

# NVH Analysis Techniques for Design and Optimization of Hybrid and Electric Vehicles

## Chapter 1

### Electric and hybrid electric vehicles – the relevance of customer expectations and preferences

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**Abstract.** Electric vehicles (EV), hybrid electric vehicles (HEV) and plug-in hybrid electric vehicles (PHEV) are promising solutions to tackle challenges following the CO<sub>2</sub> emissions of the transport sector. Due to the slow market growth questions arise how to foster the adoption of such technology. Therefore, it seems necessary to develop a clear understanding of what benefits EV/HEV/PHEV could provide to the public and potential customers. In this context, low noise emissions, as one of the key characteristics, could play a decisive role in reaching a higher market share. In the chapter on customer expectations, several aspects of the customer evaluation of EV/HEV are examined. First, noise as a key characteristic and methods to assess its role for customer acceptance are investigated. In the second contribution it is discussed how vehicles with an electric power train affect different kinds of emissions and how early adopters cope with such technology. In the third contribution attitudes towards EV and perceived barriers of potential customers are reported. Together the contributions provide an overview of which features of EV are relevant, not only for potential customers, but also for the general public. This could be used to further promote vehicles with an alternative power train.

#### 1 EV/HEV noise from a customer's perspective

Looking at the impact of electric vehicles and hybrid electric vehicles on noise emissions in general, Jabben et al. [1] discussed that EV could have a positive impact on the noise level in cities as noise levels in urban environments could be reduced particularly at junctions and on roads with low average speeds. As high noise levels have been found to be related to health issues such as sleep disturbances [2] and cardiovascular risks [3], the low noise emission of EV/HEV could have a positive impact on the wellbeing of inner city residents. Nevertheless, particularly at junctions where different road users need to interact with each other, safety is of utter importance. This creates a dilemma: silent cars could contribute to lower urban noise levels on the one hand, but on the other hand, they could have detrimental effects on traffic safety by endangering vulnerable road users. The question therefore arises, how the public and potential customers evaluate the noise emission of EV/HEV. Some features of vehicles that may influence purchase intentions and satisfaction of consumers are the perceived noise and the vibrations produced while driving, given

that sound is associated to brand quality. In this sense, interest has increased in recent years to know what customers look at when they discuss sound quality [4] and how they evaluate such quality [5].

Research on the attitudes and acceptance of potential EV customers mainly regarded noise as an additional factor that contributed to the innovative and futuristic feel of such vehicles. Gärling [6] investigated acceptance of EV in Sweden and reported that, according to the drivers, the low noise of the EV was part of the driving pleasure. Similar findings from France were reported by Labeye et al. [7]. In studies on EV acceptance, participants also referred to low noise emission as a generally desirable characteristic of EV [8]. Reports from UK fleet drivers revealed considerable differences in the evaluation of the low noise. Although the drivers generally welcomed this feature, some mentioned concerns pertaining to the safety of pedestrians [9]. German field studies on the acceptance and road capability of EV also revealed that EV drivers appreciated the low noise of such vehicles [10, 11]. Applying qualitative and quantitative methods, Cocron and Krems [11] found that drivers expressed safety concerns for other road users prior to driving an EV for the first time. As the drivers gained experience with the EV safety, concerns decreased and the subjective comfort due to this feature increased. Such opposing trends can also be found if drivers test EV for only a limited time, e.g. during an inner city test drive [12].

Summing up the driver evaluation of the noise of EV/HEV one can conclude that customers seem to reflect on sound and noise emissions of EV/HEV. Furthermore, they seem to be well aware of the advantages and disadvantages of this feature. In annex 1A of this chapter, methods will be presented on how to assess the customer evaluation. This is complemented by a review examining the implications of EV on emissions in general. Annex 1B presents a review from Portugal on the adoption of electric vehicles and impacts on noise, energy consumption and air pollution. Annex 1C provides an overview on attitudes and perceived barriers in a study from the Czech Republic.

## 2 Conclusions

The contributions in the chapters on customer expectations and preferences (annex 1A-1C) provide an overview on issues of utmost importance for potential customers. Customers, in particular those who didn't have the chance to test electric vehicles, seem to be unsure if electric vehicles are affordable and suitable to meet individual mobility needs. As reported by Zámečník and Šucha (annex 1C) from the Czech Republic, high purchase price, insufficient infrastructure of charging stations and the limited range of such vehicles are perceived barriers which keep customers from even considering buying electric vehicles. Nevertheless, Zámečník and Šucha also report that potential customers perceive electric vehicles as environmentally friendly. This could be used as an important attribute in the promotion of such vehicles.

The ecological impact of electric vehicles is also addressed in the contribution by Rocha, Melo, Rolim and Baptista (annex 1B). Focusing on the impact on noise, energy consumption and air pollution, the authors discuss current findings which

indicate high potential of electric vehicles in energy efficiency improvement and delocalization of local pollutants emissions. These benefits and an affinity for innovative technology particularly attract early adopters. Studies from the US [13], Portugal [14] and Germany [15] indicate that early adopters are typically highly educated and middle-aged men who live close to bigger cities. Characterised by affinity not only for innovative but also environmental issues, these customers could serve as disseminators of EV/HEV technology.

The question now arises how to reach the more sceptical part of the public. Field studies on road capability and user acceptance from the UK [16], France [17] and Germany [18, 19] indicate that individual experience could play a vital role in this context. With regard to the limited range as one of the key characteristics of EV, Franke and Krems [20] argued that, with increasing experience, EV drivers adjust their range preferences resulting in a smaller range need after three months. This indicates a better fit between subjective and objective range needs.

Low vehicle noise is another important feature of EV. As mentioned above the evaluation of this feature seems to undergo a change with increasing experience, even though this might be different, for instance, in Asian traffic environments [21]. One could argue that noise in general could play a much more important role in the promotion of vehicles with an alternative power train. This was the starting point for the work reported by García del Castillo and Cocron (annex 1A). Creating a structural equation model (SEM) based on existing user research on noise evaluation, the authors define relevant factors for a NVH evaluation and test these assumptions empirically to further refine the SEM model.

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## *Annex 1A*

### **Methods to assess customer expectations related to vehicle noise, vibration and harshness**

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**Abstract.** Due to their reduced noise emissions especially at low speeds, EV and HEV not only raise traffic safety concerns but also questions related to noise vibrations and harshness (NVH). In the present contribution we examine the relevance of NVH issues related to the customer evaluation of EV/HEV as these factors could be crucial for acceptance and adoption of such technology. Based on earlier work we created a SEM model of relevant factors which arguably determine the customer evaluation of NVH issues. In a second step we collected questionnaire data ( $N = 128$ ) to empirically test our model. The obtained data will also be used to further refine our theoretical assumptions about relevant factors in NVH evaluation of potential customers.

#### **1A.1 Creation of a questionnaire on EV/HEV noise**

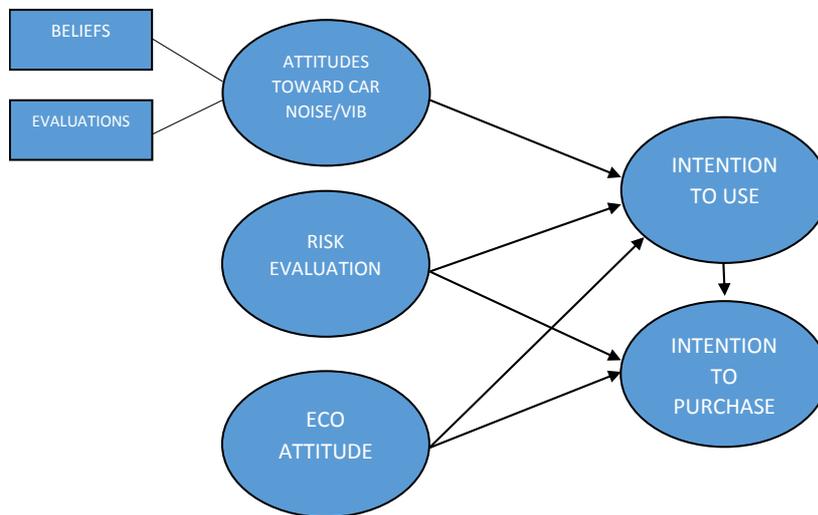
In this study we set out to design a Structural Equation Model (SEM) linking different variables involved in the intention of use and purchase of Electric Vehicles (EV) from a customer-centered expectation related to noise and vibrations. SEMs have proven to be useful tools in behavioural sciences for identifying the theoretical background of certain phenomena, as is the case regarding attitudes [1]. From this perspective—with the aim of contributing to the creation of a solid theoretical framework that will substantiate our research and using the SEM methodology as a structure— we designed a number of items to evaluate these variables. In this sense, we intended to fulfil the following objectives:

1. Compilation of questionnaire on EV/HEV noise
2. Pre-test with a sample of German students
3. Compilation of final version of questionnaire based on feedback/data of pretest
4. Make questionnaire available online (appropriate server, privacy, data handling)
5. Start of data collection (dissemination of link within COST/EU level)
6. Descriptive analysis of data for COST Action

As discussed above, the main objective was to design a SEM and to collect information on the variables involved by means of a questionnaire. Following the proper literature review, we designed the model proposed in Figure 1.

The variables included in the model are:

- Attitudes toward car noise/vibration
- Risk evaluation
- ECO Attitude
- Intention to use
- Intention to purchase



**Fig. 1.** Customer expectations hypothesized model

Once the model was designed, we collected the questionnaires related to the variables that could be considered interesting for analysis and we selected the relevant items for our study. Furthermore, through several meetings with the staff of the Professorship of Cognitive & Engineering Psychology at Technische Universität of Chemnitz, we designed new items based on the existing literature.

The selected items were grouped according to the variables in the model and loaded onto the LimeSurvey website hosted at the University to ensure data confidentiality and storage safety. We displayed the questionnaire online to facilitate the data collection.

## 1A.2 Pre-study on EV/HEV noise

After completing the item loading and server setup, we performed several tests to verify the adequate functioning of the items, thanks to which several errors were corrected. Once we finished the questionnaire and evaluated its function, we sent a mass mailing to all the students enrolled in psychology studies both at the Technische Universität of Chemnitz (Germany) and at the Miguel Hernández University in Elche (Spain) to begin the data collection. Similarly, we used on-site lessons to discuss the research and to request collaboration.

### 1A.2.a Sample

Initially, 177 datasets were obtained. However, after filtering and selecting the valid data, 128 remain at the time of writing out this report. The obtained sample is comprised of 23.4% female and 76.6% male subjects, the majority of which are Spanish (66.4%) and German (18.8%) nationals, although other nationalities are also present, such as British, Colombian, Greek or Thai (Table 1). The majority of the sample has less than 24 years old (65.5%) and are mainly students (83.6%).

Table 1. Nationality

	Freq.
Argentinian	1
British	12
Colombian	1
Estonian	1
German	24
Greek	1
Hungarian	1
Portuguese	1
Spanish	85
Thai	1
Total	128

Regarding the type of vehicle regularly used, more than half of the sample (54.7%) uses a combustion engine vehicle practically every day, besides public transport on a daily basis (14.8%). The majority of subjects state that they do not use electric or hybrid vehicles (EV/HEV) as a regular form of transport.

## 1A.2.b Results

### Attitudes toward car noise

The most representative results from the section on “attitudes toward car noise” show that a majority of subjects (83.6%) agree with the main idea behind this survey, in which the issue of noise inside the vehicle while driving is considered to be an important aspect (Figure 2).

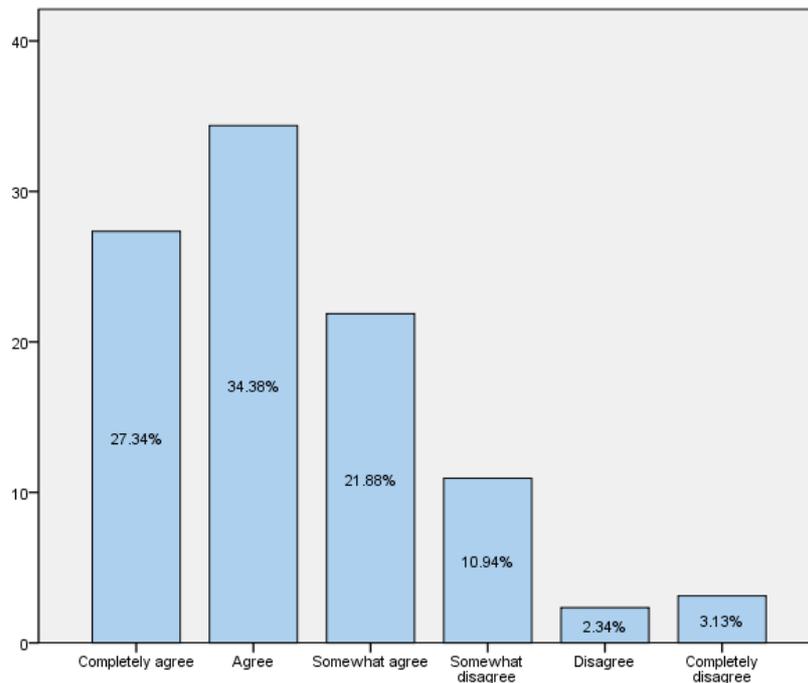


Fig. 2. Item “I think the noise inside the vehicle is an important matter while driving”

In line with these results, the majority of sample subjects (51.6%) prefer not to hear any engine noise while driving and feel uncomfortable when hearing any background mechanical noises such as gear-shift (57%). Concerning vibrations, the majority of subjects report feeling uncomfortable when they are produced during travel (60.9%). Furthermore, users seem to be comfortable in any way with some noise if it is produced while driving (65.7%). In terms of quality, the noise of the engine is associated with performance (64.8%). When asked directly about the comfort of electric vehicles that produce no engine noise during driving, most subjects agree with such claim (62.5%). However, they do express that they need some sort of engine noise—even if only on a slight level—for a more comfortable drive (59.4%), besides acoustic feedback to estimate the speed of the vehicle (67.9%). The aspect of noise

inside the passenger compartment during driving must be specified precisely in order to identify the exact criteria employed by users when referring to comfort. This is because subjects prefer not to listen to any noise from the engine, although they do not enjoy driving in a total absence of noise either, as we have already seen.

The idea that people could benefit from silent vehicles (55.5%) and that modern cars should be as silent as possible (58.7%) is in direct confrontation with the majority's perception that pedestrians need to be able to detect noises from vehicles (82.8%).

As for the type of noise modern vehicles should produce, the sample is not in favour of a "futuristic" noise (58.6%) or a noise resembling a "mobile telephone" (68.7%). They consider it important to take interest in the engine noise produced by their vehicles (69.6%). They also pay attention to every noise produced inside their cars (82%), whether normal engine vibrations (82.8%) or strange (96.2%) or irregular noises (93.8%).

Another of the ideas underlying this survey is that subjects place value on the silent character of electric vehicles, even to the extent of regarding it pleasurable (72.7%). They also point out that such a characteristic would contribute to the quality of life in urban areas (86.7%). Regarding the quality of vehicles, silent vehicles are perceived as having a greater technical quality than noisy ones (75.7%).

### **Intention to use & purchase**

The majority of subjects would recommend an EV to their best friend (66.5%) but do not consider buying a vehicle within the next year (86%). On the other hand, when asked about their purchase intention during the next 7 years, the percentage of subjects that consider making a purchase increases significantly (53.1%). The same result is obtained when asking the subjects if they are sure that they will be driving an EV next year; the majority believe that they will not (86.8%) although 45.4% believe that they will within the next 7 years. Despite their long-term intentions, the majority of subjects when asked believe that their next car will not be an EV (76.5%).

### **General attitudes toward EV & risk evaluation**

The majority believe that EV are the solution to the problems of air pollution (88.2%), that they play a major role within our transport systems (87.6%) and are the means of transport of the future (83.6%). Despite this evaluation, when it comes to weighing out the hazard potential of an EV due to its low level of noise emission, the majority believe that such a characteristic might be dangerous for traffic (57%) although it would not entail an excessive hazard (54.8%). In general terms, the majority describe EV as appropriate vehicles for daily use (81.3%), providing a pleasant driving experience (72.7%).

### 1A.3 Discussion

The present research aimed to design a SEM model to contribute to the theoretical background about the customer perception regarding NVH of EV/HEV. In this context a questionnaire was built to analyse the customer's expectation and attitudes towards car noise and its relevance in their behaviour as users and potential buyers. According to previous research, our results support the idea that the noise and vibration emission of the EV/HEV is an issue of concern for both drivers and pedestrians [2] that could influence their use and purchase behavior.

Results of the questionnaire also revealed that car drivers use the engine noise as a reference of a proper functioning of the vehicle and as a potential indicator of a breakdown. If noise occurs during driving accompanied by vibrations, users perceive that as uncomfortable. These findings are in line with studies by for instance Parizet et al. [3] who found interesting interactions between vibrations and noise while driving through a simulation, underlining the impact of vibrations on driver comfort. Our results additionally reveal that drivers mainly prefer a noiseless ambient while driving without becoming a total noise-free situation. Consequently wide and individual noise definitions are necessary to be pursued in future research. Although the majority of people who have participated in this study think silent vehicles are better than noisy ones, pedestrians require some type of sound to detect vehicles and avoid accidents. Blind road users in particular rely on auditory cues when navigating in traffic [4] and seem to be at higher risk. As HEV/EV are more difficult to detect at low speeds [5, 6], concerns have been raised about the safety of blind pedestrians [7]. Acoustic Vehicle Alerting Systems (AVAS) alerting bicyclists and pedestrians might be a viable option, although one could argue in accordance with Sandberg [8] that safety improvements could be evened out following an inadequate sense of safety among road users.

Regarding the consumer's intent to purchase an EV/HEV, our results suggest that age and economic status might determine the purchase behavior since these vehicles are considered an expensive acquisition. Considering that the validation of the questionnaire is still ongoing and due to the small sample size of this study, our results should be considered with caution and should be regarded as a first step to better understand the relevance of NVH issues for the customer perceptions of EV/HEV technology. Similar to other studies [9, 10] price is one of the main barriers to acquire an EV/HEV. Other variables such as range could also be an important factor to determine whether this kind of vehicle is selected for example as a main car or as a second one, as Skippon and Garwood pinpointed [11].

Concluding it can be stated that the creation of a SEM model and the collection of questionnaire data provide a useful basis for a better understanding how potential

customers evaluate NVH issues of EV/HEV. Nevertheless, due to the small size and the limited representativeness of the sample the obtained results need to be validated. This is the next step in our approach to address the issue.

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## *Annex 1B*

### **Adoption of electric vehicles and impacts on noise, energy consumption and air pollution – a review from Portugal**

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**Abstract.** Electric vehicles (EV) and Plug-In Hybrid Electric vehicles (PHEV) are considered one of the possible contributors for the development of an urban sustainable environment. By increasing the penetration of these alternative technologies, a huge potential for reducing air pollution and GHG emissions from road transportation appears and, additionally, at low speeds these alternative technologies also present lower noise impacts. This paper includes an analysis of the emission trends, both in Portugal and in EU, regarding noise, air pollution and GHG emissions in the transportation sector. The main purpose of this paper is to present an overview of several case studies performed in Portugal, focusing not only on the assessment of EV and PHEV acceptance and adoption by consumers, but also on the expected environmental impacts in terms of energy consumption and emissions, at a local level, considering several penetration scenarios and their application in logistic operations. Results from interviews conducted with a group of early-adopters indicate that lower energy and running costs, higher comfort and reduced environmental impacts are considered the main advantages of EV. An easy adaptation to the vehicle was observed, although some concerns still persist regarding the vehicle autonomy and also about safety of pedestrians, related with the absence of noise emitted by the vehicles.

#### **1B.1 Introduction**

According to the UN Department of Economic and Social Affairs [1], the number of persons living in urban areas increased significantly in the last decades, and reached approximately 54% of the world's population in 2014. As one can see in Fig. 1, in Europe and in 2014, about 73% of the population was located in urban areas. That number is expected to increase to 82% by 2050. In what concerns Portugal, the percentage of urban population is about 63% and projected to grow to 77% by 2050. These numbers highlight the importance of environmental parameters related with health and well-being, namely, air and water pollution, climate change and noise.

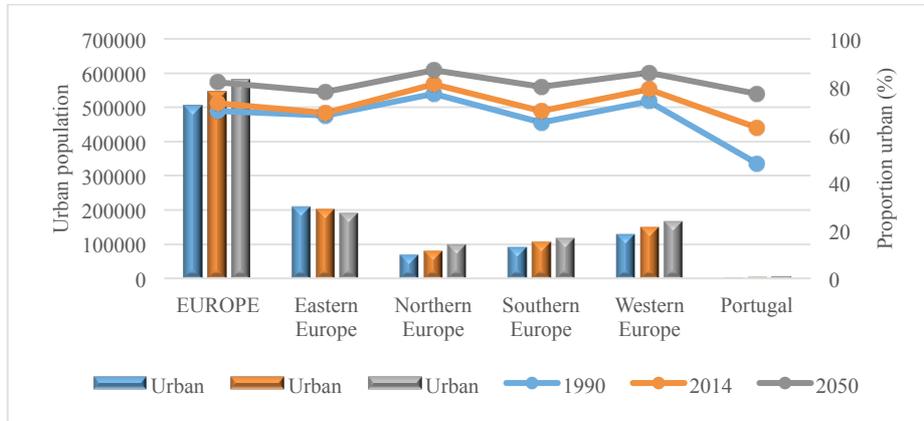


Fig. 1 - Urban population and percentage of urban population in Europe, adapted from [1]

With the approval of the first environmental code (Law 11/87, 7th April), there was the responsibility to issue, every year, a report with the environment status and concerns named as "SoER - State of the Environment Report", whose intention is to disseminate environmental information to the public. In 2006 a national survey was conducted regarding the relevance of SoER and the contents, in which respondents could identify the most relevant environmental problems. According to their opinion, the reported environmental issues also highlighted air pollution, climate change and noise, respectively with 33%, 28% and 11% [2].

These topics are even more important as the number of road vehicles has increased since 2010, both in Europe and in Portugal. Consequently, the average vehicles age is also growing, with more than 60% of the Portuguese passenger vehicle fleet over 10 years of age [3], older than the average in Europe with less than 50% of the passenger vehicles older than 10 years [4].

In fact, older vehicles have significant impacts, with an increase in energy consumption (mostly fossil fuels) and higher local pollutants emission levels. As stated, in 2012, by the WHO's International Agency for Research on Cancer [5], air pollution derived from diesel engines exhaust was proven to be a definite cause of cancer. This concern supports the awareness, motivation and change of attitudes of the population regarding responsible transport choices, as risks from road transport emissions are now better acknowledged. A research project from Staffordshire University [6] identified three key milestones to major changes in public attitudes: (1) "demarketing" campaigns intended to demonstrate that some behaviours are socially and culturally unacceptable; (2) announcements by relevant medical groups, highlighting the negative effects of those actions; (3) demonstration that a large number of communities already implemented the desired measures/actions [7].

The characteristics of vehicles in circulation (number, type and age) have repercussions in our cities and it is often acknowledged that many cities implement extreme measures to reduce them, namely, permanently closing streets to traffic, constraining traffic circulation - by day or by period of time, creating low or ultra-low

emission zones (LEZ/ULEZ), increasing green areas and the number of trees, or adopting new noise mitigation measures.

Another possibility is the shift to more sustainable technologies. In this context, a number of countries, such as the United Kingdom [8], the United States of America [9], France and China [10] have developed strategic plans concerning the adoption of alternative vehicles in their countries, focused primarily on consumer characterization and their preferences towards these vehicles and on the impact on mobility patterns. Portugal also promoted a strong investment in electric mobility, namely with the launch of the Electric Mobility Plan [11], which included the deployment of a public recharging infrastructure, with 1,300 slow and 50 fast public recharging points available across the country.

As a result, manufacturers have been investing in promoting and introducing these alternative technology vehicles in their fleets [12] and a small group of early adopters has already embraced them. Nonetheless, mass commercialization is far from happening. Consequently, in the near future, the market share of already established technologies such as hybrid electric vehicles will most likely raise and, in the long term future, the market share of alternative vehicle technologies such as PHEV and EV among others will start to rise.

In fact, according to the European Automobile Manufacturers Association (ACEA), a total of 415 896 of alternative fuel vehicles (AFV) were registered in the EU (23 countries) in the first three quarters of 2015, in a total of 10 409 776 passenger vehicles, which corresponds to a 4% share in the new vehicle sales in this period [13].

In this line of thought, the presence of alternative vehicle technologies, such as EV and PHEV is a relevant and an essential contributor to a more sustainable future. These technologies present much higher efficiency performance, eliminate air pollutant emissions from the Tank-to-wheel stage [14], [15] and also emit less noise, which is very relevant in an urban context and an essential contributor for a more sustainable future.

## **1B.2 Noise, air pollution and climate change in Portugal: evolution concerning road transportation**

The approval of the Portuguese constitution in 1975 stated the right to well-being and a healthy environment and the responsibility of the government to provide those conditions. In particular, after joining the European Union in 1986, Portugal has shown an increasing concern with respect to the environment and approved multiple legal documents, in order to regulate activities with impacts on the environment and to establish limits for diverse environmental parameters, including noise and air pollution (emissions and quality) and, as mentioned previously, started to annually report the state of the Portuguese environment.

Regarding noise, in Fig. 2, one can see the percentage of the population that has complaints about noise since 2010. The urban population is represented on the left, and the graph on the right refers to the population of the entire country. It is possible to observe that about 1/3 of the urban population and about 20% of the total

population are consistently disturbed over the years by the existence of noise emission. In Portugal, the percentage of annoyed persons has always been higher than the European average.

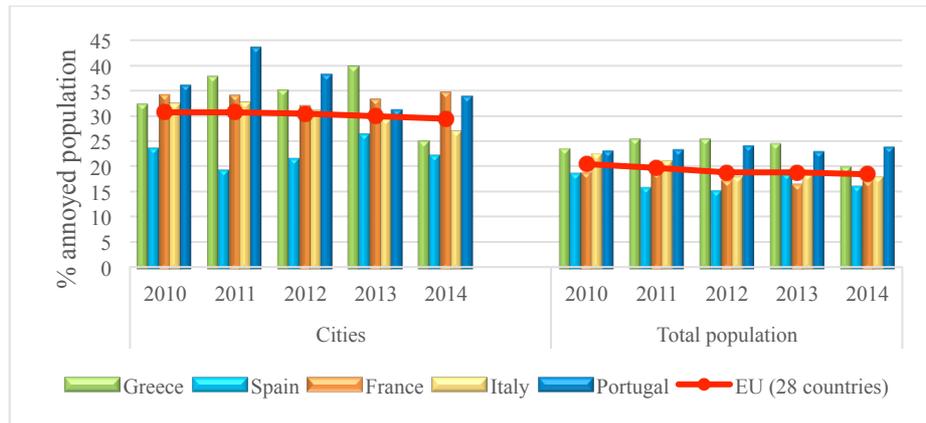


Fig. 2 - Percentage of the population complaining about noise from neighbours or from the street (source: SILC), including degree of urbanization [16], [17]

The regularity in these figures reveals not only a rising concern of the population, but is also related with the movement of the population into the cities, as previously mentioned, together with the increasing number of vehicles in circulation. In spite of noise mitigation measures to protect urban areas (low noise pavements, noise barriers, reduced speed zones, etc.) and the reduction of noise emission from vehicles, the percentage of annoyed population did not decrease. In fact, according to the latest report from the Portuguese Environmental Agency (APA) [18], the number of persons exposed to high noise levels from major transport infrastructures (above 55 dB(A) and not considering Lisbon) represents, approximately, 8% of the Portuguese population, of which 6% derive from road infrastructures. Referring, exclusively, to major urban areas and agglomerations, the same study indicated that 69% and 54% of the urban population, respectively in Lisbon and in EU, is exposed to noise levels over 55 dB(A). Considering all sources of environmental noise in presence, it was concluded that road traffic was responsible for 42% of the excessive noise levels in Lisbon and about 46% for European agglomerations.

According to Haling and Cohen, cited in [15], for velocities exceeding 40 km/h, the noise emitted by EV and PHEV (when in fully electric mode) is marginal when compared to all vehicle noise sources (like noise from tires and from aerodynamic shape of the vehicles). In fact, it is only at low speeds and low traffic densities that it is possible to detect higher perception of this type of noise, mostly in the night-time period, as during the day and regular traffic conditions EV and internal combustion engine vehicles (ICEV) do not differ. As a result, electric mobility appears as a new possibility in noise mitigation in city context.

With respect to air pollution, since 2005, in most European countries the concentration of particulate matter (PM) has decreased [19]. In the EU, the average concentration decreased from  $28.1 \mu\text{g}/\text{m}^3$  in 2005 to  $24.9 \mu\text{g}/\text{m}^3$  in 2012. In general terms, EU Member States deployed measures to decrease the exposure to PM by reducing the proportion of diesel vehicles in urban areas, lowering the average age of the passenger vehicle fleet, diversifying energy sources (especially for heating) and setting up policies at country level to reduce exposure.

In Portugal, this decline was even more significant, as it is possible to observe in Fig. 3, in 2005 the concentration reached  $32.5 \mu\text{g}/\text{m}^3$  and about  $24 \mu\text{g}/\text{m}^3$  in 2012. In the case of Portugal, the reason for these decreases was not exactly the same as the ones observed in Europe. In Portugal, the most relevant direct sources of PM emissions are the combustion of biomass by the household sector and the emissions from road vehicles, by their impact on urban areas [20]. Regarding PM, the annual threshold has been fulfilled but, regarding the daily limit value, the exceedances persisted and were detected primarily at traffic stations (44% in 2012), followed by urban and suburban background (33% in 2012) and, finally, the stations of industrial influence (22% in 2012). Despite its importance, the contribution of transport to the global PM emissions has been significantly reduced not only by the efficiency of new vehicles, with lower energy consumption (including hybrid vehicles), but also due to the adoption of the EURO 6 standards, which involved the introduction of end of line technologies that can reduce direct emissions from vehicles exhausts (eg, particulate filter and EGR systems - recirculation of exhaust gases).

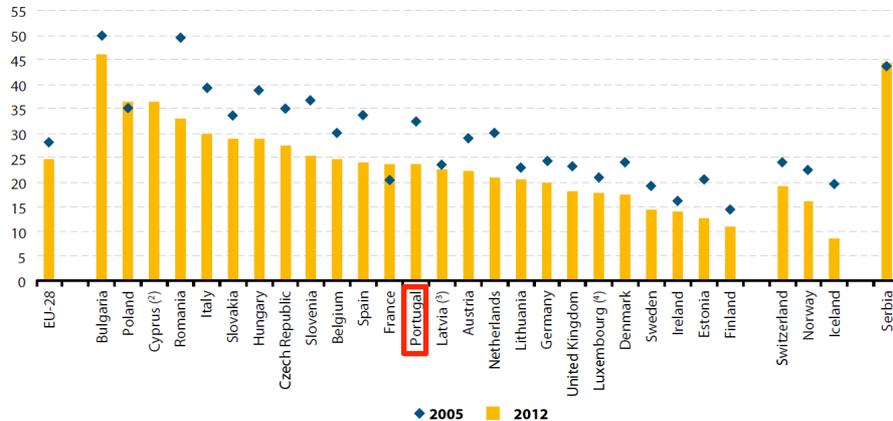


Fig. 3 - Percentage of urban population exposed to air pollution, by particulate matter, by country in 2005 and 2012 (micrograms per cubic meter) [19]

Concerning air pollution and climate change, the use of fossil fuels conveys large environmental costs as it is responsible for contributing massively to GHG emissions. In 2013, the transportation sector was responsible for 32% and 40% of the final energy consumption, respectively in Europe and in Portugal [21]. In Portugal, this indicator has decreased by 12.6% between 2010 and 2013. In Europe, road

transportation is the leading contributor to energy consumption and CO<sub>2</sub> emissions, responsible in 2013 for 82% of the sector's energy consumption and about 94% of the sector's CO<sub>2</sub> emissions. Portugal presents a similar trend, with the road transportation sector being responsible for 81% and 96% of the sectors' energy consumption and CO<sub>2</sub> in Portugal's road transportation emissions [22].

### **1B.3 Electric vehicle adoption in Portugal**

Electric vehicles seem to have many advantages to make them one important vehicle technology of the future [23], [10]. However, there are also a number of drawbacks, which users will have to take into consideration and, therefore, will require the need to make complex and balanced assessments when deciding to purchase an EV and PHEV.

Across early adopter's countries and consumers with stated intent to purchase electric vehicles there are some common social demographic characteristics. According to recent studies by Carley [23] and Hjorthol ([24], users are mainly between ages 30 and 50, highly educated, with high incomes, environmentally sensitive, belonging to households with more than one car, and living in or in the vicinities of large cities. In Portugal, the results from an on-line survey, performed to assess willingness to adopt PHEV, are in line with those social demographic characteristics and indicated higher EV and PHEV purchase probabilities for those who did not own a vehicle. Respondents were more aware of the existence of pure electric vehicles with little knowledge of PHEV, however after a brief explanation of the technology preference to acquire PHEV surpassed the EV, due its extended autonomy and fuel flexibility [25].

Another study performed in Lisbon with private EV early adopters revealed that drivers had an average age of 49.2 years and a driving experience of up to 30 years. The fleet users had, on average, the age of 36.7 years and a driving experience of 19.6 years [26]. With the main objective of assessing users' satisfaction and adaptation to fully electric vehicles, early adopters, both private users and business users from the city of Lisbon participated in this study. Portuguese EV early adopters, indicated environmental and economic (energy and running costs) factors as main motives for purchasing an EV. These motives follow the trend already found in other studies in which lifestyle, environmental and economic factors (energy and running costs) stand out as reasons to adopt an EV [23], [27]. In the same study and regarding their charging routines, 92% charged the vehicle at home mainly during the night and only 17% charged during day time. In terms of street charging, only 38% of the users interviewed stated to use street charging points. Private drivers use the vehicle as a replacement for their conventional everyday vehicle, even though they still own at least one ICEV. They use the EV for commuting and running errands, mainly in urban contexts. Besides referring to environmental factors as the main motive influencing the companies' decision to acquire an EV, fleet users from Portuguese companies also mentioned the positive image as a motive to adopt an EV. Portuguese fleet users stated they didn't charge the vehicle after using it (42%). If they charged the vehicle, they did it in the vicinity of their workplace, but this was usually done by

drivers who used the vehicles several days a week, and 25% also charged on the street. Concerning the vehicle's disadvantages, both private and fleet users considered the vehicle's autonomy as its main drawback (77% and 83%, respectively). The charging infrastructure was also considered a negative aspect by both private (15%) and fleet (25%) users. Fleet users mentioned the vehicle's acquisition cost as a disadvantage (33%), but only 15% of private users mentioned this aspect. Some of the fleet users (17%) mentioned the absence of vehicle noise as a disadvantage of the EV, while none of the private users mentioned this aspect [23], [10], [28], [29], [24]. Autonomy stood out as the main concern for both private and fleet drivers when driving the EV, at 85% and 50%, respectively. Concerns for pedestrians, safety and speed were also mentioned but with less emphasis.

The assessment of the energy and environmental impact of the technology was undertaken using a Life Cycle Assessment (LCA) approach, considering a Well-to-Wheel (WTW) analysis. This approach includes: the Tank-to-Wheel stage (TTW), referring to fuel consumption and emissions resulting from moving the vehicle during the driving cycle and; the Well-to-Tank (WTT) stage which accounts for the fuel production [30]. For this, private drivers filled a daily report diary collecting data such as, day of the month, number of daily trips, km travelled and energy recharged (kWh) per day. Mobility patterns revealed that users made an average of 3.5 trips and travelled an average of 40 km per day [26]. These findings are consistent with those found in the study developed in California with NEV adopters [27].

The performed LCA analysis indicated that EV represent considerable reductions both in energy consumption and in CO<sub>2</sub> emissions (35–43% and 58–63% respectively), when compared to conventional vehicle alternatives run by gasoline or diesel. The results follow the trend found in other research findings that also indicate CO<sub>2</sub> emission reductions in urban contexts [14].

## **1B.4 Impacts of adopting electric mobility in Portugal**

When assessing the impacts of electric mobility, it is important to consider the energy shifts associated to this alternative. A study performed for the Portuguese fleet, presenting a full life cycle vehicle technologies and energy pathways analysis, concluded that vehicles powered with hydrogen and electricity present considerable lower Well-to-Wheel (WTW) results in both energy consumption and CO<sub>2</sub> emissions. However, when considering only the Well-to-Tank (WTT), both alternative technologies show higher values than those of gasoline and diesel [30]. Another study evaluating future energy consumption and emission scenarios for the Portuguese road transportation sector reveals that the introduction of alternative vehicle technologies can lead, in the long-term (2050), to energy consumption reductions between 2% and 66% and between 7% and 73% for CO<sub>2</sub> emissions. However, in the short-term, it is essential to focus not only on the challenges and opportunities of each technology but also on the development of taxations and policies to promote public transportation use [31]. Penetration scenarios of PHEV and EV reveal that by 2020 the introduction of these technologies will still be scarce. By 2030, a limited impact on CO<sub>2</sub> emissions is expected to be observed [32]. Although EV present lower lifecycle CO<sub>2</sub> emissions,

this difference will depend on the carbon intensity of marginal electricity production used to charge the vehicles [33]. As a result, it is necessary to ensure that the demand for electricity that will come from penetration of EV in fleets will be met by electricity of renewable sources [32].

When looking in more detail into the main obstacles for the widespread dissemination of EV, the cost attribute leads the list, particularly in what concerns the purchase and battery cost [34]. In the niche market of urban logistics EV introduction have started to appear and are described in the most recent literature on the topic [35], [36], [37]

A comparison of the conventional vehicles (ICEV) with electric vehicles for urban goods delivery in Lisbon was carried out by Melo, Baptista & Costa [34]. The study focused on the particular potential of replacing conventional vans with small-size electric vehicles (SEV) on city logistics operations. In their calculations the authors included the private stakeholders' interests, which are related to operation costs levels (running and driving costs), service levels, and efficiency. Simultaneously, its balance with public interests, related with sustainability, quality of life, mobility, and environmental issues were also addressed. The study compared four scenarios of 5%, 10%, 30%, and 70% of SEV replacing diesel vans used in transport and unloading operations. The four scenarios were tested on different geographical scales: street and city levels. Authors estimated how the use of SEV in city logistics affected traffic, energy consumption, and emissions. The respective operating and external costs were quantified and the acquisition and battery issues are discussed. Results from the study revealed that the replacement rate SEV/van is determinant to make a decision on whether or not to use SEV replacing vans. This is to say that if the electric vehicle replacing the conventional one is able to assure the same delivery capacity, SEV are economically competitive. If not, it is economically better to keep the conventional fleet. Moreover, when analysing the effects of such replacement in terms of local impact, SEV have a better performance at the street level rather than at the city level, due to its physical dimension. SEV can be used within normal road traffic merely as a niche of market (replacing less than 5% of conventional fleet vehicles). Under such context, the study reveals that SEV benefits exist, but they are not significant enough to drive suppliers for their adoption.

The same conclusion is pointed out by Ahani [38] who estimates through modelling when suppliers should sell their conventional vehicles to replace their fleet with EV. Results from this study also reveal the market is not ready yet for a widespread penetration of electric vehicles. An identical inference is obtained by [39] who assessed how these replacements could occur in passenger transport. The authors concluded that the fleet operator from a car sharing system would take 8 years to economically achieve its break-even point. Such time span is obviously neither acceptable nor desirable from a decision maker's point of view. Public incentives, particularly through the replacement of public administration own fleets, can help to deploy this technology and overcome the initial opposition from suppliers and private users.

## 1B.5 Conclusions

The transportation sector has a direct causal relation with energy and environmental impacts. Therefore, it is crucial to explore the potential of alternative vehicle technologies to substantially reduce some of the negative burdens of the transportation sector. In spite of the higher purchase cost associated with alternative technologies which hinders its fast adoption, electric mobility may greatly contribute to energy efficiency improvements and delocalization of local pollutants emissions. Electric mobility also raises important challenges in the field of noise, since, at low velocity, it is a silent technology, and, as so, it may raise safety issues that have to be tackled to achieve a widespread adoption of this technology.

In terms of alternative vehicles adoption, the studies performed in Portugal reveal that even though people are aware of the existence of electric vehicles, there may not be a complete knowledge on the several types of technologies available. So, there is a need for more awareness campaigns, incentivizing not only the adoption of such technologies, but also promoting the different types of alternative vehicles coming onto the market and explaining how they are suited for one's mobility demands.

It is also important to acknowledge the driver mobility patterns when adopting these technologies, since PHEV might be a better solution over EV if the driver needs to drive long-distances daily and in highway context. Regarding early adopters, their socio-demographic characteristics are similar to the ones found in other studies. Participants were relatively young, highly educated, environmentally aware and living mainly in urban contexts. Drivers adapted easily to the vehicle, stating that EV main advantages over conventional technology include its lower energy and running costs, comfort and environmental factors. However, drivers also mentioned other concerns related not only to the vehicle's range, but also to safety issues mainly connected with pedestrians. Such concerns are a consequence of the absence of noise emitted by the vehicle, since pedestrians might not be aware of the vehicle approaching.

Considering that alternative technologies may contribute considerably to the decrease of noise levels at low speeds, the issue of safety due to lack of noise emission must be addressed. The fact is that drivers and, consequently, pedestrians will need to adopt new safety procedures and behaviours, in the near future, or an advisory technology should be developed and included in new versions of the existing and future models to overcome this issue. As such, adoption campaigns should be also supported with educational programs designed taking into consideration safety procedures not only for the drivers but also for pedestrians.

Even though early adopters consider these types of vehicles as the car of the future, and that the market is rising in Portugal, they also emphasize the need for more purchase incentives. These can be related not only to financial issues but also to circulation measures, promoting the circulation of EV in dedicated lanes and parking infrastructures or in conventional vehicles restricted areas.

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## *Annex 1C*

# **Users' decision to buy HEV and EV – results from the Czech Republic**

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**Abstract.** The present study deals with the attitudes of people in the Czech Republic towards electric vehicles. Research was carried out in the form of an ad hoc questionnaire, which was filled out by 245 persons aged 17-81 years from all over the Czech Republic. The results show that for most respondents the acquisition of electric vehicles is not conceivable. The most common reason is the cost. Other reasons are the small number of charging stations, a small boot, and limited range. The results also show no statistically significant differences between men and women in their respective attitudes towards electric vehicles in general. The exception is the attitude to the fact that electric vehicles are environmentally friendly and the issue of purchase price. Women are less likely than men to perceive the cost of electric vehicles as excessive. At the same time, women (unlike men) consider electric vehicles much more environmentally friendly.

### **1C.1 Introduction**

Recently, several surveys have been carried out in the EU to collect feedback on electric vehicles from potential consumers, test drivers' familiarity with electric vehicles, and investigate their interest in purchasing an electric vehicle, as well as inquiring about their priorities for improving the features of current electric vehicles [1, 5]. In the Czech Republic a survey on attitudes towards electric vehicles for small, medium, and large enterprises was included in the "Elektromobil Prague" project. The results indicate that up to 70% of all the respondents (Prague companies of different sizes) were considering purchasing an electric vehicle within the next five years (by 2016) and up to 30% of them stated that they would do it. More than half of the companies included in the survey had their own fleet of over 10 vehicles and a quarter more than 500 vehicles [6].

### **1C.2 Method**

Rather than companies, our research focuses on individual residents of the Czech Republic. The questionnaire was distributed via a link on social networks and the presentation of links to websites dealing with transport-related issues. In order to ensure the recruitment of subjects older than 50 years, the questionnaire was

distributed among this population group personally. It took an average of 20 minutes to fill out the anonymous questionnaire. The respondents were asked specific questions with the option of ticking the answers within the following range: “Definitely yes”, “Probably yes”, “Probably not”, “Definitely not”, and “I do not know”.

The initial sample was composed of 271 individuals, but 26 participants were excluded from the analysis because of data loss. Finally, we were working with 245 persons surveyed (134 women and 111 men). All the participants were aged 17-81. The research sample comprised 128 persons who were employed, 40 persons on parental leave, 29 entrepreneurs, 28 students, 13 pensioners, and six unemployed. Three respondents did not specify their economic status. The sample came from the entire country – from all 13 regions. The representation of individual regions, however, was uneven. The largest group of people (84) lived in the South Moravia region and the city of Prague was represented by 36 persons. 90% of the respondents had a driving licence.

In the data analysis, we worked with raw scores generated by the respondents’ answers on the scale. With the exception of gender, the research sample was unevenly represented relative to the population. First, we conducted a simple analysis of the frequency-response range of the answers. Because of the uneven distribution of the sample, we also worked with a non-parametric test. To determine the difference in the variables between the groups, we used the Mann-Whitney U test for independent samples, because of the failure to achieve the above normal distribution of the variables in the research sample. Seeking to further explore the size differences between the variances, we also investigated Cohen's  $d$  and  $r$  as effect sizes.

### 1C.3 Results

When the respondents were asked what they knew about electric vehicles, their answers mostly related to three topics: environmentally friendly, run on electricity, and costly. There were also answers that electric vehicles take a long time to charge for a relatively short trip. The opinions about these points could be summarised as follows. All but two of the subjects considered electric vehicles expensive. The topic concerning the costs of electric vehicles is also related to the fact that only 12% of the respondents thought that they could buy an electric vehicle. 70% of the people participating in the survey thought that they would not be able to buy an electric vehicle. The rest of those surveyed currently do not know if they could buy an electric vehicle.

When asked whether the sales of electric vehicles would increase significantly in the next five years, many respondents (40%) answered probably not, but another 28% thought so, perhaps because this question might have been confusing. To the question of whether electric vehicles were safe, the majority of the respondents replied “Definitely yes” or “Probably yes” (61%). 13% of the respondents believed that electric vehicles can be used for travelling long distances. 37% of them believed that their friends could consider them fools for buying an electric vehicle. A total of 73%

of the respondents thought that electric vehicles were environmentally friendly modes of transport. 55% of the people in the research sample were considering purchasing a vehicle within the next five years (not necessarily electric). When asked whether they would choose an electric vehicle when buying a car, 96 (42%) out of the total of 226 respondents answered “Probably not”. Another 73 persons (32%) said that they would definitely not buy an electric vehicle. Only 27 respondents would be willing to purchase an electric vehicle, of whom 21 (9%) chose the “Probably yes” response, and only six (2%) of them would definitely buy this type of vehicle. The remaining 30 respondents did not know whether they would buy an electric vehicle or not. The reasons for not buying an electric vehicle included: the high purchase price of the vehicle (95% of the respondents); the small number of charging stations for electric vehicles (91%); the short range (distance travelled for one charging) – referring to it as a “city car” (85%); the small size of the vehicle (77%); limited battery life (76%); the short driving distance of the vehicle (68%), and the low top speed (30%). The respondents who said that they would not buy an electric vehicle generally provided a combination of several reasons. Multiple reasons for not buying an electric vehicle were given by 60 respondents (25%). Only one reason for not buying an electric vehicle was given by 57 respondents. This was also the only reason given by a total of 32 respondents (13%). 44 respondents (18%) mentioned the purchase price along with another reason. The second most common reason for not buying an electric vehicle was its short range, mentioned in a total of 48 cases (20%). According to the respondents, the third most common problem is the limited number of charging stations, as stated by 23 respondents (9%). In summary, the reasons for considering buying an electric vehicle were: low operating costs (87% of the respondents), environmental friendliness (69%), and low noise (72%); 74% of the respondents would be encouraged to buy an electric vehicle if they could recharge their batteries at home, and 66% of the respondents would purchase an electric vehicle if they were motivated to do so by governmental incentives. Some respondents would also welcome better performance of electric vehicles, simple charging facilities in the vicinity of their home, the possibility of having the vehicle repaired in a standard car repair shop, the availability of spare parts, or the possibility of using an alternative unit in the event of a flat battery. Several respondents stated that they would buy an electric vehicle if it was largely subsidised.

Analysis using the Mann-Whitney U test resulted in differences between the responses of the men and the women. The greatest difference was found in the attitudes of the men and the women to the idea that electric vehicles are environmentally friendly. Women are more likely than men to believe that electric vehicles are significantly more environmentally friendly. Within the sample as a whole, the women reached an average ranking of 142.81 (Mann-Whitney U), with the men reaching an average of 99.09. These differences were demonstrated at the 1% level of significance. Statistically significant gender differences were also evident in the respondents’ attitudes concerning the prices of electric vehicles. Men were significantly more likely than women to consider electric vehicles “very expensive” (Mann-Whitney U – men: average ranking 131.37, women: average ranking 116.06).

## 1C.4 Conclusions

When thinking about the future market for electric vehicles in the Czech Republic, one should see the companies in Prague (the capital) as the target group, rather than individuals or households. Generally, electric vehicles are perceived as costly and as providing less comfort. The environmental issues are of less importance to the general public in the Czech Republic. Surprisingly, women appear to show more friendly attitudes towards electric vehicles than men. As it is usually the men who do the buying, women can consider the issue within a wider context, not ending up preoccupied with the purchase price, seeing it in a slightly more hypothetical way. The low willingness to buy is supported by the fact that there are no subsidies in the Czech Republic and that the purchase cost is compensated for by low operating costs only when such a vehicle is used as a company car (e.g. taxi). As this sample was representative only in terms of gender and people from large cities and with higher education were overrepresented in it, further research is needed to uncover more aspects and to collect valid data from the Czech Republic.

## 1C.5 References

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