POLITECNICO
DI TORINO

Collegio di
Pianificazione e
Progettazione

Master's degree programme in

Territorial, Urban, Environmental, and Landscape Planning

Curriculum: Planning for the Global Urban Agenda

Master Thesis

Sustainable mobility in the Metropolitan of Turin: Spatial-based electromobility diffusion scenarios and their pairwise efficient policies

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Academic Year 2021/22

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0 GLOSSARY OF TERMS AND ABBREVIATIONS

BEV (Battery Electric Vehicle): refers to any vehicle that only uses electricity from the grid.

EV (Electric Vehicle): refers to any vehicle that runs either partially or entirely on electricity (also see 'Plug-in Vehicle').

HEV (Hybrid Electric Vehicle): refers to any vehicle that uses both an electric and a gasoline motor. Electricity used is generated on-board, therefore, there is no plug-in or electricity from the grid.

ICEV (Internal Combustion Engine Vehicle): refers to any vehicle that uses petrol fuel exclusively.

PHEV (Plug-in Hybrid Electric Vehicle): refers to any vehicle that is similar to the HEV, but the electricity used is both generated on-board and from the grid.

PEV (Plug-in Vehicle): refers to any vehicle that is chargeable via electricity from the grid (including PHEVs, and BEVs) (also see 'EV').

1 INTRODUCTION

Today the main discussed topic regarding the dissemination of electric vehicles (EVs) in Italy is to diminish air pollution and the nation's reliance on petroleum products, specifically, fossil fuels used in the industry and mobility sector (Guidotti et al., 2009[1], Buekers et al. 2014[2], Viola et al. 2017[3], Sofia et al. 2020[4]). According to Sims et al., 2014[5], In the past 45 years, 80% of increases in CO2 emissions have come from road transport. Strategic plans such as Green Paper 2007[6], White paper 2011[7], and EU Directive on Alternative Fuels Infrastructure 2014 [8] are all in line with a broad scale global introduction of electromobility that is considered a significant measure for reducing greenhouse gas emissions from the transport sector. Electric vehicles (EVs) are vehicles partially or entirely powered by electric motors. They divide into different sub-branches such as Battery Electric Vehicles (BEVs), Plug-in Hybrid Electric Vehicles (PHEVs), and Range-Extended Electric Vehicles (REEVs) (Plötz et al., 2014)[9] that are all parts of the answer to the ecological improvement and sustainable mobility.

In Italy, According to the National Infrastructure Plan for the Recharging of Vehicles powered by Electricity (*Piano Nazionale Infrastrutturale per la Ricarica dei veicoli alimentati ad energia elettrica* – PNire)[10] prepared in 2016 by the Italian Ministry of Infrastructure and Transport, the transport sector accounts for about 30% of both Italy's energy consumption and its CO2 emissions. Despite the fact that the penetration of EVs in the Italian market is yet less than 20% (Statista, 2020), policy-makers consider EV diffusion at a massive level as a legitimate response, particularly in the cities, to handle contamination issues. The studies focusing on stated preferences and EV registrations, highlight that in the current operating conditions EVs are mostly designed to be used in urban/metropolitan contexts (Chen et al., 2015[11]). According to International Energy Agency, more than 9,000 EV charging stations are assessed to have been introduced or are under establishment in Italy, among them 80% private and just 20% public. This number, according to the report published by Statista Research Department in November 2020 is precisely 12150 charging points, which in comparison to the same data in 2019 shows a 46% growth rate. Region-wise, the data shows that Northern Italy has the highest number of charging points with a total of 51%, and the same applies to the number of "fast charge" charging points with 53% of the total. Following this statement, in all 92 Italian provinces, public charging stations are present, and mostly located in the principal metropolitan zones and urban areas.

According to Romero Lankao et al.2019[12], It is essential to orient EV research activities towards comprehending the characteristics and relationships among 'urbanization, electromobility, and cities' with 'urban actors' identified as main players in this domain. Despite the approvement of this argument, criticizing and examining the theory is essential since it is not thoroughly considering all EV diffusion aspects such as diverse contexts. With a global transition towards electric vehicles, it is gainful to debate the problems related to geography, space, and place. One of these emerging issues is the uptake of EVs in suburbs or rural areas. Some studies (Aultman-Hall et al. 2012[13]; Dimatulac and Maoh 2017[14]; Liu et al. 2017[15]; Ferguson et al. 2018[16]; Morton et al.2019[17]; Zhuge and Shao 2019[18]) emphasize on the high-density urban areas as the only suitable context for EV uptake while others (Newman et al.2014[19]; Plötz et al.2014[9]; Wappelhorst et al.2014[20]; Fornahl and Wernern, 2015[21]) state that EVs are not a permanent solution to traffic congestion and public space occupation issues. This thesis research provides a spatial state of affairs in the Metropolitan City of Turin and it explores how EVs are perceived and discussed to fit within rural, suburban, and urban categories by users and potential adopters.

Once the scope of EV diffusion is clear, contextual characteristics such as settlement density, mobility behaviors, and individual preferences, form the modality and the quantity of this diffusion. The situation examination led in this work shows the most efficient context-based policies that would cause fair dissemination of EVs, in line with sustainability goals. The proposed policies are to tackle CO2 outflows, traffic congestion, public space intake, and network fragmentation in a homogenous fair way based on the spatial aspects and user characteristics. This study is done with specific reference to Turin's metropolitan area which offers a higher edge for intervention in terms of the number of conventional vehicles that can be supplanted with EV.

The research questions that are leading this thesis research are listed below. The methodology used to find an answer to these questions is mainly the Spatial Multi-Criteria Analysis applied in the surface of our study area, Metropolitan of Turin.

- What socio-spatial factors affect EV diffusion?
- In what ways do the intensity of socio-spatial factors affect the urban, suburban, and rural areas?
- What are the most effective policy practices regarding EV diffusion in Turin's Metropolitan area?
- How does the promotion of EV diffusion help increase sustainability in spatial contexts?
- What impact do the context-adjusted policies have on reaching sustainable development goals?

This research addresses the knowledge gap regarding the co-relation between EV diffusion in different urbanized-level territories, and their pairwise supportive compatible policies in our area of study. Furthermore, the final outcomes, in case of adoption in the future mobility plans, could lead to an increase in this sector's sustainability.

At the moment, Italy is developing several initiatives to create and develop the required infrastructure for EVs to function at a great scale. The framework in which these practices are held can be mentioned in three phases. First, the development of new charging points and creating an infrastructure network. Second, monetary grants for private and public activities to make local private infrastructure. Third and last of these initiatives are pilot projects that optimize the technologies related to electric infrastructure, logistics, business models, and EV diffusion. This thesis aims to participate in the knowledge production regarding the development of sustainability by suggesting fair efficient policies in the mobility sector. The results are specifically measuring spatial variables in the Metropolitan of Turin, however, the methodology is applicable to other similar spatial contexts.

1.1 STUDY OBJECTIVES

The aim of this study is to recognize an extended spatial context for EV diffusion and assess the possibility of this diffusion in the urban, semi-urban, and rural areas in Turin's Metropolitan. This variable is assessed, in compliance with Paola Pucci's [22] study on Milan's urban area, in four different scenarios happening in three density-wise different contexts with diverse socio-economic and mobility patterns. Profiling of the EV users helps to understand the characteristics of potential EV consumer and in accordance with that, effective factors in EV diffusion has to be extracted from both the literature and a comparison between the same-subject studies already done on different cases. The mentioned factors have different weights in each of the scenarios based on the characteristics of the area and the users. The baseline scenario is the most simplified one, in which the same weight is implemented to all the defining factors in our area of study. The other three main scenarios are different in the weights assigned to either the "mobility patterns", the "built environment" characteristics, or the "socio-economic profiles" sectors, each comprised by some sub-categories from literature, to be assessed with.

Another significant focus of this study is regarding the effective policies suitable for the different contexts derived from diverse EV diffusion scenarios in Turin's metropolitan area. In line with this, one of the aspects carried out in this study is describing the role of diverse incentives for promoting EV's diffusion in each spatial context. In other words, answering these questions: "based on the context, *what incentives are critical to increase or promote EV diffusion? and what groups of buyers respond to different types of incentives?* "The compatibility of existing policies and incentives in the current situation in Italy and The Metropolitan area is the matter of investigation in this thesis study. In the end, suggestions of possible effective policies/incentives that can affect mobility sustainability in a positive way, are given based on the spatial characteristics of the study area.

1.2 EXPECTED OUTCOMES

The investments on the electromobility topic in Europe are vast, among them are studies that inform the policy-makers to take into account a complex set of aspects from technical to social and environmental ones. Having the mentioned studies as a basis, this research is aiming to address the urbanistic point of view to the phenomena of EV diffusion.

This research investigates the possibility of EV diffusion in urban areas along with the missing contexts in the current development plans of e-mobility in Turin's Metropolitan area. Furthermore, the results of the study can contribute to the decision-making of governments in the development of the tools in order to manage the diffusion and maximum use of alternative energy vehicles.

To proceed from the primary results of this research towards policy setting and decision making, scenario maps that contain integrated spatial data are in use. These scenario maps are means to explore the possibility of a phenomenon based on the significance of a bold criterion(or a set of criteria), in the spatial setting. Observations related to the transfer of research knowledge and interpretation of the electromobility scenario make it possible to conclude the preferred mobility policies from the urbanistic point of view. Additionally, the impact of expert ideas on the political decision-making results will be integrated with the experience of the Italian users collected in a questionnaire conducted to survey the significance of cost, time requirement, acceptance, and other criteria effective in promotion measures of electromobility.

2 PROFILING OF EV USERS

In this section, some mutual characteristics among EV users are extracted to identify the common indicators used in different case studies for measuring EV diffusion in an area. These factors vary depending on the characteristics of territory and the users in terms of socio-economic data, mobility habits, and other measurable attributes related to them. The nominated variables can be used as indicators for developing the EV diffusion scenarios in further sections. An analysis of the existing literature has been performed for some early EV-adopter countries to investigate the demographic information related to the users, and eventually their mobility habits. The main goal of this investigation is to carry out a thorough inquest on effective EV diffusion factors and their share in EV diffusion in diverse spatial and geographical settings.

2.1 EV USERS IN EUROPEAN NORDIC COUNTRIES

The profiling of EV users in European Nordic Countries was performed by (Benjamin K. Sovacoola et al, 2018)[23] to collect data on the demographics of electric mobility. The primary method was an online survey (structured questionnaire) including three parts with a total number of 44 questions.

The first part gathers information about the vehicle ownership [24]and the existing mobility patterns of respondents, for instance how often they drive their vehicles/other modes of transport, for how many kilometers, how much they are willing to pay (WTP) for a new vehicle, etc.[25] The second part targets the information about what features do users value most or least when they consider future acquisitions, such as safety of the vehicle, size, acceleration, etc. Some questions are specifically extracted from the literature about electric vehicles for instance charging stations availability and infrastructure[26-29], battery life, range, etc. The mentioned questions are asked in a rate-based mode so that the respondents can rate these features according to a five-option type of LIKERT scale[30] ranging from very unimportant to very important. The last part of the survey includes the basic demographic information such as gender, age, education, occupation, and more detailed questions about income, political affiliation, and environmental sensitivity.

The survey was distributed online and the respondents could answer anonymously. The research design was intended to minimize dishonesty and promote sincerity. The survey respondents are a mix of 4322 “random respondents”, the statistical population acquired through a survey hosting firm, and 745 “non-random respondents” who were invited by the authors to participate in the online survey. In Table 1 the summary of survey distribution is reported.

Country	Respondents (random)	Respondents (non-random)	Total
Denmark	953	185	1138
Finland	962	143	1105
Iceland	496	214	710
Norway	959	103	1062
Sweden	952	100	1052
Total	432	745	5067

Table 1 – Summary of survey distribution

Source: Author's elaboration, 2021

In 

Figure some of the results of the survey are presented in different demographic charts. As mentioned in the methodology of this study, random and non-random statistical population are used to provide a homogenous and representative sample of the society in which the study was carried out. For instance, the respondents in accordance with the users of EV in Nordic countries, are almost equally from both genders and there is also a portion of non-binary users.

Figure 1 – Demographic characteristics of Nordic survey respondents

Source: Survey of EV users in Nordic countries, Benjamin K. Sovacoola, et al, 2018

The following main characteristics such as age[9, 24-26], occupation[14, 24, 31], education[14, 15, 24, 31-33], and income[11, 15] are extracted from the literature and measured in the context of Nordic countries. The results regarding each factor are described as follows:

- **Age:** The youngsters are the biggest fans of EV with an age range between 25 to 34 years old. Most probably this factor is related to driver's license age limit, graduation, employment, and income stages.
- **Occupation**: A very notable amount of EV users are occupied in the private sector.
- **Political leaning:** Social-democrats, socialists (green party) and liberals are together forming more than half of EV users.
- **Level of education:** The largest group of EV users hold a post-graduate degree. And the second largest group are under-graduates. Which together form almost 75% of the users (3/4 users hold a university degree) this again has a relation with employment and higher income.
- **Level of income:** Most EV users have an income between 30 to 50 k€ annually (even if many people do not feel secure indicating the details about this factor).

- **Driven Kilometers:** Most EV users drive EV to short distances like going to work during their daily routines (less than 20km/day)
- **The number of vehicles in the household:** Almost 75% of EV users own a non-EV car.

Despite the well-distributed charging infrastructure in Nordic countries, the lot of most kilometers driven per day has a peak of around 40–60km/day which can indicate the discomfort of EV usage for the long distances. The outcomes about occupation, show a significant relationship between car ownership and age. EV interest peaks for the 25–34 age group and that this cohort also has a high interest in terms of EV experience and they care more about the environmental impacts of vehicles. price wise the age group of over 65 (the retirees) were willing to pay more, often over € 30.000. On paper, the elderly may represent an attractive market for electric mobility, even though they have relatively not much EV experience, a low EV ownership rate, and little interest in EVs. Between these young and old age cohorts, are the middle-age group of 45–64 years. This group falls between the extremes. They have high car ownership numbers, higher driving distances per day, moderate interest (relative to the younger and older groups) in EVs, scoring a bit lower on environmental impact while deeming EV range and public charging is more important for them. In general, this group age seems to expect more reliability and stability from their cars.

2.2 EV USERS IN THE UNITED STATES

The profiling of EV users in the US was performed by (Scott Hardman et al, 2016)[34] where the distinction between two groups of adopters is considered (high-end adopters and low-end adopters) assuming differences in the price and features of the vehicles owned: Nissan Leaf for the low-end adopters and Tesla for the high-end adopters.

The target of this questionnaire was North American owners of battery electric vehicles (BEVs) by the end of 2014, due to the fact that around 40% of the BEVs across the world were used in the United States. However, the questionnaire was left open to all BEV owners worldwide. 340 fully completed surveys were collected between July and December 2014.

The questionnaire was distributed online among the online forums related to electric cars and more specifically Nissan and Tesla. Some of the forums that were used are listed:

- Telsamotors.com, the official Tesla forum.
- Reddit.com/r/teslamotors, an online forum with a sub-area for Tesla enthusiasts.
- Reddit.com/r/electric vehicles, an online forum with a sub-area for electric vehicle enthusiasts.

- Nissan and Infiniti Car Owners, a forum for Nissan and Infiniti owners, including the Nissan Leaf.
- Leaf Talk, a Nissan Leaf owner forum.
- Speak EV, a forum for owners of any electric vehicle.

The study used the online survey methodology to gather data and this online questionnaire can be divided into three sections:

- The first part gathers socio-economic data,
- The second part collects psychographic information,
- The final section asks for information on respondents' opinions of their vehicle's attributes and also asks them about their future BEV purchase intentions.

Profiles of respondents (in all three terms that were mentioned above) were measured to understand if there are any statistically significant differences between low-end and high-end EV adopters.

The following main characteristics of the sample used can be extracted from the study as follows:

- The respondents' sex is mostly male with the percentage of 92.6
- Age is spread widely, however, most respondents are middle-aged with 73.8% of the sample between 35 and 64 years of age.
- The level of education is high with 16.4% holding a doctorate or equivalent, 28.1% with a master's degree or equivalent, and 40.6% with a bachelor's or equivalent (This means that 85.1% of the sample has received a University level education.)
- The level of income within the sample is high, with 76.5% earning more than $90,000 per year.
- The number of vehicles per household in this sample is 2.5, which is higher than the US average of 1.9 in 2014.

The processing of data was done by different methodologies and tools such as the Chi-square test and *T*-test which are tools to show the significant differences between a sample and a null hypothesis. Due to this data and methodology to evaluate the difference between low-end and high-end EV user characteristics. The results for each part are presented.

Socio-economic results:

According to the surveys done on similar studies, the socio-economic profile of low/high-end users composed of factors such as the number of people in the household[11, 15, 35], level of income[24, 32], and other factors are extracted and the presented as follows.

Gender: both groups have a low number of females however, high-end adopters are comprised of more females than low-end adopters. The percentage of female high-end adopters in this study was 11% compared to only 4.3% on the side of low-end adopters.

Age: the survey result shows that high-end early adopters are of a higher age than the early adopters of low-end.

Level of education: There is a significant difference in the level of education between high and low-end adopters. High-end adopters hold a higher level of education. Holding a doctorate or equivalent in terms of percentage is 23.9 for high-end adopters and only 10% for low-end adopters. 34.8% of the master (or equivalent) degree holders are of high-end while this number is 22.2% for low-end adopters. In total, the respondents with a University level education, are 92.3% of high-end adopters compared to 78.9% of low-end adopters.

Level of income: According to the results, both sets of adopters have a high income. However, the high-end adopters' income level is significantly higher than the low-end adopters. The percentage of early adopters who earn more than $180,000, for the low end is 12.6% whilst this number for high-end adopters is more than 62.6%.

The number of vehicles in the household: There is not any significant difference between samples and the null hypothesis regarding this factor. Both household types have higher car ownership in comparison with the US average.

Conclusion: All the collected and tested data show that there is no difference in car ownership, but significant differences in age, gender, education, and income. On average high-end adopters are having higher socioeconomic status than low-end adopters.

Psychological traits results:

Among all the questions for this part of the survey, the null hypothesis was rejected only for two questions. These null hypotheses were "There is no difference in the **length of the innovation-decision period** between high and low-end adopters" and "The **level of empathy** does not differ between high-end and low-end adopters". Results show that the level of empathy among high-end adopters is significantly higher and that they often take less time to invest in an unknown technology. According to Rogers' theory[36], early adopters show the same attitudes in terms of risk-taking and spending less time on investing in new technologies. In this sample, therefore, high-end adopters are more representative of early adopters in Roger's theory.

Vehicle Features:

Brand: Having a superior brand is mentioned only by high-end adopters compared to ICEVs whilst low-end adopters stated their vehicles as having a similar brand.

Perceptions of vehicle image: High-end adopters precipitate their vehicles with a superior image than ICEVs. This is while low-end adopters find their vehicles to be similar to ICEVs.

Price: Results of the survey show that low-end adopters view the cost of BEVs slightly more than ICEV, whilst high-end adopters believe that the purchase price of their vehicle is similar to ICEV. It is conceivable that every adopter bunch isn't contrasting their BEV with the ICEV which they recently possessed rather they are making correlations between their BEV and a vehicle that they see as being in a comparative vehicle class.

Vehicle rang: Low-end adopters stated that the range of their BEV is worse than that of a similar ICEV. On the other hand, High-end early adopters stated that their vehicles have a similar range as ICEVs. This result was predictable since the estimated range of a Tesla BEV is 270 miles, whilst the range of a low-end BEV is less than 100 miles.

Time to refuel: Results show that the time to refuel a BEV compared to that of an ICEV, according to high-end adopters is similar, whilst low-end adopters believe that their vehicles take a longer time to refuel than ICEVs. This result is surprising due to the view of high-end adopters since the time to fully recharge a Tesla BEV is much longer than an ICEV with fossil fuel.

Means for performance: The superiority of BEVs to ICEVs was admitted by both groups of adopters. The difference was in the intensity of this superiority. High-end adopters believed that their vehicles are by far superior to ICEV, whilst low-end adopters stated that their vehicles are just slightly superior.

Vehicles' lifestyle fit: BEV users, both demonstrated that compared to ICEVs, their vehicle is a better lifestyle fit. Among them, high-end adopters found their vehicles to be a better fit than did the low-end adopters.

For the factors such as **running costs, fuel economy and environmental impacts** both groups indicated a superiority of BEV to ICEV, with no significant difference between high-end adopters and low-end adopters. Regarding the fuel economy, BEVs have inevitably a better situation compared to ICEVs.

To sum up, 3 of 10 vehicle attributes tested were without significant difference between low and high-end adopters. Whilst, 7 other factors showed that high-end adopters have more positive views about their vehicles compared to low-end adopters.

2.3 EV USERS IN CALIFORNIA (USA)

The study presented by (Jae Hyun Leea, Scott J. Hardmanb, Gil Talb; 2019)[37] uses the methodology of multiple cross-sectional questionnaire surveys conducted by the Plug-in Hybrid & Electric Vehicle Research Center at the University of California. The survey gathers responses from 18000 PEV users, including the data of PEV buyers from 2012–2017 in California. However, the study does not include all 18000 respondents, but only 11037 responds, due to the incomplete socio-demographic information of some respondents.

In the study, 4 main representative clusters were identified (see Table):

1. High-income families representing the largest cluster with 47.9%, formed by higher income, middle aged[26, 38], mostly male, home-owning, highly educated households[15, 24, 33], and with more people in the household.
2. The second cluster (Mid/high-income old families) with 26.9% formed by mid/high income, education, and drivers in households. In particular, households in the second cluster were older home-owning households[25, 32].
3. The third cluster (Mid/high-income young families) accounts for 19.6% of the total. It had some differences in respect to the second one, even if the households in this cluster were similar in terms of income, education, and the number of drivers in households. Moreover, the third cluster is formed by younger households of which half rent and half own their home.
4. Middle-income renters represent the smaller cluster (5% percent of PEV owners). People in this cluster were middle-aged, middle income, with a high portion of males, with fewer people in the households, fewer cars, and mostly rent their home. Annual household income for this cluster is on average compared to the California state median.
5. The last portion added for the comparison reason is the socio-demographic data of 1650 Tesla owners. They have more in-common characteristics with high-income families with a slightly lower number of females and older age range. They also have a higher average income in comparison to high-income families

	High-income families	Mid/high-income old families	Mid/high-income young families	Middle-income renters	Tesla buyers
Nr of PEV buyers	4676	2500	1786	425	1650
Income (k$)	252.2	127.5	127.3	71.1	311.1
Age	43.5	53.5	30.7	47.2	46.5
Proportion of Females	0.24	0.26	0.33	0.48	0.22
Proportion of home owners	0.92	0.96	0.55	0.26	0.93
Nr of vehicles	2.60	2.44	2.15	1.56	2.53
Nr of people in Household	3.23	2.54	2.79	1.74	2.89
Nr of Drivers	2.28	2.12	2.01	1.48	2.17
Education*	2.52	2.07	2.18	2.08	2.45

Table 2 – Socio-demographic characteristics of four clusters

Source: EV user survey in California, Jae Hyun Leea, Scott J. Hardmanb, Gil Talb; 2019

According to this study, the characteristics of early adopters of PHEVs in California, change over time and this is proved by using multi-year survey data. The following main characteristics are listed as changes in latent class distributions 2012–2017. Comparing the data year by year shows how the PEV market changes and how different are the characteristics of early adopters for each year. This methodology is used to predict the future early adopters and define proper policies/incentives to elaborate PHEV use.

- Although High-income families were the largest group across every year, their proportion has been gradually decreasing (from about 55.6% in 2012 to about 40.5% in 2017), except for 2015. In contrast to the shrinkage of the proportion of new PEV adopters in this group, an increase is seen in the absolute number of adopters in this cluster as the market grows and this increase may continue until 2023.

- The total number of buyers in the high-income cluster is still growing as the market for PEVs grows.
- The proportion of Mid/high-income old families has not changed substantially except for the slight decrease in 2015; their proportion has so far remained between 22.7% and 30.5%.
- The proportion of Mid/high-income young families and Middle-income renters began to increase in 2013 and 2015, respectively. However, these Mid/ high-income old families have been relatively stable in terms of year-to-year cluster size. This group has grown from 10.8% in 2012 to 24.2% of adopters in 2017.
- The market thus far mostly consists of High-income families, with Mid/high-income old and Mid/high-income young families also making up a sizeable share.
- The proportion of Middle-income renters, though growing, is still small at 7.9% in 2017. Middle-income renters form the smallest cluster from the beginning (2012) with 2.1% and the end (2017) 7.9%. which accounts for the fastest growth among the clusters. Identifying these heterogeneous PEV adopters is an important contribution for policymakers, car-makers, and academic organs.
- The proportion of PHEVs amongst each class was higher in 2012 regardless of socio-demographic cluster membership (over 70%).
- For High-income families, Mid/high-income young families, and Mid/high-income old families, the proportion of PHEVs decreased between 2013 and 2017. This is presumably because of the introduction of more BEVs to the market.
- The proportion of PHEVs for Middle- income renters decreased between 2012 and 2014 but increased again between 2015 and 2017 (64% and 69%, respectively).

2.4 EV USERS IN SWEDEN

The study presented by (Iana Vassileva a, Javier Campillo; 2017)[39] is gathering the socio-demographic characteristics of electric vehicle owners in Sweden and their car preferences, main use of the EV, etc. The study is based on 399 achieved surveys in 2015 compiled by EV owners in Sweden. The questions included in the survey could be divided into four different groups:

- Questions about the socio-economic data (personal and household characteristics): age and gender, place of living, type of home, the composition of the household (number of children, ages, etc.), educational levels and average income, etc. Some of this information is shown in Figure 3.
- Questions for targeting the user's motivation and use of their electric vehicle[9, 24, 31, 40], for example, main reasons for purchasing the electric vehicle; level of satisfaction with their EV, etc.
- Questions for gathering information on EV driving and charging patterns: average distance traveled per day[9, 11, 31]; when the electric vehicle is charged (divided into weekend and weekdays); the location for charging the vehicle[24, 26-29] (e.g. at work, at home); etc.
- Questions for targeting information about the technical specifications of the EVs, for instance, the capacity of vehicles' batteries.

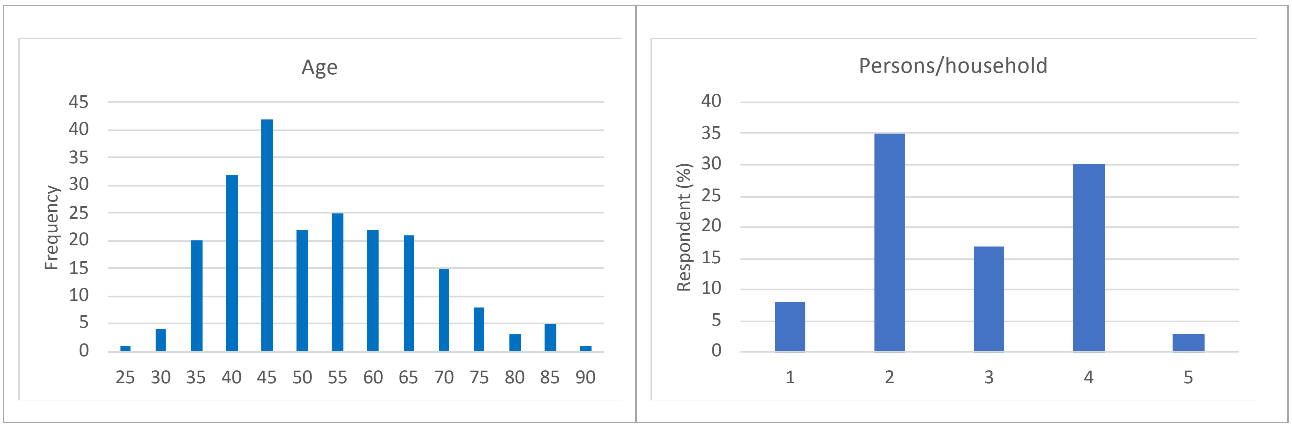


Figure 2 – Some social characteristics of EV owners in the survey
Source: EV user survey Sweden, Iana Vassileva a, Javier Campillo; 2017

The following main characteristics can be extracted from the figure above and the results of the study:

- Starting with the gender of the survey respondents, out of the 247 respondents, 19% were female and the other 81% were male (according to the result of other studies, mostly EV early adopters are male. Therefore, this sample is fairly representative).
- Most of the respondents are of the age between 40 and 45 years.
- regarding the EV owners' income levels, Responses were divided into three groups: lower than 50 000 SEK (approx. 5350 EUR); 50 000e100 000 SEK (approx. 10700 EUR); and above 100 000 SEK. The results of more than 53% of the respondents was an income between 50K and 100K SEK monthly. 26% of the EV drivers in Sweden had monthly salaries of more than 100 000 SEK.
- about the education levels of the household members above the age of 18, respondents were asked to indicate the number of people in the households with only primary school education; with only high school degrees; and with University degrees. Of all 247 respondents, 76.5% said they have a University degree. This percentage is showing a high level of education among the early adopters of EVs.
- The number of family members in current EV owners' households in Sweden is 2- member families with 35% of responds or families with 4 members composing 30% of the answers.
- To identify the main use of EVs among early adopters; respondents had to indicate the usage of their vehicle whether it's for private purposes or work. The results show that 80% of the respondents use the electric vehicle only for private purposes; 1% indicated that they use their cars for work-related activities; and the rest of the respondents (19% of the drivers) indicated that they use the EVs for both, work and private purposes.
- Regarding the number of vehicles in the household including ICE vehicles, 14.5% stated that they only have one vehicle in the household, which is electric. 56% of EV owners responded to have two vehicles in the household, Among them in 5.7% of these households both vehicles were electric. The next group with 28.7% indicated they have 3 vehicles per household; about 15.5% said 2 out of these 3 vehicles were electric. Moreover, out of the 210 respondents with more than one vehicle, 186 (88.6%) answered they "would definitely consider using only an electric vehicle in the near future".
- Regarding the level of satisfaction among existing EV drivers; 69% of the respondents (the total number of 242 respondents) indicated that they are very satisfied with their EVs; 29% said they were satisfied, and just 1% said they were fairly satisfied or not satisfied at all.

The outcome of the study regarding the profiling of the EV users in Sweden shows that the users are mostly male, with a medium-high range of income; holding a university degree; living in a 2 or 4-member family, and in houses usually located in low population density area. They mainly use their EVs for private reasons, and even though they usually own a second car, their EVs are used as the primary vehicle. They are very satisfied or fairly satisfied with their electric vehicle and the major part of them would consider using only electric vehicles in the near future. No significant differences were found between male and female EV owners in regard to their motivation for choosing an EV, for both gender groups, environment and cost efficiency were the main reasons selected. The countries with similar characteristics as Sweden could benefit from the identified characteristics of current EV owners in their initial stage of implementation, to know the expectations in terms of early adopters.

Swedish EV owners drive a distance between 30 and 100 km per day and the charging mostly takes place at night and at home. This is a valid argument that can help reduce range anxiety which is identified as a major barrier to the adoption of EVs. The results of this study could give an insight to the decision-makers in order to apply strategies and tools to develop EV diffusion in Sweden. Based on the survey result controlled charging schemes is an effective way to allow high EV penetration levels on local distribution networks. Additionally, load-shifting strategies should be developed to prevent overload the electric grids during evening peak hours, when most EV drivers come home and plug their vehicles to charge. To achieve a sustainable diffusion of EVs, local and national bodies should concentrate on providing support for the planning of the location of charging stations in densely populated areas, for instance, slow charging stations should be located in private boxes and areas near to the drivers' homes where the cars can be left charging during the night.

2.5 COMPARISON

A comparison has been carried out regarding the results of the user-profiling studies to better understand the context-based differences in each area of study. The fact that the statistics' population among these contexts are different should not be ignored. However, in the mentioned studies, samples are reliably representative of EV users in the same geographical context.
Gender difference is a noticeable aspect between Nordic countries and The United States. In a country like Sweden, female EV owners are holding 10% more of the total number of EV users in comparison to California. This might be because of the progressive situation of Nordic countries towards gender equality, and feminism. The second important aspect of this comparison that differs from one context to another is the age of EV users. In contrast with California and the US in general, the age of EV users in countries of northern Europe is much lower (30 for Nordic countries and 50 for the US) and unlike Nordic countries, in the US these statistics are quite spread. The income of EV owners in the Nordic countries is between 50-70 k€ annually, while for the US the average income of EV buyers is more than 90 k$ dollars per year. In the US, high-income families formed 40.4% of PEV buyers in 2017. Mid/high-income old families have been relatively stable in terms of year-to-year cluster size in the US. Whilst, Mid/high-income young families are 24.2% of adopters in 2017. Middle-income renters are the smallest cluster with 7.9% in 2017 which experienced the fastest growth. The study about the US shows that the market is not homogenous, therefore different policies should be applied accordingly to develop a market environment that will enable all different consumers to purchase and use PEVs. This is while the

government in the Nordic context provides more opportunity by giving incentives equally to all the citizens regarding the feasibility of EV purchase. For instance, the overall low electricity prices in Sweden is an incentive that makes electric vehicles very attractive, especially to the younger people with relatively low income (50123 SEK/household as the average for the group of 26-35 years old).

One similarity between the two contexts of Nordic Europe and the US is the percentage of university degree holders among the current EV users, which is about 80 to 85% accordingly. This factor seems to be a stable characteristic among EV users unrelated to the context.

Comparing the number of vehicles, this number per household in the US sample is 2.5, which is higher than the US average of 1.9 (US Department of Transportation, 2009)[41]. While this number for Nordic countries is at least two vehicles per household (from which one is non EV) for 75% of the sample.

On the other hand, the Nordic countries show an influence between gender and car ownership, driven Kilometers, EV experience and, the ownership of electric vehicles, all orientated towards men. Education has not a strong effect on the EV market in Nordic countries since the current users are almost equally with and without a higher education degree. Occupation and employment also influence EV diffusion. In Nordic countries, non-profit organizations and non-governmental organizations based on their willingness to pay, are more interested in purchasing the EV. The same interest is seen in occupations in academic fields, most probably due to the availability of information.

The influence of age is more visible, with ownership of electric vehicles more focused among the younger middle-aged (25–44 years). This range of age also shows higher interest for the safety and cost savings attributes (maintenance) of EVs. In contrast with some of the literature, this study indicates that larger families as well prefer to own electric vehicles, and household size correlates to car ownership and greater daily travel needs. The study also lists unemployment, disability, and illness among the strong barriers to EV experience and ownership. Table 3 sums up the results of the process of looking for measurable factors in the literature in order to quantify EV diffusion among the early adapters. The questionnaire prepared in this thesis is focusing on the most repetitive factors in common between all the case studies.

	Nordic Countries	Sweden	The United States	California
Gender	Y	Y	Y	
age	Y	Y	Y	Y
occupation	Y	Y	Y	Y
Political Leaning	Y			
Education	Y	Y	Y	Y
Household Income	Y	Y	Y	Y
Km per day by car	Y			
Car ownership	Y	Y	Y	Y
Home ownership		Y		Y
Number of people in the household	Y	Y	Y	Y
Number of drivers				Y
Level of satisfaction with EV		Y		
Type of usage (personal or for work)		Y		

Table 3 – Main factors studied in the surveys for EV users profiling.
Source: Author's elaboration, 2020

3 MAIN LEADING FACTORS IN THE MARKETING OF EV

The market penetration of new technologies and electric vehicles as a slightly new-to-market invention is growing day by day. Consumers exhibit different levels of readiness (Parasuraman et Colby, 2007)[42] to embrace their role in interaction with these new technologies. In this section, the main leading factors to purchase an electric vehicle, from the consumer's point of view, are studied. These factors are investigated in different countries, among them specifically Japan (progressive in the use of EV in Asia), Germany (a representative of European countries), and Sweden (one of the early adopters in EU) are chosen to be studied in detail.

3.1.1 JAPAN

Japan is home to many new technologies among them PHEVs and EVs specifically with a high rate of use. According to McKinsey & co.'s EV index in 2012 Japan has gained first place among the countries for readiness to EV supply and demand. The government has also, incentivized the use of electric vehicles as well as providing the needed infrastructure for the functioning of the massive adoption of EVs. In the process of identifying early EV purchasers in Japan (McKinsey & co, 2013)[43] what is seen is the bold presence of "Green Tech Savvies," who are environmentally conscious people who love cars and new technologies. Green Tech Savvies mostly have high-income rates, live in their own unit of housing, and are in possession of usually more than two cars. Another characteristic of green tech-savvies is that they also have backgrounds in science or technology, higher educational levels, and larger families with kids at home. They are socially active, avidly gather information about cars through various sources, and are willing to pay for new technologies, and tend to drive only shorter distances. They aspire to contribute to protecting the environment, usually have solar panels on their houses, and tend to live a green sustainable life.

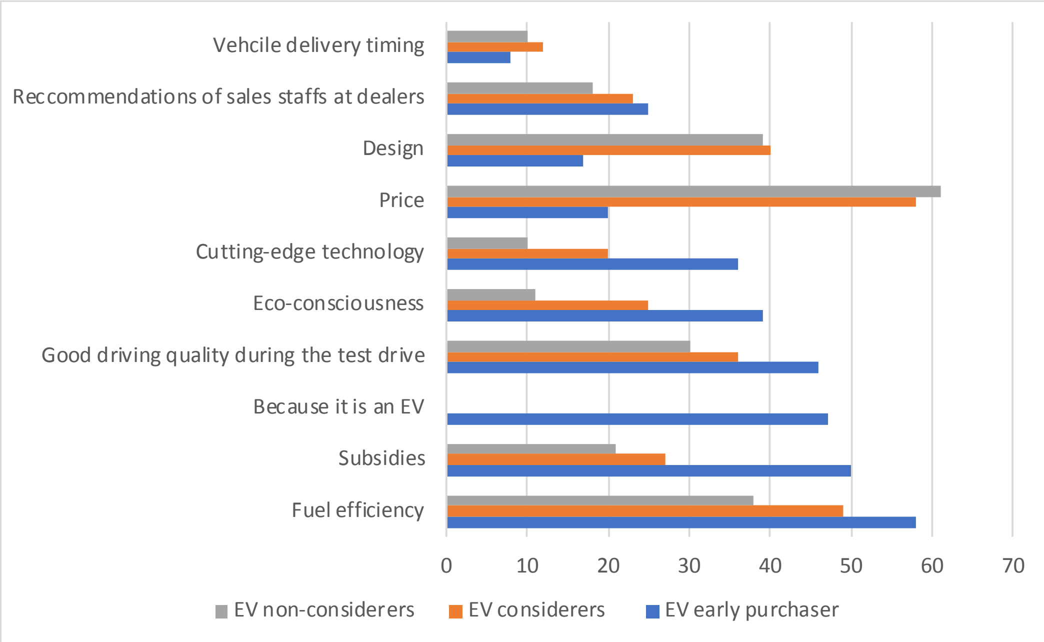


Figure 3 – Reasons for purchase EV by costumers in Japan
source: Electric vehicle owner survey, Mckinsey and Co., 2013

Early EV adopters, considerers, and non-considerers with the common point of "having bought a new car in the past 2 years", participated in an online survey regarding the motives/barriers of purchasing an EV in Japan. The results show that over half of the early EV adopters listed fuel efficiency as an important factor to buy an EV while half mentioned subsidies. Meanwhile, the non-considerers listed price and design as the most significant barriers to purchasing an electric vehicle.

3.1.2 GERMANY

In a likewise research, done in the context of Germany (Trommer, Jarass, and Kolarova, 2015)[44], an analysis of representative data collected from over 3,000 BEVs and PHEVs owners in Germany partially confirms that the consumers of this type of vehicle have a higher average income, a higher educational level and having more cars at their disposal per household. However, the data demonstrates that aspects such as socioeconomic characteristics and their attitudes differ significantly among EV users. A more detailed list of the results of this survey is presented in figure 4.

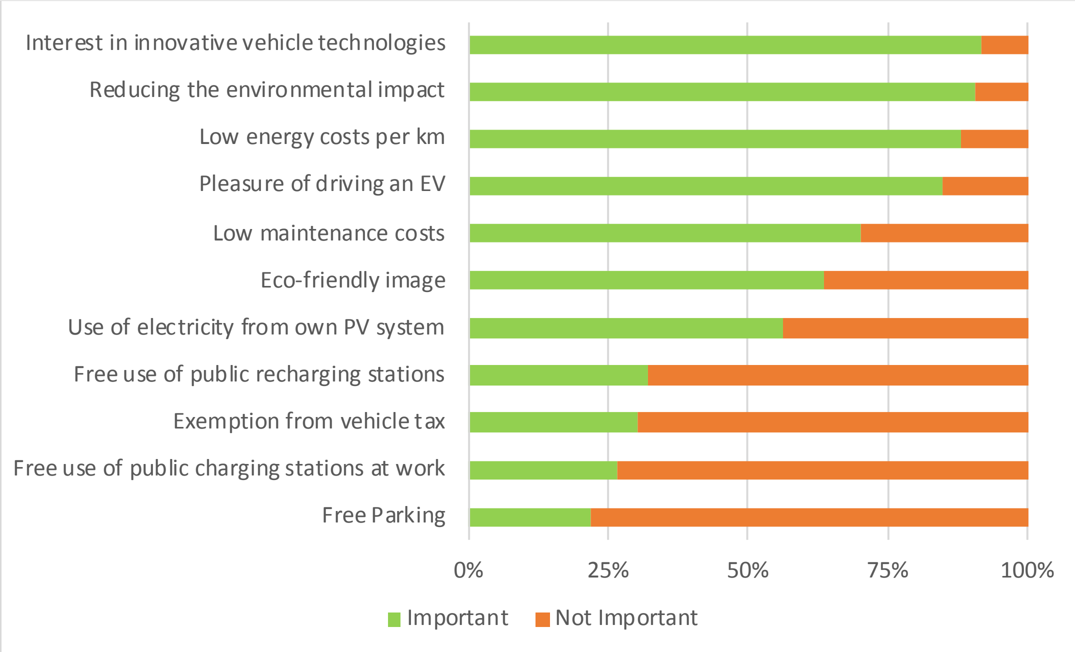


Figure 4 – Relevancy of factors influencing the decision of buying an EV in Germany

Source: EV user survey, Trommer, Jarass, and Kolarova, 2015

In the case of Germany, what is visible is the first 5 most rated reasons to purchase an electric vehicle include Interest in innovative vehicles, environmental aspects, fuel costs, the pleasure of driving an EV (This case was one of the main motives in Japan) and low maintenance costs.

3.1.3 TENERIFE (CANARY ISLANDS)

According to the results presented in the research of Tenerife (Maria Gracia Rodríguez-BritoD et al, 2018)[45], and in compliance with the literature regarding EV early adopters[46],[47],[35] the following indicators were found significant to dispose of the willingness to purchase an EV.

- Readiness to use new technologies;

- Environmental consciousness;

- High-income older males with high educational attainment.

According to the survey, another significant finding is that giving clients fundamental data on EVs can build up their WTC (willingness to change) to an EV. 17% of the individuals in this survey said that they would switch to an EV in the case of getting informed properly about the basic characteristics of EVs. Access to data is crucial for the potential adopters in order to think about the general points of interest in the EVs, carry out a comparison between similar options, and visualize the compatibility with their lifestyle. (Rogers[36] and Erdem et al[48])

This study has categorized EV adopters in a very similar way that Rogers[49] has done in the diffusion of innovation theory. Therefore, the sample has two main categories of early adopters and late adopters, with each compiling half of the population of the sample, and then other main sub-categories namely innovator early adopters, early majority, late majority, and laggards. The results of this study are presented accordingly.

Early adopters with almost 7% demonstrate two psychosocial profiles. Both these groups have high WTP (willingness to pay) for they are the first possible group to purchase an EV. The difference though, between these 2 groups is the fact that individuals in the first group with 5% are seen as tending to show an impulsive and not reflective behavior which is guided by feelings and sentiments, though the second group with 2% has a more tendency towards showing a reflective behavior yet with a specific inclination to risk. Both these groups are considered potential early adopters due to their willingness to pay. Early adopters are an important group to attract the early majority to the EV market and their effect on purchase decisions for the subsequent group is inevitable.

The early majority shares 42% of the market and therefore it is the group that ought to be given more consideration; simultaneously, it is conceivable to attract them to purchase an EV. Like the previous group, there is an internal sub-division based on the psychological traits of the individuals: 27% with the tendency to show impulsive behavior, and 14% show reflective behavior. These sub-categories can help in facilitating the marketing of EVs. People in this group are inclined to purchase an EV and have a fair amount of WTP, however insufficient to obtain an EV in the current market. Thus, price limitations, incentives, and the presence of medium-class EVs would permit that these customers could become users of EVs.

The late majority is composed of 37% of the participants. The main characteristic of this group is having a specific avoidance in risking, a lower level of impulsivity, and rejecting the innovation adoption. This group would not buy an EV until the prior adopters have entered the market.

Laggards with a bit more than 13% of the sample population, show an inclination towards ICEVs for reasons qualified as "taste", and completely decline to change for an EV. They are known for paying a high amount of attention to vehicle properties such as design, driving experience, appearance, etc. which separates them from the previous groups.

3.1.4 SWEDEN

In a study done in Sweden context (Iana Vassileva a, Javier Campillo, 2017)[39] The main reasons for choosing an EV over an ICEV according to the drivers of electric vehicles classified by their gender are presented in figure 5.

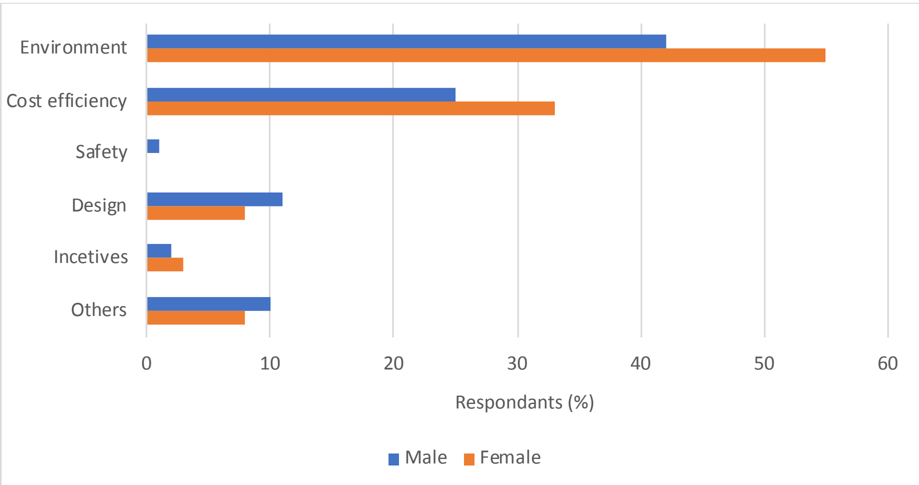


Figure 5 – Main reasons for buying an EV by gender in Sweden.

Source: Survey of EV users in Sweden, Iana Vassileva a, Javier Campillo, 2017

The motive that matters more for both males and females with accordingly 44% and 55% of the whole participants, is the vehicle's effect on the environment. The second important factor of EVs for the users in Sweden is cost efficiency which is referring to charging and maintenance costs. This factor is more important for males with 34% and less for females with 25%. The users who chose the option "others" as the most important motive for purchasing an EV, indicated that they are interested in the new technologies and the excitement of pioneering in the use of this technology. The comparison between males and females shows that they have the same motivations for choosing an EV even if the participants are not equally from both genders.

According to VaasaETT [50], The overall electricity price in Sweden is low and for this reason, electric vehicles are very attractive. This factor is important particularly to the younger groups due to their relatively low income (average income of the age group of 26-35 is around 50 123 SEK per household). In all age groups, less than 20% of the respondents selected any of the other provided reasons (design, incentives, safety, others). Unexpectedly, the group with the highest percentage of respondents (20%) that chose the design of the car as one of the reasons for choosing an electric vehicle, was the group of 71 to 75-year-old, where all other age groups show a very low interest in the design of the vehicles.

3.2 OTHER COUNTRIES

Costumer concerns derived from surveys worldwide, show similarities in different countries. All of the factors below are listed based on the percentage in order to carry out a comparison in the barriers of EV diffusion market in diverse backgrounds. In the study presented by Deloitte, 2018[51] the priority of factors changes depending on the spatial condition and the economic context of that country.

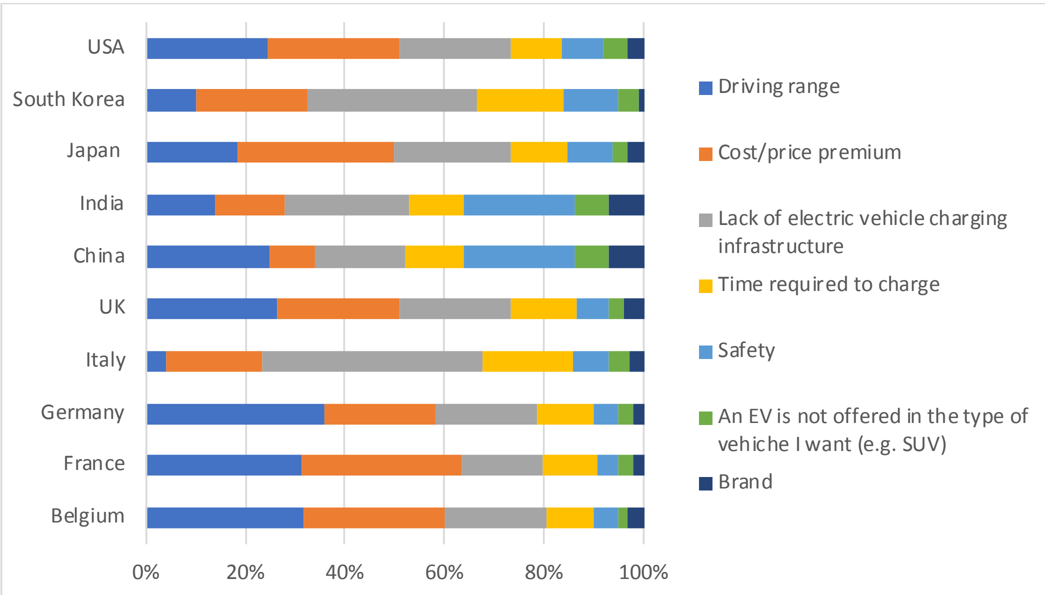


Figure 6 - Main factors for buying an EV in different countries.

Source: BEV adoption survey, Deloitte, 2018

According to this study, the 4 most important unsettle factors that BEV users indicated are high cost, driving range, absence of adequate infrastructure, and time requiting process of charging. Regarding the statistics of the consumers in Italy, the most important factor is the lack of infrastructure and then in the second place, the cost premium of the electric vehicles. With slightly the same percentage, the time required to charge is in the fourth place of importance for Italians. Considering the final goal of this study which is to produce different scenario maps regarding the diffusion of EVs in Turin's metropolitan, based on the characteristics of the area and population statistics, some suggestions in the policies will be discussed to help overcome the spatial barriers in the EV market and consequently promoting the diffusion of electric vehicles to improve the life quality in terms of pollution, traffic and diminishing other problems related to ICEV's massive use.

3.3 CONCLUSION

In a comparison carried out regarding the previous sections, despite the difference of the statistics in different contexts, there are significant similarities in the main effective factors on the EV diffusion mentioned in each of these studies. The main difference though, despite the similarity of repetitive factors, could be mentioned as the stressing and the importance of each factor for different backgrounds (the most important factors are rated differently for each context, depending on the social, spatial, and economic aspects of the study area). There are also very similar prohibiting factors, rated differently as well, among different contexts that lead people not to be considering buying an electric vehicle.

The main outcome of this comparison is taking into account both leading and prohibiting factors in the marketing of EVs to have a wider perspective on future horizons and to provide the needed infrastructure for this thesis research. The usage of the effective factors data extracted from the case studies is to conduct a questionnaire compiled by potential EV users to identify the weight of each factor in the EV diffusion scenarios. Even though, at the level of this thesis, the results of the questionnaire are presented only. While for the purpose of weighting the indicators, Paola Pucci's study has been used. In the possible further developments of this research, the weight of the factors could be deducted from the questionnaire results presented in the upcoming sections.

Along with the common factors measured to define the profiling of EV users, some additional indicators are seen in the related literature that is essential for elaborating the different EV diffusion scenarios. Table 1 summarizes the main diffusion factors extracted from the literature and their relevance in our research. Scenarios are created accordingly to the different weights and based on these scenarios proper policies are suggested to guarantee the most beneficial possible future diffusion modality of EVs in Turin's Metropolitan in Italy.

	Indicator	Studies which process it	The relevance in our research
Profiling of the contexts	Population density	Morton et al. (2018); Chen et al. (2015); Dimatulac & Maoh (2017)	measure of the density of potential users of Evs
	Type of Housing (Detached House; Semi-Detached House; Terraced House; Flats/Apartments)	Morton et al. (2018); Namdeo et al. (2013)	measure of the availability of private garage or off-street (garage) and public parking
	Charging Points	Hackbarth & Madlener (2013); Hardman et al. (2018); Sierchiula (2014); Liao et al. (2017); Morton (2018); Collavizza et al. (2017); Morton et al. (2018)	measure to encourage the diffusion of EV
	Electric Vehicles per 1000 cars	Morton et al. (2018)	measure of the high propensity to use Ev
	Hybrid Electric Vehicles per 1000 cars	Hardman et al. (2018); Sierchiula et al. (2014); Liao et al. (2017); Morton (2018); Collavizza et al. (2017); Morton et al. (2018); Hackbarth &Madlener (2013)	measure of the high propensity to use Ev
Profiling of the "early adopters"	Age of the inhabitants	Morton et al. (2018); Plotz (2014); Namdeo et al. (2013); Hackbarth & Madlener (2013	measure of the level of interest and willingness to use and purchase an electric car; particularly high in the age groups of less than 50 years
	High School Qualification (% on the total inh)	Liu et al. (2017), Dimatulac & Moach (2017); Morton et al. (2018); Saarenpaa et al. (2013); Cecere (2018); Liao et al. (2017); Kim et al. (2014)	measure the high level of school education as a proxy for environmental attitudes
	Income	Morton et al. (2018); Chen et al. (2015); Liu et al. (2017); Dimatulac & Moach (2017); Saarenpaa et al. (2013); Kihm&Trommer (2014); Cecere (2018)	measure of the high-income population, as propensity to purchase an Ev, based on the high cost of EV
	Type of Employment: Full Time; part Time, Unemplyed, Retired;	Morton et al. (2018); Dimatulac & Maoh (2017); Kihm&Trommer (2014)	measure of the "lead markets" for the adoption of electric vehicles.
	Household composition (n. of the person by unit)	Liu et al. (2017); Kim et al. (2014); Dimatulac & Moach (2017)	measure of the propensity considering that a larger households are expected to own larger vehicles and as such would be less inclined to favor EVs given the high cost
	Home ownership	Saarenpaa et al. (2013); Morton et al. (2018), Namdeo et al. (2013)	measure of the propensity to support the cost of installing the domestic electric charging system
	Car ownership (n. in each family)	Morton et al. (2018); Namdeo et al. (2013)	measure of the car availability and indirectly of the individual propensity to use the car
	No car ownership	Morton et al. (2018)	measure of the car availability and indirectly of the individual propensity to use the car
	N. of daily trips	Liu et al. (2017); Hidrue et al. (2011)	measure of the travel frequency, considering that EVs are convenient in terms of total costs only after a number of kilometers of 25,000 / year.
	Average travel distance in the daily displacements	Chen et al (2015); Kihm&Trommer (2014); Plotz (2014); Danielis (2015)	measure of the average distances travelled, considering that EVs are convenient in terms of total costs only after a number of kilometers of 25,000 / year.
	Modal share in the daily displacements	Morton et al. (2018); Danielis (2015); Plotz et al. (2014); Kihm&Trommer (2014)	measure of the preference and propensity to use the car

Table 4 – Indicators, resources, and relevance in thesis

Source: Milan's spatial dimensions of electromobility, Paola Pucci, 2021

4 SPATIAL FACTORS IN E-MOBILITY DIFFUSION

Following the common belief, electric mobility diffusion is mainly bounded to the spatial setting of cities. Cities, as spatial areas with a concentration of regional economy, culture, politics, and transportation, are considered as an attraction to the surrounding areas. The advantages of city living have directed the flow of population from rural to urban areas. Mobility of population in urban and rural areas has played an important role in promoting the rapid growth of urbanization rate (Shang et al. 2018) [52], and the same effect with the opposite direction is visible, meaning the development of urbanization has also contributed to the promotion of mobility in the region (De Shirbinin et al, 2007) [53].

Conventional urban economic theory[54-56] demonstrates that transportation systems decrease the density by increasing the spatial extent of the city if they reduce the cost of transportation. Thinking of an EV transportation grid managed and promoted by the metropolitan city, in the case that it covers the entire extent of a metropolitan area, and considering that the final cost for the use of this system is more convenient than using ICEVs, could potentially encourage sprawl and cause new, electric-car traffic congestion on the roads. This type of transportation system results in a new urban form, that is less centralized in comparison to the early 20th century rail-dominated cities, or the formless sprawl facilitated by the high range of fossil fuel vehicles. The reason for this difference in form is the limits that the EV network is applying in the range of sprawl. A factor that does not exist in the widespread conventional systems.

The assessment of EV diffusion according to the studies that are focusing on the urban area as a definite context for e-mobility, is summed up in collecting and analyzing the early adopter/user preferences along with the demographic data such as age, gender, occupation, income, etc. This is while looking at the e-mobility from a regional view, the major part of the space occupied, area-wise, in urbanistic literature categorized as the suburban or rural area is neglected in these assessments. Pucci (2021)[22] believes that the usage of technical and demographic data, solely, is risking the exclusion of areas and potential users for which EVs can produce appreciable environmental and behavioral results, such as rural areas and low-density settlements. Therefore, we can say what is not bold in the resembling studies is the spatial condition (built environment and infrastructure) and the patterns of mobility such as daily inflow/outflow, car dependency, etc. A possible reason that could explain the fact that socio-spatial factors in the literature regarding EV diffusion are rarely seen is that these factors are qualities not easily measurable. However, this cannot negate the importance of their assessment in the transition phase of conventional vehicles to their electric pairs in an urban or rural area.

This study is aiming to extract these socio-spatial factors out of the studies in favor of these subjects, as emerged from the previous review of the literature on the adoption of EVs (see chapters 2 and 3), and assessing them in the context of Metropolitan of Turin located in the northern region of Italy. These data could be used to generate different scenarios based on diverse weights of criteria deriving from the socio-economic, geographical, and travel pattern assessment results in the future developments of this study, while as per the points of this research, the pre-defined factors and weights in the Pucci's paper are in use. In the previous sections, the focus was on the discoveries of studies identified with the same contextual conditions and the same will to leaning towards EV adoption. The overlapping factors in Pucci's research and studied cases are going to arrange the determination of relevant indicators to apply in our area of study (Metropolitan of Turin).

4.1 LITERATURE REVIEW (SPATIAL CONDITIONS)

Literature regarding EV diffusion according to Aultman-Hall et al (2012)[57] states that except for a few, studies assume that EVs may be an energy solution for transportation only in urban areas and not rural. In other words, most of the studies done on the subject do not take into account the spatial distribution of the travel demand.

This is while on the other hand, according to AVERE 60% of the market demand for electric vehicles is stated by the population living in rural and semi-urban areas, where the zones are not only underserved by public transportation but also poorly represented in the combined initiatives in favor of electric vehicles. Studies done by Charlene Boyom et al (2016)[58] and Paola Pucci (2021) are in the list of few studies that have taken this important spatial aspect into account.

Regarding the urban application of electric vehicles, the impacts and changes applied to the face of cities, sustainability increase, policies, and other spatial aspects of the EV distribution, a growing literature is in perspective. Some of these reference studies are differentiated by topic :

- Electromobility from the environmental point of view:

  Electromobility as an environmental solution in polluted urban areas with the focus on cities(2020)[59, 60]

- Electromobility and sustainability :

  Increasing the sustainability in different aspects of the EV adoption, from implementing the infrastructure(2020)[61] to Ecological urban scape solutions for sustainable urban development (2021)[62]

- Policies regarding electromobility:

Policy-wise, publications like the EV City Casebook (RMI, 2012) are applicable as a reference of examples of socio-technical experimentation. Practices and policies to adopt sustainable development goals and in particular electro mobility integration in the megacities of the first world countries (2012)[63] and urban areas of developed case studies (2021)[64], and also decision Making Support for Local Authorities Choosing the Method for Siting of In-City EV Charging Stations (2020)[65]

- Case studies of Electromobility diffusion:
  Several pieces of research can be found in the literature regarding analysis of surveys conducted with electric vehicle trial users (Everett et al, 2011)[66], participants in electric vehicle test-drive (Skippon and Garwood, 2011[67]; Campbell et al, 2012[68]; Graham-Rowe et al, 2012[69]) and ethnography into families with electric vehicles (Heffner et al, 2007)[70]. There are likewise concentrates on the perceptions and points of view of vehicle owners in general (Moons and de Pelsmacker, 2012[71]; Peters et al, 2011[72]; Pol and Brunsting, 2012[73]). The results of these studies are usually taken as positive for EV uptake.

In relation to the spatial aspect of EV diffusion, the studies can simply be followed in two dimensions.

The first group of studies focuses on the proposal of possible scenarios to assess EV adoption track in the medium-term period, considering both the factors of time and space for EV demand (Higgins et al. 2012[74]; Zubaryeva et al., 2012[75]; Kihm and Trommer, 2014[31]; Pucci[22], 2021).

The rest of EV diffusion studies' focal points are early adopter's characteristics, providing maps of EV registration, and forecasting the residential locations of potential EV adopters (Campbell et al. 2012[68], Morton et al. 2018[24]; Pucci,[22] 2021).

Besides these two main groups, there is a third category that points out the optimal charging infrastructures simulations in the urban area (Namdeo et al. 2014[25]; Bailey et al. 2015[76]; Adenaw et al. 2021[77])

To address the spatial context gap in the chosen resources, a mix of all mentioned factors borrowed from main categories of EV diffusion studies allows us to describe the spatial characteristics and the geographical variation in EV adoption.
In the context of this study (metropolitan of Turin), the literature has been examined to answer the question that regarding EV diffusion, apart from the usual context of urban areas, are rural and semi-urban areas the right contexts to be considered in the diffusion of EV? If the answer is yes,

what factors are effective in this distribution? On the basis of defined effective factors, what type of EV distribution should be promoted, and how the policies are going to make a change?

Reasons such as zero emissions, being noiseless in operation, not requiring power when motionless (i.e. in traffic), and having reasonable acceleration, make electric vehicles suitable for the urban context. On the other hand, EVs are not a good option for traveling outside or between urban areas due to their limitation in range and speed. This is while for urban trips which have relatively shorter distances and durations, EVs are quite suitable and their limited range is not deemed as an issue. In addition, due to the relatively high fuel uptake in each start of the conventional cars, EVs function better in congested areas, namely dense urban areas, with lots of stop-starts in driving. Another plus of the urban area as a suitable context for EV diffusion is the fact that due to the population density, the infrastructure investments for charging points are more worthy because of the classic economies of agglomeration. With all these factors taken into account, the connection between EV diffusion and urban area is inherent. (Newman, D, Wells, P, Donovan, C, Nieuwenhuis, P & Davies, H 2014)[19]

Literature regarding the EV adopter attributes, show a direct relationship between the leaning to purchase an EV and gender, income, education, number/type of cars owned, level of environmentalism, and passion for new technologies (Hidrue et al., 2011)[47]. Based on the stated preferences in this study, being young or middle age, being environmentally-friendly, having a university degree, expecting an increase in fossil fuel price in the near future, having space to install an EV charger, being likely to buy a small/medium car, taking at least one long car trip per month, and tending to purchase new technologies available make a consumer more statistically likely to be "EV-oriented." High-density populations with a more probability of having high-income, university degrees, and technology-oriented leaning outcomes could be found in urban areas more than sub-urban and rural areas. Therefore, a higher potential EV consumer population exists in the cities. This does not mean that the policies regarding EV diffusion in urban areas should necessarily be the replacement of every and each ICEV with an EV, for that this is not a decent solution to the overwhelming car presence in these areas.

On the very opposite side of what was said are rural areas, that could be considered as an option for EV diffusion all in another form compatible with the area's characteristics. Focusing on urbanism has recently failed to match functional user trips and behavioral leaning with EV attributes. Meaning most of the possible superiorities that electric vehicles might have over traditional diesel vehicles are potentially lost. Electric vehicles either used by corporate or retail owners, have to be used intensively to be cost-effective. The initial acquisition cost (which is relatively high) can be offset by lower running costs, and in the long term, the consequent advantages such as improved air quality can be achieved. Environmental benefits of EV diffusion in congested urban areas where electric vehicles are not the only means of transport and there are numerous alternatives (i.e. diesel-fueled public transportation) it is not so promising to realize such gains. (Newman, D, Wells, P, Donovan, C, Nieuwenhuis, P & Davies, H 2014)[19]

The areas that can be considered problematic for EV adoption are the suburban ones. The characteristics of these areas are low residential density and high kilometers driven. The results suggest that EVs are viable for suburban mobility demand but their diffusion requires special consideration for power supply and vehicle-charging infrastructure.[57]

It very well may be accepted that early adopters will be people who feel more reliant on their vehicles. This reliance might be because of where individuals live, as it requires longer time per each daily trip for those living in the rural contexts, and public transportation in these areas is often less evolved. As such, in such locations, the pilot surveys from the ENEVATE[1] project suggest new patterns of EV demand may be compelling.

Urban, suburban and rural areas are defined with little consistency in the literature of urban ecology (Raciti et al. 2012; Theobald 2004) [78, 79]. According to Raciti the simplified common measures for defining urbanization are factors such as demographic statistics, linear distance from a major city, percentage of Impervious surface, and road density. Newman et al. regarding the boundary of urban and suburban area state: “Following the OECD urban-rural typology, with urban areas constituted as those demonstrating a minimum population density of 300 inhabitants per km^2 aligned to a minimum population of 5,000 the ENEVATE pilots can be regarded as split between the urban, suburban and the rural.” (Newman, D, Wells, P, Donovan, C, Nieuwenhuis, P & Davies, H 2014)[19]

4.2 CASE STUDY OF TURIN’S METROPOLITAN AREA

The Metropolitan City of Turin (Città metropolitana di Torino) located in the Piedmont region, Italy is a large-area territorial body of the second-tier local authority whose territory coincides with that of the pre-existing province of Turin. The concept of the metropolitan city was introduced on the 8th of April 2014 (Legge 7 aprile 2014 n.56) and became operational on the 1st of January 2015. It is comprised of the city of Turin as the capital, and 311 other municipalities (comuni), holding the title of the province with the highest number of municipalities in Italy. The overall population counts for 2.23 M of which 51,6% are Females and 48.4% are Males (Tuttitalia statistics, 2020). People aged between 35 to 59 years old represent 49% of the whole share of the population, the biggest age group including half of all residents. The average age in this area is 47.1 years old that falls into the “middle-aged” category.(Tuttitalia statistics, 2020).

[1] ENEVATE was a European Union-funded three year programme designed to support and accelerate the uptake of e-mobility in North West Europe.

Turin Metropolitan City			
Country	Italy	Municipalities	312
Region	Piedmont	Population	2.230.946
Capital	Turin	Density	320/km2
Established	1 JAN 2015	Area	6,827 km2

Table 5 – Study area characteristics

Source: author elaboration,2021

The Metropolitan City of Turin is in charge of performing the former Province's duties, including the annual upgrade and development of the metropolitan territory Strategic Plan, and systemizing the constitution of the interrelated systems for the management of the public services.

Decreasing natural resource consumption is a major objective for the departments of The Environment Department, and The Land, Transport, and Civil Protection administrations of the Metropolitan City of Turin, including soil protection especially in the mobility sector and infrastructure planning. It is worth mentioning that the prevention of environmental disasters is also planned within these entities.

In Turin's metropolitan area, general road networks to improve traffic flow, such as underpasses and flyovers, as well as railways are present in a large scale. Two railway stations of "Porta Susa", and "Porta Nuova" along with the subway line known as "Metro Torino" are the main transport poles in the area.

The suburban car network forms a fundamental part of the mobility system of the metropolitan area, served in addition to the railway service to cover the transportation in the routes not served by train lines. Similar to what happened in other large Italian cities, the car network is mostly made up of lanes and routes formed in the absence of an overall plan, a legacy of situations that are often anachronistic and not responding to the most recent urban dynamics. This network is still strongly based on the Fordist city model of the 60s / 70s, mainly serving the large industrial production poles, which, in cases where they are still active, have a significantly reduced activity.

The Metropolitan City of Turin is involved in all work packages and provides the perspective for managing Green Infrastructure (GI) related to urban areas and how GI functionality assessment can inform policies and community actions. Pursuant to art. 1 paragraph 11, of the law 7 April 2014, n. 56, The Metropolitan City of Turin, has agreed to identify 11 "homogeneous zones" in its territory, in order to allow effective participation and sharing of the Municipalities in the government of the Metropolitan City. Homogeneous zones constitute the operational articulation of the Metropolitan Conference for the purposes defined by the Statute of the Metropolitan City of Turin and are governed by specific regulations approved by the Metropolitan Council, after consultation with the Metropolitan Conference. These zones also constitute an articulation on the territory of the activities and decentralized services of the Metropolitan City and can become an optimal environment for the organization in the associated form of municipal services and the delegated exercise of functions of metropolitan competence.

They express opinions on the acts of the Metropolitan Council that specifically concern them and participate in the shared formation of the Strategic Plan and the Metropolitan Territorial Plan. The 11 homogeneous areas are characterized by territorial contiguity and by the presence of a population not less than 80,000 inhabitants.

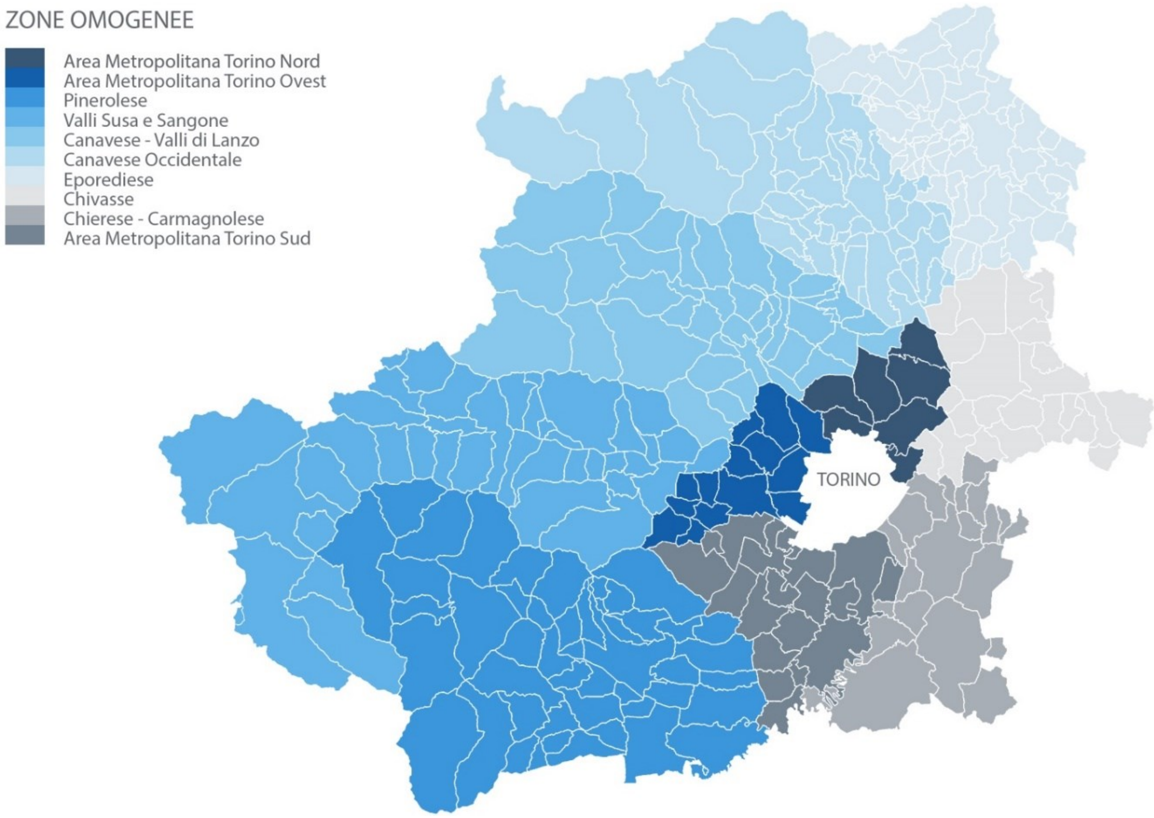


Figure 7 – Study area characteristics

Source: SPISA,2021

Following the density map as a common factor for measuring urbanization, the large patch of Turin is representing the core urban area in accordance with the definition of urbanized contexts in terms of demographic measures and the presence of a noticeable concentration of road nodes and stations. The first belt around this patch (prima cintura) is where urban sprawl takes place and therefore matches the characteristics of the sub-urban area around the urban center with less density. Alongside are rural areas, comprised of varying levels of smaller settlements interspersed with significantly less developed elements of the countryside and a high percentage of Impervious surfaces, shown with the lightest color.

The study area hotspots and their division into the urban, suburban, and rural categories are shown based on density measurement in figure 7. This map is going to be used as a baseline for the different scenarios in the upcoming chapters.

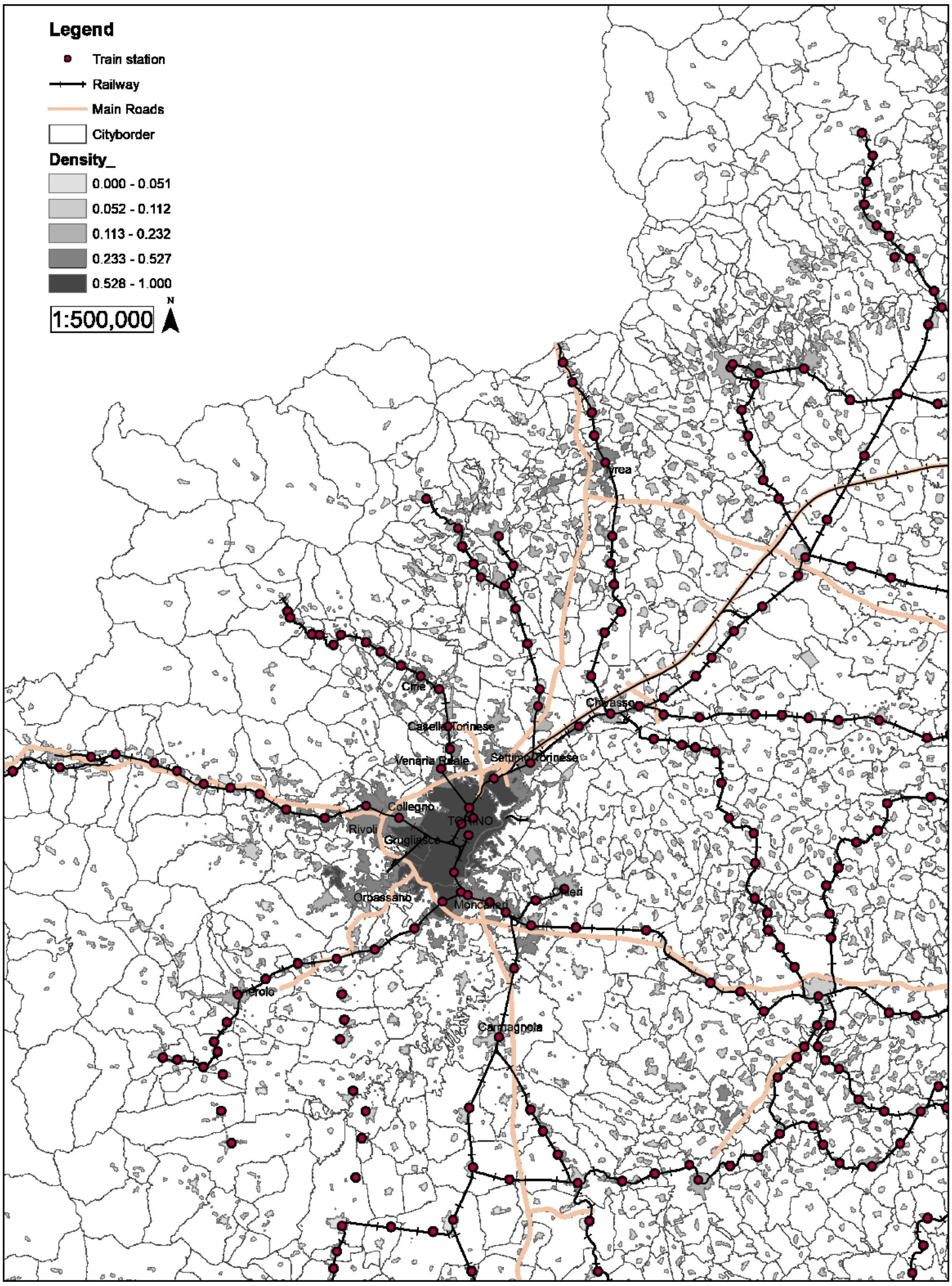


Figure 8– Study area density map

Source: author elaboration,2021

5 POLICIES REGARDING EV IN NORTHERN ITALY

5.1 LAWS AT THE NATIONAL AND EUROPEAN LEVEL FOR THE DEVELOPMENT OF EV DIFFUSION

Electric vehicle diffusion is regarded as an important aspect of government policy with the main goal of generating a transition to a low-carbon mobility system in Italy and the wider European frame of reference. According to Harrison and Thiel[80], to support the diffusion of electric vehicles, political actors are confronted with the planning of public charging infrastructure. The initial step in the planning process is to identify how much public infrastructure is needed. Hardman et al.[38] stress the necessity of a regular charging option, for instance, home or workplace charging, to guarantee the success of the primary EV market phase in the countries with high availability of private garages. This is while according to the study of Helmus et al.[81] in the Netherlands, in the countries with low availability of garages, the management focus should be more on unified public charging infrastructure and not private ones.
The second important element in the charging infrastructure planning is the availability of high-power charging stations along the travel corridors that enables long-distance driving.[82] This type of fast charging facility is complementary to the first option which is used on a regular daily basis, and it is highly dependent on the length and the frequency of long-distance trips.[83]

Laws to meet EU objectives[84] regarding the alternative fuel usage and decreasing the emissions from the transportation sector in Italy are listed in the table below:

Name	Date	Context
EU-Direction 2014/94/EU	2014	Arrangement of measures regarding the implementation of infrastructure for alternative fuels, with the goal of decreasing oil dependency and mitigating the environmental impact of transportation.
Legislative Decree no. 257	2016	Providing the minimum necessities for the implementation of alternative fuel infrastructure (including EV). by the end of 2020, a sufficient number of charging stations open to the public must be implemented to guarantee interoperability between existing stations and any to be implemented in the future, and contingent upon market needs, that EVs can function in urban and suburban contexts at least.
PNire – National Infrastructure Plan for the recharging of electric-powered vehicles	2016	Construction of infrastructural networks for the charging of EVs. It was drawn up with the goal of characterizing explicit rules to ensure the unitary enhancement of e-charging administrations at the national level.
Ministerial Decree of 3 August 2017	2017	Defines the assertions, declarations, certifications, and technical reports to be submitted. Along with the SCIA concerning the development of charging infrastructure for EVs.
ECObonus	2019	Allocating a total of €312 million to subsidize sustainable driving in 2021. The aim is to cut net emissions to zero by 2050 and for electric vehicles to replace polluting models by 2035 or earlier.
Legge di bilancio	2021	the national government has launched a new €420 million scheme that offers additional incentives on top of the current Ecobonus to promote electromobility.

Table 6 – laws and regulations regarding EV diffusion development
Source: European Union law, 2020

5.2 SUBSIDIES OR TAX INCENTIVES TO MOTIVATE CONSTRUCTION OR OPERATION OF EV CHARGING STATIONS

One of the most important requirements of potential EV users prior to the EV adoption is the assurance of adequate public charging facilities. In addition to this basic demand, the users expect the speed of public charging poles to be similar to conventional refueling. Taken these requirements into account, research and political interests in public charging are focused on fast charging alternatives with high power rates. Since electric vehicles are relatively recent in the market, the evaluations for future client needs are not so accurate. Promoting the use of this whole system can be done by the introduction of direct subsidies or tax incentives both in the station construction and the purchase by the final ends of the chain.

At the beginning of 2018, in order to develop an integrated network of the EV charging points infrastructure, an agreement was formed between the Ministry of Infrastructure and Transport and the Regions including the subsidies listed below:

- 35% of the project value for the construction of slow or fast AC direct current recharging systems, with the guarantee of at least one socket which delivers a power of at least 22 kW; and
- 50% of the value of the project for fast DC recharging systems with power equal to or greater than 50 kW or for domestic type charging.

The Italian government has incentivized the construction and operation of charging stations by contributing to the costs of the action. The contribution is paid as a discount on the final purchase price in the form of a reimbursement for the amount of contribution or a tax credit following Art. 17 of the D.Lgs 241 of 1997. This kind of incentive can't be combined with any other national incentives. In addition to this recent vehicle purchase incentives scheme, the Law of 2019 introduces a tax deduction for the purchase and installation of charging stations for electrically powered vehicles. This scheme is valid from 1 March 2019 up to 31 December 2021 and it covers 50% of total costs, up to 3.000 euros, which can be deducted from taxes in ten annual installments of the same amount. The map below shows the results of these policies in different parts of Italy.

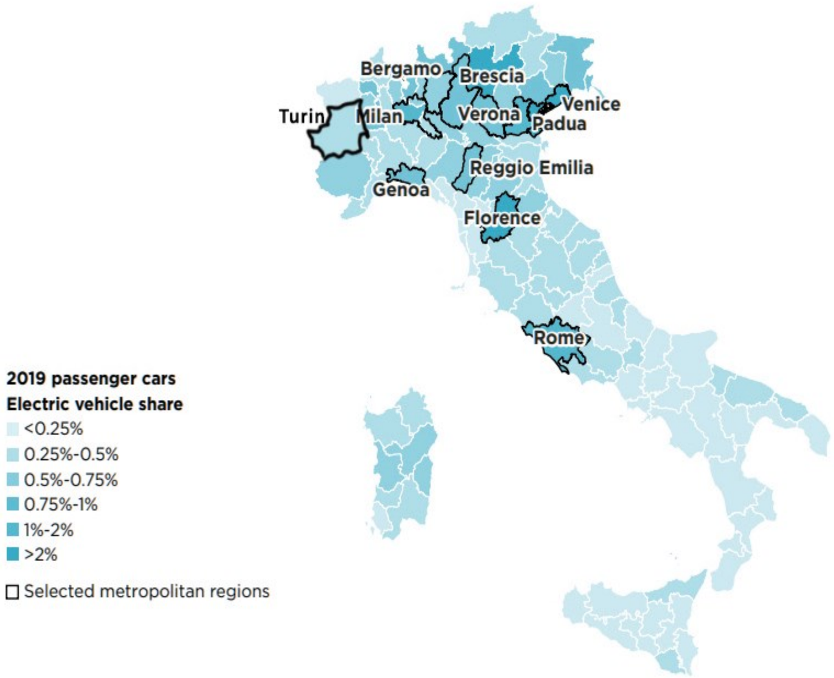


Figure 9 – EV share in the passenger cars ITALY data

Source: theicct, 2019

5.3 SUBSIDIES OR TAX INCENTIVES FOR PURCHASING EVS

Additional to the lack of a unified EV charging infrastructure network in Italy, the electro-mobility market in this country despite the high growth rate, is insignificant especially when compared to other industrialized countries, possibly because of the absence of functional policies and measures for the promotion of electro-mobility related technologies. The map of EV share in the passenger cars registered by the end of 2019, shows a low level of 1% almost everywhere in Italy except for the northern parts of the country.

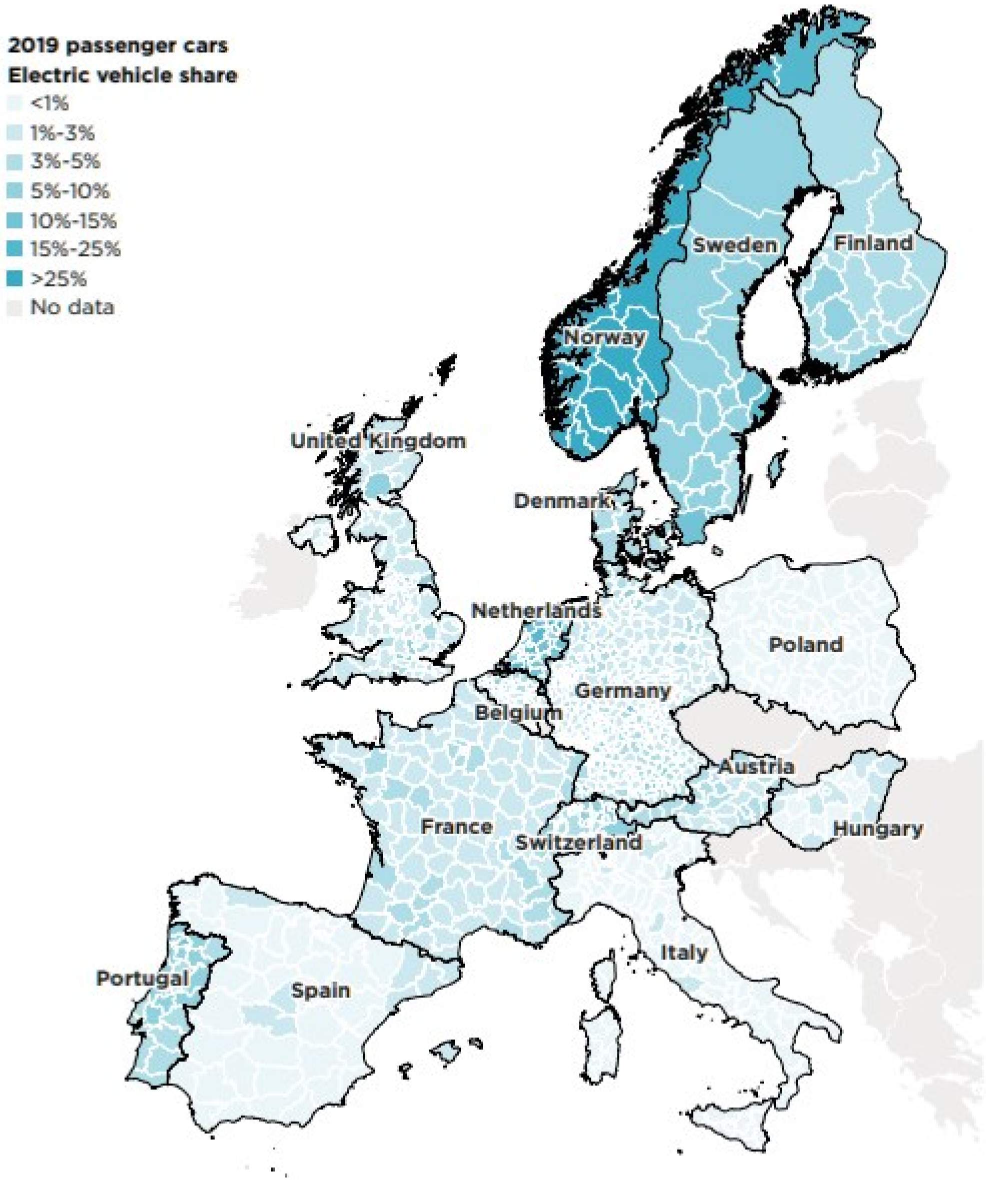


Figure 10 – EV share in the passenger cars
Source: theicct, 2019

The total share of Italy's EV sales accounts for only 0.9% despite being the fourth largest EV market in Europe. This is while according to Statista the internal growth rate of new sales of EV from 2019 to 2020 is about 207%, indicating that a transition towards electric transportation is in progress. One of the potential barriers to electric car purchase is the high vehicle and battery cost. A set of incentives for purchasing electric cars are introduced by the national government so that a cycle of positive feedback forms and helps increase the supply share of the market and eventually results in a reduction of the price. The strategy, applied by the national Italian government, to tackle this obstacle is to provide bonuses in the form of purchase payments of €4,000 for BEVs and €2,500 for most PHEVs. Italy exempts taxpayers from annual EV ownership taxes. Additionally, some regions benefit from additional tax incentives. The electric vehicle registration share in the Veneto region is over 3%, three times more than the national average and highest in Italy. Tuscany region owns the second-highest EV registration share on a total basis. Turin is not among the top 10 cities when it comes to EV registration ranking. It is notable that the electric vehicle share in the northern regions of Italy is higher than in the south in general.

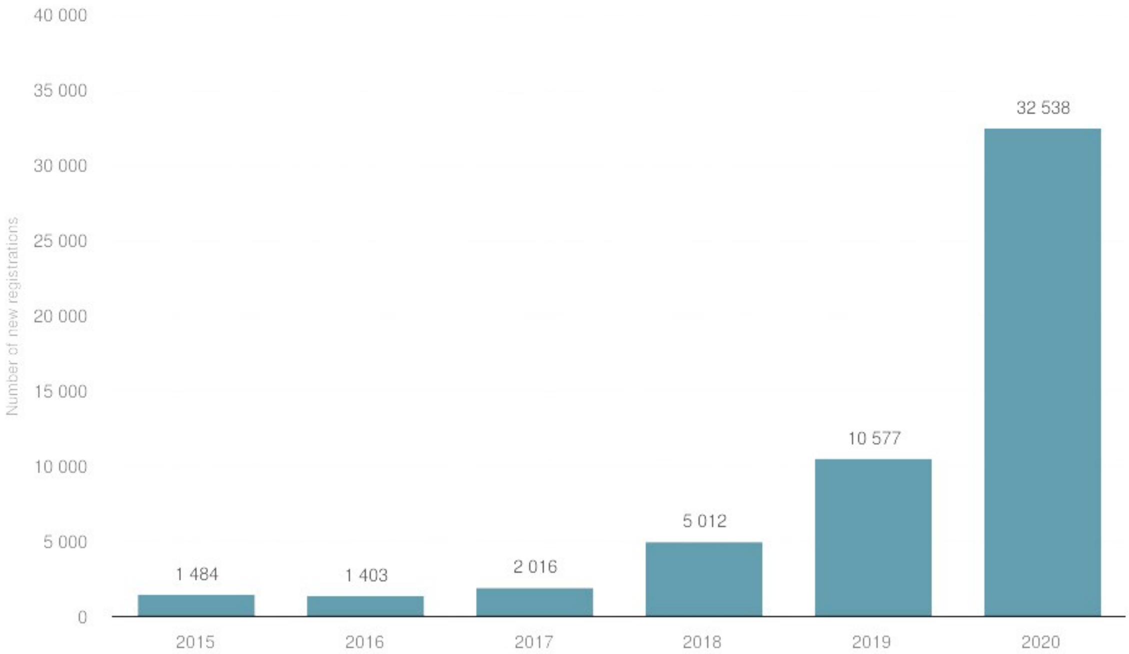


Figure 11 – Annual number of EV registration in Italy
Source: UNRAE, Statista, 2021

Incentives to purchase EVs can be offered in the form of discounts from manufacturers, subsidies, or tax breaks. These incentives can be framed by differentiation in taxation which is technology-neutral yet in favor of low-emission (or zero-emission) vehicles, penalizing the old generation of polluting cars. From 2013 to 2015, the Italian government set an incentive scheme on the basis of CO2 emissions, to encourage the low total emission (BEC) cars purchase. According to the EUKI report about emission reduction strategies for the transport sector in Italy[85], purchase incentives were categorized based on the CO2 emissions of the to-be purchased vehicle. In this scheme, the acquisition of the cars with the emission less than 50 gCO2/km had the incentive of 5,000 euros, cars with emissions from 51 to 95 gCO2/km, 4,000 euros, and finally, for the emissions from 96 to 120 gCO2/km, the incentive was 2,000 euros, which in the last year of validity of this plan, decreased to 3,500, 3,500 and 1,800 respectively. The total amount of the fund allocated in 2013 was 40 million euros, in 2014, 35 million euros plus the 28 million euros remaining from the budget of last year, and 45 million euros in 2015 which was eliminated by the Financial Law of 2015. Additionally, another form of the set incentives was the tax reduction/exemption based on which the owners of electric vehicles for the 5 years after the registration of the EV, are exempt from payment of the circulation tax, and pay 75% of the cost for each following year.

In recent years, with the approval of the Financial Law 2019, a new Bonus-Malus incentives scheme has been set on an “experimental basis” for the years 2019 to 2021, for the purchase of new vehicles [FLAW, 2019]. This Bonus scheme introduces a contribution between 2000 to 6000 euros for the purchase, even in financial leasing, of a new motor vehicle in the M1[2] category, priced less than 50.000 + VAT and with carbon emissions less than 70 gCO2/km. The incentives are categorized based on vehicle’s emission ranges, namely 0-20 gCO2/km and 21- 70 gCO2/km, (i.e. rewarding hybrid or electric vehicles), and to the opportunity that the purchase is accompanied by the delivery or scrapping of a vehicle of the same category formerly approved Euro 1 to Euro 4. Summary of the most recent incentives/subsidies are gathered in table 7[86].

[2] M1 Category: Vehicles designed and built for the transport of persons, having a maximum of eight seats in addition to the driver's seat.

Type of Incentive	Description
Purchase Subsidies	Incentives are granted to consumers who purchase cars emitting up to 60 g/km of CO2 (so the measure actually supports the purchase of BEVs and of few PHEVs models which are the only compliant with the 60 g/km threshold). The amount of the incentive depends on whether the beneficiary ensures the scrapping of a car from Euro 0 to Euro 4. Without scrapping: - vehicles emitting from 0 to 20 grams per kilometer of CO2 receive an incentive of 4.000 euros; - vehicles emitting from 21 to 60 grams per kilometer of CO2 receive an incentive of 1.500 euros. In case of scrapping: - vehicles emitting from 0 to 20 grams per kilometer of CO2 receive an incentive of 6.000 euros; - vehicles emitting from 21 to 60 grams per kilometer of CO2 receive an incentive of 2.500 euros. A temporary increase from August 1, 2020, to December 31, 2020: The increase in premiums will apply from August 1 until the end of 2020 for electric and hybrid vehicles up to a gross list price of 61,000 euros. Specifically, without scrapping purely electric vehicles will be subsidized with 6,000 euros during this period instead of the previous 4,000 euros. Anyone who scraps their old combustion engine in connection with the purchase of the electric vehicle will even receive 10,000 euros (previously 6,000 euros). Hybrids with CO2 emissions of between 21 and 60 grams per kilometer will be subsidized with 3,500 euros or 6,500 euros if an old car is decommissioned at the same time. These rates were previously 1,500 and 2,500 euros respectively. The increased incentives are financed partly by the state and partly by the car manufacturers.
Ownership Tax Benefits	Electric vehicles are exempt from the annual ownership tax for a period of five years from the date of their first registration. After this five-year period, they benefit from a 75% reduction of the tax rate applied to equivalent petrol vehicles in many regions.

Infrastructure incentives	Tax credit granted to taxpayers who install EV charging infrastructures up to 22 kW. It amounts to 50% of the purchase and installation cost up to EUR 3.000, to be split into ten equal annual tranches.
Company Tax Benefits	"Starting from 2020 fringe benefit cars emitting up to 60 g/km of CO2 are taxed at a lower rate (25% on conventional parameters related to average journey and cost per kilometer) compared to the previous taxation (30% applied to all vehicles on the basis of the abovementioned parameters). At the same time, the new legislation introduces different rates based on car emissions: - 30% for cars emitting from 61 to 160 g/km; - 40% for cars emitting from 161 to 190 g/km; - 50% for cars emitting from 191 g/km upwards. In 2021, the percentages will be partially reviewed as follows: - 50% for cars emitting from 161 to 190 g/km; - 60% for cars emitting from 191 g/km upwards. "
VAT Benefits	4% reduced VAT for disabled persons who purchase cars
Other Financial Benefits	Free access to the LTZ and free parking in many urban centers for hybrid/electric cars.
Local Incentives	Free access to the LTZ and free parking in many urban centers for hybrid/electric cars.
Public procurement	According to Italian budget law for 2020, public administrations when renewing their fleet have to reserve a 50% quota for the purchase or rental of electric, hybrid, or hydrogen vehicles.

Table 7 – incentives existing in Italy regarding EV diffusion development
Source: Eco bonus incentives in Italy, 2019

About 200 million euros of the total national budget is allocated to the new vehicle purchase contribution and tax deduction for charging infrastructure installation, of which 60 million € is the budget for 2019. For the years 2020 and 2021, an annual budget of 70 million euros is allocated to the mentioned incentives. The contrary of the Bonus scheme is the Malus scheme set by the Financial Law 2019 which imposes an extra tax, charged to the ones who buy, also in financial leasing, an M1 vehicle, with CO2 emissions greater than 160 gCO2/km. Particularly, the scheme refers to 4 ranges of CO2 emissions starting from 161 gCO2/km up to over 250 gCO2/km.

CO2 emissions g/Km	Tax (euro)
161-175	1100
176-200	1600
201-250	2000
>250	2500

Table 8 – Tax deduction incentive for EV diffusion development
Source: Eco bonus incentives in Italy, 2019

In the Financial Law 2019, apart from the Bonus/Malus scheme for M1 vehicles, another incentive scheme, for a total budget of 10 million euros is introduced regarding the purchase of brand new electric or hybrid 2 wheel vehicles from category L1 and L3 with power up to 11 kWh. The scrapping of an old vehicle of the same category registered Euro 0, 1, and 2 should accompany the purchase. The contribution covers up to 30% of the price of the new vehicle, with a maximum of 3.000 euros. This contribution can be acquired in the form of a discount on the purchase price from the seller to the buyer. The manufacturers or importers of the new vehicles, also, in this case, reimburse the seller for the amount of the contribution and recoup the charge as a tax credit.

6 QUESTIONNAIRE AND RESULTS

Taking advantage of the wide literature about EV profiling and user preferences, and following the case studies in which questionnaires were used as the main tool for the measurement of variable factors, a questionnaire was designed for defining the criteria weight table and target the main transportation tendency of residents in Piedmont region and in particular Turin's urban area. Due to the climate change and environmental debates, many environmental regulations in European markets, including Italy, were set. This lead to the growing diffusion of electric alternatives for the transport sector. According to Statista, from 2018 to 2019, the rate of electric vehicle sales in Italy has doubled. From 2019 to 2020 this rate has tripled and the percentage of cars with electric propulsion increased from about 0.1 percent in 2015 to around 0.5 percent in 2019, and 0.9 percent in 2020. Having in mind that the final number of EV users in Italy despite the high growth rates, is not very significant yet, the questionnaire is distributed in all of Italy to cover more possibilities of EV user inclusion. Following Pucci's paper, three main themes of the questionnaire are "socio-economic information", "built environment" and "mobility pattern", in compliance with these themes, a very last part considering a mixture of all three mentioned schemes, was added to assess the main barriers of EV diffusion from the user's perspective. The acquired information can be used as a tool to define the importance of each factor in EV diffusion, the correlation between them, and a useful barrier-resolving database for policymakers to consider. At a greater scale and for further study developments, these results can be used as a tool to define weights for different EV diffusion scenarios in Turin's urban area. However, in this thesis research according to the context similarities, the weights in use for the scenario-making are taken from Paola Pucci's paper with a suchlike subject applied to Milan's urban area.

6.1 DATA ANALYSIS

The survey's distribution was online and anonymous, with a research design intended to maximize honesty and promote candor. The questions were designed in an impersonal condition due to the psychological studies of survey design which demonstrate a direct relation between the impersonal condition of questions and the honesty of responses. According to Stephens-Davidowitz 2017, "people will admit more if they are alone than if others are in the room with them" [87]. Therefore, For achieving the most honest answers, internet surveys are better than phone surveys, which are better than in-person surveys. The questionnaire used in this study was distributed online and through the authors' canals. The questionnaire has been distributed in the Italian language to avoid any possible confusion due to the language barrier of the target population.

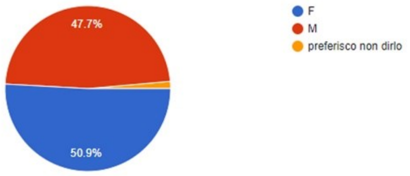
This survey was compiled by a mix of 285 non-random respondents facilitated through an online version where the authors invited the public to participate. This already excludes surveys that were incomplete (although we did not allow people to skip questions) or the results that obviously contain false answers. The questionnaire along with the raw data acquired is presented for reference.

The main topics of the questionnaire were conducted using the three-step procedure as adopted in the pilot study, "socio-economic data", "built environment" and "mobility patterns", along with a side focus on the barriers of EV diffusion in Metropolitan of Turin where the questionnaire was mostly distributed. For the last part, a modified 4 option Likert scale has been used(Norman et al, 2010 [88]). In this method, respondents can express their agreement to a potential barrier based on a statement describing it, choosing an option between two extremes of "totally disagree" and "totally agree". However, unlike the normal Likert scale, in this modified version the neutral value has been eliminated from the options to find out a direction towards the extremes. 285 participants compiled the questionnaire, among which 7.4% were owners of an EV, 60.7% indicated that they are considering buying an EV in the next 5 years, and eventually 31.9% were not considering purchasing an EV at the moment. 85% of the non-EV user respondents admitted that they did not have any practical experience driving electric vehicles, which is indicating a lack of practical knowledge that could potentially result in less EV purchase interest. This is while only half of the EV user respondents had this opportunity before their purchase, meaning the practical knowledge before the purchase, in our statistical society, is only partially affecting the final decision. The statistical society is representative of Turin's urban area (for reference see chapter 4) with participants equally from both gender and the 18-70 years old age coverage. The finding in this study should be treated with caution until a larger sample of EV adopters take part in the survey.

Informazioni socio-demografiche

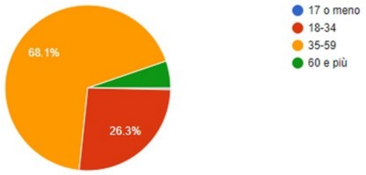
Sesso

285 responses



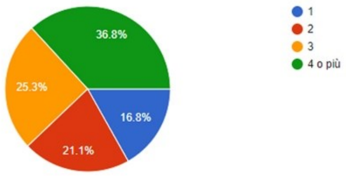
Età

285 responses



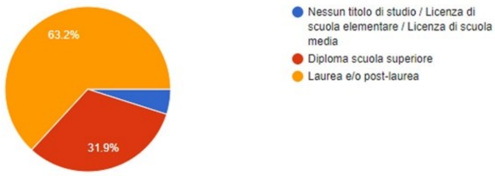
Numero componenti del nucleo familiare (incluso te)

285 responses



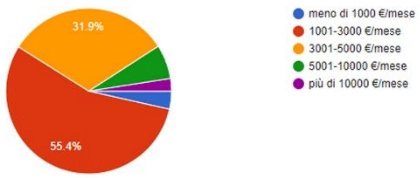
Livello di istruzione

285 responses



Qual e' il tuo Reddito netto mensile familiare?

285 responses



6.1.1 SOCIO-ECONOMIC DATA

Starting with the demographic data, there are almost equal shares of gender with slightly more Female participants and a low number of people who prefer not to indicate their gender. As mentioned previously, our statical population perfectly reflects the large-scale demographic data of Turin's metropolitan area.

The main age group participating in this survey with the title explicitly indicating electromobility, with 68% of the total, were between 35 to 59 years old which according to what was said in chapter 4, is the biggest age group with half share of the total population. Their participation is indicating the interest of this age group that can be explained due to their stability in work and power of purchase, especially the ability to buy EVs that are higher in price when compared to diesel cars. The second biggest group with slightly more than 25% are youngsters with the age range between 18 to 34 years. Due to the references of this study, the interest of younger generations in electric vehicles and new technologies is not deniable.

Regarding the number of components in the family, the majority of the participants leave in relatively big families with 4 or more components. The percentage of other groups decreases with the number of family components. The smallest group is the one-nuclei families who live alone and by themselves. The survey data shows that 57% of the respondents who indicated owning an EV live in families with at least 3 components. Likewise, 65% of the families that said they are considering buying an EV in the next 5 years were composed of 3 or more people. This shows an inclination towards EV use in the larger families in Turin's metropolitan area.

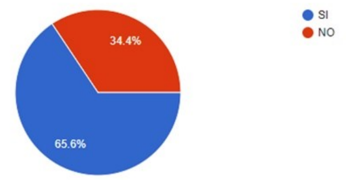
Regarding the data about education, more than 63% of the respondents indicated having a university degree which is followed by about 32% of people with a college degree, which in total accounts for more than 95% of respondents holding a degree. The percentage count for actual or potential EV users is as well 95% for the people with a degree and only 5% for the ones with no official education.

The last question of this part is about the monthly income that due the psychological factors is considered as the question with a higher risk of dishonesty in the responses. Although, more than half of the target group have chosen 1001 to 3,000 euros per month as their net income, about 32% have chosen a net income of 3,001-5,000 euros and about 3% said that they earn more than 10,000 euros monthly. Survey data indicates that half of the respondents who were already EV users or interested in becoming one, have an income between 1000 to 3000 euros per month. On the other hand, only 8% of this group have a relatively high income (more than 5000 euros/month).

Informazioni territoriali

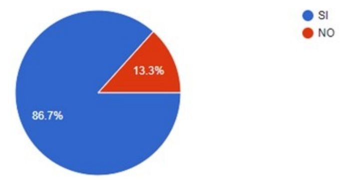
Hai a disposizione un posto auto privato (box, posto in cortile, ...)?

285 responses



Vivi o risiedi in Piemonte?

285 responses



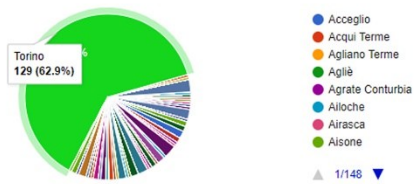
Informazioni territoriali

In quale Provincia vivi?

247 responses

In quale Comune vivi?

205 responses



6.1.2 BUILT ENVIRONMENT

In the second section, participants were asked to identify where they live. Based on the postal code (CAP), and the baseline map, the population of the living area and eventually context of the urban, semi-urban, and rural area is extractable. More than 85% of the respondents are residing in the Piedmont region and rarely from other regions in North Italy. The majority of them, roughly 96%, live in Turin province and more than 60% chose the municipality of Turin option as the city where they live in. There is an agglomeration of respondents with the CAP code of 10138, 10126, and 10128 which refer to the Crocetta, and San Salvario zone. The other postal codes are widely spread all over our study area. Based on the property taxes and the price of land and buildings, the mentioned agglomerated zones are considered as the areas where people with higher economic levels live in. 60% of the EV-related population (current or future users) reside in the municipality of Turin and the other 17% of them live in the municipalities in the first belt (prima cintura) around Turin. This demonstrates that based on our results, 77% of the EV users are located in the main urban patch and suburbs around it. In our case, the incentives and encouraging policies should be targeting these two contexts relatively more than rural areas in the metropolitan setting.

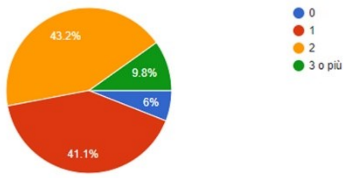
POLITECNICO DI TORINO

Collegio di Pianificazione e Progettazione

Abitudini di mobilità

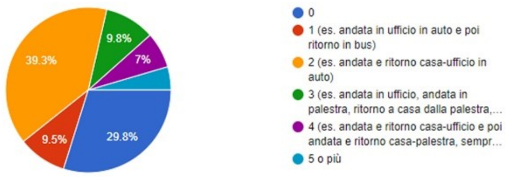
Numero di autoveicoli posseduti dal nucleo familiare

285 responses



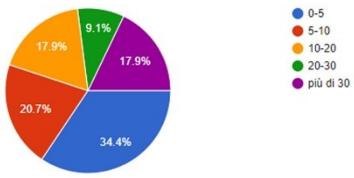
Quanti spostamenti in auto fai in media in un giorno feriale ?

285 responses



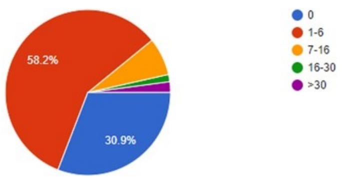
Quanti km al giorno percorri mediamente con l'auto?

285 responses



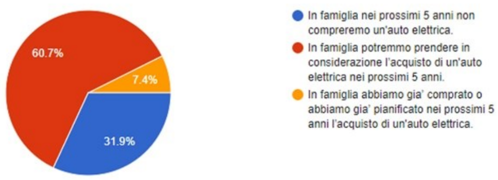
Quanti viaggi fai in auto all'anno con distanza maggiore di 400km? (Es. La tratta Torino-Bari e Bari-Torino equivale a 2 viaggi)

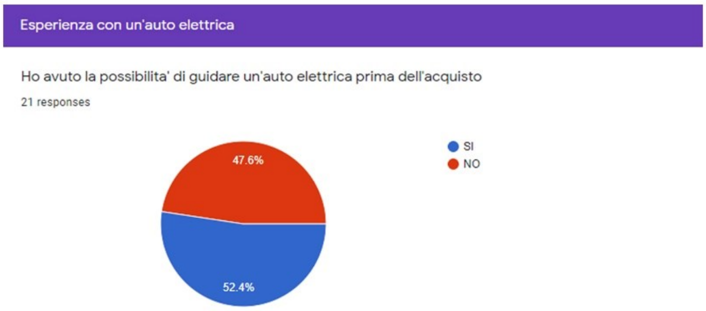
285 responses



Acquisto di un'auto elettrica :

285 responses





6.1.3 MOBILITY PATTERNS

The third part of the questionnaire aims to gather data on the mobility patterns of the users. Owning a private box as a potential option for running home-charging facilities is roughly 65%. The number of vehicles owned by the family unit is 1 and 2 with a percentage of around 40% for each of these two groups. About 10% indicated that they have more than 3 vehicles in their family and the rest are commuting without a private car, which based on the previous information indicating that respondents mostly live in Turin, a relatively dense crowded city with a functioning public transport system, this result is expected. Among the EV users, 55% are owning 3 or more vehicles. This increases the chances that buying an EV is still not considered as a definite option but a complementary one, perhaps due to the barriers that still exist in our study area. To maintain the main positive aspect of EV diffusion which is decreasing pollution and traffic issues, policies should target the needed requirements in the market and introduce EVs as a reliable means of transport that fulfills all types of commuting trip essentials.

Regarding the number of movements by car per day, almost 40% of the participants have chosen 2 times per day which is for instance commuting to work and coming back home. In this case, other daily movements are not with personal vehicles but rather by using public transportation, bike, monopods, or either walking to the destination. About 30% of the respondents, on the other hand, specified that they don't use a car for their daily displacements.

In answer to the number of trips further than 400km per year, 60% of the participants chose 1 to 6 trips, which according to the reviewed literature is considered as the lower limits in which EVs are suitable for the lower maintenance and usage costs to be beneficial over the general higher price of the vehicle. This is whilst 30% said that they don't use private cars for traveling to destinations further than 400 km.

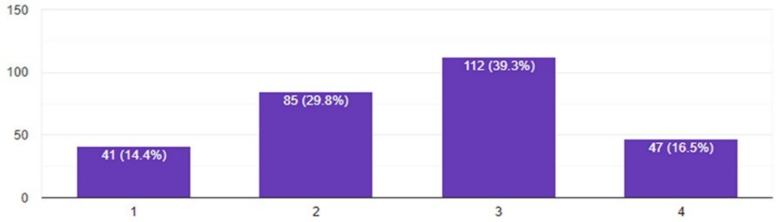
Regarding the electric vehicle general knowledge, 70% of the total number of participants chose options 2 and 3 which indicates that they are somehow indecisive about having enough EV knowledge. Considering the rapid technological improvements, one can hardly admit mastering the mass of knowledge on a topic. Although this is a generic modern age issue, it can be a valid explanation for the EV user confusion derived from the results. This conclusion can be admitted according to the results of another question in which 85% disagreed with the statement that using EVs and the technologies related to them is difficult. Practical and theoretical knowledge are confronted in this set of questions.

Suggesting by Herd literature[89] while coming to adopting decisions, people tend to discount their own beliefs and imitate others. It is also indicated that the results of the adoption decisions taken in this way are not stable and can be easily reversed during the post-adoptive stage. Therefore, the pace of EV adoption and the imitation theory can have affected the general perception of EV buying considerers, that with only the majority having acknowledged having a fair knowledge (options 2 and 3) or no knowledge at all (option 1) about EVs (summation of 67%), they still considered purchasing one. It is worth mentioning that according to Herd a knowledge of this type deals with the risk of being fragile and reversible.

Auto elettrica

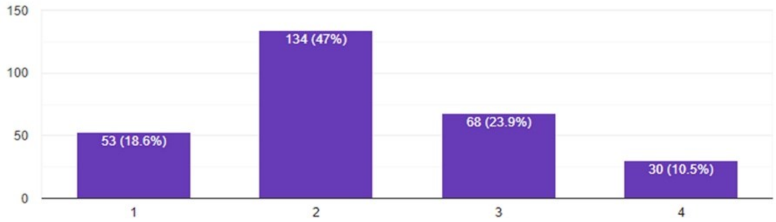
Conosco la tecnologia alla base del funzionamento dell'auto elettrica

285 responses



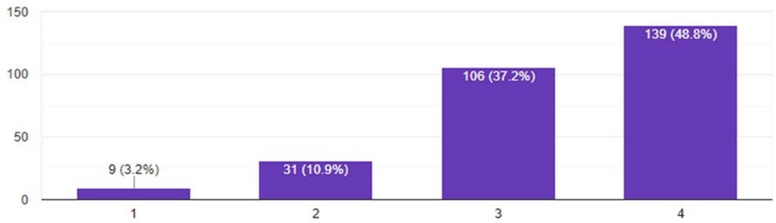
Sono sempre fra i primi ad usare nuove tecnologie

285 responses



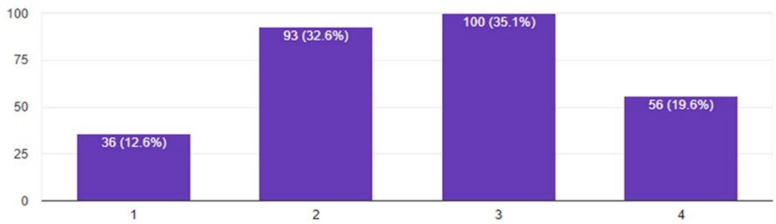
La situazione ambientale del luogo in cui vivo mi preoccupa sempre di più

285 responses



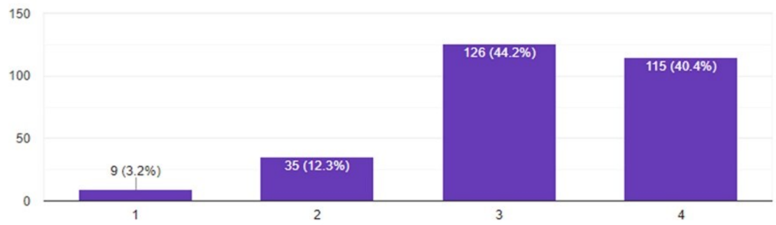
La necessità di ricaricare frequentemente vista la limitata autonomia della batteria rende l'auto elettrica poco pratica nell'uso quotidiano.

285 responses



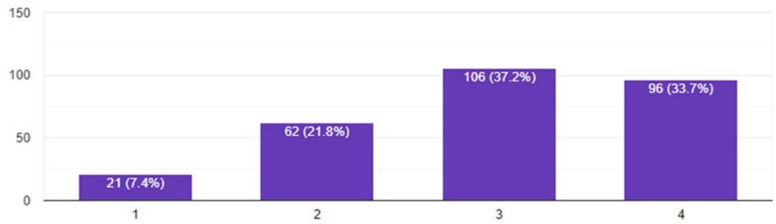
Utilizzare un'auto elettrica richiede un'attenta pianificazione dei viaggi.

285 responses



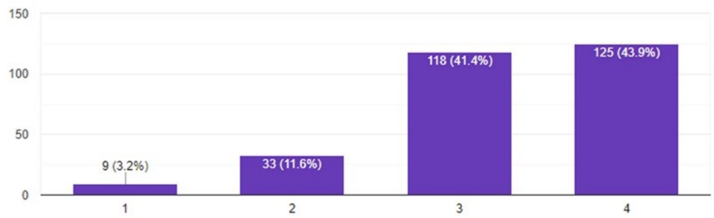
Mi preoccupa la possibilita' di rimanere senza carica viaggiando con un'auto elettrica

285 responses



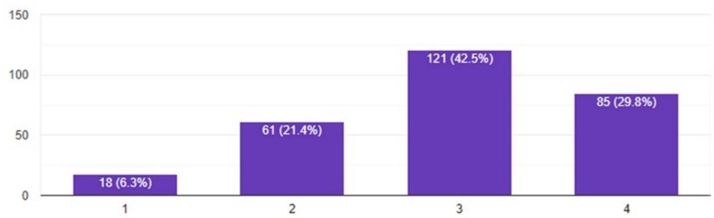
Utilizzare un'auto elettrica per lunghe distanze è difficile a causa della scarsa presenza di stazioni di ricarica in autostrada.

285 responses



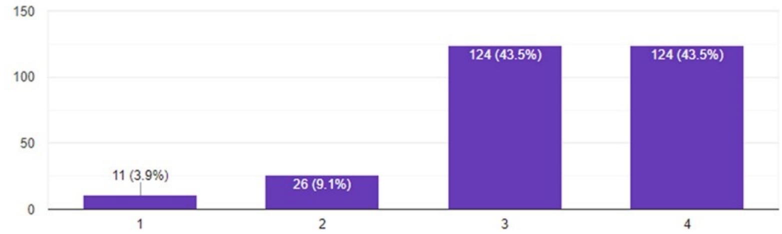
Ricaricare un'auto elettrica durante il viaggio richiede un tempo troppo lungo

285 responses



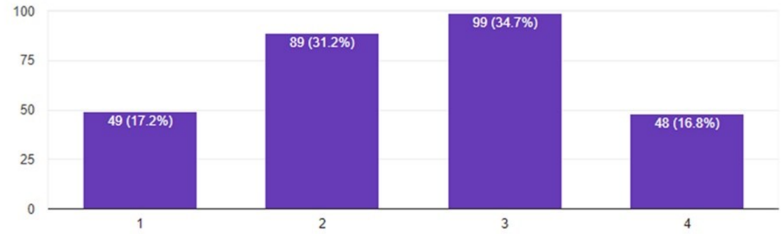
Il numero delle colonnine disponibili per la ricarica e' ancora troppo basso.

285 responses



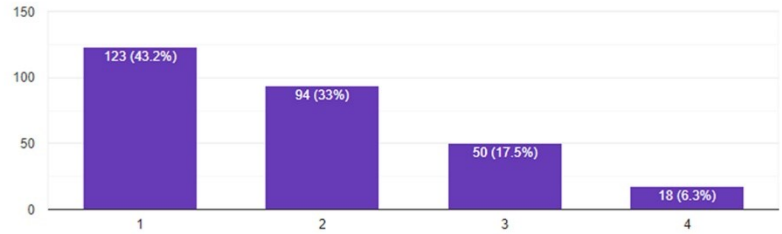
Mi preoccupa che il prezzo dell'energia elettrica per la ricarica domestica aumenti le spese in bolletta.

285 responses



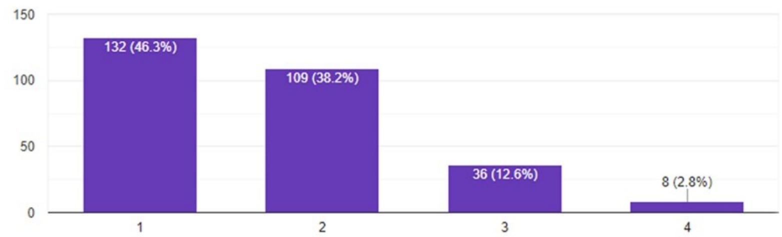
E' rischioso utilizzare un'auto elettrica vista la presenza di una batteria che potrebbe dare origine ad incendi.

285 responses



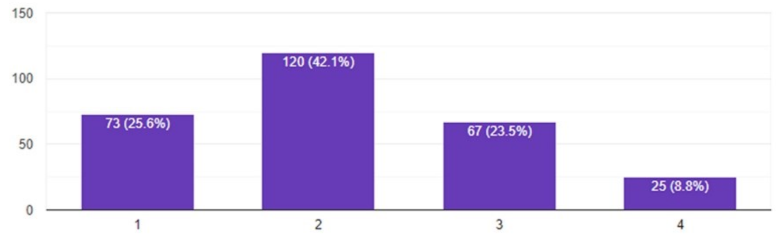
Le auto elettriche sono dotate di tecnologie complesse e difficili da utlizzare

285 responses



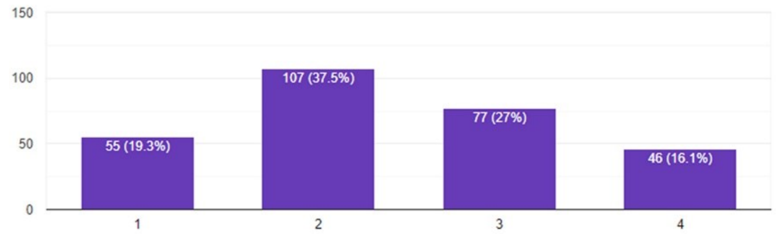
Le auto elettriche inquinano come le auto tradizionali in quanto l'elettricità per ricaricarle è generata anche da carbone e petrolio

285 responses



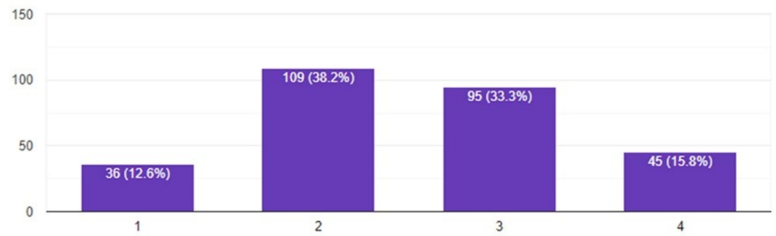
Le auto elettriche inquinano come le auto tradizionali a causa dello smaltimento della batteria

285 responses



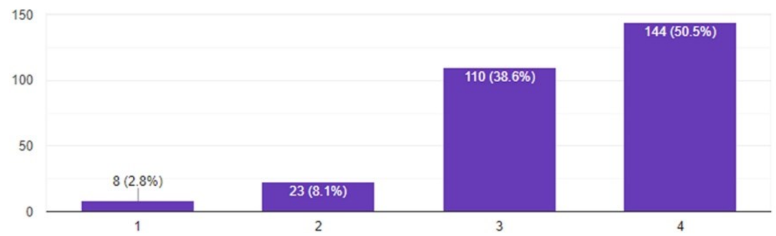
La batteria delle auto elettriche non si sa ancora bene quanto duri.

285 responses



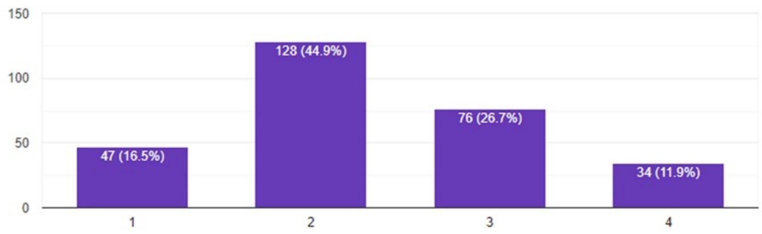
Il prezzo d'acquisto dell'auto elettrica è ancora elevato.

285 responses



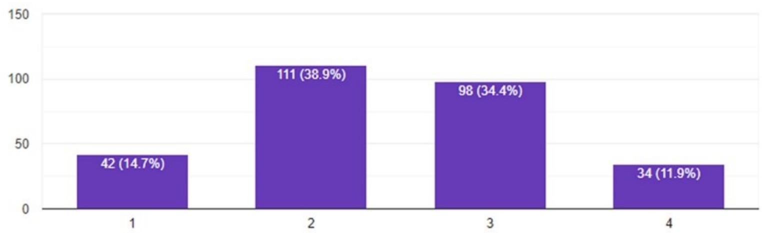
Se molte persone acquisteranno auto elettriche, il costo dell'energia elettrica aumenterà

285 responses



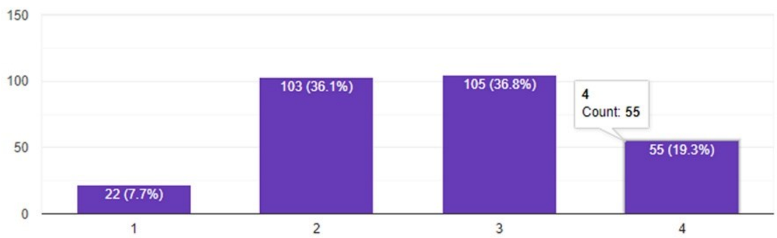
L'auto elettrica comprata oggi potrebbe deprezzarsi molto rapidamente

285 responses



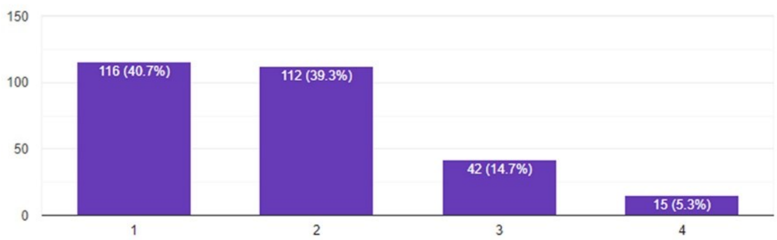
C'è un numero insufficiente di meccanici preparati per intervenire sulle auto elettriche.

285 responses



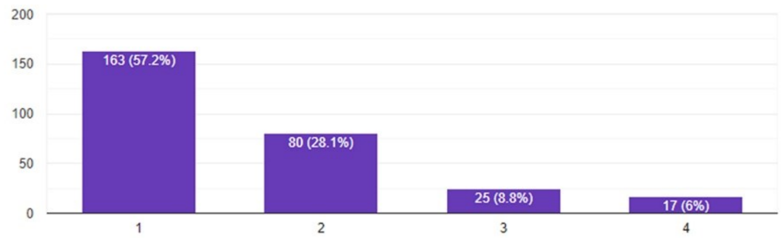
Le automobili elettriche non hanno un'accelerazione sufficiente.

285 responses



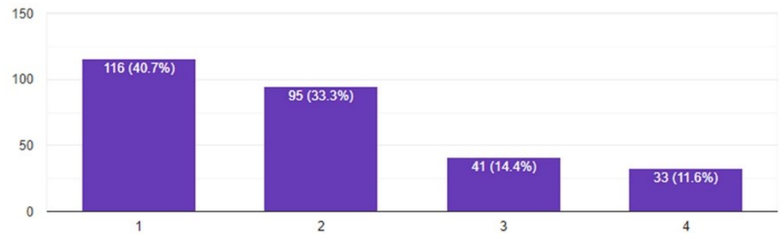
Preferisco guidare auto tradizionali per sentire il suono del motore

285 responses



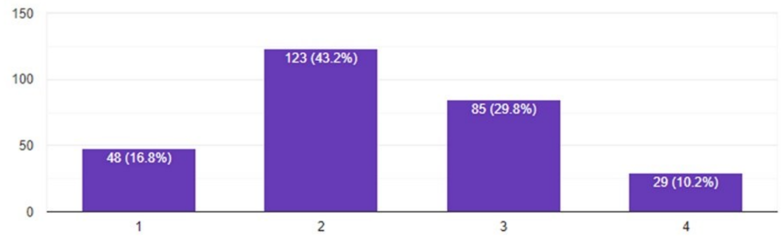
L'utilizzo di corsie riservate, parcheggi gratuiti e ingressi in ZTL non agevolerebbe l'acquisto di un'auto elettrica

285 responses



Il costo di manutenzione dell'auto elettrica e' superiore rispetto ad un'auto tradizionale.

285 responses



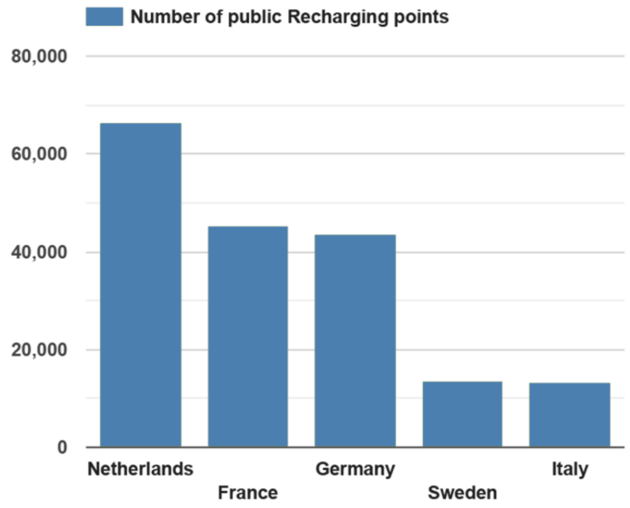
6.1.4 BARRIERS TO EV DIFFUSION

Considering our results, the main challenges to EV ownership that prevents potential users in the metropolitan of Turin from purchasing an EV, are listed accordingly:

Cost – EVs' initial cost is more when compared to the same model petrol- or diesel-fueled vehicles. 90% of the participants specified that EV's cost is notably high compared to their average income and therefore the affordability of EVs is low in our study area. On the other hand, The price of the battery notably influences the final price of the vehicle. Rapid enhancement in battery technology is likely to bring EV prices in line with those of combustion-driven vehicles within the next decade, due to an expectable decrease in production costs. Economies of scale, once the adoption number is high enough, can also play a role in decreasing the price.

Pollution and Environmental benefits – Almost half of the respondents demonstrated their firm concern (option 4) and another 37% mentioned being fairly worried about the environmental issues in the city they live in. Given that our statistical population shows an agglomeration in Turin, this apprehension is not out of context. According to Forni et al.[90], Turin has ranked the highest Italian level of PM10 air pollution and is amongst the most polluted in Europe. In recent years, however, an improvement in the air quality can be seen as in the index for the most polluted cities in Europe. Turin has upgraded its position towards being less polluted from being ranked the 4th polluted city in 2018 with the pollution index of 74.49 to the 12th in 2021 with an index of 71.28.

Charging infrastructure – The basic required factor that would favor a rapid EV deployment is a well-developed network of charging points. It represents a fundamental prerequisite that would lead the potential users to purchase an EV instead of an ICEV. Although Italy according to the European Alternative Fuels Observatory is the fifth country in the European ranking with the most EV charging points after the Netherlands, France, Germany, and Sweden, the spread of charging stations is still fragmented. The scarcity and fragmentation issue is approved by 85% of respondents (options 3 and 4) as a serious barrier to considering EV adoption. Parallelly, this factor is precipitated as the insufficient number of recharging points, by the user. The results of the questionnaire show that 87% of the participants do not consider the number of charging points in Italy sufficient. The limited duration of the battery charge is another EV adoption barrier. Since the average range of each full vehicle charge for EVs is around 200 – 300 km, we can conclude that EV batteries have a low range in comparison to ICEVs. 85% say that this makes traveling to distant destinations difficult as they should plan their trip carefully in advance to avoid the fear of remaining without enough battery during their trip.



country	Number of public Recharging points	Total
Netherlands	66461	66461
France	45413	45413
Germany	43633	43633
Sweden	13564	13564
Italy	13214	13214

Figure 12 – Number of Public EV charging stations

Source: The European Alternative Fuels Observatory, commissioned by contract by the European Commission., 2020

Time –While the quantity of charging infrastructure is important, the quality of the charging infrastructure, or in other words, where they are placed and how they operate is equally influencing the fast development of E-mobility. 72% of the responses established the statement that the time required to recharge EVs is of their concern. Comparing the regular electric charging speed with refueling at a petrol station requires a longer time for EV users to be able to use their vehicle. The frequency of recharging after on average 250 km due to the limited battery capacity requires even more time. Marked deployments in the grid of fast-charging stations all over the territory would definitely foster an obvious increase in demand for EVs.

Another obstacle to the diffusion is the lack of full interoperability between the charging infrastructures managed by different private providers, which have different charging methods and are not always compatible with every EV model available on the market. Further numeric goals to obtain an integrated fast-charging network are demonstrated in the figure below.

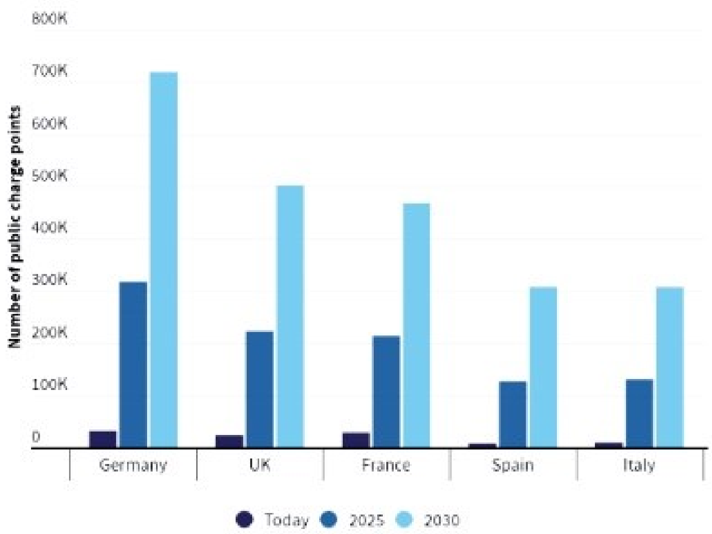


Figure 13 – Number of future EV charging stations

Source: The European Alternative Fuels Observatory, commissioned by contract by the European Commission., 2020

7 METHODOLOGY AND TOOLS

Despite the wide expansion of EV diffusion in the first world countries and the studies related to them, EV studies done about this phenomenon in Italy are few. Urban practices and territorial methods to measure EV diffusion are still under-researched fields in the literature. This research aims to contribute to research knowledge, in order to develop the connection between urban planning and EV diffusion. At the same time, this applied research suggests the development of policies and practices to maximize the efficiency of this diffusion to obtain consequential sustainable mobility. Since the baseline used in this case is Pucci's paper, the goal of this research is to develop the hypothesis of the efficiency of place-based policies introduced in that study. To reach the aims of this research and find an answer to our thesis questions both quantitative and qualitative data were used. The primary data collection was done using the questionnaire tool, in order to spot the users' comprehension of positive and negative aspects of EV diffusion. Alongside these data, the scenario maps represented in the upcoming section are formed using secondary data collected from statistical databases.

7.1 PRIMARY DATA

Questionnaire:

Data in this field research has been collected through the application of a self-completion household survey distributed over different channels in Italy with the focus on Turin's metropolitan area (Turin as a center and urban/rural areas around it). For the demonstration of possible EV diffusion scenarios and differentiate one from another, the crucial factor is a diversified weight for the spatial criteria. In order to allocate weight to each criterion, the result of the questionnaire is a helpful tool. Meaning, the most important factor for each spatial context is the one with the highest stress, in the gathered responses. Therefore, the main objective of this questionnaire is to investigate what is the impact rate of different variables concerning different aspects of EV diffusion in the urban, semi-urban, and rural contexts and the magnitude of their importance in order to define the weights. However, in the structure of this cross-sectional thesis research, the data is analyzed only considering the current situation. Despite the perspective to use the questionnaire as a possible tool to define the weight table, due to the lack of accessibility to an adequate EV user population as participants to the survey, the weights table in Pucci's research is adopted and applied to the pre-defined criteria in our study area. Each of these categories is divided into some subcategories (i.e. population density and the daily travel distance) extracted from the literature (Liu et al.2017[15], Hardman et al., 2018[38], Morton et al., 2018[24]). The weight assigned to criteria according to Pucci (in the further developments, according to the questionnaire) is going to define diverse scenarios for EV diffusion. Along with these main results, the relationship between the factors and the possibility of some synergy or co-relations is derivable while analyzing the questionnaire results.

The sampling method used in our questionnaire is “probability sampling” which involves random selection of participants. The results of this sampling type allow us to make strong statistical inferences about the whole study group.

The total number of individuals that should be included in the target population is equal to the number of people living in the Metropolitan City of Turin, which according to Statista in November 2020 is precisely 2,212,996 among which 62% (1,371,983) are between 14-59 years old, 12.2% are over 65 years old (571,007) and the rest are categorized in the age range of 0-14 which is out of this research’s interests. According to this population size, the sampling size could be calculated with the formula below (Source: Surveymonkey).

$$\text{Sample size} = \frac{\dfrac{z^2 \times p\,(1-p)}{e^2}}{1 + \left(\dfrac{z^2 \times p\,(1-p)}{e^2 N}\right)}$$

- **N = population size**
- **e = Margin of error (percentage in decimal form)**
- **z = z-score**

The z-score: indicates the number of standard deviations a given proportion is away from the mean

The Margin of error(confidence interval): The level of trustability of a survey. This number in percentage demonstrates how much the survey results is reflecting the views of the overall population. A smaller margin of error increases the precision of the answers.

Sampling confidence level: A percentage that shows the level of confidence that the population selects an answer within a specific range.

According to these definitions and the formula, a target population of 2,260,000 people with a confidence level of 90%, and a 5% margin of error (equal to or less than 5% is recommended), the sample population of 273 people could count as adequate in terms of result trustability. This means that If 50% of our statistics sample in answer to the most important barrier to EV diffusion pick “insufficiency in charging points”, we can be 90% sure that in case we have asked the opinion of the entire relevant population, 45% (50-5) to 55% (50+5) would have picked the same answer.

Although the confidence level for most official researches is 95% or more, this research did not reach enough participants (384 answers needed) to present the results within that percentage of confidence.

7.2 SECONDARY DATA

To address the research question regarding the proper policies that conform with the contexts’ level of urbanization, scenario maps are decent representative tools. To transform the secondary statistical data into their spatial realization, the Multicriteria Analysis (MCA) method is used (Kurka et al., 2013)[91]. MCA is a set of systematic procedures for designing, evaluating, and selecting decision alternatives on the basis of conflicting and incommensurate criteria. However, this method uses aspatial (conventional) multicriteria methods for analyzing and solving spatial problems (Ligmann et al., 2008) [92]To make the geographic information technology more accurate and relevant in analyzing decision-making problems (in our case planning and policy management problems), GIS and MCA are integrated and Spatial MCA (SMCA) or GIS-based MCA (GIS-MCA) is introduced(Van Haaren et al, 2011)[93]. SMCA is a group of instruments and methods that transforms and aggregates spatial geographic data and the defined preference values in order to find solutions for decision-making debates. SMCA can be thought of as a collection of methods and tools for transforming and combining spatial (geographic) data and preferences (value judgments) to obtain information for decision making.

The spatial-problem solving using SMCA according to the literature adopts one of these two main methods

- Methods that are based on value function. Among them weighted linear combination (WLC) methods, multi-attribute value/utility models, analytical hierarchy/network process

(AHP/ANP), and reference point (RP) methods (e.g. Malczewski 2006[94], Boroushaki 2010[95], Ferretti and Montibeller 2016[96], Shenavr 2014[97]).

- Methods that follow outranking relations namely ELECTRE (ELimination Et Choix TRaduisant la REalité) and PROMETHEE (Preference Ranking Organization METHod for Enrichment Evaluations) (Chakhar and Mousseau 2008[98], Esmaelian et al. 2015[99]) Following Pucci's footsteps in Milan's case, the Analytic Hierarchy Process (AHP) in combination with the WLC method is the selected approach used to visualize EV diffusion's spatial realization maps.

INDICATOR'S DATA RESOURCES

Sources of the raw data aggregated to apply the SMCA on Turin's metropolitan area are all secondary. The detailed information about these sources and the calculation methods are explained in this section.

7.2.1 BUILT ENVIRONMENT

The spatial setting of the target area (the urbanization level), the abundance of transport facilities, and the density of the population are all options that inevitably affect the EV diffusion due to the differences they can make in demand for EVs. In answer to the different demands, an adequate supply plan should be organized and applied to the related setting. In order to evaluate the current situation of demand and supply in a specific setting, a criterion under the name of the built environment is introduced to cover this part of society's characteristics. Assessing this criterion requires the measurement of two factors of density and supply which are introduced followingly.

DENSITIES

- The density of the urbanized area

The level of urbanization of an area according to EUROSTAT is identified by density measurements. This is both in terms of population and built area. According to urban-rural typology, density is higher in the urban areas both in terms of population and the built environment. An urban area is where urban clusters are placed. They are clusters of contiguous grid cells of 1 km² with a density of at least 300 inhabitants per km² and a minimum population of 5,000 (Dijkstra and Poelman, 2014) [100]. Anywhere out of these areas is considered a rural setting. An intermediate definition is placed between two settings of predominantly urban and predominantly rural, which is called urban extension or semi-urban area. The main characteristic of this area is large expanses of sparsely populated territory. The share of the total population living in rural areas in the semi-urban settings is between 20 and 50 percent (EUROSTAT regional yearbook, 2014)[101]

- Population density

Due to the abundance of facilities, opportunities, and entertainment in cities, people from rural and semi-urban areas tend to commute to the cities. Therefore, the population sum used in calculating the density of each municipality is more than just the official residents of that municipality. This number in addition to the registered residents includes people who commute for working in that municipality (which is other than their actual place of residency), tourists, and temporary residents. The latter two categories are not stable statistics. Therefore, for the post-metropolitan territories, according to PRIN atlas, an index including the balance of internal commuter flow (inbound minus outbound), and 1/3 of the total beds (in hotels and complementary establishments) per municipality divided by the urbanized area is introduced to calculate a thorough population density that covers the temporary residents of the metropolitans such as tourists, work commuters, students, etc. This index was initially developed in a National Research “PRIN Atlante post-metropolitani” which is an Atlas for post-metropolitan territories, to monitor the urban regionalization processes in Italy[102].

SUPPLY

Transport supply can have either positive or negative effects on EV diffusion. An exemplar of a negative effect is that in a city with a well-functioning integrated public transportation network, EVs are less required in comparison to an equal scenario where the transport system is not working efficiently. On the other hand, electric transport supply such as EV charging infrastructure is essential for the diffusion of this type of vehicle in urban and extra-urban settings.

For measuring supply indicators in our study area, the final summation of both negative and positive factors is of use.

- Railway stations

To derive this number for each area, according to several studies (Chorus and Bertolini, 2011[103]; Caset et al. 2018[104]; Vale et al., 2018[105]), a buffer with a radius of 800m and the central point of the railway station is considered as the catchment area for calculating the percentage of inhabitants, mostly in suburbs, who can easily access train stations for daily inter municipality movements which is a potential prohibitory factor for EV diffusion. The buffer standards follow a minimum of 400m and a maximum of 850m threshold that eventually depends on the transport means and their velocity (Walker, 2012)[106], The faster the mean of transport, the further pedestrians are willing to walk to arrive there. (Daniels and Mulley, 2013[107]; El-Geneidy et al., 2014[108]).

This indicator in our study is measured by counting the inhabitants in the catchment area of 800m around the regional railway stations as the main alternative transport-mean to cars and private vehicles which affects EV diffusion negatively.

- Charging station

The supply of EV charging stations is the most important indicator for the promotion of EV diffusion in an area. This indicator includes public and private charging points at the municipal level. The home charging facilities are excluded from this calculation.

7.2.2 TRAVEL PATTERNS

MOBILITY

- Mobility index

Mobility index is a density concept that measures the total inflows to a city and outflows from it, over the official number of employees in that context. Considering that EV use is financially convenient in terms of cost-benefit analysis, only after a high number of working kilometers, this index is useful as a tool for EV diffusion measurement. This index is calculated as the summation of the commuter inflows and outflows which demonstrates the total daily displacements, divided by the employed population of the municipality. The outcome is the density of daily work trips.

Commuting to work and back if on a large scale, according to Politecnico di Milano Energy and Strategy Group (2019), superior to 15K km annually, can be significantly cost-effective when it comes to electric vehicles and their high initial purchase prices.

- Commuting average distance

The average distance traveled by commuters between each pair of municipalities multiplied by the number of outgoing displacements divided by the total number of displacements results in commuting average distance which is important for the reasons explained in the previous indicator. According to Pucci, this distance has been calculated as an average Euclidean distance from the geographical centroid of each municipality, starting from the official routable network and considering the origin and destination of each commuter trip.

CAR DEPENDENCY

Car dependency can directly influence the applied policies in spatial settings. Where the car dependency and as a result, the dependency of car use is high in an area, usually in suburbs where public transportation is not well-functioning, policies lean towards incentivizing the EV purchase. In the opposite scenario, where the alternative of public transportation is considerable, car-sharing promotion is more effective to reach electric transportation goals. To measure the propensity of a population on car use, the indicators below are used:

- Car ownership

The first step to understanding a population's dependency on cars is to measure the percentage of car ownership. This number in this research is calculated as the car ownership number per 1000 people for each municipality. This data is available on ISTAT, The Italian National Institute of Statistics (Italian: Istituto Nazionale di Statistica; Istat).

- Car modal share in commuting flows

Among all means for commuting, the percentage related to using a car as the main transport vehicle shows the individual's preference for cars over all other means of transport. This data is available on the mobility agency of the Piedmont region (agenzia della mobilita piemontese) for the year 2013.

- Car euro 5 n 6

This indicator indirectly shows what percentage of the population is willing to change or update their car models. The categories that divide all vehicles according to pollutant emissions, start from class Euro 0 and Euro 1 and reach Euro 6 B, C, and D for the more environmentally friendly ones. Calculating the portion of Euro 5 and 6 cars over all car registrations identifies the portion of the population that potentially shows interest in upgrading their car to an EV. This index is calculated as the number of cars registered with Euro 5 and 6 certifications over all car registration per municipality. The primary data to calculate this indicator is available on ISTAT.

7.2.3 SOCIO-ECONOMIC DATA

Referring to the sources mentioned before, EV diffusion in an urban environment is directly affected by user characteristics in that society. According to the studies focusing on EV-user profiling, each circumstance is unique in the definition of this profile and differs from other geographical, cultural, and economic circumstances. All the data regarding the census of population, economic, environmental, and social census in this research are all taken from ISTAT which is the main referral entity for national census statistics in Italy.

Most of the data used are produced by ISTAT at the municipal level which is counted as the lower-tier local authority level of the Italian administrative geography.

DEMOGRAPHIC CONDITIONS

Demographic data are important to measure the relative tendency towards EV use. In the previous sections, the indexes were extracted from the literature and the case studies. Eventually, the most relevant ones are listed here to be measured in the area of Turin's metropolitan.

- Young population

According to the literature, youngsters are the ones more interested in EVs. Thus the age range differs from a geographical context to another, the general age range covering most of the studied areas is between 18 to 50. The ratio of this age range over the people with the age between 51 to 70 composes this indicator. The choice of the age range is due to the minimum age for driving in Italy (18 years) as the lower threshold, and 70 years old as the upper limit for adopting new technologies.

- Young families without children

Young people not only individually but also in family units are the most interested group in the EV market. The available resource of data regarding young families (ISTAT) presents this index categorized by the status of having children. Thus, according to the recent UN reports, families without children are more open to adopting new technologies in their life due to the common belief of negativity of technological innovation on family concepts and children. Therefore, this indicator with a low contribution to the demographic data indicator can be calculated and used.

- House ownership

This factor is going to measure the propensity of families in the investments for the home charging facilities. The data for each municipality is simply derived from the percentage of families owning a house to the total number of families in that municipality.

ECONOMIC AND PROFESSIONAL CONDITIONS

- Income

The dependence of EV diffusion on the economic level of the population is undeniable. Especially due to the relatively higher initial cost of EVs in comparison to internal-combustion vehicles, this factor becomes bolder when it comes to the choice between these two options. To have an overall measurement of this factor in different spatial contexts, an average income of the population is used. The data is available on ISTAT.

- Employment rate

This index is developed based on the Lead market concept which is a term used in innovation theory. This concept denotes a country or region, that is a pioneer in adopting innovations. The way this concept works is by sending signaling effects to "lag" markets in other areas, which causes the triggering of a process of global diffusion. According to Marian Beise [109], innovations that have been adopted successfully by the users in a lead market, are more probably the subject of a worldwide diffusion than the preferable innovative designs in other countries or regions.

Companies and their employees form a lead market that can act as stimuli for EV diffusion in the same spatial setting where it is located. This number is simply calculated as the number of employees over the population between 14 to 65 years per municipality (the age range for the potential workforce).

- Educational level

Studies have discussed the importance of science and education in developing concept-understanding that underpin environmental issues, which potentially lead to pro-environmental behaviors. [110] This social relevance is measured in our study area by the percentage of graduates over the population aged over 20 years (median graduation age) per municipality.

In table 9, all the indicators and the formula to calculate them are presented.

	Criteria	Indicator	Utility	Measures	Relevance in this research	Contribution to criterion
Built Environment	Densities	The density of the urbanized area	+	Larger class patch index (LCPI)	The Measure of the spatial possibilities of EV diffusion	40%
		Population density	+	[Inhabitants + balance of commuter flows + 1/3 total beds (hotels and complementary)] / urbanized area	The Measure of the density of possible EV users	60%
	Supply	Railway stations	-	Inhabitants inside a catchment area of 800m with the centrality of railway stations (percentage)	The Measure of the quantity of public transport in contrast with EV diffusion	30%
		Charging Stations	+	Number of private and public charging stations (excluding home charging points) in each municipality	The Measure of the quantity of EV infrastructure in favor of EV diffusion	70%
Travel Patterns	Mobility	Mobility index	+	[Inflows + ouflows] / employed population	The Measure of the density of daily displacements considering that EVs are cost-efficient for the use above 15K annually	40%
		Commuting average distance	+	Distance between every two municipalities in outflows (km)	The Measure of the average distance traveled	60%
	Car dependency	Car ownership	+	Number of cars / 1000 inhabitants	The Measure of personal preferences to use cars	40%
		Car modal share in commuting flows	+	Car modal share / total daily displacements (percentage)	The Measure of the car use levels in comparison to other transport means	40%
		Euro 5 and 6 cars	+	Number of euro 5 and 6 cars / total number of registered cars	The Measure of the high propensity towards car update	20%
Socio-economic profiles	Demographic conditions	Young population	+	Population between 18 to 50 years old / 51 to 70 years old	The Measure of the interest in EV purchase/use. Particularly high for the age range of under 50	50%
		Young families without children	+	Young families with no children / total number of families (percentage)	The Measure of interest in EV share/use	20%
		House ownership	+	Families with house ownership / total number of families (percentage)	The Measure of willingness to invest in home-charging facilities	30%
	Economic and professional conditions	Income	+	The average income per municipality	The Measure of the willingness to pay for a higher-priced vehicle	50%
		Employment rate	+	Number of employees / population between 14 to 65 years old (percentage)	The Measure of lead markets on EV adoption	30%
		Educational level	+	Number of graduates / total population over 20 (percentage)	The Measure of educational level as a proxy for pro-environmental behaviors	20%

Table 9 – Weight Matrix for different scenarios of EV diffusion development
Source: Pucci, 2021

8 SCENARIOS

The word "Scenario" up to now is mostly used in contexts regarding planning literature.(Zentner, 1982[111]; Godet and Roubelat, 1996[112]; Godet, 2000[113]; Chermack et al., 2001[114]; van der Heijden, 2005[115]; Rigby and Bilodeau, 2007[116]; Roxburgh, 2009[117]; Chermack, 2011[118]). This work presents a simplistic multi-scenario urban development using scenario analysis method with the intention of facilitating decision-making for urban and transport planners in different contexts with diverse levels of urbanization in the Metropolitan of Turin. Among different types of scenarios, in this research, policy scenarios are used. This type of scenario-making does not aim to predict future but rather identify possible future conditions that are stable and coherent based on a series of key assumptions (van Notten et al. 2003)[119]. Therefore, using these scenarios as the main approach can make policies and plans future-proof by identifying strategic problems[120], and adding more resilience to the final decisions. According to Bankes, in an uncertain world, policy analysis is often facilitated by an exploratory approach rather than solid modeling that tends to give definitive answers [121]. To be noted that in this research the outcome is not a single result but rather a bandwidth of results to allow testing for different future possibilities.

Different scenarios are made as supportive tools that create alternatives among which comparisons could be carried out and an integrated final logical decision can be adopted regarding the EV diffusion's urban management and coupling policies to promote this diffusion.

In order to create the scenarios, both the Analytic Hierarchy Process (AHP) and Weighted Linear Combination(WLC) approaches are used to run the value-based SMCA (Saaty, 2005, 2008[122]). The first approach (AHP) contains a multicriteria weighting method (Feizizadeh et al., 2013[123]) where ratio scales can be derived from paired comparisons using the scale of intensity. This is while AHP permits both quantitative and qualitative information use and is based on problem definition, defining the hierarchy tree, comparative judgment, and synthesis of priorities (Malczewski 1999[124], Karlsson et al. 2017[125]). To weight and prioritize scenarios in this method the SMCA has been carried out in the following analytical phases. First, a pairwise value matrix was made for each indicator (positive and negative) extracted directly from data sources (the database created for GIS map production). Later on, the extracted data were normalized using the maximum and minimum values to become comparable. The next step was to calculate the six main categories summarized in table 9 by summing up the sub-categories in each sector and finally apply the diversified group of weights based on the weight matrix indicated in table 10 for each scenario. The final score for each municipality is calculated following this formula:

$$EVs\ potential\ index = \sum_{j=1}^{n} w_j a_{ij}$$

wj= the relative weight attributed to the criterion Cj

aij= the value of the spatial unit (municipality) Ai based on the criterion Cj

This methodology helps to compare alternative scenarios and consequently, reach the purpose of the method which is decision-making and finding the most effective policy measure that can address mobility sustainability for each unique scenario. In the final outcome, the number attributed to each municipality is how likely is the EV diffusion development in the offered policy framework. The reason why this method is relative in this thesis is that the outcome supports geographically targeted interventions (incentive or regulation policies, as well as supply and services for e-mobility) that can contribute to a fair and sustainable diffusion of electro-mobility.

	Indicator	Baseline Scenario	EV Sharing Scenario	Private High mobility Scenario	Private High Budget Scenario
Built Environment	Supply	0.1667	0.25	0.1	0.12
	Densities	0.1667	0.28	0.07	0.6
Travel Patterns	Car dependency	0.1667	0.1	0.28	0.24
	Mobility	0.1667	0.1	0.25	0.18
Socio-economical Profiles	Professional and economic condition	0.1667	0.15	0.15	0.3
	Demographic condition	0.1667	0.12	0.15	0.1

Table 10 – Weight Matrix for different scenarios of EV diffusion development
Source: Pucci, 2021

In the geographical-based multi-criteria analysis (SMCA), in case of possible changes in the decision making, the definition of each of the scenarios above can be modified, and eventually, by assigning different weights to the criteria, different results of EV diffusion possibility for each municipality are expected.

8.1 BASELINE SCENARIO

The baseline scenario is used as a comparison base map, produced with the balanced weight as the same weight is being assigned to all the different criteria and the aim is to provide a baseline for further developments and carry out a comparison with high contrast.

This scenario is not identifier due to the equally attributed weights, however, it can show a general potential for EV diffusion in each part of the Metropolitan area. The point of elaborating this scenario is to generally comprehend the potentials of different contexts for EV diffusion, although without specific policy orientations related to them. In other words, from the policy-making point of view, this scenario has the capability of adopting all possible types of policies in the upcoming sections, including EV sharing promotion policies, purchase promotion policies, and private budget incentives to increase the propensity of early adopters.

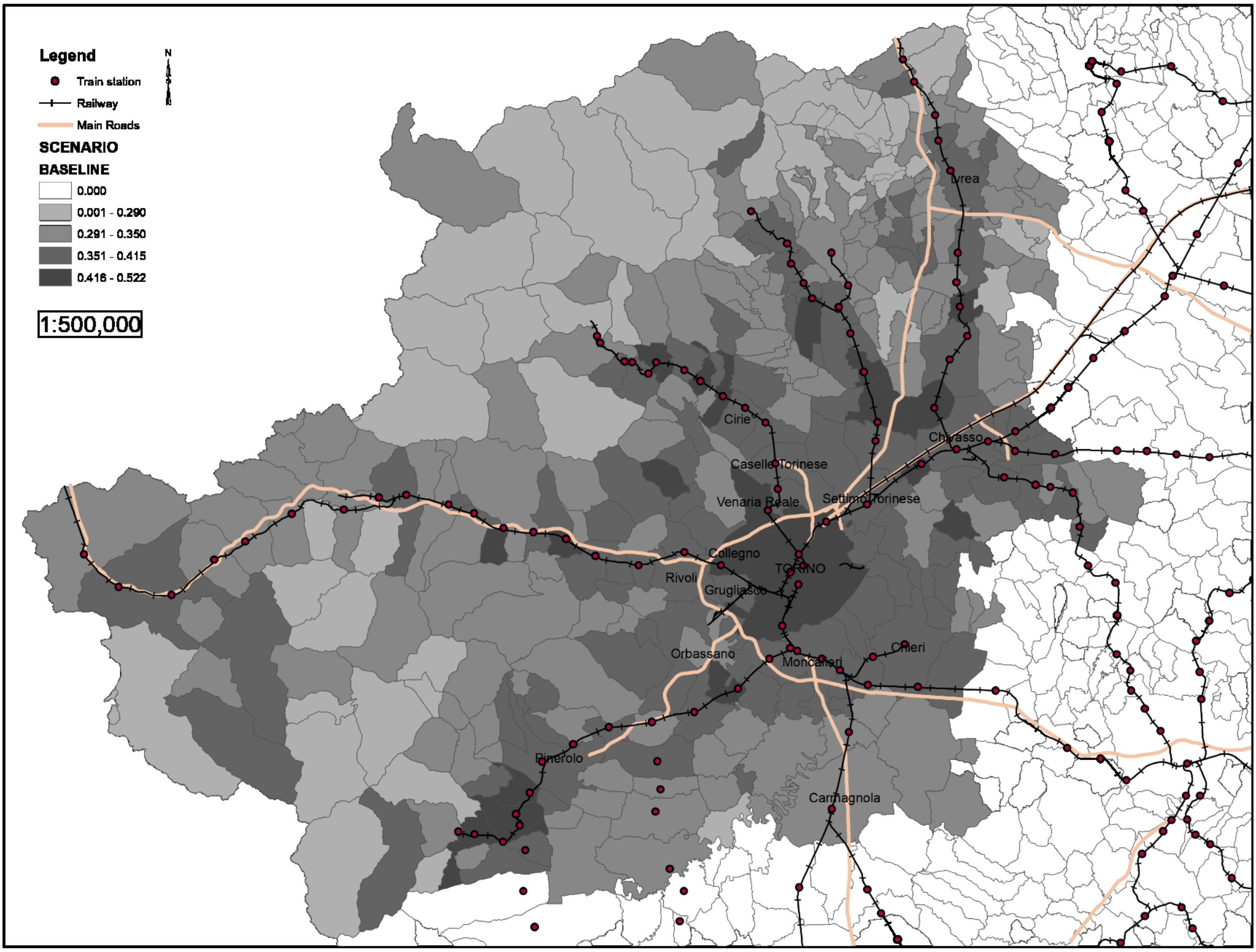


Figure 14 – Baseline Scenario map

Source: author elaboration,2021

This map simply shows that in case we assign equal weights to the different indexes, the city of Turin and mostly the cities along the railway lines are better settings for the EV diffusion (darker color spots). Municipalities that surround the darker spots and corridors are also showing higher scores on the elevated map. This observation can be explained by the last-mile issue that mentions less efficiency in the last leg of a trip comprising the movement of people and goods from a transportation hub to a final destination. Therefore, people are dependent on their private vehicles to improve efficiency and decrease costs.

8.2 EV SHARING SCENARIO

EV sharing scenario is highlighting the factors that are favorable for shared mobility. Sharing fleets can be functional in the areas with high population density and high amount of supply, where the short travel distances are multiplied by a large number of users and this makes the traveled distance high enough for the initial investment to pay off in long term. In this scenario, the weights assigned to urban densities and public transport supply are relevantly high, and at the same time, car dependency has a very low assigned weight due to the existence of alternative transportation means. These characteristics could be found in the big-size cities with densely urbanized areas where the conditions for EV sharing are promising.

In the metropolitan of Turin, these characteristics can be seen in the city of Turin, the first belt municipalities, the high populated towns that are mostly developed around the train stations, and relatively large municipalities all around the metropolitan area such as Bardonecchia and Ivrea.

The proper mobility policies in this spatial context should be focusing on the promotion of EV sharing mobility and enhancement of vehicle occupancy rate[3]. Along with this main focus, a restricting policy for private vehicle use can be effective to lead people towards the use of sharing alternatives. The main profit of EV use in this kind of urban fabric is to reduce the congestion problems, decrease the consumption of public spaces, and cover a larger service area as complementary to the public transportation system. Therefore, the policies should not only be supporting car sharing but also preventing the replacement of private fossil-fuelled cars with private electric ones. A good example is assigning congestion charges also to the private EVs that could be an effective restricting policy in this context.

Right placement for charging infrastructure in EV sharing scenario in order to facilitate e-sharing mobility for the internal commuters are in the commercial malls, business centers, and the metropolitan public transport hubs. However, along with the network of charging infrastructure inside the city, in this scenario, a linear network of fast charging facilities is of great interest. The reason for this claim can be seen in the EV sharing scenario map as the distribution of municipalities with higher rates in this map are along the railway corridors (Fig. 9). This distribution represents a compelling spatial condition for circumscribing fast-charging stations, in the form of multi-service transition hubs around the railway stations that can optimize the supply. Additionally, these hubs can be focal points for the integration of EVs with railway networks that can lead to intermodality and better management of the electric network.

[3] A single-occupancy vehicle is a privately operated vehicle whose only occupant is the driver. The drivers of SOVs use their vehicles primarily for personal travel, daily commuting and for running errands.

According to Pucci, a transport hub as a complementary transport infrastructure to the public transport supply promotes sustainable transitions areas. This outcome is guaranteed if there are efficient policy measures that act on the supply side (availability of public recharging stations), and on the demand side (access, regulation, and pricing) as well. The application of these measures helps reduce the use of conventional vehicles and promote shared use of EVs, ensuring a continuous rotation between them.

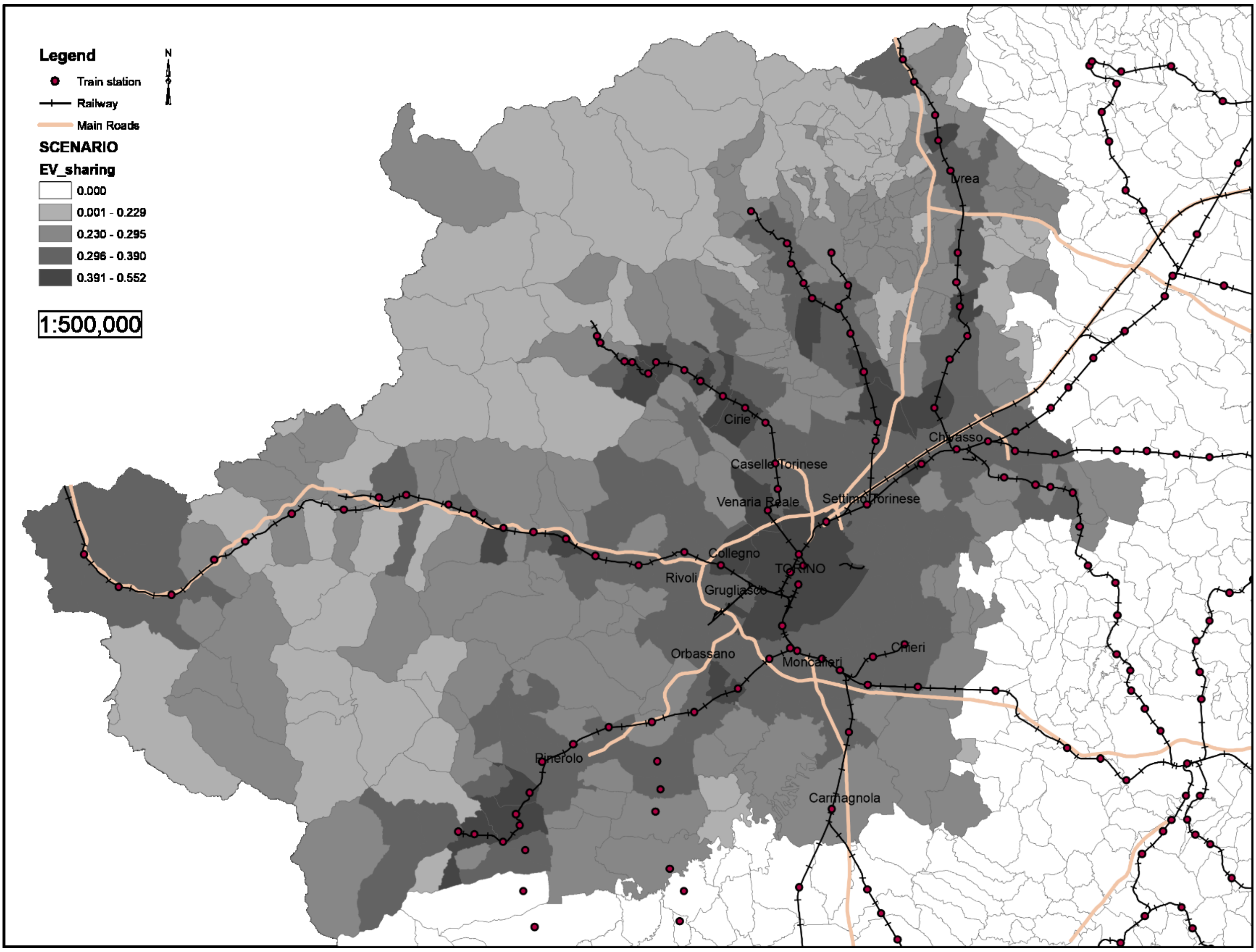


Figure 15 – EV Sharing Scenario map

Source: author elaboration,2021

8.3 PRIVATE HIGH MOBILITY SCENARIO

Private high mobility is a scenario that considers a significant leaning towards the high levels of car use. This indicator that measures car usage is presented as car dependency in the weight matrix. The second important factor in this scenario is the mobility indicator which measures the average distance traveled by the users together with the density of daily displacements. According to Energy and Strategy report (2019), the usage of electric vehicles pays off the operational costs only If the traveled distance is greater than 15K km in one year. For this reason, among all the measured criteria, higher weights are assigned to car dependency and mobility indicators.

This spatial pattern is specifically seen in the areas with medium to low urban densities where the public transportation and sharing fleets are not developed enough to be considered as the dominant mode of transportation for the settlements. In addition, the demand for these types of alternatives is taking place mostly in an intricate scattered spatial and temporal frame. Therefore, the policy-makers avoid investing in the development of public or shared transport infrastructure in the sprawled areas. In such context, settlements as a result of this cycle, are pushed to depend on private vehicles for mobility. However, the main differentiating index here is the average distance traveled, which for medium-low density settlements, this number is quite higher than the dense urban ones. In order for EV purchases to be competitive in the market, the distance traveled should be high enough to pay off the initial investment costs.
According to what was mentioned, the target of this scenario is to spot where car dependency and annual mileage traveled by the settlements are both of a high value. The spatial realization of these characteristics can be seen in rural and urban sprawled areas around the center of metropolitans.

The private high mobility map shows darker spots for the municipalities with low urban densities where the phenomenon of urban sprawl in the form of low-density fabric can be seen. This is while Turin and the high-density first belt cities (e.g., Rivoli, Orbassasno, Grugliasco, and Settimo Torinese) around it are all showing lower values and as a result lighter colors. (Figure. 10)
Unlike the previous scenario, in the urban sprawled fabric, the policies that are incentivizing car sharing or public transport use are not effective due to the low demand for them. Therefore, an efficient proper policy in this context should be centralized around reducing the EV purchase barriers that have been gathered specifically for this study area through the questionnaire (e.g. high cost, absence of infrastructure, etc.), and at the same time providing financial supports for both purchase of EV and providing fast-charging infrastructure along the corridors of connection between these areas and the city of Turin. Policies regarding the charging infrastructure address the provision of high-speed charging stations in the main transport junctions, construction of multi-service hubs around the highways, and equipping those areas with parking service for electric cars in order to reinforce the exchange of ICEV to electric vehicles.

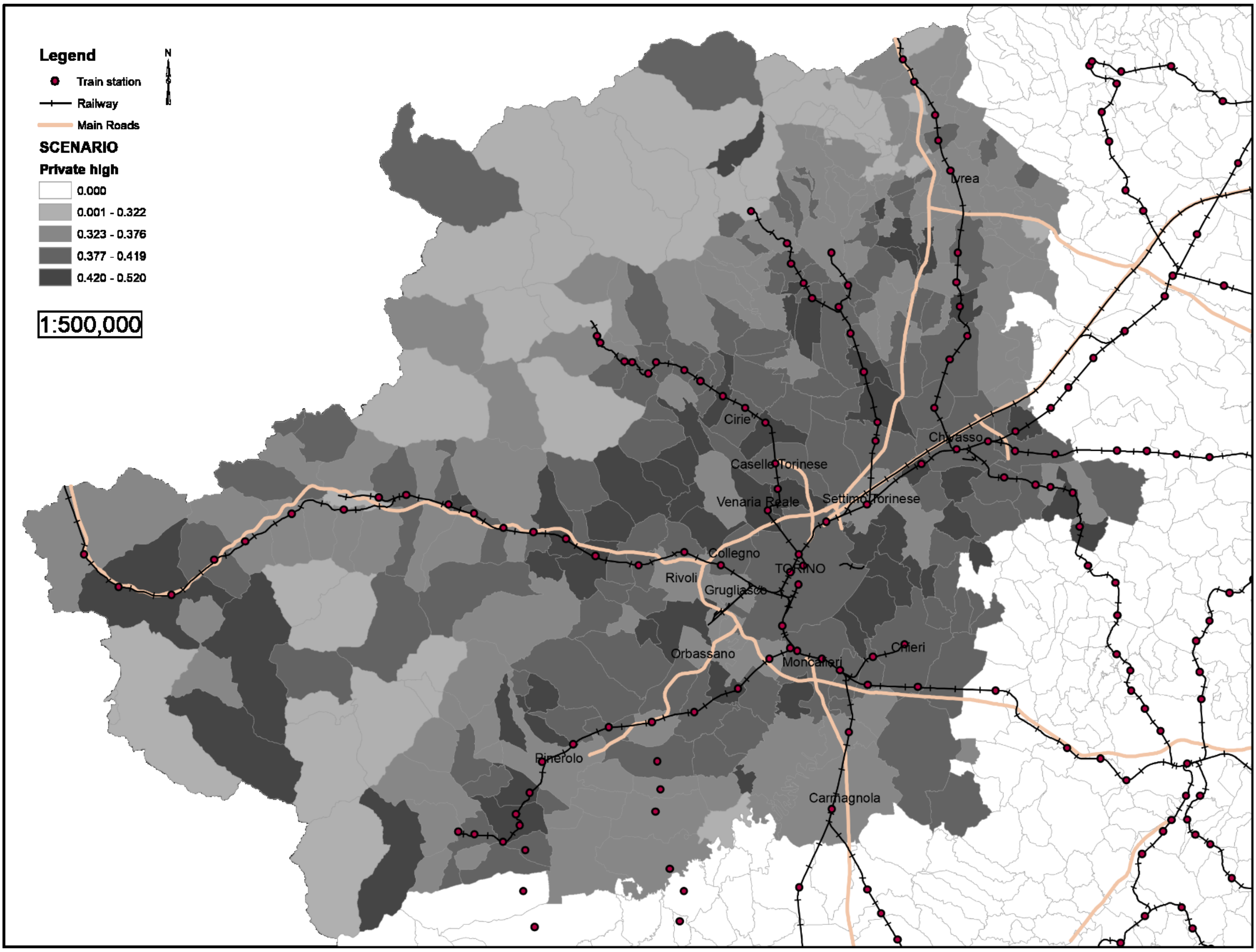


Figure 16 – Private High Mobility map

Source: author elaboration,2021

8.4 PRIVATE HIGH BUDGET SCENARIO

The private high budget scenario is focalizing on identifying the spatial possibility of having a high number of early adopters regarding electric vehicle purchase and use. Therefore, the municipalities that are more likely to have a high rate of first investors for the EV technologies are the ones with a higher propensity to spend. Eventually, these areas are potentially known as the areas with higher average income due to the fact that the purchase of an EV along with a home charging system without particular financial supports in the form of subsidies for manufacturers and consumers, costs much more than a similar model ICEV. Areas with high average incomes are cities with a high amount of population density where agglomeration economies allow the settlements to have extra financial benefits. According to Giuliano and others [126], agglomeration economies are generating geographic clusters, if external benefits are greater than the added costs of higher rents, wages, and transport costs that agglomeration generates.
In the private high budget scenario map, the most weighted criterion is the density of both built area and population, which is an essential factor for the second most weighted criterion, high professional and economic condition, to happen. The darker spots on the map show Turin and the surrounding cities, and it grows all along with the railway stations where there is a higher density value for the nearby municipalities compared to the distant ones. Turin in this scenario is the city with the highest value and therefore, the highest possibility for early EV adoption among its settlements.
These municipalities due to their high propensity to spend caused by high fiscal measures, in case of getting incentives, are easily stimulated to adopt EV diffusion in form of private electric mobility. For this reason, the adopted policies in this theme should focus on incentivizing the purchase of EVs in form of discounts to the user and manufacturer, public facilities for the EV users, and providing an integrated charging infrastructure since one of the most important barriers of purchasing an EV according to 85% of the participants in our questionnaire for the settlements of this area are indicated as insufficiency in the number of station and scarcity of the already existing ones.

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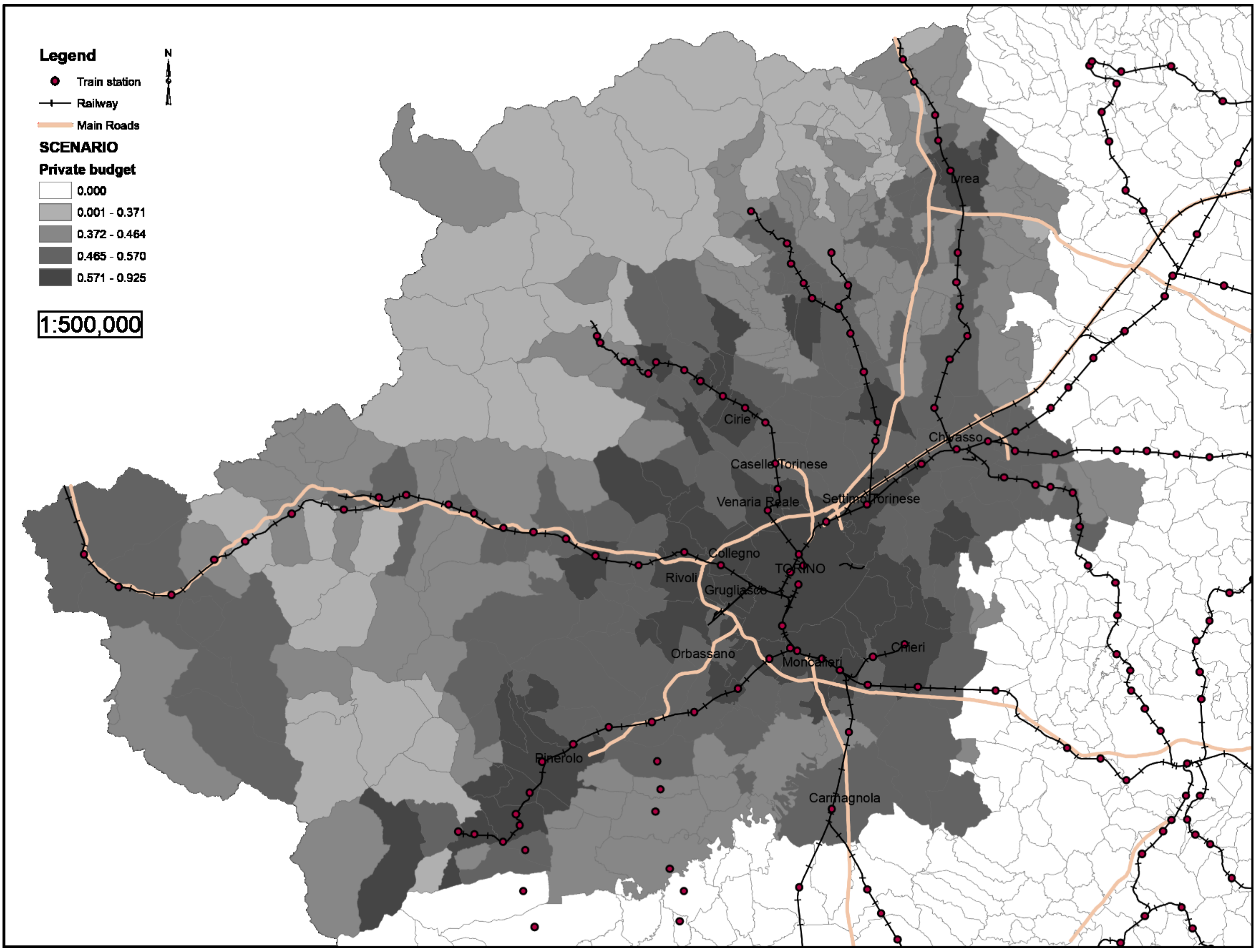

Figure 17 – Private High Budget Scenario map

Source: author elaboration,2021

The city of Turin as the center of the Metropolitan area owns the highest value in the Private High Budget scenario (the first place) and EV sharing scenario (the fourth place). This result demonstrates that the main short-term orientation of policy-making decisions in the city of Turin should be towards the promotion of EV purchasing, and eventually, EV sharing incentives. Improvement of multi-modal integration, providing fast-charging stations in the transport hubs and along the TPL[4] corridors while facilitating the use of private cars permits policy-makers to promote both scenarios. The currently adopted policies in the city of Turin including the incentives for purchasing EVs, parking facilities, and toll exemptions for private electric vehicles, are covering the proper policies for the promotion of the high budget scenario. This is while, EV-sharing fleets are growing in Turin more and more, and consequently, the personalized charging stations are being built by each of these companies in different locations in the city. As a long-term plan, policy-makers should focus on the integration of different types of charging stations in order to prevent the chaos of specified charging infrastructure which is not useful for the charging of other types of electric vehicles. According to our results, in the municipality of Turin, promotion of the high budget scenario policies in order to attract the maximum amount of early adopters could be a proper short-term plan. Whilst, in case of early adopter saturation, applying the policies related to the EV sharing scenario is going to lead the transportation sector towards sustainability.

[4] Local Public Transport

9 CONCLUSIONS

9.1 RESEARCH AIMS AND RELEVANCY

There are diverse explanations for how electric vehicle adoption and distribution is affected by the spatial context, suggesting that diversities in the quality and the quantity of this diffusion cannot be attributed to a single factor. Rather it seems probable that a mix of elements with diversified intensities accounts for distinct EV diffusion scenarios. The long-term executive management of this relatively new technology in the context of cities, suburbs, and rural areas requires relevant decision-making studies backed up with scientific evidence regarding the proper policies and practices that best apply to the context in question, at the regional, provincial, and municipal levels. Even though the financial incentives are the most appreciated stimulants among policies for purchasing an EV, according to (Lieven, 2015[127]) public investment in charging infrastructure, as the presence of it is mandatory, acts more effectively in EV diffusion than monetary grants or any other types of incentives. Prohibiting policies or in other words, disincentives are also significant policies in controlling ICEV use and promotion of EV diffusion. According to (Hardman, 2017[128]) to set incentives and disincentives, policymakers should carefully consider the spatial conditions, the regulatory environment, local travel patterns, and consumer preferences to determine the most viable policy interventions in each area. Understanding the complex interplay of factors, their intensity, and then demonstrating various highly probable spatial scenarios based on the bold attributes (higher intensity) of the context provides us with the data that can effectively foster the EV adoption and diffusion plans in order to improve sustainability in the mobility sector.

This research aims to spot the best matching EV diffusion policies for Turin's metropolitan area, through the SMCA methodology using both AHP and WLC as complementary approaches. The reason this subject was chosen for this thesis research is the newly growing sector of electromobility in Italy, and the lack of empirical knowledge on the context-centered urban transportation policy-making patterns that can be a principled guideline to go towards sustainability and fulfill the SDG goals, more precisely goals regarding sustainable cities, responsible consumption and climate actions (N.11, 12 and 13).

The essentiality of this discourse is because nowadays, theoretically, electromobility is widely suggested as a solution for environmental problems. This is while there are loads of critics about the practical efficiency of EVs. From the environmentalist point of view, even though the currently existing EV technology is not considered zero carbon emission due to the contamination released during the manufacturing stage of batteries, the recycling transaction at the end of batteries' life, and use of fossil fuel as the main source of energy production in the country to run this process, yet EVs as they are today, to a great extent, are greener than ICEVs. From the urbanistic point of view, EVs are equally problematic when it comes to traffic congestion and the occupation of public space in cities with large-scale EV adoption. From the social point of view, EVs can not be adopted by a great portion of the population due to their high initial cost and therefore utility of EVs is possible for a small variety of users. Taken into account all these critics, an integrated policy-making baseline should be developed based on the characteristics of each context, to tackle all these problems and make EV diffusion readily possible.

9.2 RESEARCH FINDINGS

In the previous parts, the questions that this research aims to answer were listed. To conclude the thesis, the answers given to the mentioned questions using our methodology are summarized and reflected.

- What socio-spatial factors affect EV diffusion?
- In what ways do the intensity of socio-spatial factors affect the urban, suburban, and rural areas?
- What are the most effective policy practices regarding EV diffusion in Turin's Metropolitan area?
- How does the promotion of EV diffusion help increase sustainability in spatial contexts?
- What impact do the context-adjusted policies have on reaching sustainable development goals?

The pathway that this research follows is first, defining the EV diffusion efficacious factors. Later on, attributing an influence ratio to each criterion and investigate the EV-diffusion possibility based on the bolder criteria. Eventually, concluding with the policy measures adopted to the context and making suggestions to improve mobility sustainability. The approach adopted to connect the urban, suburban, and rural space with the EV diffusion, is to go through socio-spatial conditions of the mentioned contexts. Studying this connection helps to develop a baseline for the site-centered policies that are unique and highly compatible with each area due to the inclusion of the characteristics of that spatial context. Considering this holistic baseline in the decision-making process and establishing a future mobility plan is vital for the planners because the rhetoric and generic ways of policy making including practices that incentivize EV purchase are missing the important socio-spatial factors in each context. To include these characteristics and present a reliable baseline for EV incentives in Turin's metropolitan area, both primary and secondary data were used. The secondary data including the effective factors of EV diffusion, in three main categories of the built environment, travel patterns, and socio-economic data were deducted from the literature regarding this subject and especially our reference study, Paola Pucci's paper. The indicated factors were measured according to the integrated data available on ISTAT for the year 2013.

Once this information is collected, a mediator approach is required to make use of the data and reach the decision-making outcomes regarding the effective context-adopted policies. The approach used in this research is the modified version of multi-criteria analysis which corresponds to our spatial needs. Spatial multi-criteria analysis (SMCA) is the methodology adopted in this research, that facilitates the decision-making process and has reliable results when it comes to spatial issues. Among the diverse approaches that can be applied to make conclusions, in our case, Analytic Hierarchy Process (AHP), in combination with the Weighted Linear Combination (WLC) approach, are chosen due to the accordance with the available data and the desired outcome. In this method, a weight table is used for each different EV diffusion scenario that has a high possibility to happen in reality. These weights can be contextualized by using a questionnaire or when the results are not trustable enough, using the existing literature on the topic.

The primary data were supposed to measure the intensity of the already known spatial factors through a questionnaire made by the author and distributed among the statistical society that this study is aiming, However, due to the agglomeration of the participants in the city of Turin and eventually insufficiency in the data regarding the participants from other parts of the metropolitan area (suburban and rural), the questionnaire results are not used for defining the weight of spatial factors in our study. Instead, a hypothetical weight table derived from the literature is used in this case.

Following Pucci's research, four scenarios were developed each with a complex of weights assigned to the pre-defined spatial factors. The reason why this approach is effective is that it illustrates the efficiency of each scenario for different areas with diverse levels of urbanization, and consequently the best matching areas (the one with the higher ratio) with that scenario. This methodology gives a highly reliable scientific base for decision-makers to define strategies, policies, and incentives to be applied in different spatial contexts of Turin's metropolitan area.

To answer the last two questions, we analyzed the data and for each scenario, and accordingly, the results are presented in classes of spatial density. Eventually, the proper policies that are effective in the development of the scenarios in each density class are mentioned.

1. HIGH-DENSITY AREAS:

In the areas characterized by higher density in population and the built environment, such as metropolitans and crowded cities, moving by private vehicles causes serious environmental and urban problems. Moreover, small traveled distances due to the immediate vicinity to the living facilities in the city context make private EVs not suitable for these areas. The reason for this conclusion can be explained by the cost-efficiency of EVs in long run. To pay off the initial high cost of the vehicle the distance traveled must be greater than 15,000 km per year. Therefore, the shared use of electric vehicles can be a potential solution to this issue.

The spatial realization of these factors in our study area corresponds to the municipalities of Torino, Grugliasco, Collegno, Beinasco, Nichelino, Venaria Reale, Rivoli, Bruino, Banchette, Settimo and San Mauro Torinese, Alpignano, Brandizzo, Moncalieri, Borgaro, Orbassano, abd Ciriè (density>1). Effective policies in such contexts include schemes that focus on car sharing promotion, higher vehicle occupancy rates, encouraging multimodal transportation, and from the opposite point of view, discouraging private vehicle purchase, minimizing the ICEV to EV car change policies for private use, and setting restrictions for private vehicles even in case of electric cars (i.e. congestion charge extended also to private EV use). The exemplars of these policies are providing electric car-sharing means in the most common transportation corridors, removing restrictions for shared electric cars (i.e. free parking, no congestion charge, etc.) equipping transport corridors and multi-modal junctions with fast EV charging stations, and also setting some prohibitory regulations such as forbidding private cars, either electric or not, from entering in limited traffic zones (ZTL- zone a traffico limitato).

2. MEDIUM-DENSITY AREAS:

In the medium-size settlements such as urban sprawled areas, where the car dependency is higher than big cities and lower than rural areas an interstitial approach is the most efficient to adopt. These areas are mostly equipped by railway stations, however, these connections are covering only some of the settlements' transport needs. For the rest, private or shared electric vehicles might be a convenient answer. The exemplars of these characteristics in our study context are Pinerolo, Susa, Avigliana, Leini, Volpiano, etc. To lead the wave of ICEV users towards e-mobility, policies such as providing free EV parking and mobility hubs with fast charging points around railway stations could promote the transaction between public mobility infrastructure and EV use.

3. LOW-DENSITY AREAS:

Lastly, in low-density settlements where due to the high distance from living facilities, the need for car use is at its peak, policies should address the purchase and use of private EVs. The lowest values in our study area show municipalities of Balme, Ceresole Reale, Massello, Noasca, Valprato, and Ribordone. In line with this approach, financial incentives for EV purchase, ICEV to EV replacement, providing charging infrastructure, and emphasizing the environmental value of all these actions could be effective.

Based on these conclusions, policy-makers should consider applying the proper policies adopted to each spatially unique context based on their socio-spatial characteristics to increase sustainability in the mobility sector. The following scheme is a generic representation of the policies compatible with each spatial environment based on the density factor. It is worth mentioning that this methodology can be used in a micro-scale scope to gain more specified results.

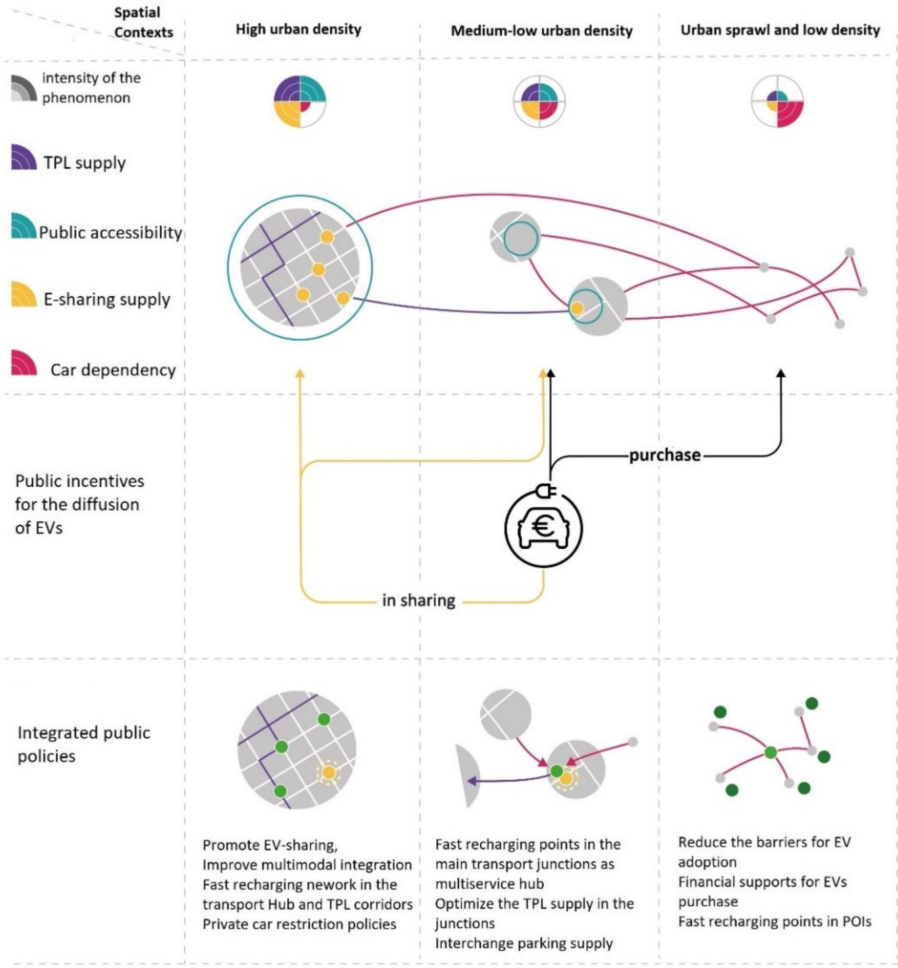

Table 11 – Policy orientation in EV diffusion development
Source: Paola Pucci, 2021

Results of the SMCA in the case of Turin's metropolitan area show different values for different categories of urban, suburban, and rural areas. The high values related to rural or suburban areas in some scenarios, admit the hypothesis of the place-based model and the fact that EV diffusion is not only limited to the cities. A coherent mobility development plan can cover all contexts and facilitate the path to sustainability.
The city of Turin as the center of the metropolitan area with the highest population density and the relatively high-income average seems to be the most compatible with the Private High Budget scenario. It is worth mentioning that Turin shows to be well matching the EV sharing scenario as well as the high budget scheme. This illuminates the fact that the most effective strategy-making guidelines regarding EV development in this area should focus on a mixed approach in which EV purchase and sharing incentives are equally promoted. However, as the high private budget and purchase incentives are aiming the early adopters and their positive replicating effect on mass late adopters, gradually the process of EV development in Turin takes a turn towards being saturated with one to one EV users (early adopters), and at that point, the sharing policy measures are to be promoted.

Following this logic, the short-term policy measures suggested for Turin are to be focusing on the promotion of EV purchase, direct financial incentives to the end-users and manufacturers, providing fast charging infrastructure along the main transport corridors, giving permission to access traffic restriction zones for electric vehicles, etc. Whereas, long-term measures are supposed to consider the promotion of EV sharing and hence enrichment of multi-modal integration, providing fast-charging points in the transport hubs and along the TPL[5] corridors while facilitating the use of shared electric cars. The proposed mixed approach takes into account both factors of time and place permitting policy-makers to apply location-based practices at the required timeline.

9.3 FURTHER DEVELOPMENTS

The methodology used in this research, however, lacks precision in some data measures due to the limited data availability by the time this thesis research has been done. The first restraint faced in gathering the secondary data required to proceed with the SMCA is that the last integrated data presented on ISTAT refers to 2013 whilst in the further developments of this report to acquire more precision, this data can preferably be updated with the up-to-date data once the availability of this kind of information is approved. Furthermore, the weight table used for intensifying the attributes

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and creating different scenarios is deducted from the related literature, whilst the initial aim of the thesis was to gather this type of data through a questionnaire that was designed and distributed among the target population to directly extract these ratios from the different stakeholders involved in the EV diffusion phenomenon. Even though the already used data are reliable, for more precision these measures can be upgraded with the direct weight table derived from the questionnaire once the acquired results reach enough diversity in the geographical distribution of the respondent's location.

Despite facing the indicated limitations, this research contributes to a more specified site-based policy-making baseline that includes socio-spatial attributes of the site and the stakeholders. Nonetheless, the results of this research have high credence and the application of this empirical evidence can help to achieve higher sustainability levels in the mobility sector not only by increasing the number of EVs but rather with the fair distribution of place-based incentives regarding them.

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