs do not attend these factors and succeed as well, because support from partner organizations might be needed. In some cities, the user presents a willingness to lives close to a car-sharing area, which affects long-term residential location decisions (MILLARD-BALL, MURRAY, *et al.*, 2005).

Car-sharing program has some possibilities to start. Business venture based on operator efforts and gaining partnerships during operation. A strong public-private partnership that public initiative offers to the operator's support and the company evaluates the market. Municipal lead is the type that authorities oversee the program and have full responsibility. Grassroots is a program that begins with local neighborhood efforts. Special purpose/research is when its deployment has previous demonstration and incentives comes from research funds. Standalone development or campus, a special case that can be conjugated with another scenario above (MILLARD-BALL, MURRAY, *et al.*, 2005).

Operators advise some previous work to be performed to support the program. Geographic market analysis, investigating neighborhood characteristics, and market research or feasibility study. Promote program and obtain partnerships and including it in transportation plans. Barriers should be investigated and mitigated (MILLARD-BALL, MURRAY, *et al.*, 2005).

The following checklist summarizes the main questions to the car-sharing program be successful:

> - Does the community have neighborhoods with the right characteristics to make car-sharing viable? Are there neighborhoods with low auto ownership and use, where walking and transit are viable options?
> - Are there established Transportation Demand Management programs in which car-sharing can be inserted; are there other commute trip reduction strategies that can recruit business members?
> - What is the depth of interest in car-sharing from different types of partners?
> - Is there a high-level champion with a strong commitment to car-sharing?
> - Are there community groups that have shown interest in starting a car-sharing program and can get a project off the ground?
> - What incentives can partners provide for a commercial operator, such as start-up funding, marketing, zoning changes, and parking provision?
> - Is there an anchor member, such as a city or business that wishes to replace its vehicle fleet with car-sharing and can provide guaranteed baseline usage? (MILLARD-BALL, MURRAY, *et al.*, 2005, , p. ES-8)

Taxonomy of car-sharing business models was performed by (REMANE, NICKERSON, *et al.*, 2016), Figure 2. Business types were classified based on current car-sharing companies. It was related to business model components (i.e., the taxonomy), business model types (i.e., the archetypes), and business model instance (i.e., the operator database). Dimension and Characteristics were classified by the perspectives of Value proposition, Interface, Service platform, Organizing model, and Revenue model. Cluster Analysis was performed and separated into seven clusters, respectively: Roundtrip, Multiple Vehicle Types; Single-Purpose Vehicles; Roundtrip, Cooperative; One-Way, Free-Floating; One-Way, Stationary; P2P (peer-to-peer), Manual Access; P2P, Automatic Access.

Figure 2: Taxonomy of car-sharing business Model.

	Dimension	Characteristics					
Value proposition	*Destination*	Roundtrip	One-way	Roundtrip with option for one-way			
	Minimum duration	At least 1 day or longer	Hourly	By the minute			
	Vehicle types	Identical or very similar vehicles available	Very different vehicles available				
	Additional benefits	Free/discounted parking	Delivery by owner	No additional benefits			
Inter-face	*Vehicle booking*	Reservation and fixed return time	Instant access and fixed return time	Instant access and open ended			
	Vehicle access	Manual key handover	Lock box for key	Automatic			
Service platform	*Booking platform*	Proprietary	Open for other providers				
	Parking infrastructure	Dedicated carsharing stations	Only attached to other stations	Street parking	Private homes		
Organizing model	*Vehicle ownership*	Operator owned	Private customers				
	Vehicle maintenance	Maintained by operator	Maintained by private customer				
	Vehicle refueling	Refueled and paid by owner	Refueled by driver and paid by owner	Refueled and paid by driver			
Revenue model	*Price structure*	By duration only	Combination of duration and distance				
	Transaction-based revenues	Service fee (including insurance)	Commission and/or insurance				
	Continuous revenues	Membership fee from drivers	Service fee from car owners	Subsidies	Advertising	Combination of multiple sources	No continuous revenues
	Organizational ownership	Private company	Cooperative	Government owned			

Source: Modified of REMANE et al. (2016, p. 9).

SPREI, HABIBI, *et al.* (2019) investigated cities in Europe and the USA and his findings are that the total rental time is close to 30 minutes, constituted by 15 minutes of driving and 15 minutes of reservation and to reach the vehicle at the parking area. FFCS (free-floating car-sharing) is a relevant mobility mode and is demonstrated to be faster in comparison to others. Considering walking trips, 85% FFCS is faster up to 30 minutes. Comparing with biking trips, 70% of them, FFCS has reached first the destination. Public transport has some complex scenarios and waiting time and sometimes is faster, although generally, FFCS time gain is between 10 to 30 minutes. For ICEV and BEVs, in this research of SPREI, HABIBI, *et al.* (2019), users decide to use BEV for slightly shorter trips even if battery autonomy is much higher. In Madrid and Amsterdam, the fact to have free of charge parking was the main reason to operators decides to have all fleet BEVs. P2P (peer-to-peer) car-sharing is a possibility since the majority of vehicle owners use their cars less than one hour per day (DILL, MCNEIL, *et al.*, 2019). Car-sharing is used for short trips for many purposes. Car ownership affects positively and directly the use frequency, rental time of vehicles. Policies and promotion activities may support in the same direction (HUI, DING, *et al.*, 2017).

One-way car-sharing is more flexible and is preferred by users being an alternative for the last and first-mile transport. This implies an unbalanced system, causing a low vehicle utilization rate. Sometimes a station may lack a vehicle or there is a vehicle without enough battery charged and another station full of vehicles ready to be used. Options are installing fast chargers, although they are usually costly and need local power grid upgrade; swapping batteries, applicable if BEV has the same battery model; or optimizing the car assignment. The last option, car assignment management with relay vehicles achieves vehicles' high utilization rate comparable with ICE fleet car-sharing. Relay cars consists to assign a vehicle even if the battery is not enough for a user to achieve the destination, and then the user exchanges the car in the intermediate station and proceeds to the destination with a relay car. If the user profile is longer trips, this solution is proper (ZHANG, Dong, LIU, *et al.*, 2019b).

Car-sharing is an alternative to add more flexibility to transport. If it competes with public transport, it may cause congestions, requiring more space, instead of reducing parking spaces. The car-sharing business model type impacts the payment terms for customers and operator financial results. Round-trip car-sharing, users generally pay for reservation, driving, and activity time, on the other hand, the one-way type does not pay for the vehicle idle time maximizing benefits (DORENBOS, 2018). Following, studies suggest how to tackles the on-way rebalancing problem.

Simulating a car-sharing system is addressed by CARLIER, MUNIER-KORDON, *et al.* (2015). Findings indicate that decreasing the relocation frequency for every 2 hours has a few impacts on the total number of satisfied demands. Combining charging with car reposition is positive and FOLKESTAD, HANSEN, *et al.*(2020) proposed a Hybrid Genetic Search with Adaptive Diversity Control to find a solution to route relocations. The algorithm reduces postponed rental by 9,4%. In Milan, Italy (BRUGLIERI, PEZZELLA, *et al.*, 2017), investigated economic sustainability issues based on worker vehicle relocation. It depends on the direct rent-time revenue from the relocation and a fixed component related to “future revenue”. If a user is satisfied, he or she will return to use the service again. A sensitive analysis concludes to consider mandatory to include this fixed revenue to “future revenue” at least 15 Euros to ensure vehicle relocation.

BRUGLIERI, COLORNI, *et al.*, (2014) conducts a study of relocating EVs observing the charging stations available in the city utilizing data from Milan transport agency. The approach is done through Mixed Integer Linear Programming to address the Electric Vehicle Relocation Problem (EVRP). The study case counts with 30 EVs running between 7:00 AM and 8:00 PM. The car-sharing simulator indicated that only 2 employees with a 5-hour daily workload are enough to provide fleet relocation in 86% of this travel demand. In the next section, the user perspective is explored.

3.1.3.1.1 Car-sharing user behavior

This section approaches social-demographic, user characteristics collected from surveys. Moreover, discuss user intention to shed private car, the target group of one-way and two-way models. Market perspectives, such as service level and transportation market share are presented.

Results from WAPPELHORST, SAUER, *et al.*, (2014) indicates that electromobility car-sharing user has some social-demographic features, mobility behaviors, and purpose. The approach with each group should be different, e.g., bike-lovers and eco-friendly persons would like to know the benefits of emissions and a complementary solution to public transportation, and innovative and technology persons would prefer the new feature.

User has more concern related to car-sharing fees than travel time. Aspects as age and gender affect the adoption of the program. Considering PEVs exists propensity to engage even more with it. This strategy associated with carpooling will avoid some cars in the city center in the long term (CARTENÌ, CASCETTA, *et al.*, 2016). SHAHEEN, CANO, *et al.*, (2016) addresses the adoption of CS with EVs for an older population. Four focus groups and a compilation of research data were performed. This research was conducted in an old community of Walnut Creek, California, United States. As the characteristics of the trips of this audience are short distances, planning, few times a month, and cost sensitivity. The results show, 30% of the interviewees would participate in this CS service with EV and 36% answered that they might participate.

Findings from WIELINSKI, TRÉPANIER, *et al.* (2017) confirm preferences from hybrid vehicles instead of electrical ones for travels longer than 24 kilometers. Factors as female users, cold weather, also decrease the use of EVs.

To predict annual vehicle travel, LI, Ruohan, KARA M KOCKELMAN (2019) proposed an estimation considering one day distance, and this information demonstrates mistakes considering this number for a year. More exact information is checking the full week distance by GPS or with even more accuracy when data comes from a vehicle with a low (first-quartile) Gini coefficient.

The study from GALATOULAS, GENIKOMSAKIS, *et al.* (2018) approaches commuting needs from a medium-size city from Spain to the university population by electric vehicle system as e-cars, e-bikes, and e-scooters/e-motorcycles. The methodology of the stated preference survey resulted in 2 out 3 persons are willing to have the benefit of this system and pay more than the public transportation fee. Initial costs of the system are estimated as fleet size based on a survey.

College students from Rome and Milan in Italy were addressed with a stated preference survey and discrete choice analysis to estimate how certain parameters influence the car-sharing use decision (ROTARIS, DANIELIS, *et al.*, 2019). Students are a relevant segment since they have low car ownership, are smartphone users, and sharing propensity. Findings point car-sharing trips are generally used for occasional trips (do not substitute commute trips), traveling late at night, or with by a group of people. In general, fare and distance to access car-sharing impact negatively although the free-floating type and electric vehicle impact positively the student chooses to use CS. This service mainly substitutes private cars and marginally taxi services.

In German metropolitan areas, WITTWER, HUBRICH (2018) observed the main reason to adopt CS is flexibility. Other aspects were comfort, parking issues, and car availability. It was identified why people do not want to own a car. Mainly reasons are cost and because people don’t need it. Since his last research in 2011, WITTWER, HUBRICH, (2018) informed that is no difference in mode use, although active users reach up to 10% of daily trips using CS. This number is higher than in prior studies.

KIM, KO, *et al.*, (2015) passed a survey through a website with participants of the newly created car-sharing program at that time, with electric vehicles in Seoul, South Korea. The motivation of this program with electric vehicles was the reduction of congestion, attitude towards climate issues, and the reduction of issues related to parking vehicles. The questionnaire's approach was intended to understand the willingness for people to get out of their vehicles, willingness to buy electric vehicles, and willingness to continue to participate in the car-sharing system with electric vehicles. To analyze the data, factor analysis was performed to reduce the number of variables from uncorrelated factors and, adequately describing the data and ordered probit model. The results on a 5-point Likert scale, the willingness to abandon the current vehicle is 2.39; willingness to buy an electric vehicle is 2.94; willingness to continue in the car-sharing system is 3.52. The variables of age and family income influence the responses obtained. Older participants were more adept at giving up their cars and participating in this service. As well as families with high income show a tendency to continue with their vehicles. The author also made some regards before the use of this information, among them is the fact of the recent implementation of this system.

CARTENÌ, CASCETTA, *et al.* (2016) investigated models between owning a car or using the CS service. When adopting the CS option, what is the behavior for the use of an EV? The survey was done with 600 drivers from Salerno, Italy, with the estimate based on the binomial logit model. The results were the interpretation of short-term choices for CS besides assumptions regarding the preference of EVs with various pricing strategies of this service. The research concluded that the best model to be used for this city is the parking area would be in the periphery of the city and the access to urban parts would be by CS. The motivation for the adoption of this model is due to the characteristics of trips in this locality, which were trips of origin from other cities and few internal. It concluded that the most statistically significant attribute is the fee price and second travel time. The sensitivity to the tariff price is perceived as the cornerstone of this system. As for the adoption of CS rather than the car's factors such as social class age and gender influence on choice and policies should be developed to attract all segments. The study showed that the use of EVs increases the change in behavior for the use of CS.

The relation between car-sharing and car owners disposing of his or her vehicle due to adoption is more relevant from users with lower household incomes as high-income ones go in the opposite direction. High incomes keep their cars. This finding is consistent with microeconomic theory. Users with cars, usually use car-sharing for shopping. The study indicates that a vehicle with a proper place to carry the goods from shopping should be considered on model vehicle choice (LE VINE, POLAK, 2019).

Car-sharing is an important tool for sustainable mobility. In most cases, it leads to reduce car utilization and users disposing of their cars, especially in a combination of station-based and free-floating systems (GIESEL, NOBIS, 2016). While the membership is increasing and car-sharing usage being more frequent, a binary logistic regression indicated that users choose to dispose of and reduce the number of cars in the household. Car-sharing is not the main reason for it, but it has an important role in this decision. Families avoid renouncing their cars since the vehicle is considered necessary for them.

In Vancouver, Canada two options of car-sharing were studied. One is free-floating utilizing a compact vehicle with 2 seats and the other is round-trip mode with a variety of vehicles proposed. Findings showed these services were complementary and together had synergy supporting users to renouncing their cars, main members from both services. One-way service was considered an additional option to have a more comfortable multimodal trip. Roundtrip service was more related to substitute vehicle ownership. Vehicle size availability and functions seem to be an important factor to reduce private vehicles (NAMAZU, DOWLATABADI, 2018).

In Seoul, South Korea, early car-sharing adoption based on survey results, demonstrated car ownership is not affected by electromobility car-sharing at this stage (KIM, KO, *et al.*, 2015). Singles have a higher willingness to car disposing and results indicated that all society when enhances sustainability behavior, being aware of program benefits, charging time reduction than will affect car ownership. This transportation type is sensitive to fee and payment systems despite association was rather weak.

The paper from CHEN, KOCKELMAN, *et al.* (2016) simulated part of the vehicle fleet from Austin, USA to be constituted by shared autonomous electric vehicles (SAEV). Findings showed the market share between 14 to 39% can reduce private vehicles substantially. Each SAEV may replace 10 to 26 private cars and only increases “empty” VMT to 7% to 9% of all travels. For traditional CSEV some studies approach the private car reduction (MARTIN, SHAHEEN, *et al.*, 2010; STASKO, BUCK, *et al.*, 2013), traffic pollution reduction, (CHEN, KOCKELMAN, 2016; MARTIN, SHAHEEN, *et al.*, 2010; MARTIN, SHAHEEN, 2011) and decrease annual vehicle kilometers traveled (VKT) (SHAHEEN, MARTIN, 2016).

The study CATALANO, LO CASTO, *et al.*(2008) demonstrated that car-sharing and carpooling with 10% of the market share of transport mode (car, car-sharing, carpooling, public transport), in Palermo (Italy) will promote mobility to areas with lower trip demands.

The propensity to adhering car-sharing, findings in Salerno (Italy), depends on the level of service of the available transport modes, and its level of service attributes, socio-economic and activity-based attributes. The weekly trip frequency and the travel distance, both increasing do not support the car-sharing system (KORTUM, SCHÖNDUWE, *et al.*, 2016). Other important topics of CSEV are charging infrastructure and vehicle relocation, these are addressed in the next section.

3.1.3.2 Vehicle recharger quantity and rebalancing

Similar services can bring benefits and ideas of how to support the car-sharing service. Using the concept of bike-sharing, FREUND, HENDERSON, *et al.*(2019) discuss planning methods for bike-sharing operating in a set of stations that there is a dock for each bike. A parallel with car-sharing can be carried out, each bike dock could be considered a parking space with a charger, for example.

Decisions of the number of docks per station, such as rebalancing the system to meet the demand, and possible expansion. It describes the entire programming models, optimization algorithms, and simulation. All these methods rely on a statistical analysis of bike-sharing data. It has data collaboration from Citi Bike New York.

Key questions for these systems are about planning and rebalancing capability. Planning tries to determine the optimal number of vehicles in each station. This condition avoids situations where the customer arrives at the station and is full or is empty to rent a vehicle. Rebalancing the system is expensive and should be done carefully. In New York, they use motorized and non-motorized rebalancing. Docks are rebalanced with a dispositive able to carry 3 bikes at the same time. A truck is effective to rebalance a large amount and long distances, especially at night/dawn. During the day, trucks are complemented by non-motorized vehicles, where bikes towing trailers that can accommodate up to 18 bikes. Optimizing these operations requires appropriate statistical analysis of past data to predict future demand patterns. If empirical cars are viable, such a strategy would make sense to be adopted. Figure 3 suggests a possible vehicle to the rebalanced, linking many vehicles at the same time.

Figure 3: The ESPIRIT train of the vehicle.

Source: Modified of Boldrini; Incaini; Bruno (2017, p. 2).

3.1.3.3 Dissatisfaction function

Relevant work on the subject is from (RAVIV, KOLKA, 2013) that defines the user dissatisfaction function to measure the number of out-of-stock events in a single station. They also defined a routing for the rebalancing problem based on the user dissatisfaction function; such routing problems and attempts to resolve them for optimization for growing regions were investigated by (FORMA, RAVIV, *et al.*, 2015), (HO, SZETO, 2014) and (SZETO, LIU, *et al.*, 2016). (O'MAHONY, 2015) aims to find the ideal configuration of bicycles at the beginning of some period and employs the user dissatisfaction function.

Data usually obtained through pick-up location, time, return location, and user. Some systems that have GPS can still observe the users' paths. This uses data to fit a stochastic model, which forms the optimization model that will be addressed. This model observes the departures and arrivals of the bicycle and travel time.

First, it was seen how the dissatisfaction function works, and then the optimization problem was addressed to find the optimal location of the bikes at a certain time of the system. The most sustainable routing for system rebalancing is done at night and so large quantities can be moved in the truck. Two reasons why the system is not rebalanced during rush hour are due to traffic causing congestion and a dynamic system of great complexity to predict it.

For the allocation capacity question, which answers how many docks should be allocated at each station, Integer Programming is used and the advantages of adding more docks to the self-balancing stations are studied.

Other initiatives besides motorized rebalancing are incentive policies for users themselves to collaborate with the operation by selecting and delivering the vehicle at nearby stations to be more convenient.

3.1.3.4 Expansion planning

For planning the expansion of the service, a regression system is used that predicts the number of users according to population, geography, and climate. The steps to calculate is to first, use demographic data, taxi usage data, and potentially other data sources to estimate parameters in a regression model that predicts nominal flows between existing stations. Second, assume that nominal flow rates between existing stations do not change after expansion. Third, use the estimated regression model to predict nominal flow rates between existing and new stations. Then calculate the user dissatisfaction curves for each number of bikes and each number of docks for the station-specific rates and ultimately solve the expansion optimization problem.

3.1.3.5 Management of car-sharing operation with electric car

The study CLEMENTE, FANTI, *et al.* (2013) wanted to highlight the impact of electric vehicles (EV) on the performance of a CS service. Evaluate different operating conditions by developing a discrete event simulation model of a CS service with generic electric cars and a real case study is analyzed and simulated.

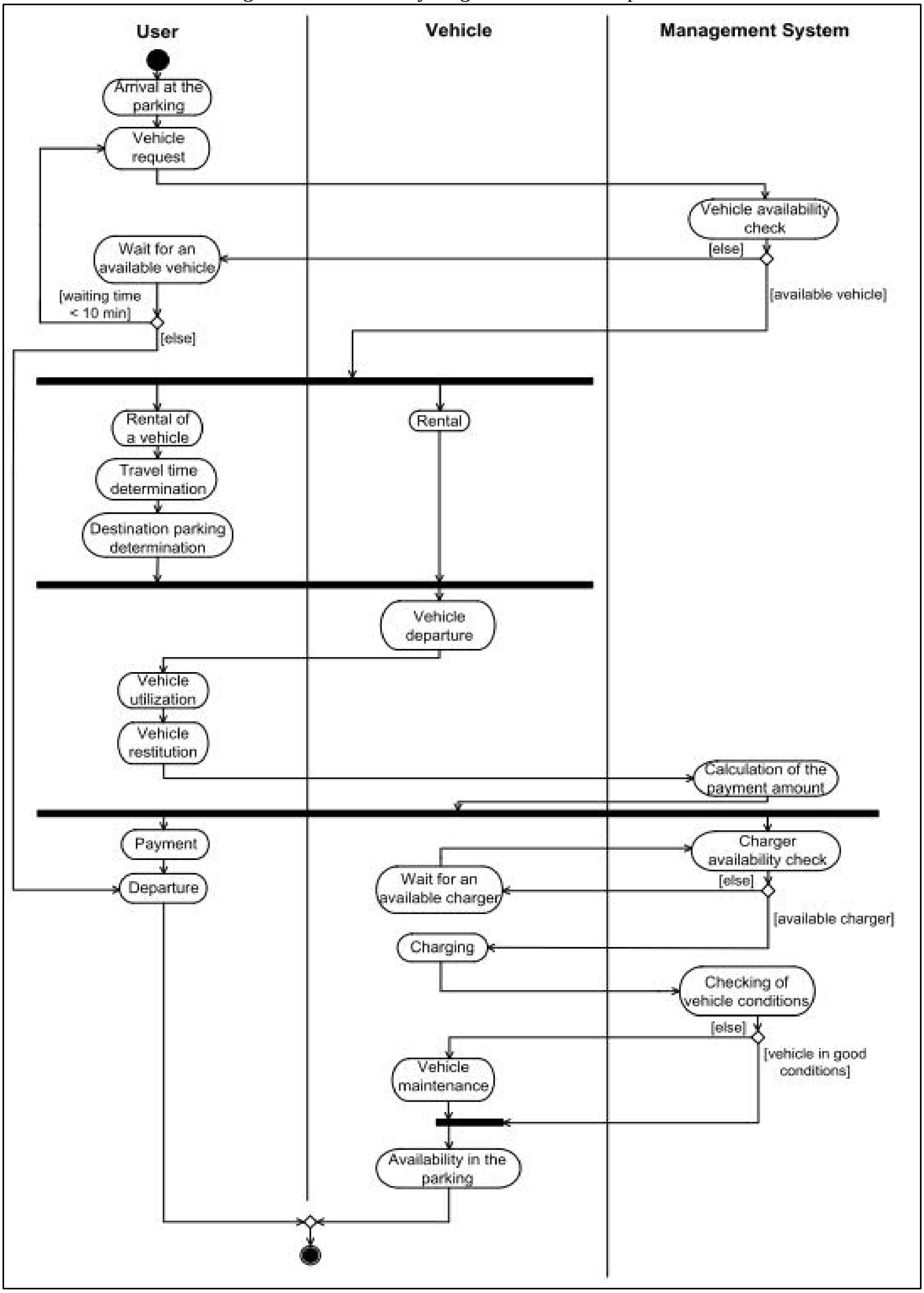
Car-sharing (CS) seems to be the most suitable system for adopting electric vehicles as it allows renting a car for limited periods for traveling within a specific urban area. This context is compatible with the autonomy ranges of EVs. A simulation approach is useful for identifying the best operational strategies and highlighting critical service issues.

First, a detailed analysis of the management of a generic CS service and the deployment of the EVs is conducted. Second, the results of this phase are formalized through the Unified Modeling Language (UML) and the class and activity diagrams are developed. Finally, a simulation model is performed in the Arena software environment. The validity of the simulation developed, and the effectiveness of different operating conditions is seen in a real case study involving the electrical service, CS of Pordenone, a city in northern Italy, and different simulations are performed.

The problem of car-sharing with electric cars needs to analyze some parameters and calibrate them. The optimum fleet size, the location of the parking areas, pricing policies, accessibility of the service, rental rules, the number of charging stations, the location of the charging stations, and the recharging policies.

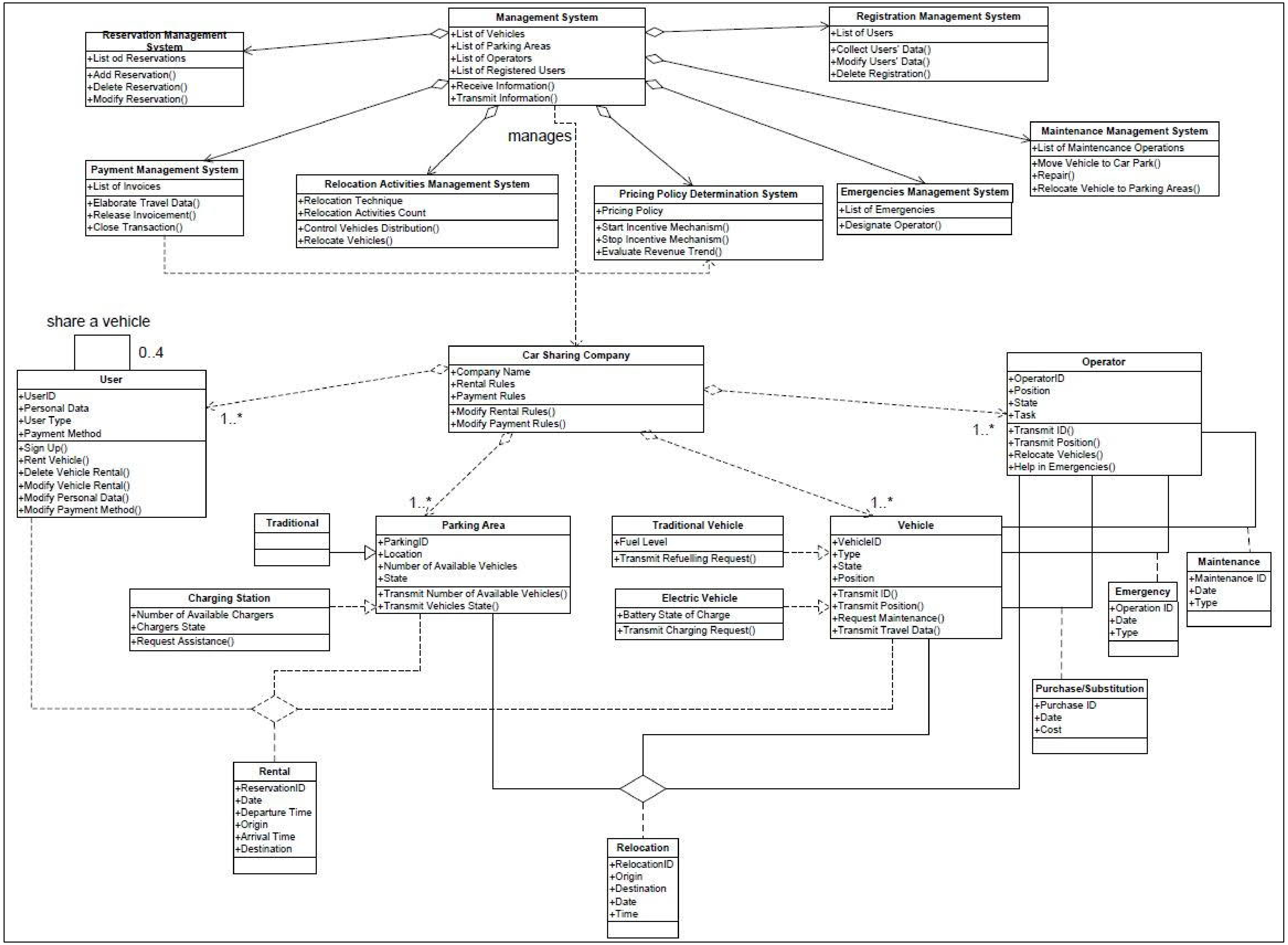
In the class diagram, describing the problem of generic CS, the following structural components can be pointed out: Management System, Reservation Management System, Payment Management System, Relocation Activity Management, System, Pricing Policy Determination System, Emergency Management System, New Customer Records Management System, Maintenance Management System, The Vehicle Sharing company, Operators, Users, and Vehicles. Next is the UML development activity diagram. The set of events is useful to highlight successively determines any process that occurs on a given system.

Figure 4: UML activity diagram for car rental process.



Source: Modified of Clemente et al. (2013, p. 590).

Figure 5: Car-sharing with electric car, class diagram.



Source: Modified of Clemente et al. (2013, p. 589).

In the case of a study in this Italian city already mentioned, the service fleet consists of small EVs, with a range of about 40 kilometers and a maximum recharge time of 1.5 hours.

From certain rules, the performance variable defined to evaluate the behavior of the service is the Level of Service (LOS), defined as the fraction of users served by the number of users in the service. The LOS metric was evaluated by a long simulation of 21600 t.u., with a warm-up period of 30 t.u. estimates that were deducted by 50 independent replications with a 95% confidence interval, half of which is about 2.2% at worst.

The results highlight the increase in the number of chargers available leads to a growth of LOS. There is a general deterioration of system performance and different parameters must be recalibrated to get the same level of service guaranteed in the traditional case (CLEMENTE, FANTI, *et al.*, 2013).

3.1.3.6 Previous literature review

The literature reviews referenced in this section are retrieved from Scopus, Web of Science, and Google Scholar. All of them address car-sharing, although they present different objectives. The next paragraphs bring the objectives and study scope of each review, in chronological order.

The literature review of JORGE, CORREIA, (2013) tackles car-sharing, mainly a two-way model since one-way was emerging up that time. The study considers some problems from car-sharing services and methods applied in the literature. Demand modeling, service performance, relocating vehicles. Methods used in literature are microsimulation, queuing-based discrete-event simulation, discrete-event simulation, regression analysis, and random utility model.

DEGIRMENCI, BREITNER (2014) yields a literature review identifying six concepts: market analysis, location, travel behavior, information systems, electric car-sharing, and sustainability. The article focus is in information systems i.e. Intelligent Transportation Systems (ITS) (connectivity), Geographic Information Systems (GIS), and Information Infrastructures (II). The study seeks to answer the questions "What is the current state of research within the area of car-sharing?" and "What is the perspective for researching information systems in the context of car-sharing? Such questions are relevant to the understanding of the subject and the technologies available. In consequence, these questions support identifying subject barriers. The methodology for reaching these answers took the first step by conducting a literary review and outlining concepts on the subject. It was also researched the publications' references (backward) as well as in which they were used (forwards). Finally, a bibliographic review with 93 articles and 6 concepts that were: market analysis, localization, travel behavior information systems, electrical car-sharing, and sustainability. On market analysis, various articles that deal with the potential market and its trends, as well as geographic, financial, and environmental scenarios are influenced by the adoption of car-sharing. Setting the region to apply the car-sharing service is one of the main challenges. There are 3 models of car-sharing, one-way, round-trip, and free-floating. Balancing cars between stations becomes an issue to be addressed. Travel behavior mainly explores the frequency of use and user's motivations. For information systems, various transport intelligence technologies, GPS, infrastructure information, and technologies to access cars are examined. Using electric car-sharing is observed the capacity to reduce carbon dioxide emissions. In the end, they discuss the potential to help sustainable transport systems, such as environmental studies to reduce the number of people who have a car and reducing carbon dioxide through the implementation of this service. Finally, with conclusions and limitations, the authors report more emphasis on Information Systems. Car-sharing is an interdisciplinary system, Degirmenci and Breitner encourage to study other areas and in other languages besides English. Other related topics such as bike-sharing, carpooling can be considered. Answering the initial motivations in the first question, a conceptual structuring of the theme was created and six concepts were identified: market analysis, location, travel behavior, information systems, electric car-sharing, and sustainability. The second question presented implications for research in information systems. The review of ERTZ, LEBLANC-PROULX, (2018) addresses sustainability in the collaborative economy, with a bibliometric approach. Relevant authors, publications, and clusters are highlighted. The study reveals influential authors like Rachel Botsman, Lisa Gansky, futurist Jeremy Rifkin, technologist Tom Slee, Russell Belk, Juliet Schor, and Susan Shaheen. The four clusters and respective main publication are (1) Conceptual elaboration on the sharing concept avenues and future perspectives, BOTSMAN, ROGERS (2010); (2) Testing of hypotheses/theories/concepts, empirical studies of qualitative, quantitative or mixed design, BARDHI, ECKHARDT (2012); (3) Solving of practical problems with a managerial orientation formal statistical and mathematical modeling and optimization focus on technology-mediated “sharing” (mutualization) systems, BELK (2014); (4) Discussing and evaluating sustainability in the collaborative economy, critical and normative assessments, threats and opportunities to reach sustainability, MARTIN, C. (2016).

The review of MACHADO, DE SALLES HUE, *et al.* (2018) approaches shared mobility in urban centers. This paper considers car-sharing, personal vehicle sharing, bike-sharing, ridesharing, and on-demand ride services as components of sharing mobility. All these transport modes contribute to reducing traffic jams and pollution issues, although they should be articulated with other strategies.

The annotated review of FERRERO, PERBOLI, *et al.* (2018) aims to introduce a taxonomy and analyze different aspects of car-sharing, including different business models like one-way, two-way, free-floating. The taxonomy of this study is a double-level classification. The first level is ‘Service specifications’ divided between the business model (one-way, two-way, free-floating, and not applicable) and engine type (engines powered by fossil fuel and ZEVs). The second level regards the research problem. This level is divided into three categories. First, optimization objectives approaching Business and service, Infrastructure, and Fleet management. Second grasps time horizon like Design, Planning and Operational and real-time. The third category is methodologies, e.g. Simulation, Stochastic optimization, Combinatorial Optimization, and Statistical analysis. In this study, all categories are detailed and defined for a better understanding. According to their study, one-way car-sharing is receiving more attention from authors than other models. Almost half of the publications consider a one-way model. The possibility to analyze publications about the free-floating model rose in the last years and two-way is diminishing. In addition, since 2013, publications including ZEVs surpass those with fossil fuel engines. Most studies address business and services for optimal objective, design for time horizon, and statistical analysis for methodology.

The study of WEBB (2019) reviews the literature investigating future perspectives for transportation. Webb approaches the mentality of transport as a service (TAAS), implications of autonomous cars, and the key role of electric vehicles. The relocation problem in one-way car-sharing networks is addressed by ILLGEN, HÖCK (2019). This study informs that strategic or operation-oriented problems are typically solved with mixed-integer programming. Management tasks problem mostly utilize simulation models.

The last review is from LIAO, CORREIA (2020), which addresses aspects of shared e-mobility as usage pattern, demand estimation, and potential impacts. Shared e-mobility includes electric car-sharing, e-bike sharing, and e-scooter sharing. The user profile is for short trips, mostly male, middle-aged people with relatively high income and education. Positive impacts on transportation and the environment combine reducing car use and car ownership, thus reducing greenhouse gas emissions.

All these previous literature reviews contribute to car-sharing systems with an electrical vehicle, although not one of them focuses on answering how to implement this service in a region or city. Thus, a literature review with this perspective should be carried out.

Following, there are comments about publications. In this study, two databases were chosen and the details about the decision making. The search will be made on the Scopus database which is the largest database of literature reviewed and Web of Science (WoS) not as large as the other one but obtains a larger scale of years of publication. WoS claims to be the most powerful and trusted research engine, helping to connect ideas and advance scientific research across all fields and disciplines. Additional benefits are coverage of older literature, and deeper citation indexing across all content, some paper detail analysis, authors unified based on ORCID and ResearcherID profiles. Also, the use of Keywords Plus, very important algorithm that analyzes the titles of cited references to identify words and phrases that occur with significant frequency. The other database, Scopus, since 2004, has a comprehensive overview of the world's scientific research output across many disciplines. It brings together the superior quality and coverage of Scopus data, sophisticated analytics. It also empowers institutions to booster performance, rank, and reputation. It identifies emerging trends, leading experts.

3.1.4 Preparation of a proposal for a review

A systematic review is performed to sort studies that support answering the hypothesis of this current research. Consequently, this review assists in answering the research question of how to implement car-sharing with electric vehicles. In this direction, is needed to know how the system works by looking for references on how the system operates or how it can be replicated for a city or region.

The research question is formulated according to PICO (population, intervention, comparator, outcome) framework and FINER (feasible, interesting, novel, ethical, relevant) criteria (YACOUBIAN, OXFORD, *et al.*, 2017). The author is the only one conducting the review. A population can be defined as citizens, visitants, and commuters from a region or a city. Intervention is car-sharing with electrical vehicles. The parameter to compare is literature standards and other car-sharing services examples in the literature. The expected outcomes are exploratory, checking possibilities for this service implementation. This study is feasible regarding no-funding need, and the study design is appropriated to tackle the research question. The author expects to create an interesting dissertation for the reader since many places in the world are still evaluating car-sharing as a transport mode to be deployed. The study novelty explores the service implementation of electric car-sharing service, not well covered in the literature, according to researches performed. This topic has not considered any ethical issues that have to be addressed in particular. Thus, the relevance of this study should stimulate further research on this topic.

3.1.5 Development of a review protocol

Up to this moment, databases and research questions were defined. The next step is retrieving publications and sorting them. Publications are discovered through keywords inserted in the database search field. The strategy to obtain publication is informed following such as detailed research protocol including paper selection criteria and analysis.

Keywords are selected from articles from well-known experts and through two seminal articles utilizing CitNetExplorer software. CitNetExplorer can be downloaded from www.citnetexplorer.nl (VAN ECK, WALTMAN, 2014). In Web of Science about lemmatization, the search engine automatically retrieves the same words with different spelling, singular and plural, and synonyms. These words are searched in Topic, which includes KeyWords Plus, an algorithm that provides expanded terms stemming from the record's cited references or bibliography, and all indexed as published titles, abstracts, keywords. Bibliometric information is obtained from each database and analyzed.

Publication's selection criteria are articles written in English; the main language used in this field. Another filter is the quality parameter A1 and A2 (Qualis-Periódicos) since findings from studies that challenge or change existing knowledge are more likely to be published in leading journals (DURACH, KEMBRO, *et al.*, 2017). Another refine is articles according to framework stated from the research question and problems most addressed in literature regards the CSEV implementation phase. The sort to inclusion and exclusion of studies is performed in Rayann software (OUZZANI, HAMMADY, *et al.*, 2016). Full-text access is uploaded in Mendeley software. After, the main information is extracted and coded in a spreadsheet of Microsoft Excel software. Following, the study analysis is performed to understand how the studies relate to each other. Interpreting the results, informing economic implications, what are main problems and how they have been addressed. By the end, inform contribution for future research.

3.2 Conducting the review

This section conducts the protocol created in the previous stage. Keywords and seminal papers are identified. Studies are selected and created codes to organize the literature. Next, the section offers a discussion of each code, how it has been addressed, and findings.

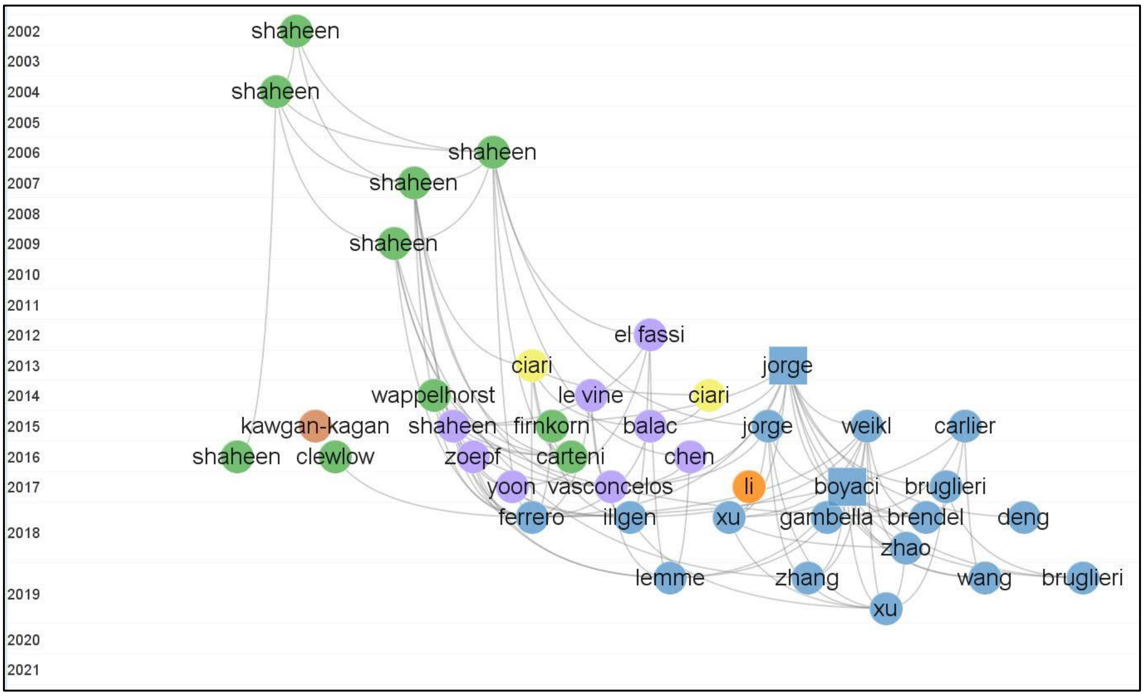
3.2.1 Research key words identification

First, choose previous literature reviews from databases, then check keywords from main well-known experts as Susan Shaheen and Diana Jorge. Often applying the term “car-sharing” and some variation using the term “electrical”. Since the target of this research is the implementation of this service, added words “implement” or “deploy”. Therefore, publications that include in topic ‘car-sharing’ and the words ‘electric’ or ‘deployment’ or ‘implement’ and these terms variations will be retrieved from the database. Thus, inserting the following string in the database TOPIC: (car*sharing AND (deploy* OR implement* OR electric*)), refined by: [excluding] DOCUMENT TYPES: (EARLY ACCESS), Timespan: All years. Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI. Results are 189 publications from the Web of Science Core

Collection. In the search string, the expression inside the inner parentheses is executed first. The symbol '*' is a search tool called truncation. The symbol retrieves none, one or more characters e.g. 'car-sharing, 'car-sharing', 'car-sharing' and other variations. Besides, this database automatically uses lemmatization. Another term is the Boolean operator 'AND' that allows combining terms in the exact way to find what we are looking for, narrowing the search results. In the case of this mentioned Boolean, all search terms must occur to be retrieved from the database. The other Boolean operator 'OR' means that any one of the search terms must occur to be retrieved. Early access documents were excluded since is a requirement to run search results in CitNetExplorer software.

The considered seminal publications are with the highest citation score i.e. JORGE, CORREIA (2013) with 35, and BOYACI, ZOGRAFOS, *et al.* (2016) with 33 citations. Both papers apply the term 'car-sharing' and words related to the problem addressed and method approach. Therefore, this strategy is aligned with the keywords utilized to retrieve publications from the database. Figure 6 shows the citation networks provided by CitNetExplorer.

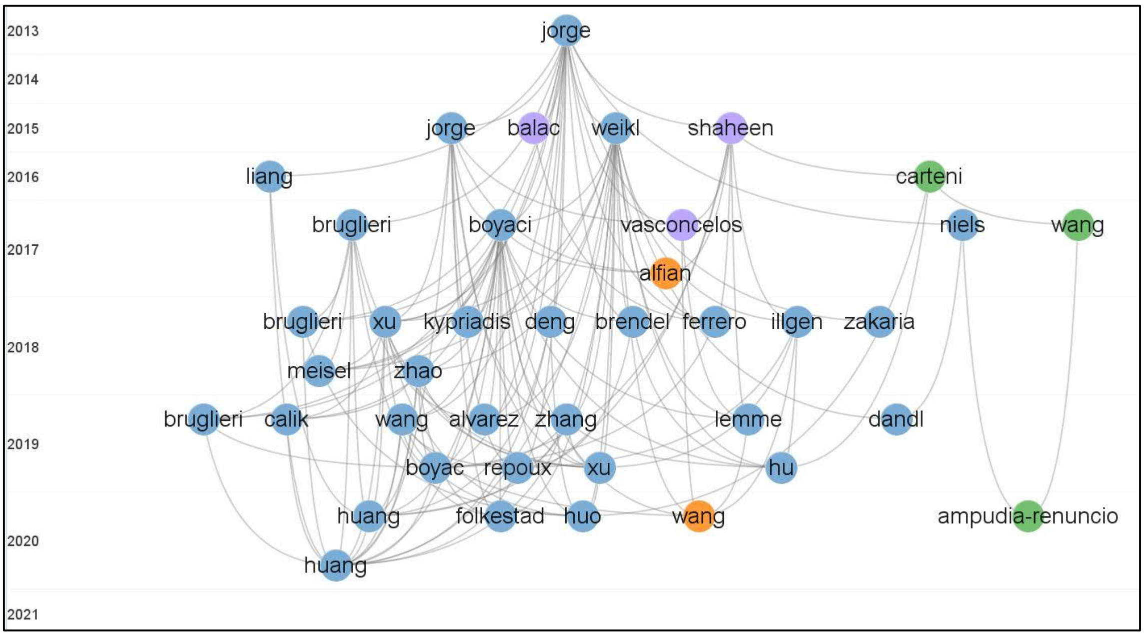
Figure 6: Citation networks



Author: provided by CitNetExplorer, overview.

Figure 6 shows each circle representing a publication. The two squares are the seminal papers. Labels represent the last name of the first author. By default, only 40 most frequently cited publications are included in this illustration. The horizontal location of publications is determined by their citation relations with other publications. Vertical location is according to the publication year. From the 189 publications, the software identified 564 citation links. Colors represent different clusters, based on their citation relations. For clustering, the resolution is set to 1.5. This parameter determined the level of detail of clustering. The number of clusters increases as the proportion of the resolution number increases. Also, the minimum cluster size is five publications. By the end, the results are six clusters of publications. Figure 7 elucidates the seminal articles better than the previous illustration. This illustration is a drill-down view of the expanded publications of JORGE, CORREIA (2013) and BOYACI, ZOGRAFOS, *et al.* (2016), including predecessors and successors with a minimum of citation links of two, maximum distance one, and adding intermediate publications. Beyond the seminal publications considered in this dissertation, WEIKL, BOGENBERGER (2015) is highlighted with many citation links.

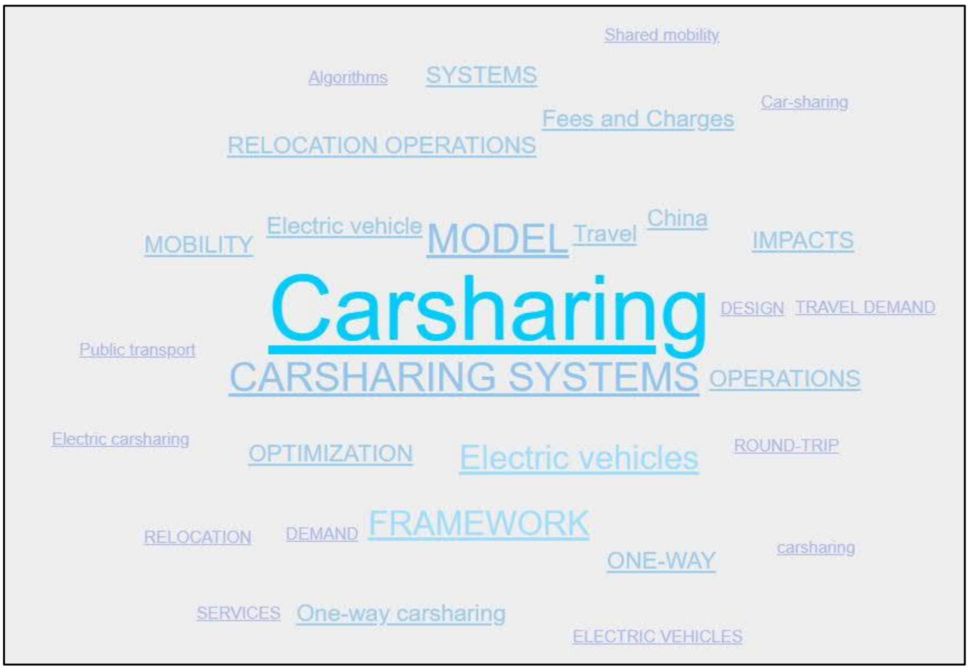
Figure 7: Seminal studies network



Source: CitNetExplorer.

The same string was used in Scopus to find publications. Next, publications of both databases were uploaded in Rayyan. This software also provides a word cloud including keywords from each indexed record. Figure 8 aims to quickly grasp the main topics presented in the studies. The words 'Car-sharing', 'car-sharing systems', 'model' are the terms more utilized in the results retrieved from databases.

Figure 8: Keywords word cloud



Source: CitNetExplorer.

The top six authors with more publications are presented in Table 2. In addition, institution, total citations, h-index, and i10-index. The number h-index is the largest number h such that h publications have at least h citations. The i10-index is the number of publications with at least ten citations. These numbers are according to GOOGLE (2021).

Table 2: Ranking of authors with more publication.

Author	Qty Publications	Institution	Citation	h-index	i10-index
Shaheen, S.A.	10	UC Berkeley	14304	54	136
Wang, Ling	10	Tongji University	713	16	24
An, Kun	9	Tongji University	539	14	17
Xu, Min	9	The Hong Kong Polytechnic University	1383	18	20
Ma, Wanjing	8	Tongji University	2424	25	87

Source: Elaborated by the author

Moreover, the results retrieved from databases present publications related to the journal. The top six journals related to a number of publications in this research are presented in Table 3. In addition, the table explores the journal quality according to CAPES (2021).

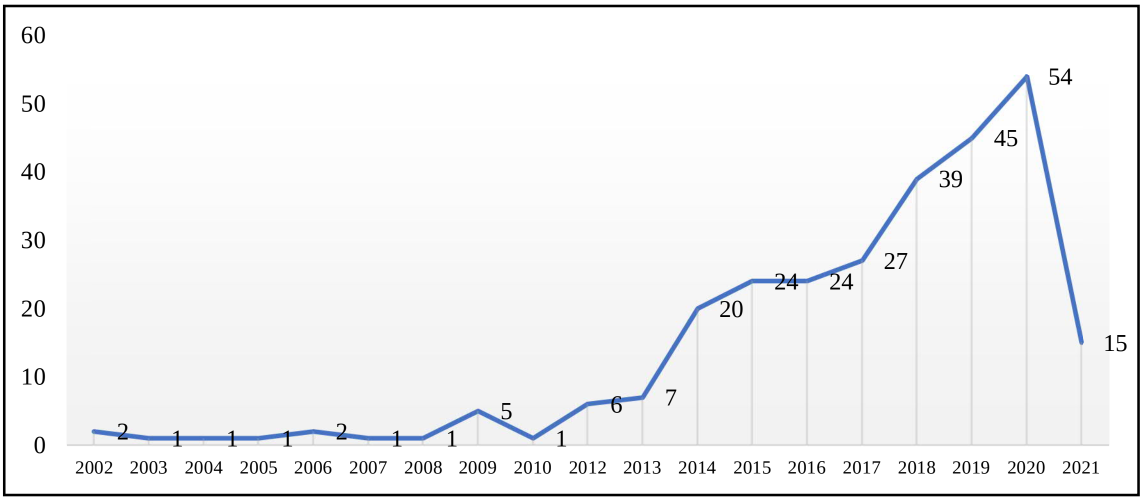
Table 3: Ranking of journals with more publication.

#	Journal	qty	Qualis
1	Transportation Research Record	18	B1
2	Transportation Research Part D: Transport and Environment	13	A1
3	Transportation Research Part B: Methodological	12	A1
4	Sustainability	10	B2
5	International Journal of Sustainable Transportation	8	A1
6	Transportation Research Part C: Emerging Technologies	8	A1

Source: elaborated by the author.

Figure 9 shows publications over the years. Since 2013, the number of publications is rising each year. The subject has been creating interest in the scientific society. In the year 2021, the expectation is that there will be many more papers published.

Figure 9: Yearly publications.

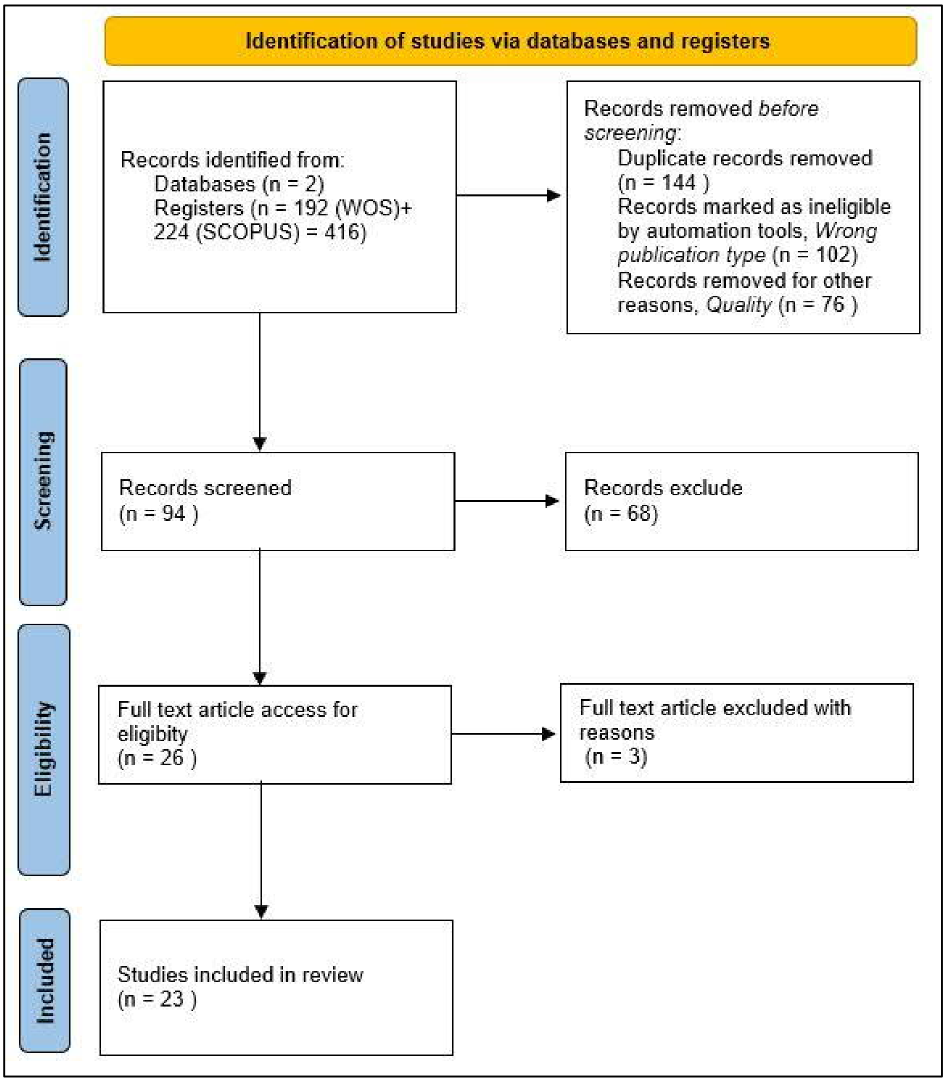


Source: elaborated by the author.

3.2.2 Synthesize literature

After retrieving publication results from databases, perform some bibliometric analysis, and apply inclusion and exclusion criteria then we perform data extraction and monitoring process to follow research protocol. In Rayyan was included and excluded publications with reasons. The included publications, full-text were downloaded from databases and uploaded in Mendeley. In this last software, is possible to highlight and create notes, supporting coding and identifying categories. Figure 10 shows the record refinement up to the included publications. Moreover, an Excel spreadsheet was created to compile extracted data and build a better organization of the included publications. This extraction template considered study findings, relationships between variables, source of data, study context, research methods, title, author, year, PICO, and country.

Figure 10: PRISMA 2020 flow diagram for new systematic reviews that includes searches of databases and registers only.



Source: Modified of Page, Moher, *et al*. (2021).

Following is the analysis and seeking to understand how the publications fit in building the literature. Implementing car-sharing with an electrical vehicle is a complex subject, involving many problems and approaches. The majority of the publications address just one of these problems more deeply and others consider fewer details although using a broader study scope. Codes were defined according to the publication's research questions, and subject. Five codes were discovered: Charging Infrastructure, CS Fleet, Implementation planning, Policies, and User profile. The main stakeholders of this service are Govern, User, and Operator (TUROŃ, KUBIK, *et al.*, 2020). These codes can be organized around the main stakeholders as Govern: Policies and Charging infrastructure; Operator: CS fleet; User: User profile; All three stakeholders: Implementation planning. The relation of codes and stakeholders is a simplistic solution, just associating the partner with the main role in the subject/code. Table 4 presents, in chronological order, the literature review codification

Table 4: Literature review codification.

Code	Techniques applied	Publication/ year	Place
Charging Infrastructure	Agent-based discrete-time model simulation	(CHEN, KOCKELMAN, *et al.*, 2016)	USA
	Mixed-integer stochastic program Benders decomposition algorithm	(ÇALIK, FORTZ, 2019)	USA
	Multi-agent activity-based simulation Mixed-integer program and maximal covering location problem P-Median optimization for charging stations.	(VOSOOGHI, PUCHINGER, *et al.*, 2020)	France
	Mixed-integer program Global polyhedral approximation of second-order cones	(XIE, WEI, *et al.*, 2020)	Generic
	Voronoi polygons Gini coefficients	(HARDINGHAUS, LÖCHER, *et al.*, 2020)	Germany
CS Fleet size	Closed queueing network model profit-maximizing optimization problem	(GEORGE, XIA, 2011)	France
	Agent-based discrete-time model simulation	(CHEN, KOCKELMAN, *et al.*, 2016)	EUA
	revealed-preference (RP) and stated-preference (SP) Monte Carlo simulation	(YOON, Taekwan, CHERRY, *et al.*, 2019)	China
	Discrete-event systems, Petri nets Queueing analysis	(FANTI, MANGINI, *et al.*, 2020)	Generic
Implementation planning	COBA (cost-benefit technique) Wardrop equilibrium procedure	(FELLOWS, PITFIELD, 2000)	UK
	Customer-side data survey Simulation method	(YOON, Byungun, KIM, *et al.*, 2012)	Korea
	generalized equilibrium based approach mixed-integer program	(NAIR, MILLER-HOOKS, 2014)	Generic

	kernel density estimation and apply Gradient Boosting Machine (GBM)	(WILLING, KLEMMER, *et al.*, 2017)	Germany
	Fuzzy Analytic Hierarchy Process (F-AHP) Fuzzy Technique for Order Preference by Similarity to Ideal Solution (F-TOPSIS)	(QU, YU, *et al.*, 2017)	China
	multicriteria decision making (MCDM) sensitivity analysis	(AWASTHI, OMRANI, *et al.*, 2018)	Luxembourg
	D numberanalysisive analysis collect data from expert, survey, sensors	(MO, DENG, 2019)	Generic
	Mixed-integer non-linear program rolling horizon method golden section line search method and a shadow price algorithm discrete event simulation	(HUANG, AN, *et al*., 2020)	China
	Social Network Analysis method Gordon's Techniques, Forced Relations Technique	(TUROŃ, KUBIK, *et al.*, 2020)	France
Policies	COBA (cost-benefit technique) Wardrop equilibrium procedure	(FELLOWS, PITFIELD, 2000)	UK
	System dynamics simulation	(GEUM, LEE, *et al.*, 2014)	Generic
	Survey Chi-square test of independence	(SUN, WANG, *et al.*, 2018)	China
	multicriteria decision making (MCDM) sensitivity analysis	(AWASTHI, OMRANI, *et al.*, 2018)	Luxembourg
	D numbers Sensitive analysis collect data from expert, survey, sensors	(MO, DENG, 2019)	Generic
	four-stage exploratory Delphi-study	(MERFELD, WILHELMS, *et al.*, 2019)	Generic
	City mobility, and EV Overview	(MOUNCE, NELSON, 2019)	Generic
	Social Network Analysis method Gordon's Techniques, Forced Relations Technique	(TUROŃ, KUBIK, *et al.*, 2020)	France
	Stated preference survey multinomial logit model Utility function	(JIN, YAO, *et al.*, 2020b)	China
User profile	Travel diary-based survey	(RABBITT, GHOSH, 2013)	Ireland
	5D model Hägerstrand's concept of innovation diffusion	(COLL, VANDERSMISSEN, *et al.*, 2014)	Canada

	Zero-inflated negative binomial (ZINB) regression		
	Survey probit model	(PRIETO, BALTAS, *et al.*, 2017)	London, Madrid, Paris, and Tokyo
	revealed-preference (RP) and stated-preference (SP) Monte Carlo simulation	(YOON, Taekwan, CHERRY, *et al.*, 2019)	China
	Nested logit model Stated preference survey	(JIN, YAO, *et al.*, 2020a)	China
	Innovation diffusion model	(ZHANG, Cen, SCHMÖCKER, *et al.*, 2020)	Japan

Source: elaborated by the author.

3.2.2.1 Charging infrastructure

The charging infrastructure is addressed in many topics in literature. In this section, we present its importance for EV spreading. In addition, papers evaluate charger types, charging time, station location, and pricing observing the service performance. Following, papers are summarized presenting their findings.

CHEN, KOCKELMAN, *et al.* (2016) is one of the most cited publications. It handles car-sharing management with electric autonomous vehicles using agent-based discrete-time model simulation. It discusses scenarios of recharging infrastructure and vehicle autonomy (maximum distance without refueling) in a city divided into thirty-two areas of a similar density of Austin, Texas, United States of America. From the work of SANTOS, Adelia, MCGUCKIN, *et al.*(2010), CHEN, KOCKELMAN, *et al.* (2016) is found that the travel distance and day hour distributions indicate that the fleet size is sensitive to battery recharge time and autonomy.

With each eighty-mile shared autonomous electric vehicle (SAEVs), replacing 3.7 private vehicles and each two hundred-mile SAEV replaces 5.5 private vehicles, with Tier II (240 volts CA) charging. With the 480-volt CC level III fast-charging infrastructure, these ratios increase to 5.4 vehicles for an eighty-mile SAEV and 6.8 vehicles for the SAEV two hundred-mile range. After a financial analysis considering the charging structure, maintenance and capital related to the vehicle, cost of electricity to charge the batteries, and insurance, the SAEV can be offered at a cost per kilometer equivalent to a private car owner, who runs low mileage and considerably lower when compared to systems that call the driver on demand (e.g. UBER). After the analysis comparing various scenarios, the operation of SAEV with cars of eighty miles of autonomy and level II charger is the lowest cost per mile.

Opening recharging stations is a high-cost investment and it needs to be well evaluated. ÇALIK, FORTZ (2019) addressed this subject using a mixed-integer stochastic program and Benders decomposition algorithm. The applied method brings good results for scenarios that already have a reasonable number of stations. For fewer stations, the model does not work very well. This model considers the potential customer demand based on relevant historical data and the expected revenue of the demand portion that could be served feasibly with the opened charging stations.

The study of VOSOOGHI, PUCHINGER, *et al.*(2020) focuses on charging station placement, charging type, and battery swapping. The work applied agent-based simulation in the Rouen Normandy, metropolitan area in France. Findings are that the service performance is dependable of charging infrastructure. Battery swapping, faster chargers, and optimal station placement contribute to higher service performance.

A service model to optimize the charging schedule based on service price is proposed by XIE, WEI, *et al.*, (2020). The main technique is a mixed-integer quadratic program through a global polyhedral approximation of second-order cones. The approach showed that with the flexible price from the grid perspective is possible to reduce peak and valleys on energy demand. On the transportation side, this solution may cause switch user preferences for the EV user on rush time. These people may opt for public transportation due to energy prices.

In Berlin, HARDINGHAUS, LÖCHER, *et al.*(2020) analyzes the distribution of charging stations. They are concentrated in the central area of the cities, although the use is relative the same among them. Voronoi polygons and GINI coefficients are utilized in the study. A suggested strategy for charging station distribution is to adopt a bottom-up approach. The public charging stations mostly attend car-sharing vehicles, although there is a private EV demand for them. Private EVs usually are recharged at home. Thus, CSEV supports the spreading of EVs, and the lack of charging structure hinds EV adoption. A relevant topic for system performance is ICEV parked blocking the access of an EV to recharge, and an EV charged using the space only for parking.

The charging infrastructure is one of the most important topics to deploy a CSEV service. Many techniques were presented and different perspectives and implications to the service are addressed. Charger type, station location, battery swapping, charging time (peak hours), are relevant subjects to be taken into account when starting a car-sharing using electrical vehicles.

3.2.2.2 CS fleet size

The EV contributes to emissions reduction and city mobility. The quantity of vehicles for a car-sharing service has been addressed in the literature. Following, present different strategies, most of them utilizing an optimization approach.

GEORGE, XIA (2011) present a closed queueing network mode and approach profit-maximizing optimization problem for CSEV fleet sizing. It seeks the profit-optimal fleet size for the operator. The study states that strategies for rebalancing the cars among stations provide a better system efficiency.

Beyond the charging infrastructure, CHEN, KOCKELMAN, *et al.* (2016) in its model also consider the fleet size. Variables that affect directly this quantity are the vehicle autonomy and charger type. However, an investigation regards investments in a vehicle with higher autonomy and a fast charger should be verified. In this study, the best arrangement was the standard EV autonomy with the fast charger infrastructure.

YOON, Taekwan, CHERRY, *et al.*(2019) presents a model using revealed-preference (RP), stated-preference (SP) surveys, and Monte Carlo simulation. The charger type has a significant impact on fleet size. From the user perspective, all car-sharing scenarios are cheaper after twenty km of travel distance. The simulation confirms that the CSEV service is profitable, estimating five years the project payback.

FANTI, MANGINI, *et al.* (2020) use discrete event system frameworks for car-sharing fleet sizing with electric vehicles. The study proposes a two-level strategy. First, the system is modeled as a discrete event system in a closed queueing network to identify the optimal fleet size considering the operator's profit. The second level is modeled by timed Petri net, to check details such as user behavior during the day.

These papers presented options to answer the fleet size. Many factors influence the quantity of the vehicles, such as relocating strategies, charger type, vehicle autonomy. All these variables are important to the service feasibility. The optimization approach seeks the operator's profit. Future studies may consider other approaches as reduction of GHG.

3.2.2.3 Implementation planning

The study scope of implementation planning of CSEV can be more specific or broad including other transport modes or projects. Following, publications presents cases approaching a specific problem in CSEV implementation; others deal with models to implement CSEV. Literature retrieved also broader study scope considering shared mobility (bikes, cars, EV) and even other projects supporting the decision to invest in the best mobility solution project (e.g. roads and other transport modes). Publications also propose a solution to find the best car-sharing service area.

According to FELLOWS, PITFIELD (2000) the UK government evaluates new roads and public transport schemes utilizing the cost/benefit technique. The same strategy that this work applies to car-sharing services. Additional Wardrop equilibrium procedure was built for the transport matrix considering CS market share 1, 5%, 3%, and 20%. The most conservative scenario results in similar benefits of major road schemes. Other CS scenarios exceed road scheme benefits. Car-sharing yields fuel-saving, road safety, public investment savings and reduce VKT, and emissions.

YOON, Byungun, KIM, *et al.* (2012) presented a paper proposing a framework for a product-service system. To confirm the consistency of the study, Yoon applied the proposed evaluation methodology and process to a car-sharing system in Korea. The proposed model articulates in customer side and provider side simultaneously. The customer side utilizes a survey to evaluate the feasibility and for the provider side service, a model feasibility test is performed. Then a final analysis is considered for the result. The framework application in a car-sharing system presents a satisfactory result.

The best design of sharing vehicles such as cars, bicycles, electric cars is addressed by NAIR, MILLER-HOOKS (2014). This study developed a model focusing in optimize the system configurations, including station locations; station capacity, fleet size, and revenue. The model consists bi-level, mixed-integer program. The work suggests that when parking costs are high and station infrastructure is low, the model reduces station quantity. The work proposed other good quality solutions, e.g. a genetic algorithm to design a bicycle sharing system for a large-scale multimodal network representing Washington, DC.

The study from WILLING, KLEMMER, *et al.* (2017) approaches the region supported by car-sharing. The objective is to identify and increase the service availability in regions demanding the service and reduces the other way around. Data from a car-sharing provider in Amsterdam in combination with points of interest (POIs) were analyzed. Thus, the work considered the influence of POIs on the CS demand and replicate results to Berlin. The prediction service is similar between both cities. The main techniques were kernel density estimation and applied Gradient Boosting Machine (GBM).

The study of QU, YU, *et al.* (2017) uses the Fuzzy Analytic Hierarchy Process (F-AHP) Fuzzy Technique for Order Preference by Similarity to Ideal Solution (F-TOPSIS) to evaluate the best option for car-sharing. F-AHP is utilized to weight indicators and F-TOPSIS demonstrates its advantage in comparing potential options. The options are rental, leasing, piggybacking, and drive-sharing. The evaluation was performed through indicators related to the dimensions: economic, environmental system performance, and social. A case study to show the applicability of the proposed framework and conduct sensitivity analysis experiments to figure out the effect of indicators on the decision-making process. The proposed approach can evaluate car-sharing options with uncertainty and vagueness.

The research of AWASTHI, OMRANI, *et al.* (2018) utilizes multicriteria decision making (MCDM) and sensitivity analysis. MCDM techniques such as fuzzy TOPSIS, fuzzy VIKOR, and fuzzy GRA are applied for sustainability evaluation of urban mobility projects. Three projects in Luxemburg were evaluated, consisting of a new tramway in the downtown, re-organization bus lines, and implementation of an electric vehicle car-sharing station-based. A sensitive analysis is performed to check the influence of input parameters in the model result. Mobility projects should consider economic, social, environmental, and technical aspects. The model resulted in choosing the new tramway in the city center of Luxembourg as the best alternative for implementation.

A mathematical tool to deal with uncertain information is applied by MO, DENG (2019). This tool, called D numbers, is employed to fusion information and check its effectiveness. A sensitive analysis is also performed to best understand influences. Data sources are experts, surveys, sensors. Mo informs the model presented is suitable for other scenarios of decision-making.

The study of HUANG, AN, *et al.*, (2020) addressed a variety of problems, such as maximize operator profit, fleet size, station capacity, relocation strategy, state of charge (SOC). Huang divided the mixed integer non-linear program model into two levels. First, dealing with station capacity and fleet size optimization utilizes shadow price and the golden section line search method. Second, the rolling horizon framework is utilized for relocating and SOC issues.

TUROŃ, KUBIK, *et al.* (2020) applies Social Network Analysis method and Gordon's Techniques named Forced Relations Technique to understand factors that promote and reduce shared services. Recommendations for the service are the possibility to customer access the quality service, develop a policy regards charging infrastructure for CSEVs, ensure user security, simple price policy. Other concerns that must be addressed by stakeholders are infrastructure, fleet condition, rental area, law requirements, location of parking spaces, and vehicle replacements.

Many tools for implementing car-sharing with electric vehicles are available in the literature. Considering the complexity of the subject during the implementation phase may occur other problems. Although the presented methods are flexible to identify them previously or during the implementation phase. Expert opinion has a considerable weight in many models.

3.2.2.4 Policies

In this section, methods to evaluate and create policies are indicated. Quantitative and quantitative approaches are addressed in the literature. Some methods utilized in the previous code (implementation planning) can be applied to policies. Next paragraphs, the point of view of policies is considered in papers.

The cost-benefit analysis (COBA) proposed by FELLOWS, PITFIELD (2000) can be used for the government to construct policies. According to the same study, UK utilizes the method. The case utilized in this paper was a project. Future studies should consider a policy to the case study, to elucidate the applicability.

The approach of GEUM, LEE, *et al.*(2014) is a model to evaluate scenarios. Thus, policies can be added to the model to attends to govern goals. The first step is building a scenario with a qualitative approach. The second step is technology road mapping and its incorporation into the scenario (quantitative and qualitative). The last step is the system dynamics solution with a qualitative approach. After these steps, scenarios, and effects are analyzed. Geum informs the need to simplify some assumptions. Other investigations would bring reliability to this study.

SUN, WANG, *et al.* (2018) present a holistic mobility solution. Car-sharing with electrical vehicles has a key role in supplementing the public transport mode. The method employed support understanding user perspective and governs creating solutions and policies for the population.

AWASTHI, OMRANI, *et al.* (2018) apply a method supporting governments on decision-making. Policies must be evaluated in long-range and the method presented in the paper are multicriteria decision making (MCDM) techniques namely fuzzy TOPSIS, fuzzy VIKOR, and fuzzy GRA for sustainability evaluation of urban mobility projects.

MO, DENG (2019) presented the D number method, utilizing data sources as experts, sensors, and reports. The method approaches a broad scope including policies. Policies can receive inputs from different perspectives and stakeholders.

MERFELD, WILHELMS, *et al.*, (2019) propose a four-stage exploratory Delphi study. The model recruited forty international experts for uncovering drivers, barriers, and future developments in CSEV. Policies have to be careful and balance to avoid hindering innovation in the short term and fulfilling their functions in ensuring safety and providing regulatory monitoring in the long term. The paper suggests the creation of a cross-functional team that includes technicians, market experts, city developers, and legal experts that will develop a legislative framework together and iteratively.

MOUNCE, NELSON (2019) offers an overview of city mobility and the relevant role of EVs and autonomous vehicles in the future. Car-sharing has to be integrated into public transportation and articulated with other modes to offer to the population an optimal public transportation solution.

TUROŃ, KUBIK, *et al.*(2020) identifies governments as one of the main stakeholders for the CSEV service. The paper recommends governments creating policies considering infrastructure for charging electric vehicles, technical fleet issues, monitoring prices, coverage area, and user security.

JIN, YAO, *et al.*, (2020b) adopted a stated preference survey, multinomial logit model, and utility function in their model to understand the membership of CSEV in Beijing, China. Results indicate CSEV is affected by policies such as quota scheme on private car plate registration and restrictions on vehicle use owing to license. Other policies are allowing shared vehicles to use bus lanes and reducing or exempting parking costs in other parking spaces additionally to car-sharing stations the paper confirms CSEV as a strategy to provide EV market penetration. Governments should take into consideration this service as a mobility tool and with operators promote adoption via advertising a positive image to the public.

Many techniques for policies are in common to implementing planning. The high weight of experts' opinions is predominant in some publications. Governments should consider CSEV as a mobility solution to the population, promoting its use. Laws should be developed considering stakeholders' opinions and techniques presented.

3.2.2.5 User profile

The user profile is the key factor for the CSEV implementation. Understanding the user or the customer behavior, operators and governments may create strategies to help them and the service to conquer longevity. This section approaches the main demographic factors and location influencing membership adoption. In addition, the relation between CS and GHG emission and mobility market share are commented on in the studies.

RABBITT, GHOSH (2013) submit a survey to the Irish population to understand the car-sharing potential adoption. The survey considered geographic, financial, and environmental factors. Findings show car owners who travel predominantly on alternative modes, can save costs and reduce GHG emissions with CS adoption.

COLL, VANDERSMISSEN, *et al.* (2014) address membership evolution utilizing the methods 5D model (density, diversity, design, distance to transit, and destination accessibility) with Hägerstrand's concept of innovation diffusion. The authors created a model utilizing zero-inflated negative binomial (ZINB) to shape the spatial diffusion of the number of car-sharing members in Québec City from 1996 to 2008. Finding are the most socio-economic factors influences membership are education, non-motorization, and family structure. Moreover, bus accessibility impact positively CS membership, confirming the completive of public transportation offering better urban mobility.

YOON, Taekwan, CHERRY, *et al.*(2019) applied revealed-preference (RP) and stated-preference (SP) surveys to Beijing citizens. In urban mobility, CSEV may represent 9% to 32% of the market share.

ZHANG, Cen, SCHMÖCKER, *et al.* (2020) using the innovation diffusion model to predicted membership, based on the existence of specific stations. The data examined are from Ha: mo RIDE car-sharing system (Toyota, Japan), a one-way car-sharing operator. Results show the membership growth should increase around transit hubs and public facilities.

The user perspective was presented in this section. The method most used in literature to understand the customer profile was through surveys direct with the population. Social demographics factors are relevant for car-sharing adoption. Localization and access to transit hub foment the use of car-sharing services. The representation of this service in urban mobility was considered 9% to 32% for Beijing, China. CSEV is a tool for complement public transportation and the potential of reducing GHG.

3.3 Reporting and dissemination

This section summarizes the literature review proposed. Each code is briefly commented, offering an overview of the subject. Implications are highlighted and future studies recommended.

This literature review started presenting previous studies and the justification for a new literature review. According to the author's knowledge, do not exist a literature review focusing on the implementation service of CSEV. Furthermore, strategies to select keywords from the database, such as seminal papers and expert papers corroborated with the choice of terms.

After, the author retrieves records from Scopus and WoS, some bibliometric displayed, such as publication over the years, authors and journals with more publications, word-cloud of keywords. The subject has been receiving attention from researchers and the number of publications is increasing mainly in recent years. Journals with high quality are publishing the subject of this current research. The authors with more publications are mainly from Asia, and some are from North America and Europe. This is the same trend of the EV market penetration previously reported, compatible with the countries from the selected publications in this literature review. The number of publications considering a one-way car-sharing model with EV is increasing over the years.

The research protocol was constantly checked to avoid bias. After the application of filters, 23 studies were selected. Next, the codification organized records around the research problem and identified 5 clusters: Charging Infrastructure, CS Fleet size, Implementation planning, Policies, and User profile. Charging Infrastructure and CS Fleet size are predominantly utilized quantitative methods of optimizing. User profile largely employs survey methods. Implementation planning and Policies mix quantitative and qualitative approaches.

Implementing car-sharing with electrical vehicles is a vast research field. It involves several stakeholders and many problems can be addressed. In the author's viewpoint, the subject is still far to be exhausted. CSEV is confirmed to be a tool for urban mobility promoting the spread of electrical vehicles and reducing GHG emissions. These findings confirm the hypothesis stated in Chapter 1, of the popularization of electric vehicles (EV) due to car-sharing, and the reduction of gases generated from the cars' emissions.

Future research recommendations are investigating policies' effect and discuss their implementation. Studies also should consider region research out of Asia, Europe, and North America. Literature employs methods sometimes far from simplicity.

The next chapter proposes a framework for implementing car-sharing with electrical vehicles. The framework seeks to be a starting point to evaluate a candidate region for car-sharing. Afterward, the framework is applied in Beijing, China. The city has a well succeed CSEV business and it allows to consider all framework steps.

4. STUDY CASE: BEIJING, CHINA

In this section, a framework for implementing car-sharing with electrical vehicles is developed and applied in Beijing, China. Such framework is built on the literature review (Chapter 3), that analysis some recognized and benchmark cases. The method of cases' selection to the study case is maximum variation, utilizing multiple heterogeneous cases to obtain data under varied circumstances. This method is recommended for exploratory research (RAGAB, ARISHA, 2018). The following sections explain how the four selected cases saturate the knowledge and attend cases heterogeneity. From the four cases, the main indicators are extracted and compared with Beijing data. To obtain data from Beijing, city reports and previous surveys were consulted. Results are registered and presented in this chapter.

4.1 Study case with multiple cases

The study case is a research that is not possible to disassociate the phenomenon of this context (GIL, 2002). Following, cases were select up to saturate the knowledge of the subject (four cases) and they are compared and thus increase the external validity of the current study.

4.2 Cases' Summary

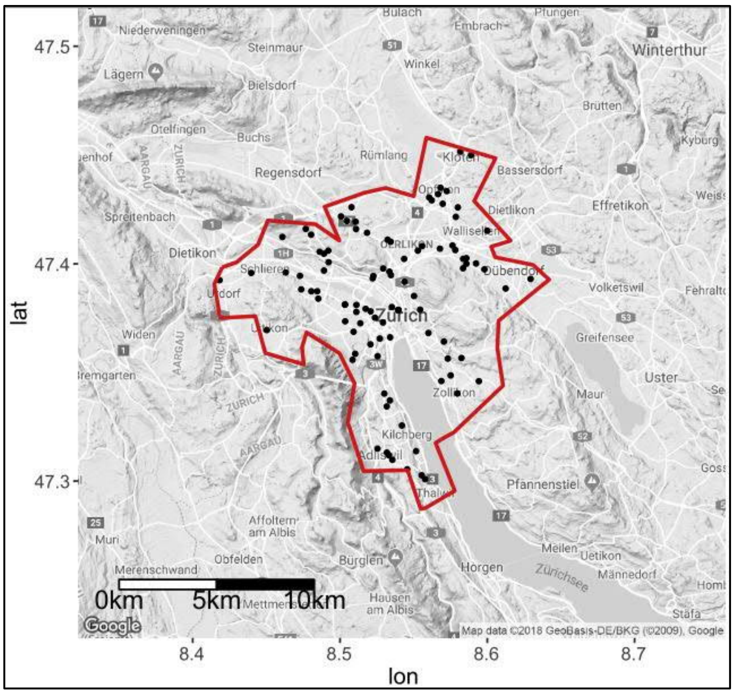
This work gathers multiple cases to attends to the satisfactory quantity informed by YIN (2001), enough to saturate knowledge regards the subject. The following cases have different points of view contributing to the study. The first, is a European case, with an Agent-Based microsimulation approach. The second case regards an Asian city concerned about car-sharing expansion and emissions. The next one is a holistic view of car-sharing. This third case considers car-sharing as an agent to provide sustainable public transportation among other modes. The last one gathers service indicators and evaluates options of car-sharing types. Thus, summarizing a European and Asian perspective as well as a holistic view among other modes, and finally, the car-sharing type diversity is also considered.

4.2.1 Case 1

Car-sharing started in Swiss and spread around the world. In Europe is notorious the increase of shared services, meaning operators adding more vehicles to the fleet, new operators coming, and car-makers (Daimler, Peugeot BMW, and others) investing in this business.

CIARI, SCHUESSLER, *et al.*, (2013) article uses Activity-Based Microsimulation to estimate car-sharing demand in Zurich (Switzerland) for car-sharing two-way station-based. The studied area has around one million inhabitants, two hundred and thirty-six thousand directed links, and more than seventy-three thousand nodes. The study focuses the access to car-sharing vehicles, and time rates. The software supporting the required computation is called MATSim. The simulation considers one hundred and sixty thousand agents representing Zurich urban area. Results are compared with Mobility Switzerland, the main car-sharing operator in the region with two thousand, three hundred and fifty cars at one thousand and two hundred stations and it is one of the leaders worldwide in terms of many customers. Figure 11 represents the service area and initial vehicle distribution according to BALAC, BECKER, *et al.*,(2019).

Figure 11: Initial distribution of the car-sharing vehicles and the boundaries of the service area.



Source: Modified of Balac, Becker, *et al.*, (2019, p. 108).

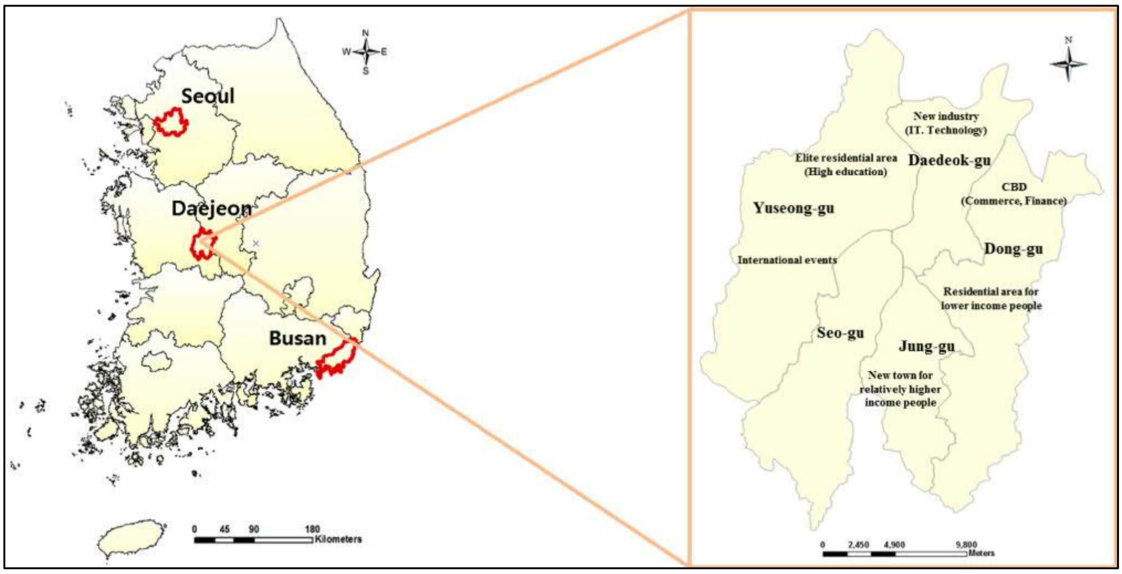
The classic four-step model for travel demand is highly utilized in the literature although for new options this model is not well suited for this purpose. The car-sharing characteristics like access time and the service is not always available, makes it even harder utilizes classic models. Car-sharing fare is composed of a mix of time and distance, generally. Each mode has several details that push the model to consider a high spatial resolution, and individual social demographic attributes (age, gender, occupation, home location, car availability, etc) to better estimate the service demand. For the simulation, daily activities i.e. work, education, shop, and leisure are also considered the following data: OD Matrix, departure time, transport modes, routes, traveling time and the cost of the trip, trip purpose, access, and egress time. Thus, the activity-based approach with a multi-agent system is recommended for this study. Utilizing MATSim, a synthetic population reflecting census data, and the city infrastructure is represented in this software creating a virtual world.

This work addresses the access to car-sharing vehicles and time-dependent fees. The software considers fixed attributes, agents' daily plans, utility functions. The intention is to maximize global utility function with the modes: car, public transport, bicycle, walk, and car-sharing. This paper considers the car-sharing fare a blend of distance and time used. Car-sharing is mostly used for travel that is not made regularly and, in many cases, involves leisure and shopping activities. The simulation results are satisfactory matching the real data, for the study purpose. The model still needs some development to support the evaluation of different scenarios and policies.

4.2.2 Case 2

The study of LEE, BYUN, *et al.*, (2014) proposes to understand the characteristics of car-sharing users from Daejeon, Korea, and advise the optimal covered locations. Utilizing GIS (geographic information system), external and internal demand is verified. Regions are ranked by a score of a grid analysis. Carbon dioxide emissions reduction is predicated on this model. An important factor is accessibility to car-sharing locations for the sustainability of this service. The following map (Figure 12) presents Daejeon, an urban Korean city.

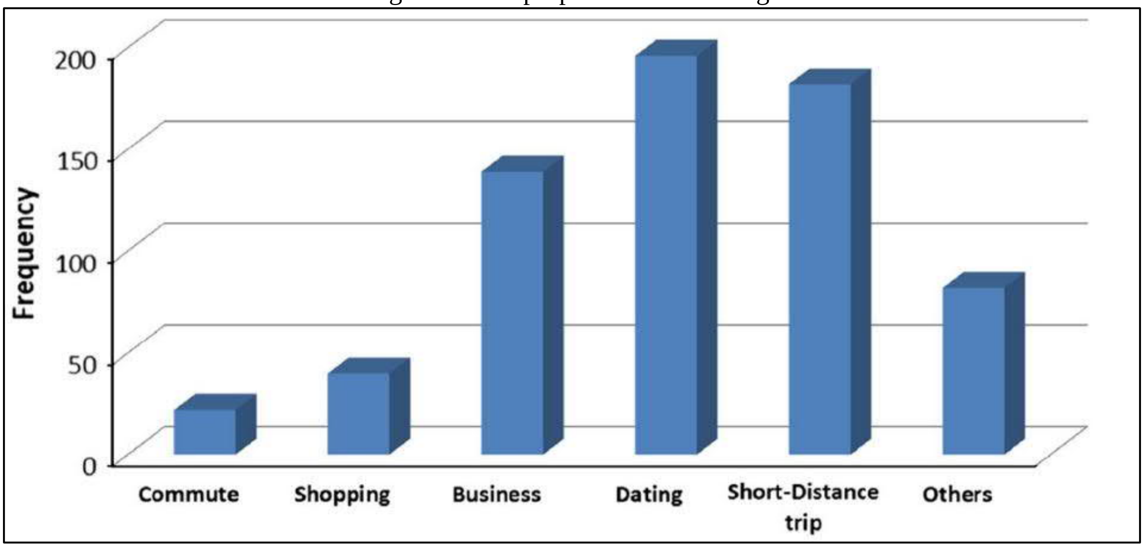
Figure 12: Map of Daejeon, the case study area



Source: Modified of Lee, Byun, *et al.*, (2014, p. 2323)

A survey also indicates the main trip purposes of car-sharing. These trips are usually for short distances and leisure activities. Other main reasons are dating, business purposes, and go shopping (Figure 13).

Figure 13: the purpose of Car-sharing

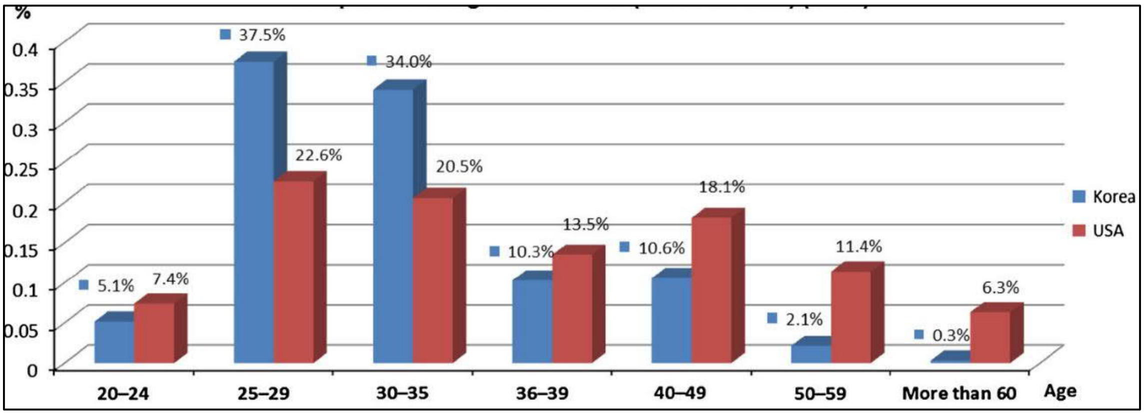


Source: Modified of Lee, Byun, *et al.*, (2014, p. 2321)

The research investigated the convenient and inconvenient elements of using car-sharing. For convenient reasons mainly are rent per hour, easy reservation and use, cheaper than a private car, on the other hand, inconvenient elements are two-way return, inconvenient reservation, search for a vehicle at the parking lot, high cost. In addition, most Asians are not comfortable with sharing a vehicle. It suggests reservations should be more user-friendly for all people and add a one-way option.

Household income has been presented as an important element to car-sharing success. A proposition from LEE, BYUN, *et al.*, (2014) is to utilize land price since this variable is related to the household income due to lack of available data. The age distribution is another element highlighted and in Korea and the USA, the most group age of car-sharing members are in the range 26-35 years old (Figure 14). Thus, universities, commercial areas are pointed as the best candidates to receive this service.

Figure 14: Comparison of Age Distribution (Korea versus USA)



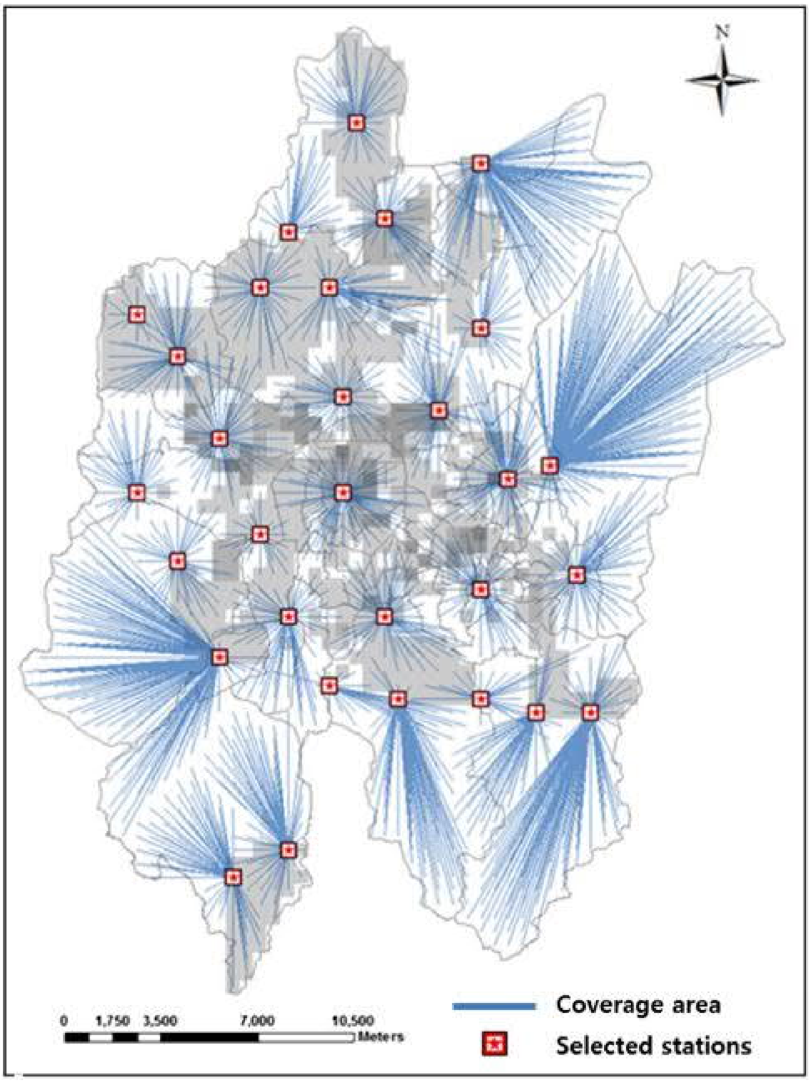
Source: Modified of of Lee, Byun, et al., (2014, p. 2323)

For commuters or people out of the city, a car-sharing service would be preferred to be close to subway and bus stations. Good access to public transportation and dense areas attracts more users.

The process of identifying the best location starts with a select location based on internal factors (age distribution, land price, commercial areas, government offices, universities, subways station) and external factors (railway stations and bus terminals). After that, a grid analysis splitting the city into square cells of 500-meter side and factors observed on an overlay analysis and were weighted for each cell and ranked. The analytic hierarchy process (AHP) technique was applied in this model to consider the importance of the indicators that impact car-sharing success. The most important indicators resulting from AHP are age distribution, commercial areas, railway stations, and bus terminals. Following a p-median model to determine the minimum total distance between users and the car-sharing stations, contributing to set the location the best places for car-sharing.

The emission reduction is calculated based on vehicle kilometers traveled by shared vehicles and car-sharing participation rate when correct attending user demand. This paper estimates mileage reduction of 7,3% and car-sharing membership in 2013 achieve 7,75% and properly distributed it will increase to 20,1% in 2030. Thus, the paper estimates a dioxide carbon reduction of 5,31% private car users in 2013 and 13,37% in 2020. Figure 15 represents the potential station location and coverage area in Daejeon.

Figure 15: Potentially sustainable and profitable locations for car-sharing companies



Source: Modified of of Lee, Byun, *et al.*, (2014, p. 2326)

4.2.3 Case 3

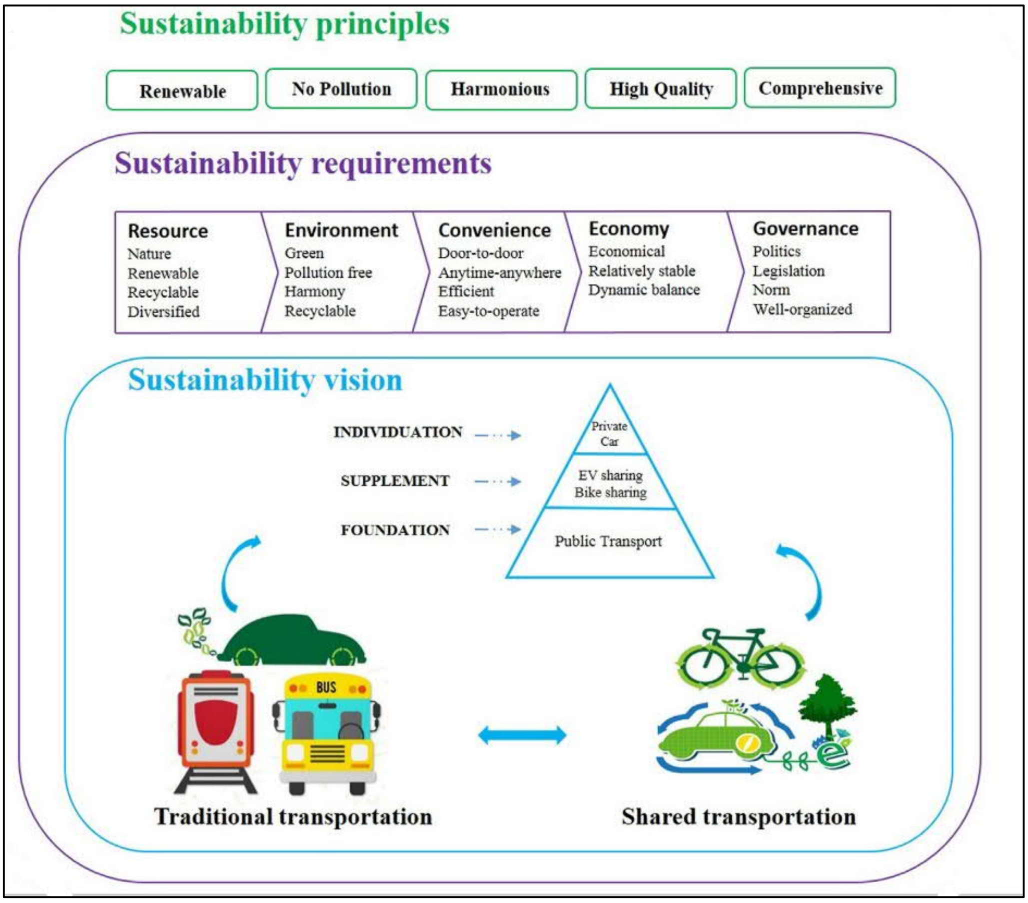
Mega-cities face issues related to traffic jams and emissions. The paper SUN, WANG, *et al.*, (2018) contributes mitigate these inconveniences through car-sharing and bike-sharing considering the perspective of the environment, convenience, economy, and Governance. The study case is Beijing in China and the author researches the current situation, feasibility, and adaptation of shared transportation. These transport modes have the potential in alleviating the traffic and environmental issues of mega-cities.

This paper first investigates the main concerns in mega-cities due to traffic and environmental. Next, evaluates the role of shared transportation to reduce mentioned concerns. Problems and solutions are sorted and summarized. And then Beijing is the study case and a survey is applied and with its results, a better understanding of the user perception is made. The paper ends by informing some considerations to promote shared transportation.

Mega-cites have some similar characteristics as high car ownership, commuting concentration, long-distance trips, rail transit system, high travel efficiency requirements, high demand for parking space.

Sustainable principles should be considered to mobility as energy from renewable resources, materials able to recycle, no pollution, reliable and safe to give users quality life, options of transport mode to offer flexibility, integrated transportation mode, holistic collaboration. Sustainable requirements involve resources, environment, convenience, economy, and governance. Figure 16, represents a triangle of a sustainable vision for mobility is proposed by authors being its foundation the public transport, and above layer, to supplement mobility with EV car-sharing and bike-sharing and on the top individuation with private car.

Figure 16: The macroscopical vision of sustainable transportation with shared transportation.



Source: Modified of Sun, Wang, et al., (2018, p. 1020)

Beijing was considered one of the most air-polluted cities in the world and some initiatives have been developed as public bicycles, traffic restriction based on the last digit plate, car purchase restrictions, and ride-hailing services.

A survey was designed to understand the user adaptation and expectations regards shared transportation performance in Beijing. The socio-economic variables are gender, age, education level, household income, and car ownership. Use intensity e.g. how many times per month the user utilizes the service and reason. User's concerns are for EV car-sharing are do not support off-site return car (for two-way option), user afraid to not return the car in time, billing mode ambiguous, price is high, vehicle autonomy, distance to the station.

Some practical considerations are before starting the service, a survey should be applied to understand concerns, intentions, needs for this service, and then develop a plan to implement. New technologies, phone applications (APPs) can support better operation and user experience. Sharing services should be a complement to public transport to better urban accessibility and both being integrated and a public-private partnership as well.

This case also highlights for bike-sharing, the national total riding distance is more than 2.5 billion kilometers, equivalent to reduce the nitrogen emissions of five hundred and forty thousand tons, reduce PM 2.5 of 4.5 billion mg, and save forty-five million liters of gasoline.

4.2.4 Case 4

The study of QU, YU, *et al.*, (2017) approaches an evaluation of car-sharing options providing main indicators to the program. Car-sharing options are:

1. Rental; a user pays for the period of use, usually for a shorter term.
2. Leasing; a long-term agreement for the use of the car, usually more than six months, and both parts cannot change any terms of the car-sharing agreement during validity.
3. Driving-for-you; this service business focuses on high-income customers, and they order the service by phone or mobile application and quite soon arrives an experienced driver. It is different from taxies.
4. Piggy-backing; this option supports the relocation service. It means that if the company would like to move a car to a target area and a user is willing to go to the same place, a good price for a win-win solution is offered. Although, is common restrictions of time rental and vehicle model.
5. Drive-sharing; users with the same destination share a car and travel costs. It is a complex service to meet the same users' desires.

The work has 3 sections. The first one consists to point twenty-four car-sharing indicators based on methodology SCUMN (Specific, Comprehensive, Understandable, Measurable, and Neutral). Following, each indicator receives a weight through the Fuzzy Analytic Hierarchy Process (F-AHP) and conducts a consistency check. The last section compares options and applies the Fuzzy Technique for Order Preference by Similarity to Ideal Solution (F-TOPSIS). A case study is conducted to validate the proposed approach and rank five car-sharing options based on those twenty-four indicators. A sensitive analysis is performed with thirty-one experiments to best understand how they influence decision-making.

The SCUMN methodology identified seventy-eight indicators based on the literature review. Some adjustment was required as indicators with the same proposition were merged, some that are not applied to car-sharing were removed and some that apply were added.

In the following step, to weight, each indicator, a method for a multi-criteria decision process called Analytic Hierarchy Process (AHP) was proposed. Thus, building a matrix comparing pair-wise indicators. This study applies F-AHP and F- TOPSIS to support these decisions since some indicators vague or uncertain. The indicators were split into four categories for better comparison (Economic, environmental, car-sharing system performance, social) with six indicators each. Following you find the result per category:

Economic: Productivity; Employment; Tax revenues; Public expenditure; operating cost; travel cost

Environmental: Emissions of air pollutants; Energy consumption; Noise Level; Land usage; Congestion; Waste

Car-sharing system performance: Accidents, Mobility; System reliability; Service quality; Car utilization ratio; Reservation acceptance ratio

Social: Affordability; Public health; Equity; Access; Customer satisfaction; Safety

Results from study cases show a higher score for drive-sharing. This option is considered the best option means users with the same destination share a car and the travel cost. Even with sensitive analysis, all experiments this car-sharing type were in the first place.

4.3 Analyzing the study case evidence

After summarizing cases, all indicators considered on them are extracted and compilated in Table 5. Firstly, an evaluation of indicators properties should have attended SCUMN principles for car-sharing (GILLIS, SEMANJSKI, *et al.*, 2016; LITMAN, 2007; MILLER, WITLOX, *et al.*, 2013) as following:

1. Specific: The indicator can be assessed independent from others, relevant to the service;

2. Comprehensive: Indicators should offer a holistic view including social, economic, and social aspects. Beyond, system operations performance should be measured.

3. Understandable: Ease understanding of indicators avoids misunderstood and as much includes more information to an indicator, it tends to become less understandable.

4. Measurable: Indicators should be accurate, and data collection easy to obtain. The Standardisation of indicators is important to compare different scenarios and options.

5. Neutral: Indicators should be impartial and do not tend to bias a favorite option.

Many of them with similar meanings or measures the same variable were grouped. By the end, thirty-nine indicators were obtained. Additionally, a table able to link each indicator and concerning case is created for a better understanding.

Table 5: Crosscheck between the indicator and case number.

Category	**Indicators**	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Total**
Social	Age	x	x	x		3
Social	Gender	x		x		2
Social	Car availability / ownership	x		x		2
Social	Traveling time	x		x		2
Social	Trip purpose	x		x		2
Social	OD Matrix	x				1
Social	Transport modes (available)	x				1
Social	Access and egress time	x				1
Social	Density area		x			1
Social	Education Level			x		1
Social	EV use			x		1
Social	Affordability				x	1
Social	Public health				x	1
Social	Equity				x	1
Social	Access				x	1
Social	Customer satisfaction				x	1
Social	Safety				x	1
Environmental	Emissions of air pollutants		x		x	2
Environmental	VKT or VMT (miles)		x			1
Environmental	Energy consumption				x	1
Environmental	Noise Level				x	1
Environmental	Land usage				x	1
Environmental	Congestion				x	1
Environmental	Waste				x	1

Economic	Household income or Land price	x	x	x		3
Economic	Travel cost	x			x	2
Economic	Operating cost				x	1
Economic	Productivity				x	1
Economic	Tax revenues				x	1
Economic	Public expenditure				x	1
Car-sharing system performance	Service quality			x	x	2
Car-sharing system performance	Car-sharing frequency use			x		1
Car-sharing system performance	Transport before reach CSEV			x		1
Car-sharing system performance	Willing to use CSEV			x		1
Car-sharing system performance	Accidents				x	1
Car-sharing system performance	System reliability				x	1
Car-sharing system performance	Car utilization ratio				x	1
Car-sharing system performance	Reservation acceptance ratio				x	1
Car-sharing system performance	Employment				x	1

Source: elaborated by the author.

After summarizing all case indicators, they were categorized in Social, Environmental, Economic, and Car-sharing system performance. In addition, some indicators are repeated among the selected cases. The total of these repetitions is also recorded in the last column of Table 6.

To identify the main indicators, this work adopts the strategy (SANTOS, Andrea Souza, RIBEIRO, 2013) utilizing the indicators most used. In this study, indicators appearing only in a single case are discarded. Thus, the final list of main indicators contains nine of them that appeared in two or more cases. All categories are filled at least with one indicator.

Table 6: Car-sharing main indicators.

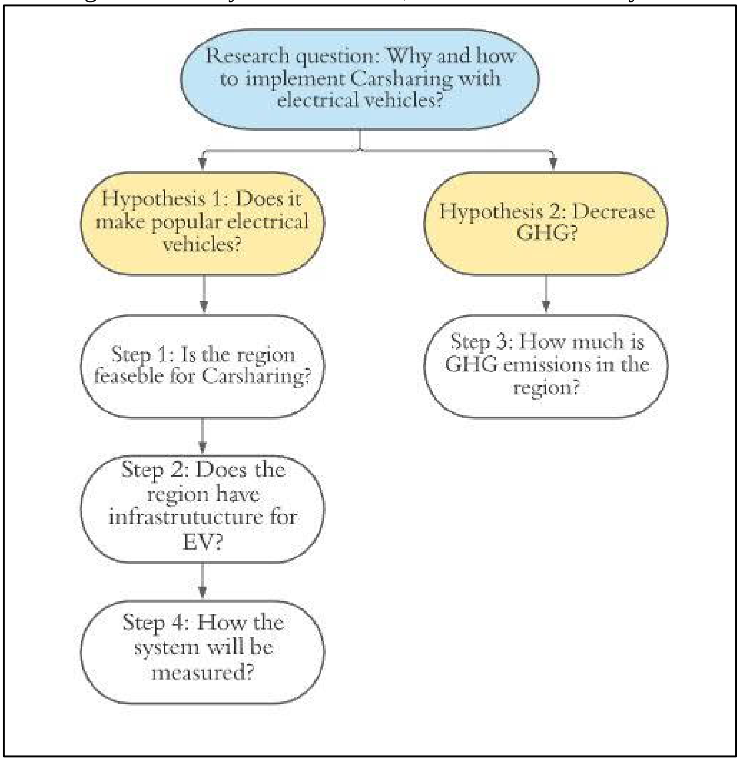
Category	**Indicators**	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Total**
Social	Age	x	x	x		3
Social	Gender	x		x		2
Social	Car availability / ownership	x		x		2
Social	Traveling time	x		x		2
Social	Trip purpose	x		x		2

Environmental	Emissions of air pollutants		x		x	2
Economic	Household income or Land price	x	x	x		3
Economic	Travel cost	x			x	2
Car-sharing system performance	Service quality			x	x	2

Source: elaborated by the author.

Next, an analytical strategy is needed, a flowchart is developed to implement car-sharing, and indicators are categorized on steps. The flowchart starts with the research question and its hypothesis. After this, different events were organized in steps to answer the research question.

Figure 17: Study case flowchart, after indicators analysis.



Source: Elaborated by the author.

Step one gathered indicators regard demography and geography. After concluding the analysis of step one, the expected result is to determine if the region has a good acceptance of the car-sharing services. Moving to step two, is investigated if the infrastructure of car-sharing and electrical vehicles are available. This step is considered charging infrastructure. Step three provides the inventory of emission. Results from this step are understanding how much emissions are related to transport and obtain an overview of the evolution of emissions reduction. With previous steps completed, step four looks at the operational indicators i.e. the service would be working, ready for the population to utilize it. The indicators were categorized as mentioned in the table following:

Table 7: Indicator categorized according to the flowchart

Step	Indicator
Step 1: Is region feasible for CS?	Age
	Gender
	Car availability/ownership
	Household income or Land price
Step 2: Does the region have an infrastructure for EV?	Charger infrastructure for EV
Step 3: How much is greenhouse emissions in the region?	Emissions of air pollutants
Step 4: How the system will be measured?	Traveling time
	Traveling Cost
	Trip purpose
	Service Quality

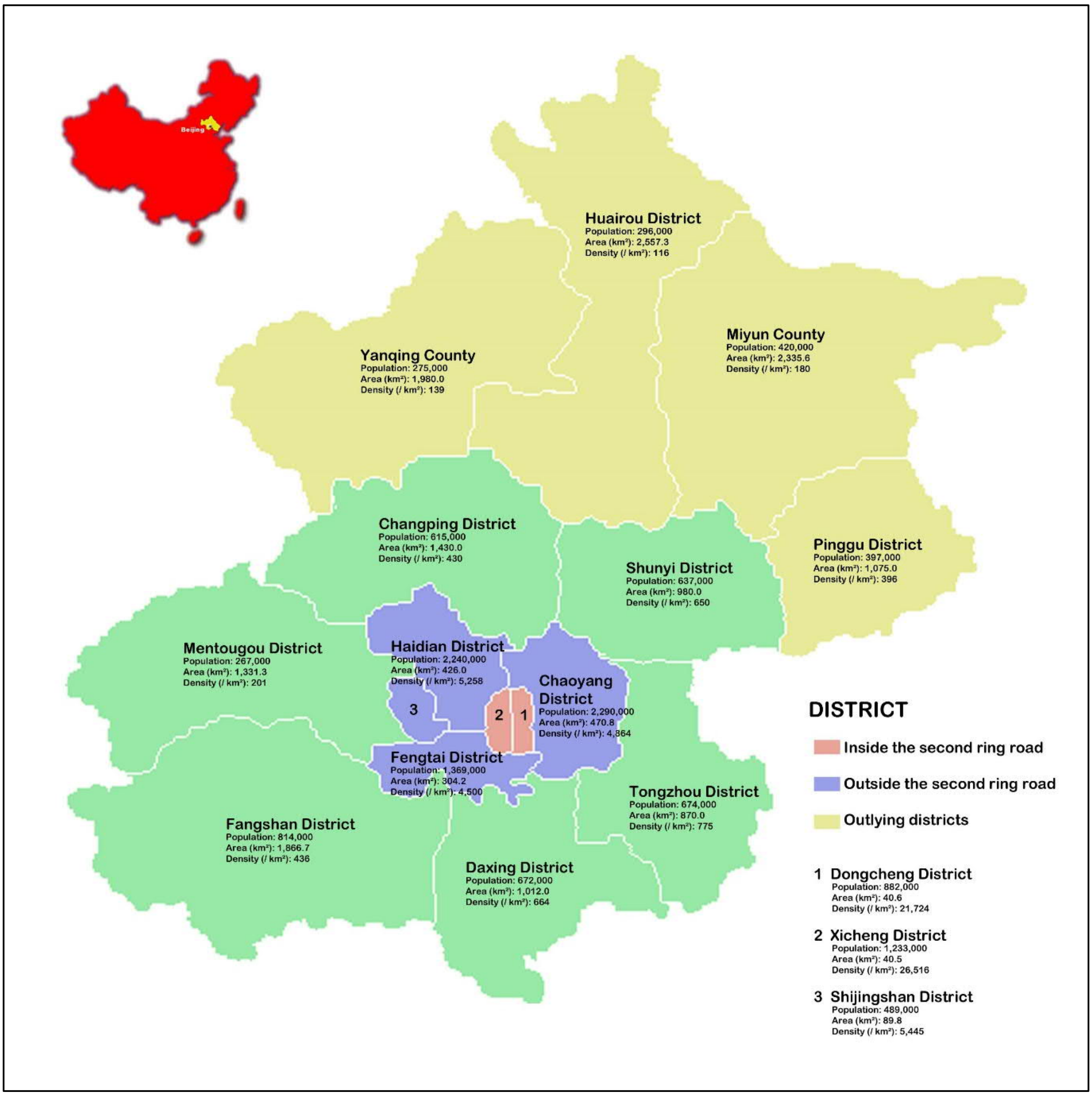
Source: elaborated by the author.

In Table 7, Step two is added an important structure to electrical vehicles. Public charging infrastructure is a key to growing the electric vehicle market (HALL, LUTSEY, 2017). The countries leading the Electrical vehicles market are the ones with the higher quantity per capita of public charging infrastructure.

4.4 Beijing mobility scenario

Beijing is the capital of the People´s Republic of China, with over twenty-one million residents in an area of 16.410,5 km² in the Northern of the country (BEIJING MUNICIPAL BUREAU OF STATISTICS AND NBS SURVEY OFFICE IN BEIJING, 2020). Beijing is a city divided into sixteen districts, as shown in Figure 18. The city is a hub of highways, subways, railways, expressways, and a high-speed network.

Figure 18: Beijing district map.



Source: Modified of maps Beijing,(2021, p.1)

Beijing like other megacities shares the same issues. A huge car fleet demands parking area, road space, traffic jams, and so on. The offer of services and jobs also provokes a commuting concentration to the city with many trip purposes. This characteristic supports the development of railway and subway networks, affording people to travel long distances. Also is expected a high efficiency of all transport modes that can impact many commuters with a reasonable fare. The last mile problem mainly for people living on the edge of the city, with an incomplete traffic trip-chain, they have to drive cars into the city, demanding parking areas and congestion (SUN, WANG, *et al.*, 2018).

Environmental and health issues caused by mobility are important topics needed to be addressed. Approximately 19% of energy consumption and 50% of oil consumption in the world are related to transportation. These numbers also yield 23% carbon dioxide emissions from various modes of transportation (ZHENG, LI, *et al.*, 2019). Some studies informed on previous sections informed the negative impact of air pollution and noise on human health.

4.5 Step 1 main indicators

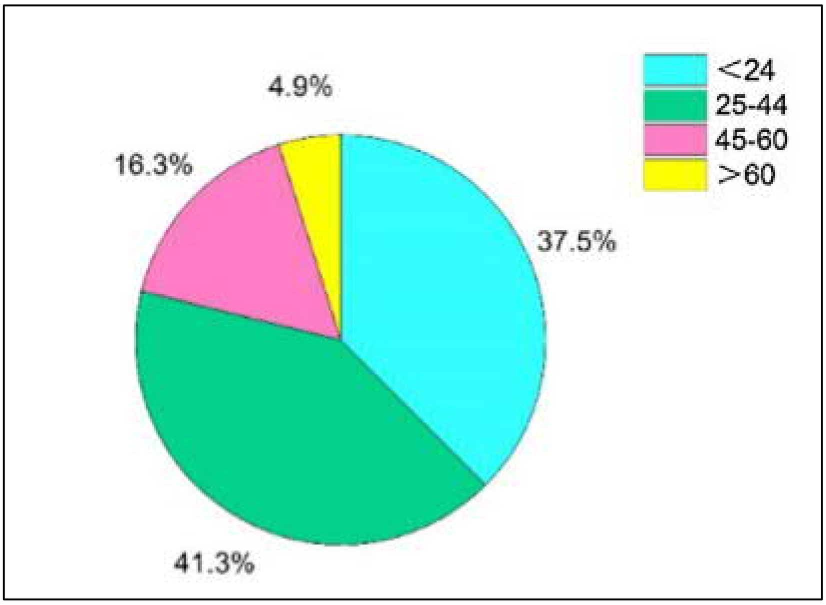
The following main indicators are related to social and demography. They are age, gender, car ownership, and household income. These indicators provide some city perspectives and the car-sharing user profile.

4.5.1 Age

Car-sharing is a transport mode that attends all ages. Although age distribution varies, and support to understand car-sharing user profile. This socio-demographic indicator was identified in three cases and is an important element for car-sharing services. In Case two, previous presented, the comparison between ages distribution of Korean and American car-sharing users presented a more representative part of users up to forty years old.

For Beijing, the survey of Sun, Wang, *et al.*, (2018) identified most car-sharing users are up to forty-five years old, representing 78% approximately. Another survey in Shangai (China), from DUAN, YE, *et al.*, (2020) results achieved similar age distribution. Moreover, the Beijing survey informs 80% of users have a college degree or higher.

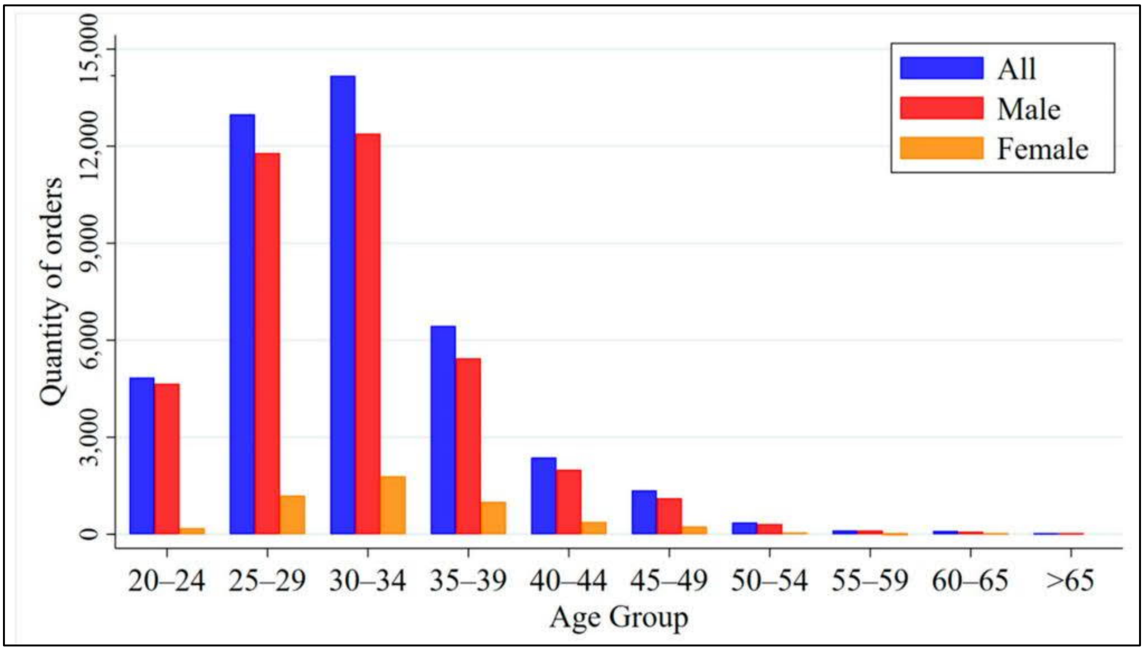
Figure 19: Beijing age car-sharing users.



Source: Modified of Sun, Wang, *et al.*(2018, p. 1026)

The survey of HU, SUN, *et al.*,(2020), in Beijing, confirms similar results, according to Figure 20. This survey suggests the development of mobile internet supports the high numbers of younger people using the car-sharing service.

Figure 20: Age and gender distribution of people who booked car-sharing orders.



Source: Modified of Hu, Sun, *et al.*, (2020, p. 23)

4.5.2 Gender

The gender subject with car-sharing has been addressed in literature (ALONSO-ALMEIDA, 2019, HJORTESET, BÖCKER, 2020, KAWGAN-KAGAN, 2015, KAWGAN-KAGAN, POPP, 2018). Men account for a higher proportion of trips than women. Car-sharing operators should promote efforts to better support women's trip purposes as shopping, transporting, or accompanying children and others. Thus, these efforts would increase their participation in this service. Safety perception is also a subject that needs attention and plays a special role in women's decision to use car-sharing.

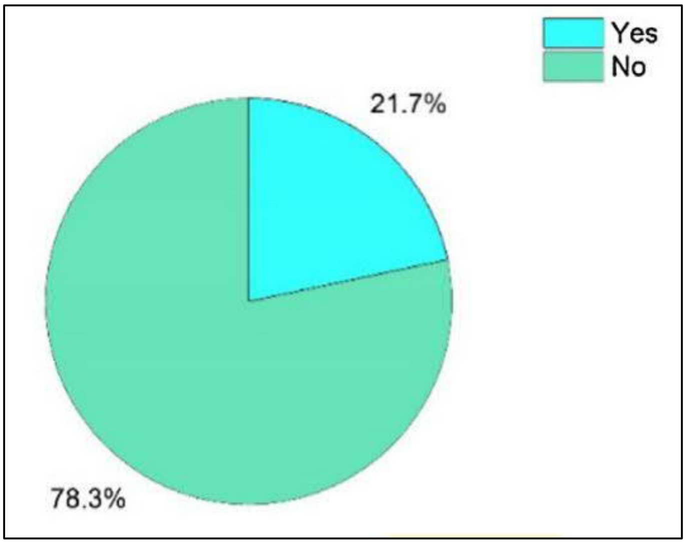
The survey in Beijing of Sun, Wang, *et al.*, (2018) counts with five hundred and forty-four men and four hundred and eighty-five women, meaning respectively 53% and 47%. For the study of Yoon, *et al.* (2017), in Beijing, no gender difference was identified related to car-sharing.

Figure 20, from the survey of HU, SUN, *et al.*,(2020) males are 86,6% of total orders. Reasons for this high difference, the study attribute to far more men with driving licenses than women in China, and male drivers tend to have better adaptability than female drivers.

4.5.3 Car-sharing availability ownership

Car-sharing service with an electrical vehicle in Beijing is attending more users without cars. Figure 21 shows 78,3% of car-sharing users in Beijing do not have any car. Many car-sharing users avoid purchasing a car due to service conveniences and parking benefits. Car-sharing reduces vehicle ownership (HAUSTEIN, 2021, LI, Zan, ZHAO, *et al.*, 2020).

Figure 21: The questionnaire analysis results of socio-economic characteristics, car ownership.

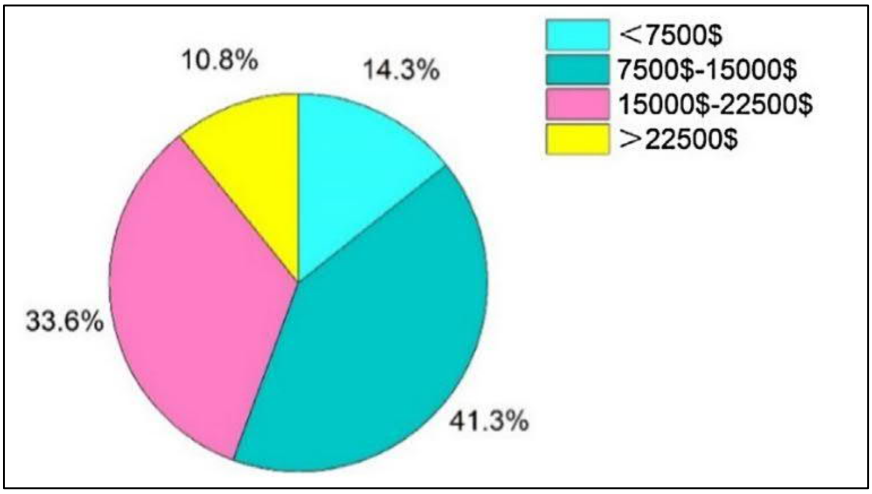


Source: Modified of Sun, Wang, *et al.*(2018, p. 1026)

4.5.4 Household income

Car-sharing with electrical vehicles according to SUN, WANG, *et al.*(2018) survey, the user profile is not for the highest and even for the lowest household income. Users belong to moderate and low-income citizens whose average yearly earning is under USD 22.500. Thus, Figure 22 shows 74,9% have annual average earning above USD 7.500 and lower than USD 22.500.

Figure 22: The questionnaire analysis results of socio-economic characteristics, average yearly earnings.



Source: Modified of Sun, Wang, *et al.*(2018, p. 1026)

After analyzing the main car-sharing indicators of step 1, Beijing is according to literature findings regards car-sharing services with electrical vehicles. Beijing has been a feasible region for car-sharing, and this step validates this information. The service attends all ages, mainly people up to 45 years old, and men are the ones who most order trips. Moreover, people with no car ownership and medium household income are the main users.

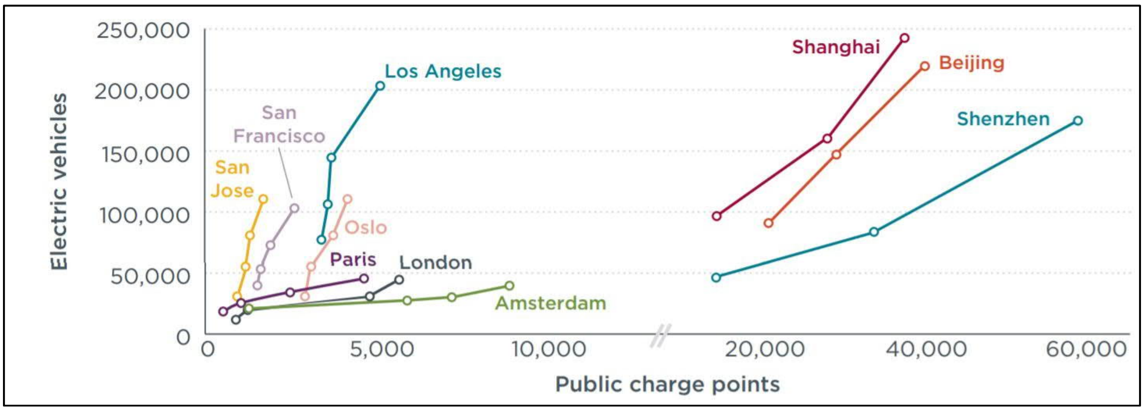
4.6 Step 2 main indicator

The current step evaluates the region charging infrastructure. This indicator is fundamental for car-sharing services with an electrical vehicle. Although it was not obtained through selected cases, public charging infrastructure is a key to growing the electric vehicle market (HALL, LUTSEY, 2017).

4.6.1 Charger infrastructure for EV

Figure 23 shows the number of electric cars and charging points in American, European, and Chinese cities over the years 2015 to 2018. The Chinese cities, Beijing, Shanghai, and Shenzhen, follow the same strategy of investments in Electrical vehicles and charging points. These cities are leading the electrical vehicle market. Comparing the quantity of charging points per electrical vehicle, Amsterdam is the city with more charging points with 4,3 per electric vehicle (EV). In second, comes Beijing with 5,3 charging points per EV (HALL, LUTSEY, 2020).

Figure 23: Global electric vehicles and public electric vehicle charging points in top electric vehicle



Source: Modified of Hall, Lutsey, (2020, p.7).

Table 8 provides the annual growth and quantity of charging points in Beijing. the city every year is investing more in this direction. Although the robust year growth, others subjects have to be addressed as lack of permanent parking spaces and inadequate electrical infrastructure (KPMG, 2021).

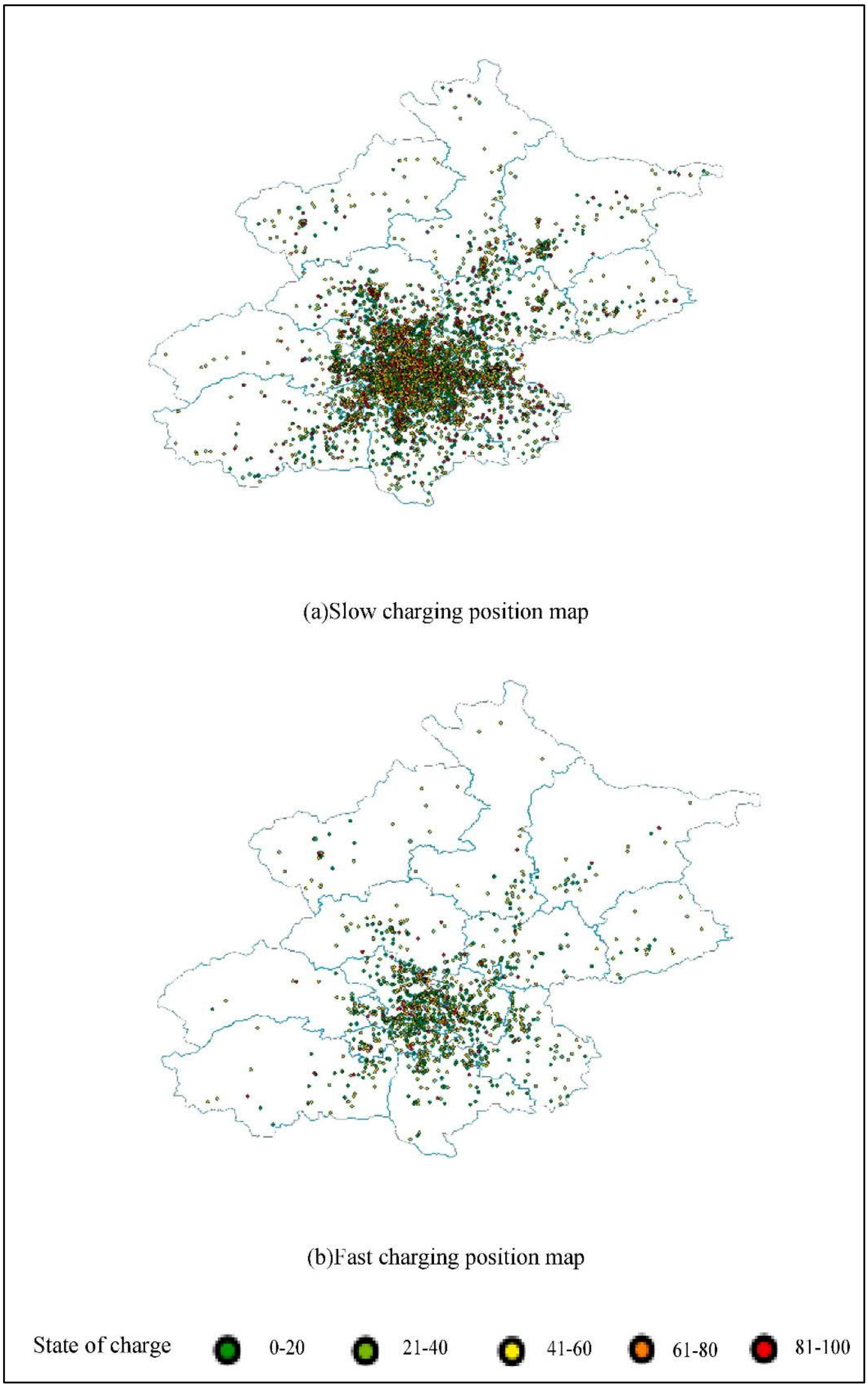
Table 8: Charging points in Beijing

Year	Public charging points in China	National % in Beijing	Public charging points in Beijing	Growth per year
2017	214.000	14,20%	30.388	-
2018	300.000	13,90%	41.700	37%
2019	516.000	11,40%	58.824	41%
2020	807.000	10,90%	87.963	49%

Source: Modified of KPMG, (2021, p. 25)

The charging points are concentrated in the inner-city districts. Figure 24 shows the city's availability of slow and fast charging points. There are more slow charging units than fast charging points. The State of Charge (SOC) is also presented in the figure. A fast charger even providing a lower charging time, it reduces the range anxiety. Thus, the user is less concerned about the battery level.

Figure 24: Diagram of range anxiety in fast and slow charging in Beijing.



Source: Modified of Zhang, Bin, Niu, *et al.*, (2021, p. 8).

Chinese cities are investing in charging points. Beijing has a broad charging infrastructure, one of the biggest in the world. The charging infrastructure attends all districts, although concentrate in inner districts. Thus, this step, after analyzing the main indicator, the region has a feasible charging structure for electrical vehicles. The step is accomplished.

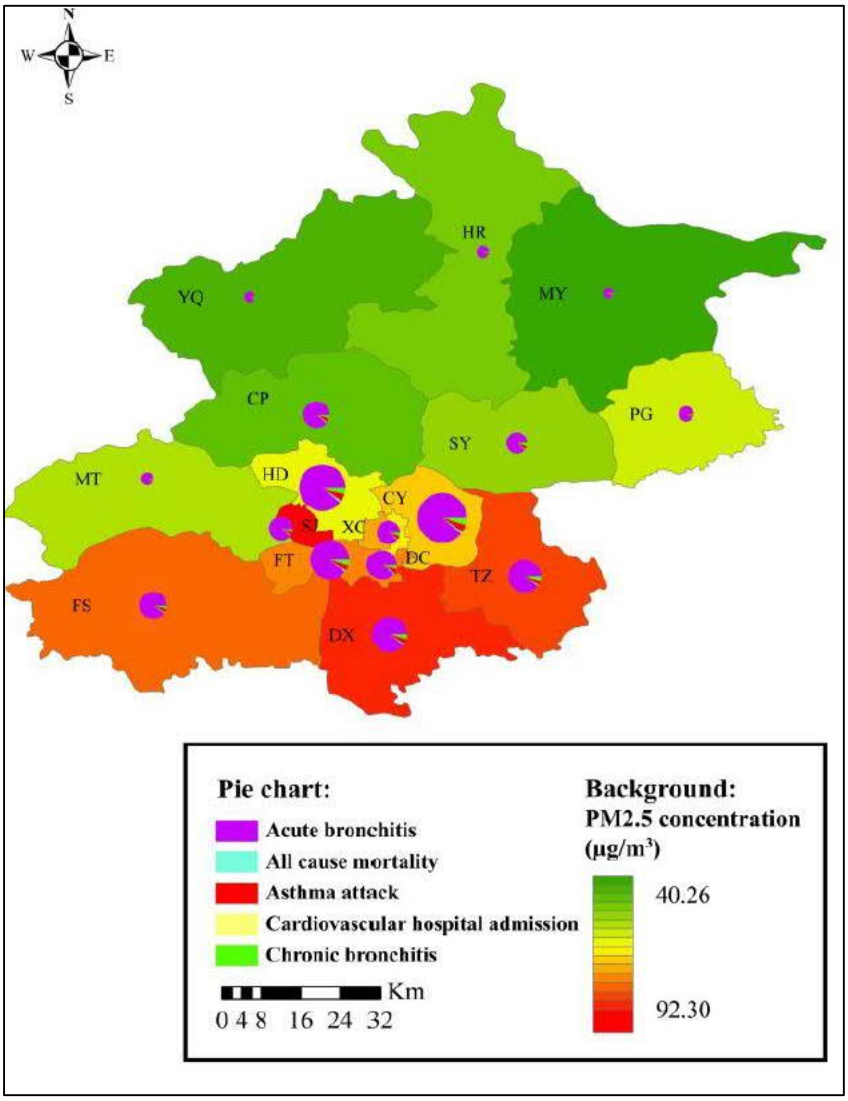
4.7 Step 3 main indicator

Step three approaches the emissions. This step provides an overview of emissions in Beijing city. Also, this phase presents the health impact due to emissions and the role of vehicles in city emissions.

4.7.1 Emissions of Air Pollutant

Beijing districts suffer a different impact on emissions. The study from (YIN, Hao, PIZZOL, *et al.*, 2017) represents how each district is affected regards PM 2,5 pollution. The central and southern areas of Beijing are more affected regards health issues causing costs to society. According to Figure 25, Daxing and Tongzhou districts are highlighted as the ones with more health issues. The pie charts in Figure 25 represent the health impact proportions and their size indicates the total cases of various health issues in each district. The issues are proportional to the population size in the study of YIN, Hao, PIZZOL, *et al.* (2017).

Figure 25: Three different health impacts in different districts.

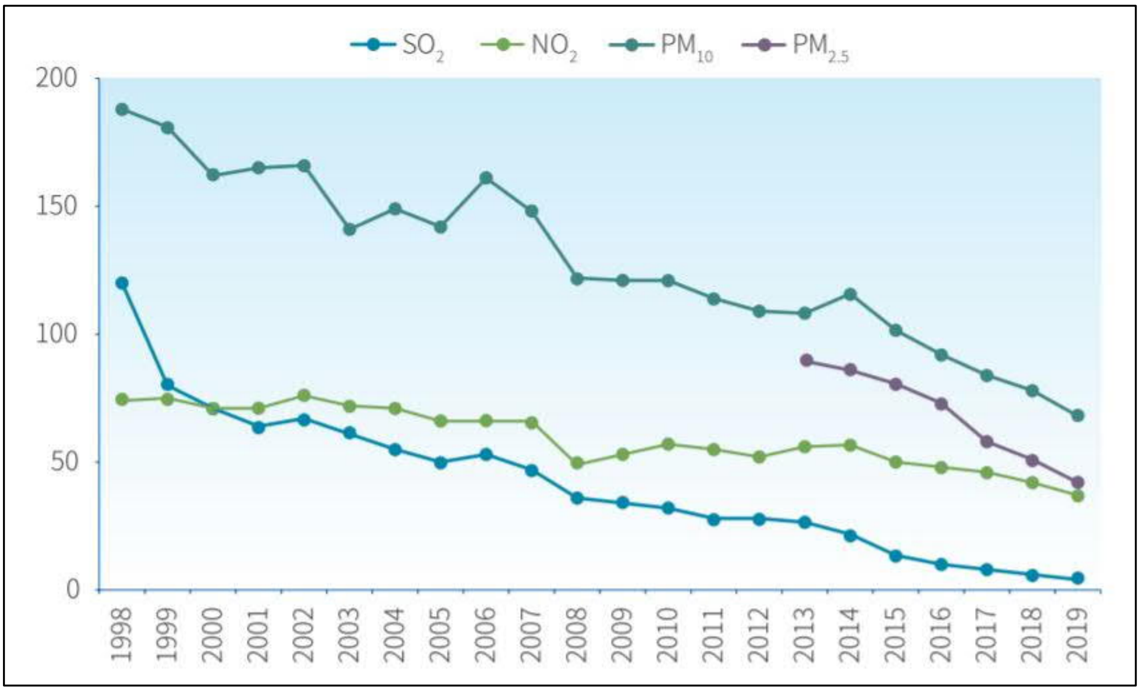


Source: Modified of Yin, Hao, *et al.*, (2017, p.6)

For reference, in Figure 25 the letters DC, XC, HD, CY, FT, SJ, MT, TZ, SY, FS, DX, CP, HR, PG, MY and YQ represents the districts of Dongcheng, Xicheng, Haidian, Chaoyang, Fengtai, Shijingshan, Mentougou, Tongzhou, Shunyi, Fangshan, Daxing, Changping, Huairou, Pinggu, Miyun and Yanqing.

Beijing is acting against this polluted scenario. Many efforts have been taken to revert the city scenario (UN ENVIRONMENT, 2019). In Figure 26, the evolution of the air quality with main pollution components registered in micrograms per cubic meter over recent years.

Figure 26: Trends of annual concentrations for criteria air pollutants in Beijing, 1998-2019

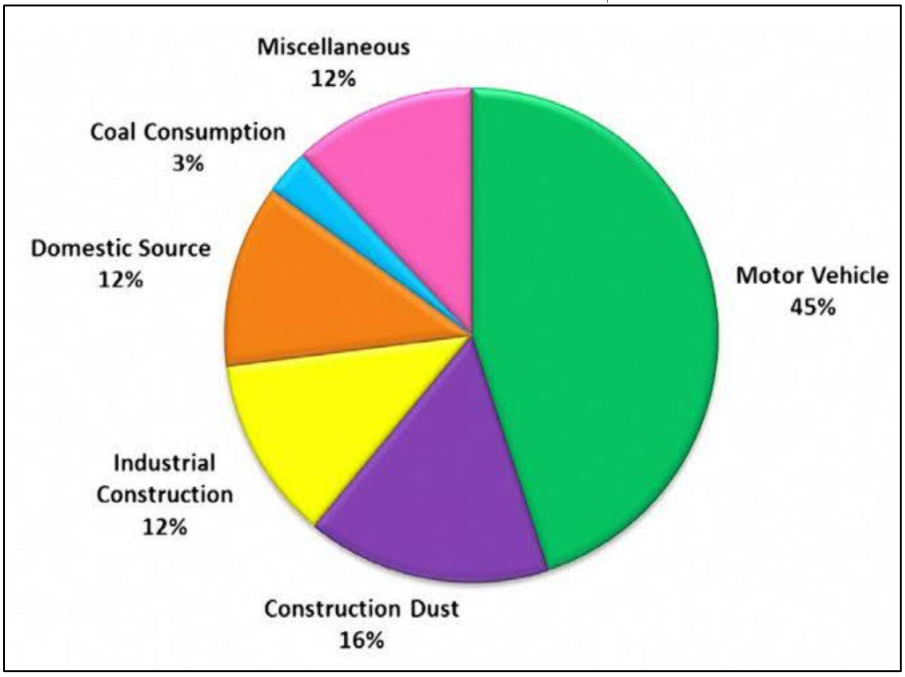


Source: Modified of Beijing Municipal Ecology And Environment Bureau (2020, p. 3)

Beijing to achieve these results, focused on a more effective air quality management system with a high public environmental awareness and investments. Coal combustion sources have been reduced since many power plants are powered by this fuel.

Vehicle emissions are a key element for clean air. Figure 27 shows motor vehicles representing 45% of city PM2,5 emissions. Many measures have been taken in this direction. Quality improvement of gasoline and diesel, traffic restrictions, clean energy vehicles, scrappage of older vehicles with subsidies, and others (UN ENVIRONMENT, 2019). According to Sun, Wang, *et al.*(2018), car-sharing with electrical vehicles and bike-sharing can achieve an annual reduction of energy consumption, by forty-five million liters of gasoline, 540.000 tons of nitrogen, and 4.5 billion mg PM 2,5.

Figure 27: Local sources of ambient $PM_{2,5}$ in Beijing.



Source: Modified of UN Environment (2019, p.23)

Thus, in this step, we observed the strategic role of electrical vehicles to reduce emissions and health issues. Over the years, emissions have been decreasing in Beijing and among other political measures, car-sharing with electrical vehicles is contributing to this reduction. This step confirms that car-sharing with electrical vehicles is an environmental tool, as well.

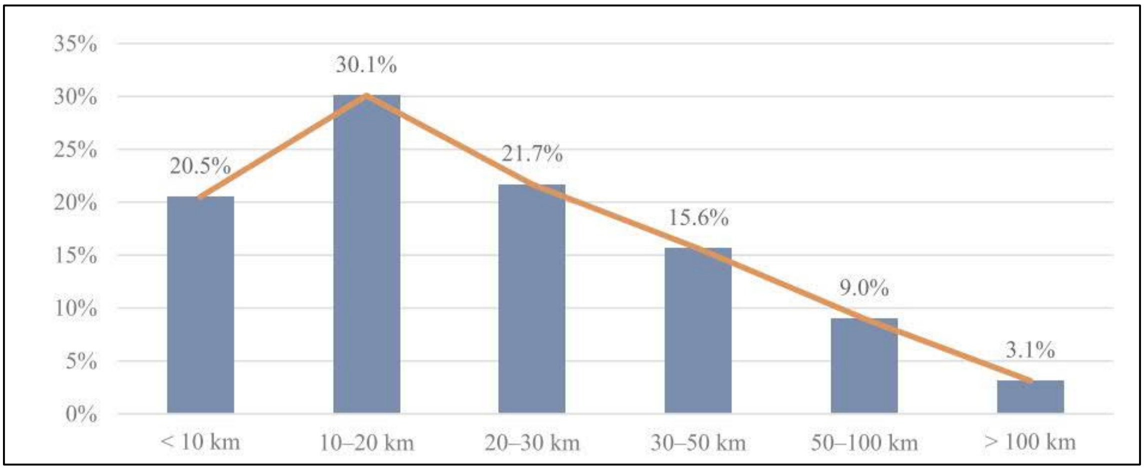
4.8 Step 4 main indicators

This step presents the main operational car-sharing with electrical vehicle indicators. The following indicators from Beijing are analyzed: travel time, trip purpose, travel cost, and service quality. Only regions operating car-sharing with electrical vehicles can accomplish this step.

4.8.1 Travel time

The survey of Jin, *et al.*(2020) shows preferences distances to use car-sharing with electrical vehicles in Beijing. Figure 28 show 50,6% of the trips are for distances below 20 kilometers. According to Zhang *et al.* (2018), in a light traffic jam in Beijing, the traffic speed is in the range of 35–50 km/h for expressways. Thus, the majority of travel time ranges of 24-35 minutes.

Figure 28: Trip distance distribution for BEV sharing.



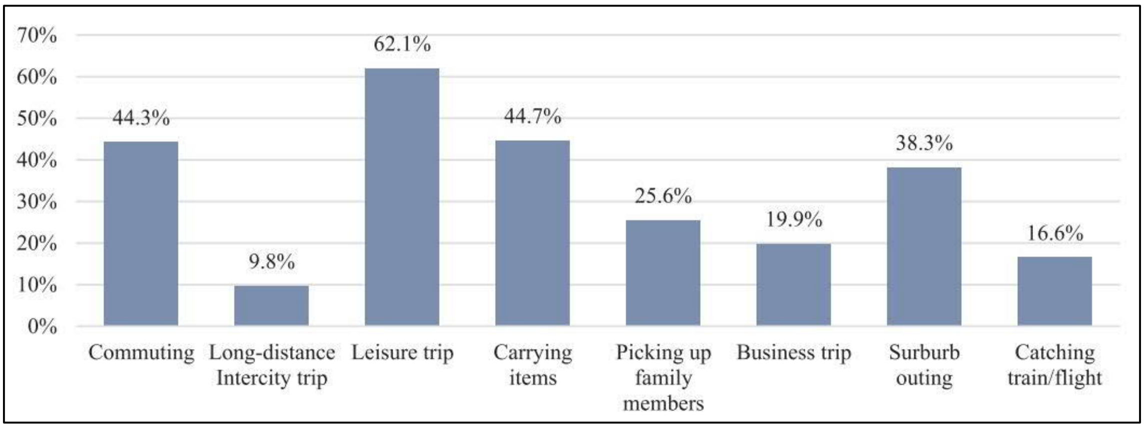
Source: Modified of Jin, et al.(2020, p. 102)

The study of Sprei, *et al.*(2019b), investigating travel time and usage patterns from twelve cities in Europe and the United States, findings address lower periods than Beijing. The main use of this service is for shorter trips, like Beijing, although with a median rental time of twenty-seven minutes and actual driving time closer to fifteen minutes.

4.8.2 Trip purpose

The majority trip propose is related to leisure activities (JIN, AN, *et al.*, 2020, SUN, WANG, *et al.*, 2018). A total of 62.1% correspondents from the survey of JIN, *et al.*(2020), will use car-sharing with electrical vehicles for leisure trips, 44,7% of the respondents will use it when carrying heavy items, 44,3% consider this service as an alternative in commuting trips, and 38.3% of them will use it for suburb outing (Figure 29).

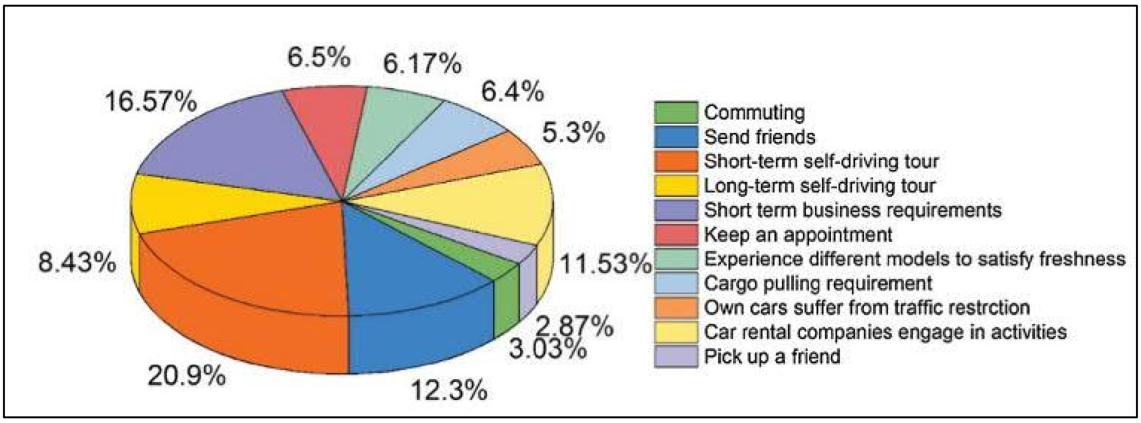
Figure 29: Trip purpose distribution for BEV sharing.



Source: Modified of Jin, *et al.*(2020, p. 102)

The SUN, WANG, *et al.*, (2018) survey, from with electrical car-sharing users from Beijing identified 20,9% of trips short-term self-driving, 16,57% short-term business requirements, 12,3% send friends as the main trip purposes (Figure 30).

Figure 30: The questionnaire analysis results of shared transportation use purpose, electric vehicle sharing.



Source: Modified of Sun, Wang, *et al.*(2018, p. 1026)

4.8.3 Travel cost

Beijing has several options for transportation. According to Table 9, sharing transportation has accessible prices for the population. It is a transport mode more comfortable and flexible than bus and subway. Although, the bus is the cheapest transport mode in most cases. Otherwise, bus travel experience often implies in-vehicle crowds and traffic jams (QIAN, PANG, *et al.*, 2020).

Table 9: Transportation mode cost.

Transportation mode	Reference	Type	Price *CNY	Approx. Price USD	Source
Private Vehicles	Gasoline price per liter	89#	5,32	0,82	("Beijing oil price", 2021)
		92#	6,60	1,02	
		95#	7,02	1,08	
Subway	Subway ticket fare	0-6 km	3,00	0,46	(ICT, 2021, SONG, 2021)
		6-12km	4,00	0,62	
		12-22km	5,00	0,77	
		22-32km	6,00	0,93	
		32-52km	7,00	1,08	
		52-72km	8,00	1,23	
		72-92km	9,00	1,39	
		Airport express	25,00	3,86	
Bus	Bus ticket fare	0-10km	2,00	0,31	(TCG, 2021)
		each +5km	1,00	0,15	
		Maximum	12,00	1,85	
Taxi	Daytime fare (From 05:00 to 22:59)	Starting	13,00	2,01	(GAVIN, 2021)
		After 3km, for each add. km	2,30	0,35	
		After 3km, for each add. km	3,50	0,54	
	Nightime fare (From 23:00 to 04:49)	Starting	15,60	2,41	
		After 3km, for each add. km	2,76	0,43	
		After 3km, for each add. km	4,20	0,65	
Electrical Car-sharing	Vehicle fare	Price per minute	0,17	0,03	(HU, SUN, *et al.*, 2020)
		Price per km	1,00	0,15	
Bike-sharing	Bike fare	Price per 30 min	1,00	0,15	(HU, SUN, *et al.*, 2020)

*Currency rate: CNY 6,47 per 1 USD.

Source: elaborated by the author.

Parking fees are also considered part of travel costs (HU, SUN, *et al.*, 2020, SUN, WANG, *et al.*, 2018). It applies to private cars and electrical car-sharing vehicles. Table 10 presents the Beijing parking fees and approximately the price in US Dollars.

Table 10: Parking fee, per period and region.

Parking fee						
	Day (7:00 a.m.–19:00 p.m.)				**Night (19:00 -7:00)**	
Region	**Within the First Hour (per 15 min)**		**After the First Hour (per 15 min)**		**per 2 hours**	
	CNY	**USD**	**CNY**	**USD**	**CNY**	**USD**
Region of I	2,50	0,39	3,75	0,58	1,00	0,15
Region of II	1,50	0,23	2,25	0,35	1,00	0,15
Region of III	0,50	0,08	0,75	0,12	1,00	0,15

Source: Modified of Hu, Sun, *et al.*, (2020, p. 12)

4.8.4 Service Quality

Service quality is an important indicator for this service (QU, YU, *et al.*, 2017, SUN, WANG, *et al.*, 2018). According to survey results in Beijing, nearly 60% of users are satisfied with car-sharing services with electrical vehicles, nearly 61% claimed to use the service and 66% of responded data are optimistic for future development of shared transportation in Beijing (SUN, WANG, *et al.*, 2018).

In addition (HU, SUN, *et al.*, 2020) suggests to a car-sharing operator (CSO) should articulate with the City government, and other transportations modes, aiming for good cooperative relations. Thus, each other can promote each other's strengths to build a package of mobile service plans.

Finally, this step provides an overview of car-sharing with electrical vehicle performance in Beijing. Short leisure trips demand more from this service. The service price is competitive among other transportation modes, therefore affordable for the population. In the end, Beijing citizens are satisfied with the service and they believe the increased use of car-sharing with electrical vehicles

5. FINAL CONSIDERATIONS

Metropolitan areas have many challenges regards mobility. Traffic jams, vehicles with passengers' overcapacity, and few options for the last mile are common characteristics in these areas. Beyond more time spent in mobility, citizen's health is impacted due to vehicles powered by fossil fuel. All this scene justifies thinking about what the city plans for its future, and possible tools to improve it. Thus, the current study investigated car-sharing with electrical vehicles, searching for effectiveness to address these issues and create a tool for its implementation. Following, this work presents a framework with four steps to implement car-sharing with electrical vehicles. The framework is applied in Beijing, China. It is a city that already has the service operating and it is possible to fulfill all framework steps.

This study observed the main techniques that have been applied to car-sharing by the literature. Main car-sharing topics were discussed in the literature review and a car-sharing implementation framework was identified as a literature gap that was explored in this research.

5.1 Main Conclusions

The hypothesis of the popularization of car-sharing with electric vehicles is confirmed during the literature review. The other hypothesis regards emissions from cars is confirmed since car-sharing services reduce VKT, the number of private vehicles, and increases the utilization of public transportation.

The case study supported understanding the CSEV phenomenon and to identify the main indicators. The multiple study case considers four cases from different locations and approaches. Indicators from the selected cases are registered and presented.

The framework was created and four steps have to be fulfilled to the car-sharing service to be implemented successfully. When applied this framework to Beijing, the first step was accomplished, and the study stated that the city is a good region to have the car-sharing service. The second step validates the huge charging infrastructure for EV, thus a car-sharing with an electrical vehicle is technically feasible. The third step showed the city emissions inventory and the key role of vehicles powered by fossil fuel. The last step analyzes the performance of the service. In Beijing, the user has a positive opinion of the service, contributing to citizens' mobility. The service is affordable and has a satisfactory quality. In the end, the application of the framework in Beijing validated the framework as a tool to collaborate in the implementation of CSEV, confirming the hypotheses that help popularize EV and contribute to the reduction of GHG. Thus, the current work can support cities to implement their car-sharing system with electrical vehicles.

Suggestions for Beijing is the City government should articulate with other transportations modes, aiming for good cooperative relations. Thus, each transport mode can promote each other’s strengths to build a package of mobile service plans. Moreover, besides the city has many public charging points, their maintenance should be an attention point to let them available when needed.

5.2 Limitations of the Study

Missing previous researches addressing implementation of car-sharing with electric vehicle is a limitation. Other characteristics such as how long car-sharing is operating, and the culture regards car ownership may influence results. Some cultures assign car ownership with prosperity and a target to achieve. Also, the study expects the popularity of the service increases over the years. The cases utilized for the framework are urban regions and rural areas need more investigation to check the framework's effectiveness. Also, collect interviews with experts would bring even more knowledge to the research.

5.3 Future Studies Proposals

The recommendation for future studies is to apply this framework to cities that the service works and compare them to this study. Moreover, a simulation study comparing the framework with real cases can be addressed. Another field to investigate is the framework's effectiveness in rural areas.

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