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ELECTRIC POWER INDUSTRY

Master's Thesis

THE ROLE OF THE GOVERNMENT AND AUTOMOTIVE INDUSTRY IN ELECTRIC VEHICLE ADOPTION: FRENCH CASE

Author: Jeroen Martens

Supervisor: Prof. Dr. Liang Dapeng

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Permission of the entry of the Master Thesis by the student :

Jeroen Martens

....

THE DIRECTOR

(Write here the name of the Director)

Signiture.: .... Date: ....../ ....../ ......

THE SUPERVISOR

Dr. Liang Dapeng

Signature: .... Date: 2014 / 6 / 6

Approval of the Coordinator of the Master Thesis

(Write here the name of the Coordinator of the Master Thesis)

Signature: .... Date: ....../ ....../ ......

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Executive Summary

In the 21st century much effort has been done on a global level to turn away from our traditional energy sources. A myriad of reports expressed their concerns about the disastrous direction our climate is evolving to. Scientists agree that the environment should be better taken care of and governments and industries have answered the call. A new industrial revolution has been born, in which humanity hopes to satisfy its energy needs while keeping the climate intact. Consequently, green energy has become an established technology that's been used all over the world. Electric vehicles could be the key to success in replacing all of our electricity generation facilities by greener and more sustainable alternatives. If everyone would drive an electric vehicle (EV) there would be (1) no more direct pollution from transport and (2) the electricity storage capacity would be sufficient to comply to the requirements to negate intermittency of green energy. Via the vehicle-to-grid (V2G) technology in combination with solar panels or other micro-scale energy sources the storage capacity of EVs can also serve consumers to actually become suppliers themselves by interconnecting the energy network which would increase the overall efficiency and reliability. Even though EVs have such high potential for societies, the success is highly dependent on the level of penetration. At this point, Norway is the only country that has attained a 1% share of EVs in the total vehicle fleet. In spite of France, the country of focus in this study, having the most advanced EV market within Europe (Scandanavian countries excluded), this study reveals that there is still room for improvement.

The present research aims first of all to unveil which factors influence the EV adoption and analyses the details of their interaction. This raises the following questions: Does a relationship exist between market variables and EV adoption and can these variables be adjusted in order to stimulate the EV sales in order to improve the society? More specifically, the variables that will be considered are:

- Relative price of the EV compared to ICE vehicles
- Relative O&M costs of the EV compared to ICE vehicles
- Electric range of the EV
- Installed charging infrastructure

- Financial support provided by the government
- Share of EVs in the total vehicle fleet

In addition to analyzing the impact of these variables on the sales of EV, this study investigates possibilities to enhance the EV sales and to optimize overhead expenses by the government (or investment by the automotive industry) towards the goal of a higher EV penetration. Not just price, but also range and vehicle efficiency make a difference to consumers. The challenge for car manufacturers lies in decreasing the price while simultaneously increasing the battery strength to obtain a higher range and increasing the efficiency for a lower fuel cost for the user. In addition, government support in the form of subsidies and tax benefits plays a significant role in the EV sales. The automotive industry depends on high production numbers and research in new technologies if it wants to adjust the aforementioned factors . While the auto industry focuses on increasing vehicle features, the government can grant financial support to those who already want to buy an EV. This approach will be beneficial for all parties. Furthermore, the results of this study will show that it is too early to make a proper conclusion on the influence of existing charging infrastructure. Two reasons are the small penetration level of charging facilities so far and the possibility that the range of this study is too short to draw conclusions on the infrastructure. A report of the OECD foresees a large increase in installed charging facilities in the next decennia (Lucchese et al., 2012). Therefore, future research will be able to determine the impact of charging infrastructure on the EV sales. That said, the conclusions of this study are certainly applicable to any country wishing to take pro-EV measures.

Finally, besides the role of the government and the corporate world, the level of acceptance of EVs among consumers is still low. This conclusion has been drawn from previous qualitative studies, and confirmed by quantitative data (Young, 2014). The EV share of the total vehicle fleet proved to be negatively related to EV adoption and the only possible reason is the lack of consumers that are being won over to the EV case. The more EVs sold in the past, the less vehicles are being sold now so the amount of potential buyers does not increase enough to support a continuous growth of the EV market. This research was based on the French case, There are numerous traditional car manufacturers that might benefit from a slower transitioning of the vehicle fleet so they can easier adapt, but even then the fact remains that all parties, including consumers, will have to contribute if we want to take this step to a sustainable future.

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List of used abbreviations

EV	Electric vehicle
ICE	Internal combustion engine
V2G	Vehicle-to-grid
TIR	Third industrial revolution
EVI	Electric Vehicle Initiative
O&M	Operations & maintenance
R&D	Research & development
IEA	International Energy Agency
UCL	Catholic University Leuven
AVEM	Association pour l'avenir du Véhicule Electro-Mobile
CCFA	Comité des Constructeurs Français d'Automobiles
VAT	Value added tax
LPG	Liquefied petroleum gas
CNR	Comité National Routier
OECD	Organisation for Economic Co-operation and Development
UFIP	Union Française des Industries Pétrolières
ACEEE	American Council for an Energy-Efficient Economy

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1. Introduction

In the late 18th century the First Industrial Revolution occurred in the UK. This implied a drastic change in human's everyday lives. From an agrarian economy the world moved to an industrial economy with the development of new manufacturing techniques (machinery) and new materials used in the process. Also the sector of transportation greatly evolved these days. Hardened roads became more of a normality whereas this was something only for important main routes before. An even more important change occurred in the railway sector with the first steam locomotive being invented and the expansion of the railway network. The First Revolution almost unnoticeably transitioned into the Second Industrial Revolution where new energy sources as coal and new uses for steam allowed for more automation which gave a boost to assembly lines and production levels as well as transport. Bicycles were patented in the late 19^{th} century and in the same period the first automobile drove on the streets. Simultaneously, but independently of those events, Rudolf Diesel invented the diesel engine of which originally the use was limited to locomotives and cars wouldn't use this type of engine yet. Most part of the 20^{th} century consisted of expanding the obtained knowledge and applying known technologies in new sectors to create a huge production era.

Recently the Third Industrial Revolution (TIR) has been described for the first time by Jeremy Rifkin, an economic theorist (Rifkin, 2011). Our primary resources, that were introduced on a big scale during the previous Industrial Revolutions, are being depleted at an alarming rate. Business mainly focus on consumption levels and try to sell as much of their products to consumers without looking at the consequences it has for the society and the environment. We will need a big change in our existing consumption model if we want the industries to change their manufacturing processes and if we want to create a sustainable society without the threat of depleted resources or irreversible changes to our climate. One of the main pillars of this so called TIR is the transitioning of our vehicle fleet to new energy vehicles that perfectly meet our need for cleaner, safer and more sustainable transport. Many countries have already acknowledged the big impact of electric vehicles on many aspects of our daily lives. There is a direct impact on pollution levels because of the reduction in exhaust gasses, especially nitrogen and carbon dioxide, and indirectly a higher penetration of EVs in the vehicles market will lead to a lower need of extraction of primary resources for electricity generation. Furthermore EVs offer new opportunities for extra storage capacity and with the V2G technology people can start acting as a distributor as well. On top of that studies show that it allows for a high level of job creation too (Todd et all., 2013). Figure 1.1 gives the cumulative sales of plug-in electric vehicles in the US for the last few years and a similar pattern can be seen in other countries from the Electric Vehicle Initiative (EVI) as shown in Figure 1.2. In 2010 the EV market is still close to being non-existing. But then the sales start to take off at an fast pace. This clearly shows the significant importance of electric vehicles in today's market already and the possibly overwhelming sales in the upcoming years if this pattern continues likewise in the future and set targets will be met.

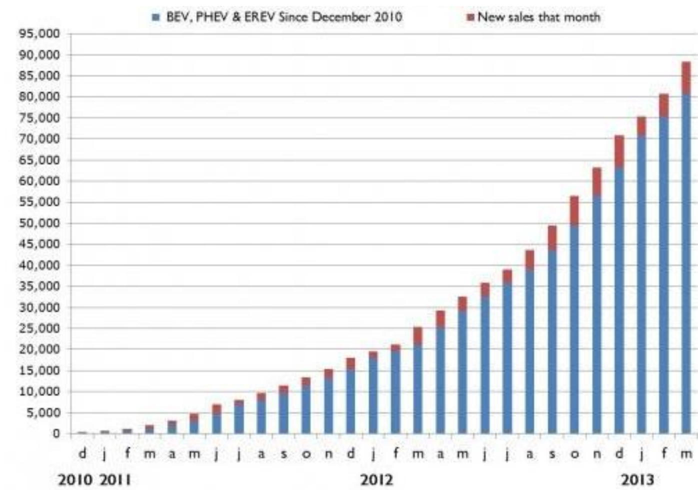

Figure 1.1. Cumulative sales of plug-in EVs in the US for the period 2010-2013
(Source: insideevs.com)

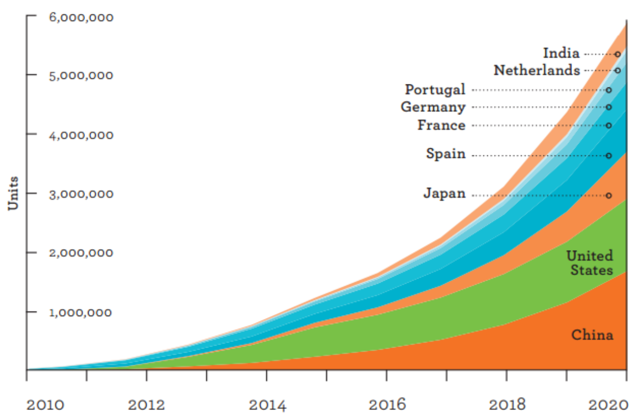

Figure 1.2. EV sales history and targets in EVI member countries
(Source: Trigg & Telleen, 2013)

Hybrids have been circulating in the automotive industry for quite some years already, but full electric cars have still not been completely accepted by the public. With modern technologies available and future expectations in for example battery R&D it is obvious that EVs will only get even more attractive in the future, but there is a lack of awareness among consumers that the technology is already competitive with conventional cars when it comes to the total cost for the user.

With this situation being the current state of art, this research will build an extensive model that takes a quantitative approach to the evolution of electric vehicle adoption based on France. The website of France's Ministry of Foreign Affairs and International Development learns us that firstly, because of implementing some environmental policies regarding emissions and secondly, due to the high amount of renowned French car manufacturers, France was able to become the largest EV market in Europe. Therefore France is deemed to be a good benchmark for other countries who wish to develop their EV market. This research will not focus on the qualitative aspects, but will provide a scheme for government and car businesses as to how they can actively influence the amount of electric vehicles taken off by consumers just by optimizing their investment mix and efforts in the short and medium term. The main quantitative variables that will be picked up to achieve this goal are on the one hand the amount of EVs and on the other hand six main intermediary variables: relative costs of the EV, financial support, range, the existing charging infrastructure, the relative O&M costs and the total amount of EVs on the road. Obviously these variables just mentioned include several smaller aspects that can each be determined by higher entities which gives plenty of possibilities for stimulating the electric vehicle market so there are many parties that would actually take benefit from this study (see Figure 3.1 further in this dissertation). Expectations are that by adjusting their efforts in the right direction and eventually coordinating their actions governments and car businesses can effectuate a positive influence on the EV sales.

The next part will give a concise description of the problem to build up more understanding about the problem and the role of this research to provide an answer to questions that are still unanswered today. In the part after that the data will be discussed and the methodology will be explained and motivated into detail to create a proper base for the study.

Afterwards the results are presented and a discussion that will interpret the results together with limitations and extra ideas for future researchers. In the end a conclusion will be drawn with advice for the target audience that reads this paper.

2. Literature Review

The literature review is divided into two parts. Firstly the most relevant literature has been summarized. Other sources have been used throughout the document, but the papers and articles mentioned in the literature study are what back up the theory this research has been based upon. When it has become clear where this paper can be situated in the academic world the second part with the problem statement will answer the key questions about the topic of this paper and provide structure to the problem. "*A problem well stated is a problem half solved*"[1] so a proper problem statement helps both the author and the reader to create more clarification and allows for a more efficient approach.

1.1. Literature study

Previous literature about the topic in line with the one done in this paper is very limited. No similar study has been done before on the same scale. Probably this is because the market of green transport is relatively new and relatively few data is available that allows for sound conclusions on the topic[2]. Meanwhile there are numerous other studies on the subject of EVs that tackle different issues. An often repeated research is a cost-benefit analysis of EVs compared to conventional cars, based on emissions or based on price. Results always point in the same direction and favor EVs over conventional cars, which makes the existing skepticism towards EVs among consumers even more odd (Kempton & Tomic, 2005), (Van den Bulk, 2009). According to these studies managing a society with a high penetration of EVs poses many difficulties which nevertheless can be easily overcome seen the high benefits of a vehicle fleet transformation. Challenges to implementing the right frameworks should be overcome so that EVs can contribute to green energy deployment, cleaner transportation and grid support (Battistelli et al., 2012). A region that is actively trying to drastically reform their transportation

[1] Quote from Charles Kettering.

[2] As mentioned before this should not stop researchers from studying as many aspects from the market as possible. If they wait another 5 years too many opportunities will have been lost not only for EVs, but also for other technologies that might be integrated into them.

model and pursuing clean goals is Beijing, China. Beijing as a region puts high hopes in electric transport which is shown by the initiatives they are taking: introducing electrical busses, increasing the number of charging stations, granting high subsidies, tax benefits, etc. (Arnd, 2013; Lui, 2012; Wang, 2013). France for its part is nowhere standing out when it comes to EV support and financial incentives. Subsidies are in place but are not above average and R&D expenditures in ICE vehicles have caused their emission levels to decrease so that tax benefits can be more likely ignored with the current tax policies (Mock & Yang, 2013). A study by Tseng (2013) shows that full-electric EVs are currenty not yet competitive with ICE vehicles without tax credits being given by the government. Total costs for hybrid EVs (HEV) are equivalent to those of a combustion engine vehicle. The study shows that gasoline prices also influence the economic profitability of an EV, but to boost affordability tax credits are a sound type of energy policy to make up for the more expensive purchase price of an EV. If this actually influences the adoption of an EV is yet unknown, because even if total costs would be equal, the attitude of potential buyers and many other factors can prevent them from buying an electric car. So the fact that relative costs of EVs compared to ICE vehicles are important is evident. And not just the purchase cost, but the maintenance cost as well. This means that even uncertain variables such as oil prices, and consequently diesel and gasoline prices, have a huge impact on EV sales since it is directly translated into a difference in operating cost (Becker, 2009). It is an important thing to create the right incentives so that people will embrace the technology and will realize the advantages it has for them, not only economically. Beijing is taking several measures towards this goal as can be read in Young (2014), Horwitz (2014) and Gong (2012). These articles explain how giving subsidies is the most direct incentive that's in place at this moment.

Vehicle adoption has been researched previously but only with respect to financial policy instruments (Sierzchula et al., 2014). The study concludes that on top of the financial and socio-economic incentives, also the existing charging infrastructure has a positive impact on EV adoption, but unfortunately their results were not significant enough to conclude that EV adoption rates can be increased by enhancing these factors. Another important source about the economic impact of electric vehicles is the article previously written by Richardson (2012). It does not focus as much on factors that have a direct influence on the adoption of EVs, but more on the benefits of mass adoption, so as to why it is important to develop the EV market. A report from Electric Drive (2014) describes beautifully the current situation of France regarding the development of EVs and puts a lot of emphasis on the future advantages of EVs and why agencies, companies and government should join their efforts to boost the sector.

Considering these existing studies it is clear that this research does have something to add to the academic literature about electric vehicles by showing a direct relationship between macro-economic variables and vehicle adoption. In addition, it might allow the market to be taken out of its theoretical context and put into practice by those parties that can actually influence the market. As described in the TIR model, Governments, car businesses and consumers are not the only winners who will come out of this, but many other markets (e.g. logistics) will also be directly affected and subject to disruptive change when this pillar of the 3rd Industrial Revolution is complete.

2.1. Problem statement

The core objective of this paper is to find a relationship between the adoption of electric vehicles and six main variables. The independent variables are range, installed charging infrastructure, relative purchase price compared to ICE vehicles, relative O&M costs, financial support and the share of EVs in the total vehicle fleet. They will be used to determine the dependent variable, namely the monthly EV sales. On a global level the EV market is a market that attracts a lot of attention and interest from various parties, economically and politically. Since more and more industries become horizontally integrated, electric transport will create an opportunity for a massive amount of businesses to create a disruptive change in their business model. EVs are still a very young concept and much advancement can still be made. However, there are several examples with enough information available that allow researchers or analysts to have a first look at the state of affairs. The next ten years will determine the future of EVs and the scope of their use. That’s why it is important now to know how to stimulate the market in the most optimal way. At the moment several factors are known that influence the sales level of EVs. But existing studies only take into account two variables at most and only seldom reach indisputable conclusions. Therefore this study will try to extend previous works and create a general model that will show how the considered parameters influence the dependent variable. In many cases the parameters can be artificially adjusted by the industry or government, so they can give the market a boost by concentrating their investment on the most relevant areas.

In the end several parties will benefit from an increase in EV adoption: (1) governments to achieve a greener society, (2) the automotive industry to breathe new life in the market and stay competitive when conventional cars become less attractive to the public, (3) other industries that depend on transport and would like to use clean transport to reduce costs or to create a better image towards the outside world and (4) end consumers that do not wish to be dependent on oil prices for their fuel and want to contribute to the environment.

3. Methodology

3.1 General overview

It is interesting to establish links between different events and open up a discussion on how the EV market might grow, but in order to reach objective conclusions it's a necessity to make the right observations and to transform the whole research question into a statistical model. The data has to be interpreted in the right way and should be adjusted so that the model returns the values that we wish to know and that are significant for our conclusion. The aim of this research is to determine to which extent the adoption of electric vehicles depends on quantitative data such as the range of the batteries, installed charging infrastructure and costs of the vehicles. Up until now there are enough studies that stress out (1) the social benefits of EVs or (2) that perform an comparative analysis regarding the costs and (3) optimal deployment studies of charging infrastructure. However, no previous conducted studies assume a direct relation between all of these mentioned variables together. Too often just a single parameter is being analyzed, but literature proves that many correlations exist and the success of the EV market will therefore depend not on just one variable, but on several of them. Many existing studies regarding the infrastructure are also limited to a theoretical framework assuming for example that nothing has been constructed yet and the country can force everyone to build a plug or charging station only at the points indicated by the study (or that they can remove any installation already built to restart from scratch). This study will not take such an abstract approach and will be based on existing data from existing infrastructure and the real market prices to come to conclusions. Ultimately, this paper hopes to create quantifiable values for the existing correlations so that a reliable prediction can be made for France to see whether they are advancing according to the set goal. Concretely this means that there should be 2 million full electric vehicles on the French roads by 2020 as declared in a plan from the Ministry of Ecology and Transport in 2009 (IEA, 2014). The dependent variable will thus be N_{EV}, the increase in the number of EVs in France. This will be the dependent variable because the model is supposed to show whether or not, with the current regulations in place, the EV adoption is high enough to reach this goal and how this eventually can be attained if the existing incentives fall short. On a regular basis new regulations are put in place to correct for earlier mistakes or to give even extra support to the electric vehicle market, but it’s important for governments to evaluate these initiative later on to see if they’d lead to the desirable outcome. The results of this study may be useful during new negotiations to see the impact of the current system and consequently to derive a more optimal investment mix from. Not only that, but the results can also be generalized and any country could use them to optimize their EV support programs.

The amount of EVs, or more precisely, the monthly increase in the amount of EVs, will depend on several factors that are enlisted in the table below. For each variable a short explanation is added that indicates why the variable is significant in the framework of this research. In the third column the source is mentioned that previously conducted a study on this variable with respect to EV sales or proved relevant relationships.

Variable	**Relevance**	**Source**
Quantitative data		
Range	People are sensitive to a possible limited driving range of their vehicle which may be a reason not to buy an EV. Or they might opt a more expensive vehicle that comes with a bigger battery and longer range.	Lieven et al., 2011
Price	Price is the most direct and visible variable for buyers and has also been identified as being the single most significant reason for a slow diffusion of EVs.	IEA, 2011
Charging infrastructure	The availability of charging facilities has been identified as a determinant of people’s acceptance levels for new energy vehicles.	Yeh, 2007 Struben and Sterman, 2008 Egbue and Long, 2012 Tran et al., 2012
Subsidies	Financial incentives from the government can be what a consumer needs to make the final buying decision. Subsidies are directly visible on the purchase price and are therefore maybe not the most efficient for the organizational point of view , but for sure a good way to stimulate consumers to buy an EV.	Sierzchula et al., 2014
Tax benefits	Similar as to subsidies tax benefits are a way for governments to enlighten the financial burden of electric vehicle owners. Many different types of tax benefits are possible which allows governments a whole range of possible measures through this medium.	Tseng, 2013

EV share in total vehicle fleet	The existing vehicle fleet has an influence on the sales in upcoming periods. Seeing more electric vehicles in the streets works like positive advertising and creates more awareness among people about EV benefits.	Sierzchula et al., 2014
Economics growth factors	Economic factors as salary, education and population are positively related with the likelihood of consumers to purchase an EV.	Hidrue et al., 2011
Fuel price	In several studies fuel prices have been identified to be a powerful predictor of hybrid EV adoption which will also affect the full electric vehicle sales.	Diamond, 2009 Beresteanu and Li, 2011 Gallagher and Muehlegger, 2011
Qualitative data		
Convenience for the consumer	Users don't want to experience inconveniences due to driving an EV. This can be related to the range of the vehicle, the charging time, …	Lane and Potter, 2007
Attitude towards EVs & environmental benefit	People might have a positive attitude when it comes to how environmentally friendly an EV is, but more common is the lack of knowledge about recent developments in the EV market and an unawareness that EVs might be sufficient to fulfill their every need.	Egbue and Long, 2012

Table 3.1. Theoretical background of the relevant data in this study

Economic growth factors will probably influence the purchasing power and the qualitative data as well, but since we're not interested in the difference of the EV acceptance levels in different layers of the society, salary and education are being left out of this study. Population will not be implemented as a separate variable in the model, but will be included in the charging infrastructure variable, because here this is considered as an added value. This is explained into detail in part 3.2.3. Convenience for the consumer and attitude of consumers towards EVs are both qualitative data so can not be directly measured. This qualitative data therefore will not be included in the model, but is mentioned anyways, because they might cause omitted variable bias in the final model. Convenience however will mainly depend on the range of the vehicle and on the existing charging infrastructure so this will indirectly be included in the equation already. Attitude of consumers can be indirectly measured by considering the price of government awareness campaigns. This factor will thus be ignored since these campaigns are not well defined and tracking the investment cash flows is quite impossible for external researchers. Environmental benefits has a social aspect to it, which has an impact on the attitude and is not quantifiable. However there's also a direct link between the amount of EVs sold and the pollution levels. This dissertation is not going to question the existing pollution models however, so these additional calculations will be left out of it. Once we know the increase in EVs it's also not difficult anymore to analyze the corresponding decrease in exhaust gases, and possibly non-exhaust gases[3], so this will not be discussed. The fact that this data is not quantifiable or available doesn't mean that they don't influence the sales of EVs, so at least they should be mentioned and this shortcoming should be stated before going more into detail in the model description.

The next figure gives an abstract overview of the research question with all variables, whether directly used in the final equation or not, included. This gives a proper overview of the factors that have an influence and on the importance compared to other factors. Afterwards in the following paragraph there will be a more detailed approach to each of the variables explaining why and how they will contribute to this study.

Legend of Figure 3.1:

- The dependent variable of the model
- Qualitative variables
- The main intermediary variables
- These variables determine the intermediary variables
- Government or industry investment can directly or indirectly influence other variables

[3] Recently a study appeared from the UCL in Belgium that shows that EVs are only slightly better than ICE vehicles when it comes to non-exhaust emissions. Obviously this changes little about the benefit of an EV, but it's an interesting path as well to look whether more improvements can be made on this aspect as well (Van Zeebroeck, 2014).

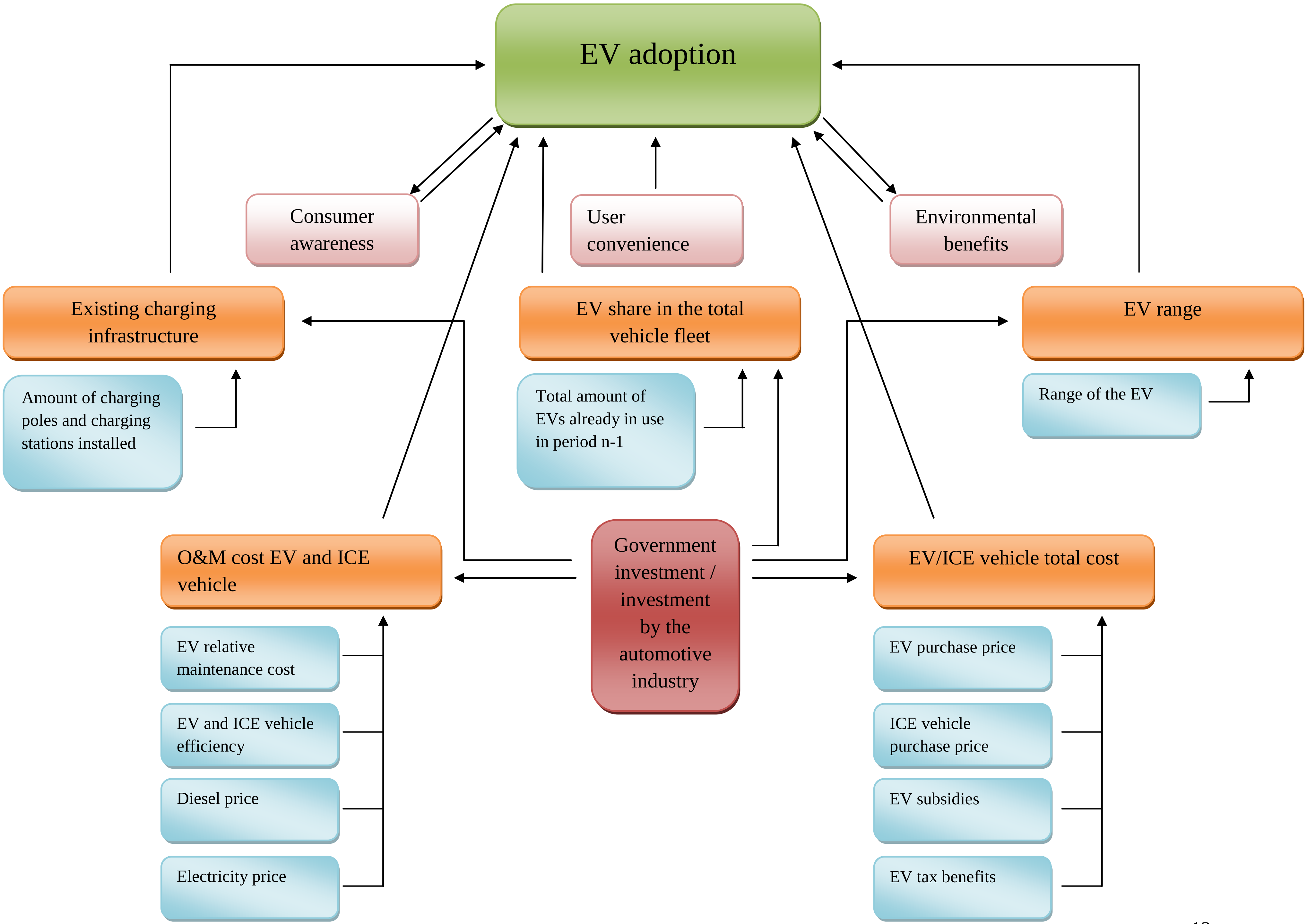

Figure 3.1. Visual approach to the problem statement and the variables with mutual relationships

3.2. Description of the variables

The variables have already been mentioned, but it is important to understand each of them before proceeding. Table 3.2 gives a description of each of the variables with their respective unit and the source where the data has been collected. The main intermediary variables are being displayed in bold, while as their components, if any, are listed below. The same notations as here will be used in the analysis of the results.

Variable	Data	Unit	Source
EV_Sales*	**The monthly EV sales**	**Number**	**AVEM**
ChIn	**Installed charging infrastructure**		
ChIn_Installed	The total amount of plugs and charging stations installed at homes, work and public places	Number	Chargemap.com
$TC_{EV/ICE}$	**Price ratio of EVs compared to ICE vehicles**		
EV_P	Price of an electric vehicle as a weighted average of the six most sold cars for each year	EUR	Car manufacturer websites
ICE_P	Price of an ICE vehicle as a weighted average of the price of the five most sold cars for each year	EUR	Car statistics websites
EV_Ben	**Financial benefits of an EV**		
EV_Subs	One time subsidy for buyers of an electric vehicle at purchase	EUR	AVEM
EV_TaxEx	Yearly tax exemptions of owners of an EV compared to owners of an ICE vehicle	EUR	Car statistics websites
$OC_{EV/ICE}$	**Relative O&M costs of an EV compared with an ICE vehicle**		
EV_MC	Relative maintenance costs of an EV compared with an ICE vehicle	EUR/km	Research by the Institute for Automotive Research (IFA)
ICE_FuelC	Diesel fuel prices	EUR/l	French national government agency
ICE_Eff	Vehicle fuel consumption	l/km	Car statistics websites
EV_FuelC	Price of electricity	EUR/kWh	OECD , Eurostat
EV_Eff	Energy consumption of the battery	kWh/km	Car manufacturer websites

EV_Range	**Average range of the six most used electric vehicles**	**km**	**Car manufacturer websites**
EV_Share	**Amount of EVs in the total vehicle fleet in the previous period**	**percentage**	**AVEM**

* This is the dependent variable.

Table 3.2. Summary of the variables used in this research with their respective sources

The following paragraphs will specify the data set of this dissertation with the necessary explanations, assumptions and transformations to prepare the data for modeling. Globally the data set covers 45 consequent monthly periods (January 2011 – September 2014) for each of the variables. The time scope had to be in months only because electric vehicles are still a modern concept and only recently countries and entities started gathering data about the market structure around them. Not only that, but given the fact that within a year there are seasonal effects on the EV sales as well it would be a false representation to base this study on yearly figures. Before January 2011 there was only a total of 138 registered EVs in France. Then the market slowly took off, which is why older data is not considered representative to draw conclusions from (AVEM, 2011).

3.2.1. Electric range of the EV. The first intermediary variable that will be discussed in the electric range of the vehicle. There are several reasons why this variable is crucial and of high importance. Apart from its quantitative characteristics the range can also be interpreted as a qualitative factor. People will have a different opinion about a vehicle according to the maximum range and this is a qualitative characteristic. This psychological influence will not be discussed here but we'll only pay attention to the numerical values for range. Range is a straightforward variable and will just be included as an absolute number equal to the real value.

$$EV\_Range = absolute\ range\ of\ the\ EV$$

Even then, through reasoning we might agree that range is not a fully independent variable, that is to say that given a certain relationship between range and EV sales, this relationship might be different with another charging infrastructure network available. E.g. if a country has superfast chargers installed all over its territory and people would never have to drive more than two kilometers to the closest charging facility, people wouldn't require such a high range anymore and eventually more and different types of EVs would be sold. This implies that an interaction term between the two might be needed. The same holds with regard to price as well. The most expensive part of an EV is the battery. It's this heavy mechanical part that has the highest cost to be produced and that determines the range of the vehicle. Not just the range but also operational costs (how long until you run out of battery and you have to pay to recharge again) and maintenance cost (mainly the purchase cost for a new battery since currently its lifespan is still only about 8 years and then a new battery has to be purchase which could cost several thousand euro's[4]) depend on the installed battery. Therefore another interaction term might be needed here. These two interaction terms will be included in the Stata model but will not be discussed individually. They do have an impact on the total effect, so they are important nevertheless.

The following figure gives us a small indication already on how the range has evolved in the past years. The range shown for every year is a weighted average of the six most sold EV models in France that actually account for more than 90% of total sales. More details are being provided in Annex A.

[4] At the time of writing an article appeared in the newspapers about a new lithium-ion battery developed by Singaporean researchers of the Nanyang Technology University. This battery is supposed to be charged up to more than 70% in just 2 minutes and also the life cycle should be 10 times the average battery that is currently used. There is still a lack of funding for full-out commercialization, but the project got recognized by international experts already so this will just be a matter of a few years.

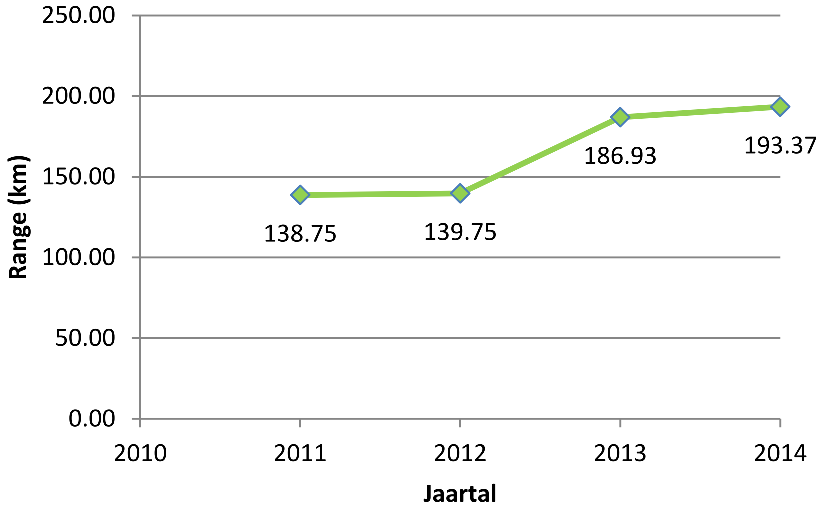

Figure 3.2. EV weighted range evolution of the six most sold models

An easy deduction comparing EV prices and their respective range make us suggest that something close to a linear relationship might exist (see Annex A, Table A). What would be very interesting is to see the marginal increase in price taken a unit increase in a vehicle's range, but this will be left to other researchers because it's not relevant here. The most sold cars are considered and since new models become popular we do not track the same models over the relevant period.

3.2.2. Purchase price. One of the main problems to overcome for EVs is the price difference compared with combustion engine vehicles. The initial cost of an EV is a lot higher which is an obstacle for many people to turn away from conventional cars. When discussing the high price of all types of new energy vehicles, it is necessary to mention the battery again. The battery cost accounts for the biggest share when building an EV, but a study from the Financial Times shows that the costs of batteries have more than halved in the last seven years[5]. Also the fact that Tesla Motors has publicly disclosed all of its patents, this happened in March 2014, to boost the EV market will further push down the production costs and consequently the retail

[5] Battery costs decreased from about 1,300 USD/kWh in 2007 to 500 USD/kWh in 2012 (Khan & Kushler, 2013).

price. Especially the batteries from Tesla Motors that are already used in other models such as the Smart ED and the Toyota RAV4 EV are higher in capacity and cheaper in price than the batteries used by competitors. The perspective of reduced purchase prices and the expected increase of gas and oil prices in the future is what will make EVs not only competitive with conventional cars but even advantageous.

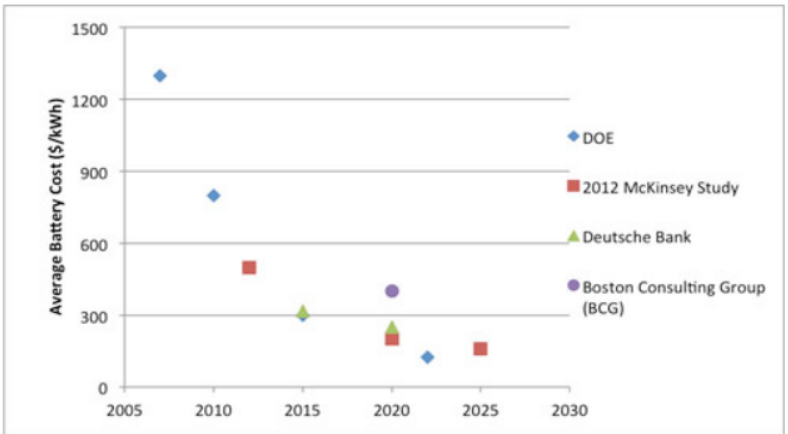

Figure 3.3. Comparison of studies on the evolution and forecast of EV battery cost reduction *(Source: Khan & Kushler, 2013)*

In the above figure we see that even considering different studies from different sources, they all agree on a significant decrease in EV battery cost and of total EV cost along with it. Both Deutsche Bank and McKinsey found that battery prices will decrease with not less than 30% per year by 2020 assuming a linear decrease. Afterwards the trend is difficult to determine, but this does mean that the purchase price goes down with 5.77% each year assuming a linear evolution. Having a more logarithmic trend does not change the fact that prices are apt to decrease significantly in upcoming years.

In our model price will not be added though as an absolute value. It would be hard and meaningless to draw conclusions from the results that would give because naturally buyers are more interested in the relative price, the purchase price of an EV compared to the price of an ICE vehicle, than the absolute number on the invoice. The price variable will therefore consist of the ratio of the EV price and the ICE vehicle price, or:

$$TC_{EV/ICE} = \frac{EV\_P}{ICE\_P}$$

with prices being gross prices based on the most bought models for each year. Subsidies or other financial effects on price will be separately discussed.

For the period 2011 until 2014 the distribution of newly registered electric vehicles in France is given in Figure 3. This study considers the six most sold models only, and the other models are assumed to be non-existing for the goal of computing a weighted average of the EV price in each year. This is a reliable hypothesis because only 5% of the whole market is left out of the calculations this way.

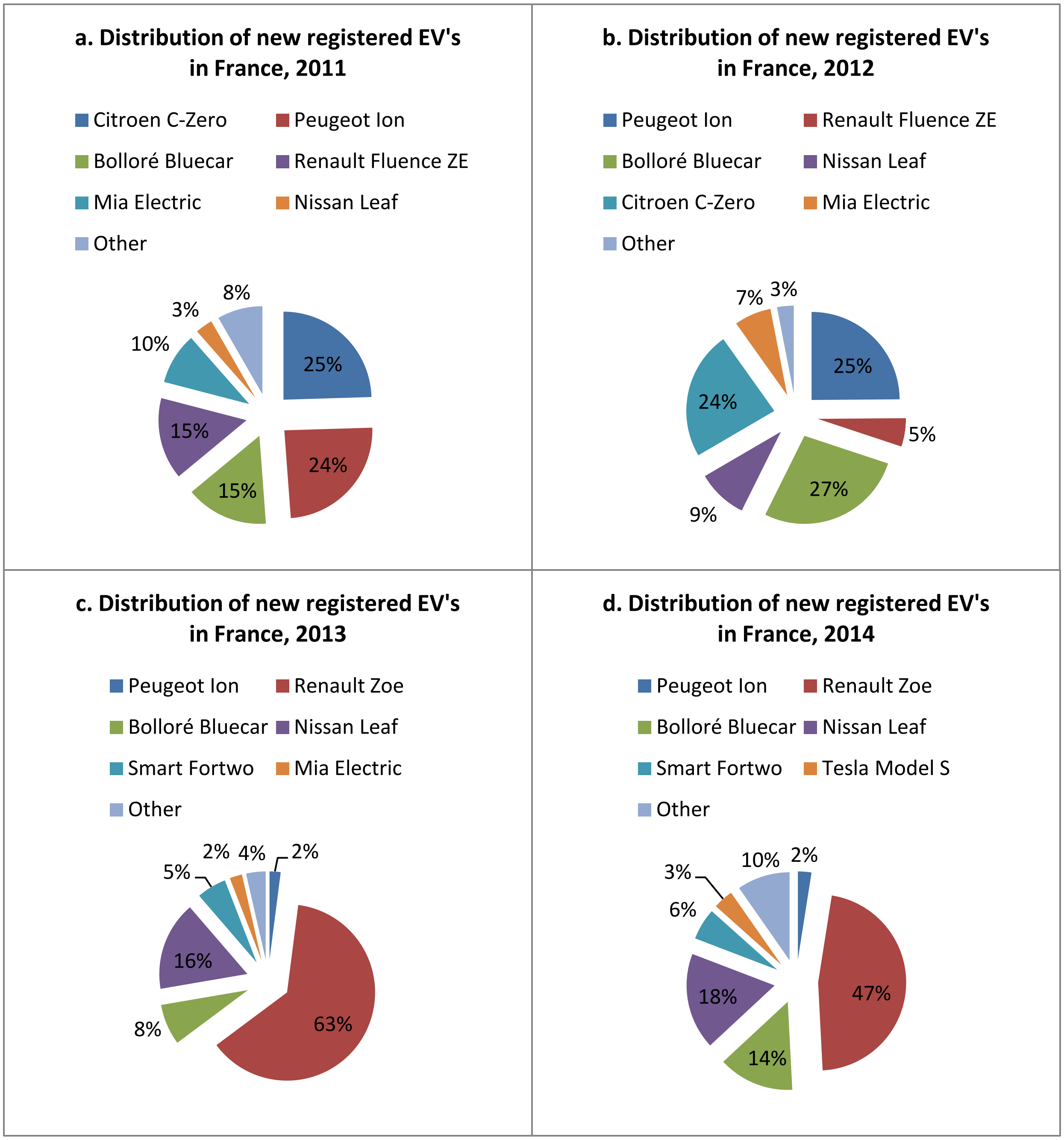

Figure 3.4. Distribution of newly registered EVs in France 2011-2014 *(Source: automobile-propre.com)*

For 2012, 2013 and 2014 (up to July) the average price of an EV in France was 27,541.53 EUR, 23,101.69 EUR and 20,800.46 EUR respectively. As expected prices go down due to the increasing learning curve and lower costs year after year. More detailed price data can be found in Annex A.

Using the price ratio instead of absolute prices has another advantage to it. Adding only the absolute EV price in our model would indicate the relationship between price and vehicles sold, but it would be impossible to interpret that result not knowing what happened meanwhile to the purchase price of ICE vehicles. Imagine the average price of an EV would decrease with 10% from year 1 to year 2, but the ICE vehicle price would show the same pattern. Consumers would still refrain from buying EVs. Indeed, no one ever said that 50,000€ is expensive for an electric vehicle if you include the lower operational cost and all the environmental benefits, but it's because the ICE vehicle price is so much lower that people are unwilling to spend this amount on their car. By considering the ratio we accept that a decrease in the EV price is necessary or an increase in ICE vehicle prices. Surprisingly these are both trends that can be witnessed in the past years. For EVs it has been made clear already when discussing the battery cost, but also the average price of conventional cars becomes more and more expensive and this is a still ongoing trend. This market is older already so several studies have been done to investigate the evolution of ICE vehicle prices in the last 5, 30 or even 50 years (Chimits, 2012; Tougard, 2011; Sallé, 2013). The concrete data used here can again be found in Annex A. In the end the gross price ratio will be able to provide the information that is relevant for this study and will cover for obvious shortcomings of the use of absolute values.

An important point of attention when using price in a model like this is that you analyze well if your price is not just the endogenous variable of the demand function and thus to be determined by the model. When using aggregated prices or market data there will be simultaneity problems with *EV_P* since this variable will very likely have some existing correlations with unobserved variables that are included in the error ε (Thatchenkery, 2008). This problem can be countered by using a replacement variable, but this would be a complicated issue since then again the price is not just determined by the technical characteristics, but also the esthetics and comfort of the vehicle. In this paper data is collected for each individual car which allows us to treat it as an exogenous variable without having to think about this problem.

3.2.3. Installed charging infrastructure. The third intermediary variable is the installed charging infrastructure. First there will be a description of the role of the government in the financial support for the charging infrastructure. Afterwards we'll go more into detail about how the expansion of EV infrastructure has evolved in the past years and its relevance in the model , but the direct government investment in monetary terms will be discussed here already.

Electric vehicles and a reliable infrastructure are two complementary goods and one is useless without the other. This is a source of uncertainty for many companies and governments because there is a risk that too much will be invested in an extensive infrastructure while the EV market won't come off in the next years which would be highly inefficient and might even ruin some companies who place their bets on the EV market. Meanwhile many potential buyers might just need this final assurance of secure charging possibilities before making the buying decision. This leads to a dilemma where neither side wants to invest too much without the other side keeping up.

The French government released a press note in 2009 that exposed a plan on the development of a EV charging network in France by 2015 (Green, 2009). They want to build not only public charging stations but also provide charging facilities in newly-built apartments and at both private (office buildings) and public parking lots. They assigned 1.5 billion EUR to the implementation of this plan. Press releases from companies as Renault and Nissan also investing in expansion of the EV charging network suggest that government investments may fall short of actual needs, but that is something this study hopes to point out. The government doesn't just concern itself with bigger projects, but also individuals wanting to invest in a charging pole are financially supported. Depending on the type (slow, accelerated, fast) of charging socket, subsidies are higher or lower up to a pre-determined upper limit of money one can get on his investment. Especially for car users in the city this should be the only infrastructure they need in their daily lives so this measure is particularly useful for them[6].

So far for the introduction to the importance of a sufficient and efficiently distributed charging infrastructure. However, only monetary government investment has been addressed up to this point. Evidently not just the investment made in infrastructure, but also the installed

[6] Concrete subsidies for slow, accelerated and fast charging plugs are respectively 1250 EUR, 2500 EUR and 10,000 EUR under a normal concession contract. The ceiling for these subsidies are 1500 EUR, 3000 EUR and 12,000 EUR (AVEM, 2014).

charging facilities affect the willingness of people to buy an electric vehicle. This is also illustrated by the recent phenomenon of online applications allowing EV owners to transmit their location and find to closest charging point in case they might run low on battery during their trip. Definitely worth mentioning here is the website Chargemap.com, an initiative that allows everyone (individuals as well as companies[7]) to register their newly installed charging point into their database and share this information with anyone to create an online platform for EV users all over the world. The amount of charging stations they have registered on their website will probably be lower than the real amount because not everyone knows about the platform or wants to make this information public. However, it is a valid assumption that with the increasing amount of charging poles, also the registered ones increase, so it is trustworthy to work with the values of the Chargemap database. This hypotheses is endorsed by the fact that previous studies also used values provided by Chargemap to create a map of the available charging facilities in Western countries (Sprenger, 2013).

The installed charging structure variable, *ChIn*, used in the model will be the sum of the registered and installed outlets. They will not be considered as two separate variables for this study. Furthermore it’s important not to misinterpret what this sum stands for. It is not relevant to include just the total number of charging facilities if we don’t know how they are spread out in the country and especially if we don’t know how many EV owners or potential EV owners there are. A detailed overview on local scale is unavailable, but we can divide the amount of charging stations by the population to see how many plugs are available per person. This gives:

$$ChIn = \frac{(ChIn\_Installed)}{Population} * 1{,}000{,}000$$

This formula will provide us in the end with the charging facilities available per 1 million residents. The next table shows the values for the first nine months of 2014[8].

[7] Not only individuals benefit from a platform like Chargemap to find the closest charging point, but companies as well benefit through more transparency on this issue. The bigger the network, the more people might be interested in buying an EV (still to be proved by this study) and the higher the sales of EVs for car manufacturers. That is why important car companies as Nissan are active partner of the Chargemap project.

[8] Complete data sets can be obtained by privately contacting the author of this paper.

Month	Total ChIn per 1M residents	Outlets/Plugs per 1M residents	Charging stations per 1M residents	Outlets/ Plugs	Charging stations	Population
2014						
January	241.0592	202.7286	38.3306	13344	2523	65822000
February	248.1927	208.5384	39.6543	13731	2611	65844000
March	252.7329	211.6938	41.0391	13943	2703	65864000
April	260.0288	216.9234	43.1054	14292	2840	65885000
May	267.3049	222.3925	44.9125	14657	2960	65906000
June	278.2867	231.8753	46.4115	15288	3060	65932000
July	286.3900	238.1025	48.2876	15705	3185	65959000
August	296.9176	245.3779	51.5397	16192	3401	65988000
September	310.5412	255.5857	54.9555	16873	3628	66017000

Table 3.3. Overview of the installed charging infrastructure with relevant data transformation (*Source: Chargemap, 2014; Insee , 2014)*

The increasing trend can already be noticed by just looking at this fraction of the total data set. This is a trend that could have been expected and that will probably continue to increase in the future, but this does not necessarily needs to have a big impact on the EV sales, since geographical positioning is maybe even more important than just the amount of charging poles.

This figure was retrieved from the Chargemap website and indicates how charging infrastructure is mainly concentrated in bigger cities as Toulouse, Bordeaux, Lyon and Paris.

Figure 3.5 Distribution of charging infrastructure in France, December 2014
(Source: Chargemap, 2014)

We can assume that once there is a sufficient supply of charging infrastructure an increase won't influence EV sales anymore. If every house and office is equipped with a charging pole and battery swap stations are available everywhere adding another charging pole will supposedly have no effect on EV adoption anymore. The opposite can also happen. If the existing charging infrastructure is just too few in numbers and increase will hardly have any effect on the dependent variable. Between these two extremes we can expect installed charging infrastructure to positively influence the EV sales. Before running the model it is impossible to say what the state of art in France is at this moment.

3.2.4. Financial support. Financial support variables are those factors that reduce the financial burden of an EV. A distinction will be made between two types of financial support variables: subsidies and tax exemptions. The variable will consist of the sum of the two.

$$EV\_Ben = EV\_Subs + EV\_TaxEx$$

The sum will be taken because tax exemptions are only assumed to have an effect at the moment of the purchase. As will be shown further in the document the difference in paid taxes has become very small which makes this a viable assumption.

3.2.4.1. Subsidies. Subsidies are a way for the government to directly influence the purchase price of the EV. Assuming buyers are sensitive to the price in their decision making progress, subsidies are a clear and obvious way of promoting a technology. In France the subsidy scheme for EVs has changed several times over the last few years. Before 2012 you would get a 5000 EUR subsidy, but a new plan foresaw an increase to 7000 EUR (Sicard, 2012). This amount was adjusted again later on in 2013 to 6300 EUR, which is still the applied level of subsidies in France (Amiot, 2013). This is only for full electric vehicles with zero emissions. Hybrids are subject to a different scheme (AVEM, 2014). An additional rule exists, indicating that the total subsidies can't be higher than 30% of the total price with VAT included.

EV_Subs = Subsidy granted on the purchase of an EV

In July 2014 a new proposition came from the Ministry for Ecology, Sustainable Development & Energy regarding the 2015 budget that suggests a new increase in the EV subsidies to 10,000 EUR. Only consumers who return their old diesel car are eligible for this higher amount of subsidies. The government hopes to work in two directions with this measure. Increase the EV sales and reduce the amount of diesel powered vehicles (Insideeev, 2014). Even though it seems unlikely that the government budget can keep up with these high subsidies in the future, France is definitely putting a lot of effort into advancing their EV market to one of the biggest in the world. It should also be kept in mind that subsidies never are a permanent solution, but only allow for the government to give a signal to the population, but after a while the market should be able to survive on its own. For this it's still too early for EVs.

3.2.4.2. Tax exemptions. In many countries the government issues certain tax exemptions to promote EVs. This is another way to lower the financial burden for buyers. The advantage with granting tax exemptions is that there are so many different types and variants of tax that a whole range of possibilities opens up for the policy makers. Government also has full control over this variable, which makes it a useful tool to create incentives in the market. Tseng (2013) even goes as far as to say that without tax exemptions EVs can not be competitive at all in the current framework. Almost all western countries have some tax exemption in place regarding EVs, whether it be a lower registration tax or decrease VAT on purchase, but especially Norway is a leading country when it comes to this support scheme. Examples of tax benefits can be the exemption of a congestion tax, adjusted VAT on purchase, … In France as well there are several different types of taxes have to be paid on vehicles. They will all be listed down here with a short explanation and the impact of them on new energy vehicles (Streetwise, 2013)[9].

3.2.4.2.1. Car registration tax. The amount of 45 EUR has to be paid per horsepower of the car when (re-)registering the vehicle. The registration tax is applicable to all vehicles on a

[9] The legal basis for these taxes are Decree No 2007/1873 and the updates in Decree No 2010-1618.

national level, but regional governments do have the authority to decide on reduction or full exemption of this tax for certain vehicle types (electric & hybrid, LPG, super-ethanol e85 and natural gas).

3.2.4.2.2. Additional registration tax. An extra amount according to the emission rate of the vehicles is added to the registration tax mentioned above according to the values in the next table.

CO2 emission (g/km)	**Tax per gram CO2**
0-200	0 EUR
201-250	2 EUR
251<	4 EUR

Table 3.4. Additional registration tax per gram CO_2 emissions (*Source: Streetwise, 2013)*

The average CO_2 emission rates in recent years of ICE vehicles are way below 200 g/km which allows us to drop this partial tax from our final calculations.

3.2.4.2.3. Pollution tax. This tax depends on the carbon emissions of the car and regulations changed several times in the last years. An EV buyer receives a bonus or subsidy at the moment of purchase whereas other buyers have to pay this extra tax as a one time penalty on the purchase of a polluting vehicle. The following table shows clearly the evolution of taxes to be paid for each type of vehicle. There is an interesting trend of decreasing emission limits, because even ICE vehicles now emit a lot less than a few years ago. This is one of the reasons why prices of conventional cars have not decreased in recent years.

<table>
<tr><th>Carbon emission rate
(in g/km)</th><th colspan="6">Tariff (in EUR)</th></tr>
<tr><th></th><th colspan="6">Year of acquisition</th></tr>
<tr><th></th><th>2008 / 2009</th><th>2010</th><th>2011</th><th>2012</th><th>2013</th><th>2014</th></tr>
<tr><td>≤ 130</td><td rowspan="7">0</td><td rowspan="6">0</td><td rowspan="5">0</td><td rowspan="3">0</td><td rowspan="2">0</td><td>0</td></tr>
<tr><td>131 - 135</td><td>150</td></tr>
<tr><td>136 - 140</td><td>100</td><td>250</td></tr>
<tr><td>141 - 145</td><td rowspan="2">200</td><td>300</td><td>500</td></tr>
<tr><td>146 - 150</td><td>400</td><td>900</td></tr>
<tr><td>151 - 155</td><td>200</td><td>500</td><td>1000</td><td>1600</td></tr>
<tr><td>156 - 160</td><td>200</td><td rowspan="7">750</td><td rowspan="5">750</td><td rowspan="4">1500</td><td rowspan="4">2200</td></tr>
<tr><td>161 - 165</td><td>200</td><td rowspan="7">750</td></tr>
<tr><td>166 - 170</td><td rowspan="7">750</td></tr>
<tr><td>171 - 175</td></tr>
<tr><td>176 - 180</td><td>2000</td><td>3000</td></tr>
<tr><td>181 - 185</td><td rowspan="2">1300</td><td>2600</td><td>3600</td></tr>
<tr><td>186 - 190</td><td>3000</td><td>4000</td></tr>
<tr><td>191 - 195</td><td rowspan="4">1600</td><td rowspan="3">2300</td><td rowspan="2">5000</td><td rowspan="2">6500</td></tr>
<tr><td>196 - 200</td><td rowspan="4">1600</td></tr>
<tr><td>201 - 230</td><td rowspan="4">1600</td><td rowspan="5">6000</td><td rowspan="5">8000</td></tr>
<tr><td>231 - 240</td><td rowspan="4">3600</td></tr>
<tr><td>241 - 245</td><td rowspan="3">2600</td></tr>
<tr><td>246 - 250</td><td rowspan="2">2600</td></tr>
<tr><td>250 <</td><td>2600</td></tr>
</table>

Table 3.5. Pollution tax scheme 2008-2014 (*Source: carte-grise.org)*

If we take the average emissions into account within the time scope of this research, it is possible to see for each year what the average emission tax paid in France is. [10] Already now we see that the most popular vehicles are the ones that do not have a lot of CO2 emissions. For each year the weighted average of emissions falls below the critical value where vehicle owners have to start paying extra taxes. Regulatory changes have made sure that this cap was reduced several times in recent years and that penalties on emissions would heavily increase. This apparently had a positive influence on consumer's choices. These days most vehicles produced already fall in the category where no pollution tax has to be paid.

3.2.4.2.4. Ancienity tax. This tax is charged on car owners on a yearly base, depending on the type of motor and the year of acquisition. Before 2014 this tax was still based on the horse power of the vehicle, but since this year an amendment was made in the law that charges owners of vehicles based on the year of release of their car.

Horse-Power	**Tax in EUR**		
	2011	**2012**	**2013**
< 4	750	750	750
4	750	1400	1400
5 - 6	1400	1400	1400
7	1400	3000	3000
8 – 10	3000	3000	3000
11	3000	3600	3600
12 – 15	3600	3600	3600
16	3600	4500	4500
16 ≤	4500	4500	4500

Table 3.6a. Ancienity tax scheme 2011-2013 *(Source*: *Streetwise, 2013)*

[10] There is also an extra amount of 160 EUR to be paid for high polluting vehicles, but only very few cars fall under this regulations which is why it will be ignored here (CCFA, 2014)

Year of release	Tax paid per type of engine (EUR) in 2014	
	Petrol	**Diesel**
< 1997	70 EUR	600 EUR
1997 – 2000	45 EUR	400 EUR
2001 – 2005	45 EUR	300 EUR
2006 – 2010	45 EUR	100 EUR
2011 ≤	20 EUR	40 EUR

Table 3.6b. Ancienity tax scheme 2014 (*Source: Streetwise, 2013)*

This new framework significantly decreased the ancienity tax to be paid by ICE vehicle owners in 2014. The reason for this is because also the traditional auto industry has invested tons of money in R&D to come up with less polluting vehicles in recent years and they made a lot of progress. Even though ICE vehicles are a lot less polluting these days than a decennia ago, the French government still aims for more environmentally friendly transport which can be seen by a new law (starting in January 2015) that foresees a 10 000 EUR subsidy on the purchase of an EV for those who turn in their old diesel-powered vehicles.

3.2.4.2.5. Company car tax. Based on the emission rate as well to stimulate companies to use electric vehicles and construct a local charging point as well. This tax is not considered because detailed information about the amount of company cars is not documented.

3.2.4.2.6. Value added tax. In France 19.6% VAT has to be paid when purchasing a car. This amount is independent of the type of vehicle. Some countries lever a lower tax on new energy vehicles and in Norway this amount is even 0%. This distinction is not being made in France, so this tax will not be included in the model. Creating a distinction, following the Nordic example, is worth consideration for future regulatory decisions.

As can be seen, electric vehicle owners do not have to pay several of these taxes, independent of the age of their vehicle. Surprisingly enough the only tax that is actively reducing the financial burden of electric vehicles in France is the ancienity tax and even there the new regulatory framework decreased the advantage of EV owners.

$$EV\_TaxBen = Ancienity\ tax_{ICE} - Ancienity\ tax_{EV}$$

3.2.5. O&M cost. Apart from the initial price, the total cost of a vehicle also includes the maintenance and operational costs. Conventional cars may still be cheaper than EVs when it comes to the production and purchase cost but everyone agrees that not only the maintenance costs are lower for EVs, but especially the fuel cost is significantly lower. Regarding maintenance issues, EV have lower costs because there are less moving components that might wear out. According to a study by Van den Bulk (2009) maintenance costs for an EV are nearly one third of those of a conventional car. This study as well as other sources do not however include the purchase of a new battery in their equation. At the moment an EV battery life is about 8 years[11], but many people use their cars up to 12 years so this cost should be considered as well. With current battery technologies there is therefore no real benefit for either EV or ICE vehicles when it comes to maintenance cost over the whole lifetime of the vehicle. This might change and require new research once new batteries are introduced in the market.

Whereas for total maintenance costs it might be hard to make a clear distinction between vehicle types, for fuel costs EVs will turn out to be a lot cheaper than ICE vehicles because of the finite amount of oil and gas and the unpredictable prices. Electricity prices are definitely lower than petrol and diesel and especially with the growing importance of green energy it might only be a matter of time for cars to produce their own fuel (e.g. through rooftop solar cells) which would decrease the fuel cost to about zero. Taking an economic approach towards the variable of operation cost tells us it might be interesting to not just consider the cost per kilometer, but to include the efficiency of the vehicle in a more explicit manner by using the amount of kilometer one can drive for each euro. As with the price the ratio is considered here, because values are only important in comparison with their alternatives.

[11] The batteries have a limited amount of charging cycles for their efficiency to decrease and the battery should be replaced then.

$$OC_{EV/ICE} = \frac{EV\ fuel\text{-}efficiency}{ICE\ fuel\text{-}efficiency} = \frac{EV\ kilometers\ per\ euro}{ICE\ kilometers\ per\ euro}$$

$$= \frac{\left(\frac{1}{EV\_FuelC}\right) * EV\_Eff}{\left(\frac{1}{ICE\_FuelC}\right) * ICE\_Eff}$$

Electricity price will be in EUR/kWh, diesel price in EUR/liter[12], EV efficiency will reflect the kWh/km and ICE efficiency L/100km has been rescaled to L/km. This ratio will give a good impression of how much we actually pay for our transport. An increase will be due to an increase in EV efficiency or a decrease in ICE vehicle efficiency and vice versa. Good cars with better motors and better quality tend to have a higher efficiency as well so this variable could well be linked to the price. However, price differences are not only due to technical modifications so operational costs are a necessary additional variable in the model. Only using the diesel prices might look shortsighted, but as can be seen in Figure 3.6 diesel and petrol prices evolve alike and considering just one of them will return the same outcome as making the distinction based on diesel cars and petrol-powered cars in the total vehicle fleet.

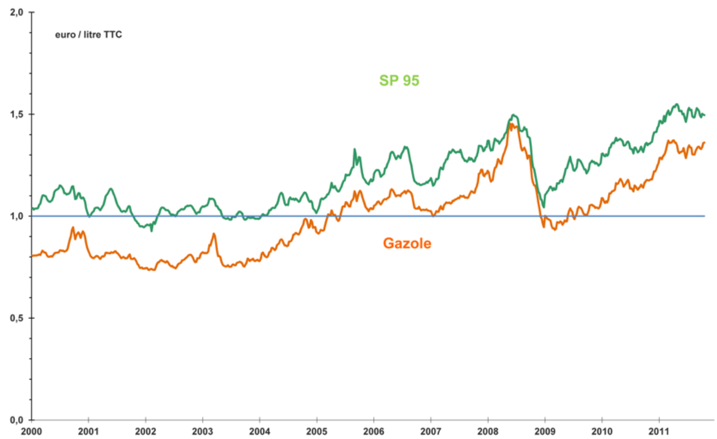

Figure 3.6. Evolution of diesel (gazole) and petrol (SP95) prices from 2000-2011 in euro per liter *(Source: UFIP, 2012)*

[12] The diesel prices in the data set do not include the taxes on the diesel price so it's not equal to the retail price.

3.2.6. EVs already sold. This paragraph has several dimensions because the background for the variable is both quantitative as qualitative. EVs already sold can be approached via the share of EVs in the total vehicle fleet, but also as the share of EVs in the total vehicle sales only.

As a share of the total vehicle fleet, it can be assumed that an increase of electric vehicles on the roads creates an awareness among people by seeing more EVs in their daily lives. Knowing that other people have bought them and a growing amount of people use them and are happy with their vehicle might have a positive influence on potential buyer's attitude towards EVs. Many governments already made compliances to a contribution for EVs by stating that they will replace a certain percentage of the governmental fleet to electric vehicles. France has made this promise and even in countries as China the government announced in July 2014 on their website that 30% of the governmentally owned cars will consist of EV's by the end of the year and a feedback program will be launched to keep this number stable afterwards (Bloomberg, 2014). More EV demand should also increase production levels which causes the manufacturers to move down in the learning curve and realize cost advantages through higher production levels which would again benefit consumers.

A second perspective for EVs already sold is to consider for each period the share of EVs in the total vehicle sales for that period. This might be of less importance than considering the share in the total fleet, but still it might indicate a certain trend among consumers and represent the value of word-to-mouth advertising. Therefore including both aspects will cover for these effects give more insight on how EV sales evolve with respect to the size of the market.

3.2.7. Investment in research & development. R&D expenses are not a variable in the model, because of the lack of variation in the considered period, but it is too important not to mention them at all. There is a lot of room for improvement still for battery technologies and other esthetical factors as well and only investment by companies or government to keep researching more economically friendly, more convenient and more profitable alternatives can cause major changes in the EV market. The French government issued a plan in 2009 that would allocate a budget of 120M EUR to R&D projects for electric vehicles between 2008 (the first sum was already invested a year earlier) and 2012. France has an inflexible power generation market and for them especially it would be beneficial to explore the possibilities of EVs on consumption levels and to use the vehicles as storage units on the micro-level via V2G technology. Research is based on more efficient infrastructure as well as on new technologies for e.g. batteries[13].

In 2012 the French government increased its efforts and raised the budget for EV R&D to 350M EUR under the motto “Investments for the Future”. The money will be portioned out over a 5-year term, significantly increasing the monthly support for alternative energy institutes and the French automobile industry. Knowing that the French automotive industry is one of the biggest in the world and that French research institutions and companies hold on to more than 250 patents in EV batteries, it seems the funds is well used and hopefully this will boost the EV market worldwide (IEA, 2014). Unfortunately a lack of transparent data on the monthly spending and allocation (linear or differently distributed) keeps this data from being a reliable variable.

3.2.8. Economic growth factors. Lastly there are a few minor variables included in the model that are an indication of the economic growth. Third world countries have other worries than optimizing their energy mix and investing in new energy transport when poverty levels are so high that most inhabitants don’t even have a car. That is why the more economically advanced the country is, the higher their efforts for green energy in general and thus EVs as well. In annex B there is a map shown of the electric vehicle initiative (EVI) member countries who accounted for 90% of the global EV fleet in 2012[14]. The map clearly shows that it is only the economically developed countries that have the resources to invest in clean transport. The population and the total amount of newly registered vehicles are indirectly included to represent these factors. On a small note should be added that, even though we assume a relationship between economic growth and EV adoption, it doesn’t have to be so that only developed and developing countries

[13] See earlier comment about new battery R&D.

[14] Norway and Canada are not part of the program even though they have a significant EV fleet which even strengthens the fact that EVs are but a ‘luxury’ for richer countries.

can invest in the technology. Smaller countries who are at a disadvantage when it comes to technological situation do have the possibility to learn from mistakes that set developed countries back over the years and to start from zero to start building in the most optimal and sustainable way.

3.2.9. The Poisson regression. Thus far, the independent variables have been discussed extensively. However, in order to obtain a reliable model, more information is needed about the relationship between the independent variables and the dependent variable. In addition, it is important to gain a better understanding of the characteristics of the dependent variable. The response variable is the amount of EVs sold per month, or more precise, the number of EV purchases per month in France from January 2011 - September 2014. Accordingly, this fits the definition of count data. The Poisson regression, a model that works with positive, discrete response outcomes, was deemed to be the most befitting model for this case. Some other examples of previous work done with Poisson are:

- The number of deaths due to AIDS in Australia per quarter from January 1983 - June 1986. (standard Poisson example by Whyte et al., 1987 (Dobson, 1990) used in academic courses)
- The number of violent incidents exhibited over a 6 month period by patients who had been treated in the ER of a psychiatric hospital (Gardner et al., 1995)

The type of outcome, as well as the time frame and regional restriction are very similar between this dissertation and the aforementioned studies these studies.

Poisson is a Generalized Linear Model (GLM) that can be written as: $Y_i = E(Y_i) + \varepsilon_i$. The expected value is being formulated as $E(Y) = \mu = \alpha + \beta x$. For any normal linear model this formula can generate negative values for x which is of course impossible for the amount of sales in a month. In this aspect Poisson is not a linear regression, but called a log-lin model since there exists a log-lin link between the dependent and independent variable: $\log(\mu) = \alpha + \beta x$. Or, as in the official quotation for Poisson: $\mu = \exp(\alpha + \beta x)$. Consequently, the log-lin model assumes a linear relationship between the explanatory variables and the log of the response variable. A purely linear link would not have satisfied the needs of this study, but Poisson being an extension of a GLM meets the requirements of the dataset. A commonly encountered problem with Poisson is the excess of zeros in the response variable. For example, in case this study would access the monthly EV sales over a certain period in Rwanda, it will likely obtain a large number of zeros in the data set. In cases like the aforementioned, other count models such as the negative binomial or zero-inflated model are more appropriate.

Another possible problem is overdispersion, i.e. when the variance is larger in value than the mean. An assumption for Poisson states that the variance has to be equal to the mean in order to use Poisson: $E(Y) = \mu = \sigma^2(Y)$. The treated dataset is subject to overdispersion and does not meet this requirement. An alternative option is to use quasi-likelihood estimation in combination with Poisson to make up for this violation. Another option is to move away from Poisson and use a normal logarithmic regression for the analysis since a normal logarithmic regression would not impose a constraint on the variance. Nonetheless, this research opted for using the standard Poisson regression for the following reason: Stata provides an option that specifies to work with a robust variance-covariance matrix of estimators. Adding the vce(robust) suffix into the program allows the variance-covariance matrix not to assume that $E(Y) = \sigma^2(Y)$, neither does the value of $\sigma^2(Y)$ has to be constant over the considered length of the study. Previous work showed that applying this method yields better results than a logarithmic regression (e.g., Santos Silva, 2006; Wooldridge, 2002).

First, in the use of a logarithmic regression it might be easy to forget to exponentiate the obtained predicted values when using a log regression. Second, all results should be transformed from ln(Y) back to Y by multiplying them by $\exp(\sigma^2/2)$ which can easily be forgotten. Advantages of Poisson are that the regression treats outcomes that are equal to zero while log regression doesn't ($\ln(0)$ is $-\infty$). In this dataset it is possible though to have natural zeros in a situation where there is no active subsidy scheme yet. Since it would be advantageous to generalize this study across countries, it would be beneficial to take into account characteristics of other countries. Accordingly, encountering very low values in the dataset is a likely scenario in another country. Moreover, small values will be able to make a difference in a Poisson model whereas a log regression will treat them wrong. The logs of 0.001, 0.0001 and 0.00001 are very different and Poisson sticks to their original variation. This is also useful because the EV share in a country or the installed infrastructure per 1M residents can take these very low numbers.

Finally, by using a Poisson model a fitted response function will be created to get an idea of the impact of each of the variables on the EV sales with the estimated standard deviation. The next section explains the results and provides a detailed interpretation in order to gain a better understanding of the response variable for interested parties.

4. Analysis of the results

In this part the results of the Poisson model will be discussed and interpret. It will become clear whether our chosen variables have an actual impact on the EV sales and how big this impact is. So to which extent do range and available charging infrastructure make a difference for consumers in their buying decision? Or is it the purchase price or operating cost that are a more important factor for people considering to buy an EV? The answers on these questions will be summarized in this part of the dissertation. Firstly some descriptive statistics will be provided that might already shed some light on the situation and afterwards the model outcome will be extensively discussed to open up a discussion on how the market can be improved.

4.1 Descriptive statistics

To be able to properly interpret all results it is important to have an idea of what the variables look like. Some descriptive statistics such as the mean, the standard error, minimum and maximum are basic information that do however give some useful information already just by having a quick look at them. This information is given in Table 4.1, the corresponding units can be found in Table 3.2.

It might be interesting to shortly point out an interesting fact from Table 4.1. An important difference between ICE vehicles and EVs is the difference in price. Not only the minimum price for EVs is a bit more than 50% higher than the minimum price for ICE vehicles, but the same goes for the maximum price. Another stunning figure is the increase in the share of EVs in the total vehicle fleet. Knowing that this value is strictly increasing over the whole considered period the share increased a hundred fold from 0.0006% of the total vehicle fleet to 0.06%. This percentage should still be a lot higher for EVs to actually start having a direct impact on transport emissions or for the promising V2G technology to be commercialized. A similar trend can be seen for the installed charging infrastructure although the increase is not as strong. The last interesting statistic that should definitely be mentioned is the change in efficiency of ICE vehicles. Especially diesel vehicles got more efficient engines in recent years. This might be reflected in a cost increase, but they consume only half the amount of fuel these days than about 5 years ago. This causes a devastating effect on the tax exemptions as well. 4 years ago EV owners received a lot of tax benefits compared to those with a conventional car, but because the efficiency and pollution of conventional cars decreased so much in the past few years, the current regulation around tax exemptions might actually be outdated and should be revised to give an extra boost to the EV market.

Variable	**Mean**	**SD**	**Min**	**Max**
EV_Sales	533.07	340.12	64.00	1,514.00
EV_Range	162.79	25.55	138.75	193.37
EV_P	26,883.42	2617.61	23,530.33	29,337.50
ICE_P	16,760.83	580.06	15,824.97	17,291.22
EV_Share	0.0003	0.0002	0.000006	0.0006
EV_Subs	6,295.56	840.17	5,000.00	7,000.00
EV_TaxEx	1,466.22	683.36	114.80	1,809.15
ChIn	120.49	109.88	5.71	310.54
EV_Eff	0.16	0.01	0.12	0.15
ICE_Eff	0.05	0.003	0.04	0.50
ICE_FuelC	1.10	0.04	1.04	1.18
EV_FuelC	0.11	0.003	0.11	0.12

Table 4.1. Descriptive statistics for the most relevant data

One more interesting figure is the evolution of the EV share in total vehicle sales compared with the EV share in the total vehicle fleet. The first one indicates for each period how big a part of the vehicle sales consisted of EVs. The latter takes the full existing vehicle fleet into account. Figure 4.1 shows the relationship between these two variables.

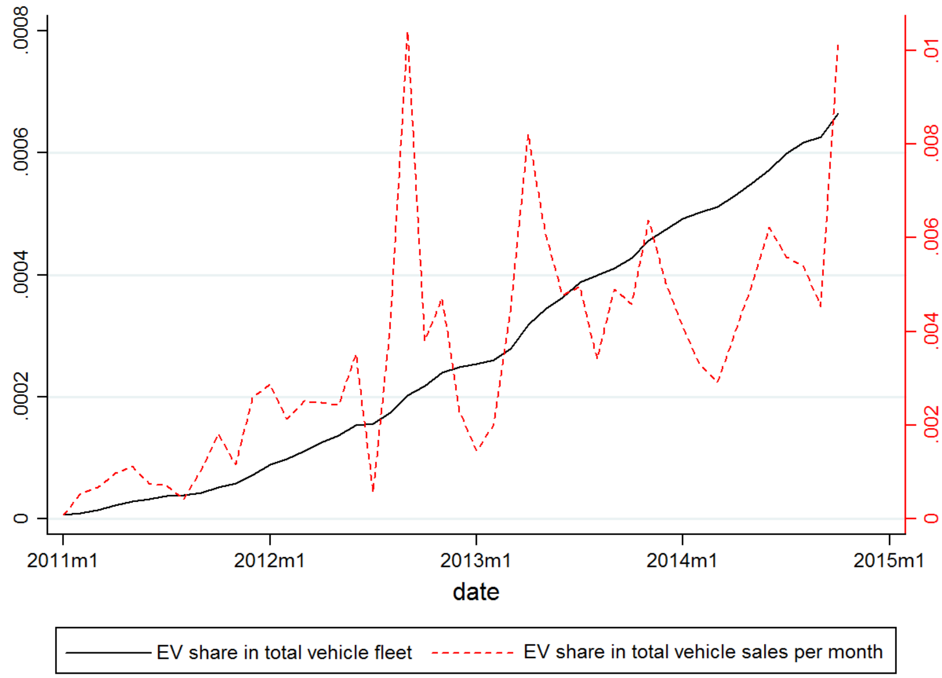

Figure 4.1. EV share in the total fleet and in the monthly sales

As expected both variables are evolving together, even though the EV share in sales is a lot more subject to unpredictable events like changes in regulation as well as seasonal effects which causes a lot of dispersion on the values. EV sales peak in August 2012 because in that month the subsidies for EVs were increased from 5000 EUR to 7000 EUR, with a cap at 30% of the total vehicle price, VAT included (Nussbaumer, 2012). Especially during the first month with this new regulation many people made use of this new subsidy scheme. In November 2013 the subsidy scheme changed again but allocated subsidies decreased to 6300. This explains the fall of EV share in monthly sales in the period after. Many similar events cause the irregularities in the graph.

4.2 Impact of the variables on the EV sales

Some impacts of variables on the EV sales have already been insinuated on earlier and some might feel natural. The question we have to ask ourselves now is how big this impact is. Here all effects will be quantified and analyzed to draw conclusions from. To have an idea of the differences a distinction will be made between (model 1) the model without financial benefits, (model 2) with financial benefits as an additional variable and (model 3) with financial benefits already included in the price ratio. The general formula after running the Poisson regression is (model 2):

$$\ln EV\_Sales = 2375.31 - 1601.24\ TC_{EV/ICE} - 448.81 \ln EV\_Range + 300.04 \ln EV\_Range\ TC_{EV/ICE} + 0.0038\ ChIn\_Installed + 0.000052\ ChIn\_Installed\ \hat{}2 - 20893.96\ EV\_Share + 3.77 \ln EV\_Ben - 37.60\ OC_{EV/ICE} + 25.49\ OC_{EV/ICE}\ TC_{EV/ICE}$$

Definitions of all variables can be found in Table 3.2. Results with their respective significance level for all three models are being shown in Annex C[15]. Total effects of all variables are displayed in Table 4.2.

As expected range has a positive effect on the EV sales. This means that people indeed place a high value on the battery power and the distance they are able to drive with their cars before having to charge again. Figure 3.5 showed that EV sales are mainly concentrated to cities where people usually have no need of moving many kilometers from home for their jobs, but apparently people still prefer to have a longer range with their cars. Also does this result suggest that the money invested in new battery R&D is definitely worth it and could give a boost to EV sales. And increasing the R&D investment is definitely possible. At the moment France is stimulating the EV R&D under the “Investments of the future program” allocating about 350 million EUR over a period of 5 years to the sector (Ragg, 2012). This is only a small percentage of the total R&D investments for the automotive industry. The total auto industry is consuming close to 15% (over 4 million EUR per year) of the total budget (IFA, 2010). The difference between both is therefore still huge and people might wonder whether France, despite the many regulations that do favor EVs, really believes in the additive value of the EV industry. Of course we have to keep in mind that the country is rich in car manufacturers and these might have a clear preference for ICE vehicle sales. The initial profit on sale might not be as big, but the factories are adapted to mass production and maintenance cost is higher[16] so also car mechanics

[15] The annex also included a short description on the names of the variables as used in Stata.
[16] This refers to the yearly maintenance on the vehicles, not the necessary battery swap.

will have higher profit margins and manufacturers will sell more separate components of their cars. The actual impact of range on EV sales is calculated according to the formula for marginal increase in a Poisson model:

$$y\,(x+1) = e\wedge(\beta_0 + \beta_1(x+1)) = e\wedge\beta_1 * e\wedge(\beta_0+\beta_1 x) = e\wedge\beta_1 * y(x)$$

A one unit increase in range has a positive effect of 29.34%[17] on EV sales, which is a pretty big effect. It is interesting to see how this effect slightly increases to 33.90% when subsidies and benefits are added as a financial support variable. This means that people will think more importantly of range when they know that they can benefit from some financial support. A possible explanation is that with a lower financial burden, people pay more attention to other characteristics such as range that then become more important for the EV sales. Even when financial support has been included in the price ratio already, which leads to lower EV prices, the range keeps its significance on the 1% level. This means that people highly appreciate a stronger, better battery and this feature will still have an influence on the buying decision no matter how low the price is. This is a strong signal that battery R&D investment is certainly not wasted money for the government.

Next we'll have a look at the financial benefits that include both subsidies and tax exemptions for EV owners. The difficulty including this as a variable without having data available for many consecutive years is that there is only little variation in both variables over time. Subsidy or tax schemes are not being revised every month but are normally fixed for a period of 2-3 years. Subsidies have a direct influence on the purchase price and are directly visible for EV owners and the same goes for tax exemptions, so both are added into one variable so as to avoid multiple similar variables with little variation in the model. When discussing financial benefits it is necessary to also mention the price variable so both will be simultaneously analyzed. Remember that the price variable in this model is not a single price but the price ratio between EV price and ICE vehicle price. This means that when EV price goes up, or ICE vehicle price goes down, the value of the price ratio will increase and vice versa. In the first model we see that price has a big effect on the EV sales, and with a P-value of 2.62 this effect is significant

[17] This result is significant on the 1% level. Significance levels are shown in Table 4.2

on the 1% level. In the second model where financial benefits have been included in the model we see how important the total purchase price actually is. The level of significance triples and the standard error gets really low guaranteeing an big negative impact on EV sales when the price ratio increases. This is indeed an expected result. Both increasing the EV prices or reducing the ICE vehicle prices will increase the price ratio and will decrease the EV sales. Price is still very important for people when they want to buy a product and seeing that a comparable product is cheaper in price, will shift their interest towards this product. The relative vehicle price is a very important variable when talking about the EV sales. Why then is the price not significant in the third model? In the first model no financial benefits have been included. Financial benefits have been separately added in the second model and are included in the price ratio already in the third case. As can be seen in the first two cases an increase-in the price ratio leads to an increase in the dependent variable. A one unit increase in the price ratio will reduce log of EV sales with 63.53 in the first model and with 36.84 in the second model, with a P-value of -2.62 and -10.45 respectively both are significant on the 1% level. This is a huge impact, but of course we're talking about the price ratio here which is more likely to evolve in terms of 0.01 units. Since the effect is non-linear a 0.01 decrease in the price ratio would result in an increase in monthly unit sales of EVs of 52, 66 or 79 units in the next period, assuming a sales of respectively 800, 1000 or 1200 EVs in this period. Truth remains that price is an important factor for vehicle sales on the level of model 1 and model 2. Financial benefits also having a positive influence on EV sales on the 1% significance level is an expected result. The effect of gross price shrinks a little bit when consumers can benefit from the existing subsidy schemes, but nevertheless both variables can not be left out if we want to explain EV sales. Since financial benefits are already included in the price in model 3, the difference between the two types of vehicles is minimal and apparently at a certain point when prices of EV and ICE vehicles get more alike people are not moved by the existing difference anymore in their buying decision. This strengthens the idea mentioned earlier that absolute vehicle prices are in no way important for the buyer, but only the relative price matters. Of course this is only when there is a policy that favors EVs and reduces the financial burden on purchase since the industries themselves are not able yet to diminish this gap between the prices. Governments know that the price is an important factor and therefore try to modify this variable to boost the EV market.. However, when governments issue high support mechanisms on EV prices and put in a lot of effort to maintain them, it would be tantamount to shooting themselves in the foot. Subsidies are there to give a signal to consumers, but are in no case meant to be permanent so the importance of price is definitely significant for EV sales. If therefore no such policy exists the automotive industry should push down EV prices or increase ICE vehicle prices if they wanted both types to be competitive and attract consumers to buy an EV.

Another variable showing a similar pattern in significance between the models is the operating cost ratio. Keep in mind that the OC ratio does not represent the actual operating costs but the ratio of the actual operating costs. The value represents the amount of kilometers the vehicles can drive for each EUR. Model 1 and model 2 return a similar result, with the marginal increase in the log of EV sales being around 3.40 for a unit change in the OC ratio. If EVs become more efficient and consume less energy while driving them, or ICE vehicles become less efficient and consume more fuel, EV sales will increase with this amount just mentioned. When vehicles prices are low enough however, buyers are less interested in the efficiency and operating costs of their vehicle (see model 3). The result has lost its significance which can only be explained that people expect a better efficiency when paying a higher price or they hope to save money on the operating costs when the purchase price was substantially high.

Charging infrastructure was pointed out as being one of the important variables in this research, but in none of the models does it have a significant impact on the dependent variable. When the model is run with charging infrastructure being the only independent variable we see that at least the trend is positive as could be expected. Unfortunately in the total model this result is not relevant anymore. This leaves some room for guessing why this might be the case. It is possible that there are just not enough charging facilities available to actually play a role in buyer's mindset. If you live in Paris for example and there are only 20 poles in the whole city, even if this amount will increase with 50% to 30, this will hardly leave an impression on you and it will not influence your buying decision. The other extreme case is also true. You still live in Paris a few years later and still want to buy an EV. By now there are 500,000 charging poles and all public parking lots and office buildings are equipped with charging facilities. An increase with 1,000 poles will not make a difference anymore since you have more than enough charging infrastructure available already. It is less likely however that this is the case in the current French EV market.

This leaves the share of EVs in the total vehicle fleet to discuss. Somewhat surprising we see very high negative effects that are significant as well on the 1% level. Again significance is lost is model number 3. First it is useful to interpret this high negative impact on EVsales. Knowing that over the course of fourty-five periods the EV share in the vehicle fleet evolved from 0.00063% to 0.063% more or less a unit increase is something that is far beyond reality at this point. More likely is a 0.01% increase in EV share which results in a 1.38 decrease and a 2.09 decrease in the log of EV sales in the first and second case respectively. This decrease is a lot less panicking than the big numbers visible in Table 4.2. This still leaves the question as to why EV share does not have a positive effect on the sales. We expected a kind of "social media effect" to exist where the increase in EVs in the vehicle market would lead to more sales and even more EVs on the roads. Instead we observe an inverse effect. The most probable explanation is the fact that EVs are still a pretty new market. Only a small group of people is fully aware of what it has to offer and are convinced of the product. If long term general awareness does not grow only this selected group will buy an EV or even consider buying one. This means that the more people actually buy an EV, the less potential buyers are left, because there are so few people that are being turned into potential buyers.

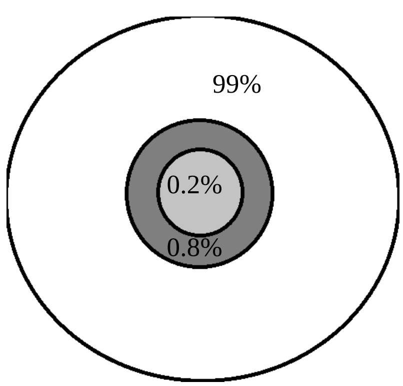

Figure 4.2. Hypothetical distribution of car owners who are not interested in buying an EV (white), those who are interested and have bought one already (light grey) and those who are interested but have not yet bought an EV (dark grey)

Figure 4.2 shows a fictive distribution of people who are and who are not interested in buying an EV in the early years of the technology. The problem is that the grey circle is growing at such a slow pace that more people shift from dark grey to light grey than from white to dark grey. This means that there is too little interest to replace each person that was interested and now bought an EV with a new potential buyer. So the more EVs are being sold in total, the less the monthly EV sales with respect to this single variable. A way to increase the size of the grey circle can be a governmental awareness campaign, a new technological breakthrough or a new player entering the market with new attractive models. This last one is exactly what happened when Tesla entered the market with their model S vehicle. If the model would have concluded that the effect was positive governments could have abided by a EV quota on the government fleet as has been done in Beijing where 30% of government vehicles have to be an EV. Even though this might not directly boost the EV market, the government will at least send out a signal that might have an impact on more qualitative factors such as attitude. This might still be a future option when more research has been done.

Lastly the seasonality of the data should be mentioned. In Figure 4.3 we distinguish three different lines representing the real values of the dependent variable together with the predictions of the model.

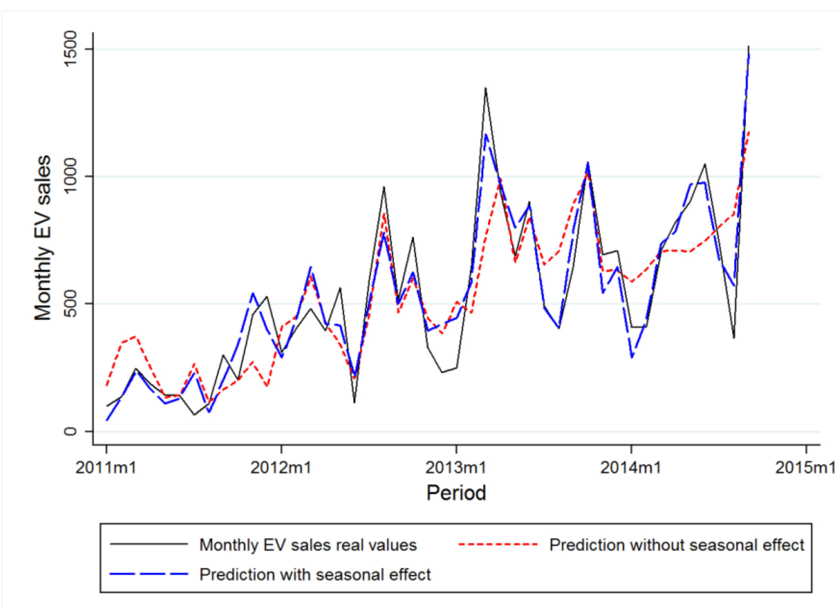

Figure 4.3. Monthly EV sales model prediction with and without seasonal effect included

Even though the red line follows the trend of the sales, the blue line is more accurate in its predictions. Just by analyzing the figure we can therefore say that there is a monthly seasonal effect with regards to vehicle sales. It makes sense that in different seasons more or less people buy cars and online as well there are thousands of blogs and website claiming to know what the best moment is to buy a car. Only trusting the figure is helpful to get the general idea however, but it would be nice to prove this with sound numbers as well. With that in mind a yearly effect was included in the model at first, but this didn't return any valid solutions. When adding dummies for each month we did find a highly significant (on the 1% level) monthly effect that had to be included in the model. This lead to the statement that EV sales are time dependent.

	Effect	**Standard error**	**t-value**
Model 1			
$TC_{EV/ICE}$	-63.525481	24.222762	-2.6225531
EV_Range	29.344099	8.8718861	3.3075378
ChIn	0.00257066	0.00940848	0.27322751
EV_Share	-13777.661	3646.3566	-3.7784732
$OC_{EV/ICE}$	3.4660807	1.4925409	2.3222685
Model 2			
$TC_{EV/ICE}$	-36.844411	3.5258406	-10.449823
EV_Range	33.895422	6.9685827	4.8640339
ChIn	0.01621404	0.00847565	1.9130144
EV_Share	-20893.956	3387.2829	-6.1683527
EV_Ben	3.7729627	.88249772	4.2753229
$OC_{EV/ICE}$	3.4030118	1.1045313	3.0809554
Model 3			
$TC_{EV/ICE}$	0.78030498	15.267791	0.05110792
EV_Range	28.210592	9.9333217	2.8399958
ChIn	-0.00524466	0.01565745	-0.33496253
EV_Share	-5693.3417	6032.0783	-0.94384413
$OC_{EV/ICE}$	-0.16912337	2.579245	-0.06557088

Table 4.2. Summary of the total effects of the variables with their standard errors and t-values to indicate the significance

5. Discussion

The aim of this study was to assess the relationship between the EV sales and several variables that can be adjusted by the government or automotive industry in order to see if anything can be done to boost EV sales. Not all of the considered variables seemed to make a difference but some did have the hypothesized effect. Each of the variables have been studied in previous literature already, but not necessarily with respect to EV adoption. This study aimed for a broader perspective where all factors that are expected to have an influence on EV sales are considered simultaneously in one model. Working with more variables will actually reduce the bias on the results that will therefore be more precise and will more likely be of use to any party willing to take action to boost the EV market.

First, a price increase was shown to render EVs less attractive and this will reduce the sales. This is in line with expectations of experts, but other than suggesting this relationship no such result has been found before based on quantitative research and especially not in combination with other factors as range and efficiency that are correlated with the vehicle price (Hensley et al., 2012). One reason for this is the fact that EVs have not been commercial for many years. This makes it difficult to execute a study over a long time scope to increase credibility of the results. On top of that vehicle prices are not often subject to variation, definitely not within a year. What has therefore been done in previous studies is to substitute the price variable by a continuous variable that changes in the short term (Thatchenkery, 2008). This study has assumed vehicle prices to be constant within a year and only change with the release of new models assumed to be at the start of a new year. This is not as precise as following the monthly variation in price. A second limitation is that a selected number of vehicles has been chosen to represent the whole market for price as well as range. Figure 3.4 shows that for EVs most part of the market has been covered by the selection, but for ICE vehicles it is not so that more than 90% of the market consists of just a small group of vehicles. Therefore only the 5 most sold vehicles have been chosen to represent the total group. Another study could thus increase this group of selected vehicles which would also lead to more precise results.

An increased range and efficiency (lower operating cost) has been proven to have a positive effect on EV sales. Previous studies already showed that fuel prices had an influence on the sales of EVs, but here we have given more dimension to the variable by including the fuel prices into the bigger equation of operating costs. Two small comments should be made here. First, the diesel price is not the same as the gasoline price and even though they evolve at a very similar rate, they are not completely identical. A distinction could have been made between the gasoline vehicles and diesel powered vehicles and treat both types separately in the model. It will be left to other researchers if this could be an added value. The considered diesel prices are also with taxes excluded as they can be found on the website of the CNR (Comité National Routier). This is not a real problem unless when some event occurs and the government decides to drastically change the taxes levied on fuel costs. Researchers should therefore pay attention whether such an event has happened within the scope of the research or not.

Also does financial support in the form of subsidies and tax exemptions lead to an increase in the sales of EVs. As mentioned in the beginning of this research already Tseng (2013) found similar results about the importance of financial support mechanisms and this study can only back up that theory. With the very small difference in taxes to be paid in recent years tax exemptions are only considered to make a difference in the initial purchase decision and future benefits are assumed not to have an impact on the EV sales. Financial support is important for consumers and not only to lower the cost of a vehicle. It is a way for the government to transmit a message to the public as well. A message that a new technology is available that should be considered by people who want to buy a new vehicle. The sudden increase in EV sales in August 2012 in France when a new subsidy scheme was introduced show that people need external factors to augment their awareness for new technologies. Much easier is to stick to old habits, but these are not necessarily the best for the society and even for the consumers personally.

One more result is the positive influence of installed charging infrastructure on the EV sales. In Table 4.2 this effect is displayed, but even though the effect is positive as was being expected, it lacked significance so no real conclusion can be drawn based on that result. This is similar to another study that was done recently. Sierzchula et al. (2014) also didn't manage to find significant results for the relationship between charging facilities and EV sales. One reason may be that the collection of data resulted from the same source, i.e. Chargemap. Even though there is no way to question the correctness of this data, it is sure that not all charging facilities have been registered online which means that many are left out of it. It is the most complete database available and definitely elaborate enough, but if somehow it would be possible to obtain data from every single existing charging pole the result may have been different. A study of the OECD predicts a vast increase in installed charging infrastructure between now and 2020, even up to 2050 (Lucchese et al., 2012). It will be interesting to execute a more detailed study on the relationship between EV adoption and charging facilities in a few years, if the OECD's prediction come true, to see if this aspect needs more investment or not to reach the minimum where it will actually start positively influencing the sales. In January 2013 the French government also agreed on a new plan that foresaw additional subsidies on charging poles. From now on not only EVs would be subsidized but those who wanted to place a charging pole at home or in the office could also count on an additional subsidy. This subsidy scheme is still in place now, but has been left out of the study because it is too soon to even start guessing what the influence is on a large scale (AVEM, 2014).

In conclusion, this research has added value to the existing literature on EV sales, especially because it focuses not just on differences with other vehicles, but actually looks at the real results on the EV sales. It is useful to know the difference in total lifetime costs of an EV and an ICE vehicle, but these are only theoretical results and do not show what the impact on the industry is. This study directly links market variables and government policies to the EV sales so as to see which factors have the biggest impact and should be adjusted in order to make a difference.

6. Conclusion

In conclusion, governments and the automotive industry are able to influence EV sales and not just in one way. The primary goal of this dissertation was to assess the relationship between market variables and the sales of EVs. Knowing the exact impact of each variable now gives the opportunity to policy makers to focus on those aspects that lead to the desirable outcome.

This study will possibly contribute to today's discussion, but also the discussion of tomorrow. Not only are we depleting all our resources in our current consuming-centered societies, but also our transportation model is outdated. About ten years ago hybrid vehicles introduced the possibilities of electric transportation and today EVs are already part of every car manufacturers' gamma. The positive impact is difficult to ignore. Not just on a personal scale for having a more quiet and smooth driving experience and being able to 'refuel' at home, but, more importantly, the tailpipe emissions are zero. This makes EVs an interesting means to achieve the national and international agreements on reducing global pollution levels. Apart from these direct advantages a high EV penetration also opens up the way for new technologies as V2G which allows them to act as micro-power plants. Since we are moving to a power network with more interconnected micro-grids electric vehicles will probably only become even more attractive in the future.

This study has shown that several factors influence the EV adoption. A lower price of the vehicle or higher subsidies will have a visible impact on the EV sales. So does an increased efficiency and a higher range. These are all aspects that governments might want to control to increase the life standard in their country by redirecting investment cash flows to the right institutions.. The automotive industry might aim on optimizing these features of their vehicles and spend less time and effort on others. This will help them to work more efficiently and to create a competitive advantage on the long term. With high levels of horizontal integration between businesses from different sectors and the continuous need for a company to innovate, EVs offer a great opportunity for companies to get ahead of the competition now that we are undergoing a new industrial revolution (Rifkin 2011).

At this point it is already visible that EVs are getting more popular and incentives and regulations from higher institutions have definitely not been for nothing. However, it is important to keep in mind that today everything is about consumption and in the end the consumers are holding the key to build or destroy a new technology. By using this paper, governments and car businesses will hopefully optimize their efforts to make EVs widely accepted among the public. There is only so much they can do to make people aware of positive aspects of EVs. After that it’s the people’s turn to take into consideration the potential of EVs for themselves, for the society and for the future when they go to a car dealer to buy their new car.

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Annex

Annex A

Make	Model	EV Type	Range (km)	Price (EUR)	Market share	Mshare after transformation			
2011									
Citroen	C-Zero	Pure-electric	130	35,000	24.52%	26.75%	**Price weighted avg 2011**		
Peugeot	Ion	Pure-electric	130	35,000	24.30%	26.51%		**29177.51225**	
Bolloré	Bluecar	Pure-electric	150	19,000	15.17%	16.55%			
Renault	Fluence ZE	Pure-electric	160	24,580	15.06%	16.42%		**Range**	**138.7538**
Mia	Electric	Pure electric	125	22,500	9.47%	10.33%			
Nissan	Leaf	Pure-electric	160	30,000	3.16%	3.44%			
2012					91.67%	100%			
Peugeot	Ion	Pure-electric	130	35,350	24.88%	25.67%	**Price weighted avg 2012**		
Renault	Fluence ZE	Pure-electric	160	24,580	5.21%	5.37%		**29337.49536**	
Bolloré	Bluecar	Pure-electric	150	19,000	27.25%	28.11%			
Nissan	Leaf	Pure-electric	160	35,990	9.25%	9.54%		**Range**	**139.7473**
Citroen	C-Zero	Pure-electric	130	35,350	23.57%	24.31%			
Mia	Electric	Pure electric	125	22,500	6.78%	6.99%			
2013					96.94%	100.00%			
Peugeot	Ion	Pure-electric	130	29,500	2.03%	2.11%	**Price weighted avg 2013**		
Renault	Zoe	Pure-electric	210	20,700	62.77%	65.11%		**23530.33347**	
Bolloré	Bluecar	Pure-electric	150	19,000	7.50%	7.78%			
Nissan	Leaf	Pure-electric	160	35,990	16.38%	16.99%		**Range**	**186.9272**
Smart	Fortwo	Pure-electric	100	24,250	5.44%	5.64%			
Mia	Electric	Pure electric	125	19,825	2.29%	2.38%			
2014					96.41%	100.00%			
Peugeot	Ion	Pure-electric	130	29,600	2.48%	2.75%	**Price weighted avg 2014**		
Renault	Zoe	Pure-electric	210	20,900	46.70%	51.72%		**25023.32004**	
Bolloré	Bluecar	Pure-electric	150	18,300	13.90%	15.39%			
Nissan	Leaf	Pure-electric	160	30,690	17.74%	19.65%		**Range**	**193.3719**
Smart	Fortwo	Pure-electric	145	25,850	5.80%	6.42%			
Tesla	Model S	Pure-electric	426	71,040	3.68%	4.08%			
					90.30%	100.00%			

Table A. Overview of the data of the reference EVs used in this study

Make & Model	Market share	Mshare after transformation	Price (€)	Efficiency (L/100km)	CO2(g/km)	Avg emiss	Avg p (€)	Avg eff (L/100km)
2011								
Renault Clio	5.6	27.3	14100	6	135	**120.71**	**15824.97**	**4.93**
Peugeot 207	4.7	22.8	14900	4	110			
Citroen C3	3.6	17.5	13750	6	140			
Renault Megane III	3.6	17.4	20600	5	116			
Renault Twingo	3.1	15.0	17250	4	94			
2012		100%						
Renault Clio	6.3	25.6	14100	6	135	**121.59**	**17062.70**	**4.96**
Renault Megane III	6.2	25.5	20750	5	116			
Citroen C3	4.5	18.5	13800	6	139			
Citroen C4	3.9	16.1	20650	4	110			
Peugeot 208	3.5	14.3	15990	4	98			
2013		100%						
Renault Clio IV	5.8	30.2	14300	5.5	127	**112.02**	**16997.01**	**4.50**
Peugeot 208	5.1	26.5	14550	4	98			
Citroën C3 II	3.0	15.6	15450	4	99			
Renault Scenic III	2.8	14.9	24700	5	127			
Renault Megane III	2.4	12.6	21400	4	104			
2014		100%						
Renault Clio IV	5.9	28.8	13700	6	127	**106.93**	**17291.22**	**4.33**
Peugeot 208	4.7	22.9	17400	3.8	98			
Renault Captur	3.5	17.1	21400	4.1	103			
Citroën C3 II	3.4	16.6	15650	3.8	99			
Peugeot 308 II	3	14.6	21250	3.7	95			
		100%						

Table B. Overview of the data of the reference ICE vehicles used in this study

Annex B

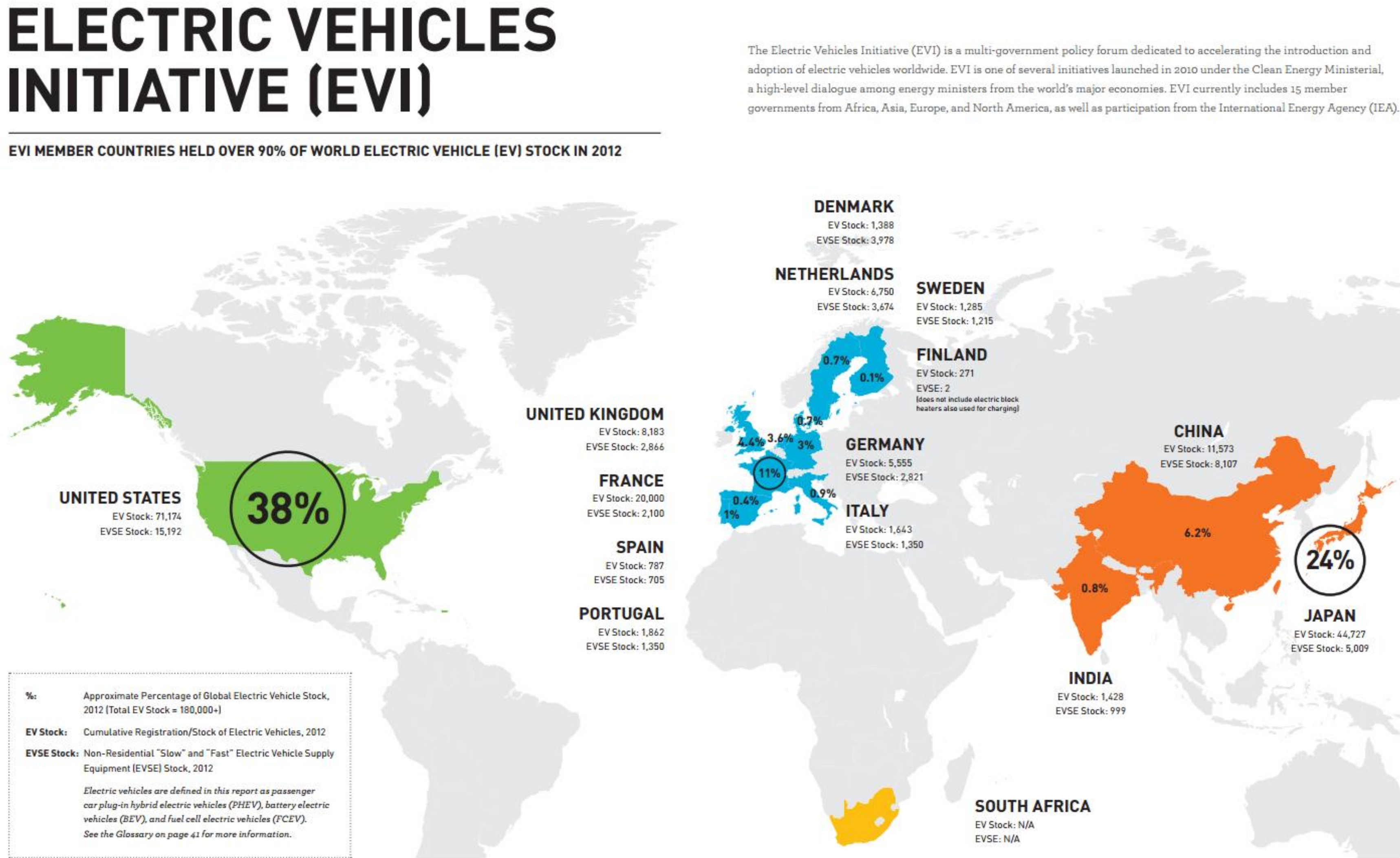

Figure A. EV stock held by EVI member countries in 2012

Annex C

Variables	Model 1	Model 2	Model 3
p1	-1,339***	-1,601***	
	(-240.1)	(-199.5)	
lr	-373.1***	-448.8***	-51.66**
	(-69.05)	(-57.21)	(-21.21)
lrp1	250.2***	300.0***	
	(-47.07)	(-38.92)	
x	-0.00233	0.00381	-0.0248
	(-0.0134)	(-0.0114)	(-0.0199)
x2	2.04E-05	5.15e-05***	8.12e-05***
	(-0.0000216)	(-0.0000163)	(-0.00002740)
evsharepp	-13,778***	-20,894***	-5,693
	(-3646)	(-3387)	(-6032)
lben		3.773***	
		(-0.882)	
ocratio	-31.01***	-37.60***	1.687
	(-9.752)	(-6.866)	(-4.632)
ocratiop1	21.43***	25.49***	
	(-6.517)	(-4.593)	
month_2	0.425**	0.419*	0.413*
	(-0.201)	(-0.233)	(-0.249)
month_3	1.101***	0.982***	1.106***
	(-0.277)	(-0.268)	(-0.29)
month_4	1.269***	1.197***	1.053***
	(-0.241)	(-0.253)	(-0.277)
month_5	1.607***	1.622***	1.065***
	(-0.264)	(-0.275)	(-0.312)
month_6	1.831***	1.771***	1.025***
	(-0.324)	(-0.286)	(-0.332)
month_7	1.633***	1.651***	0.887**
	(-0.351)	(-0.307)	(-0.373)
month_8	1.854***	1.537***	0.526
	(-0.472)	(-0.349)	(-0.417)
month_9	2.525***	2.175***	0.970***

	(-0.411)	(-0.339)	(-0.366)
month_10	2.808***	2.583***	1.364***
	(-0.48)	(-0.379)	(-0.425)
month_11	2.724***	2.760***	1.110**
	(-0.488)	(-0.367)	(-0.511)
month_12	3.046***	3.153***	1.165*
	(-0.543)	(-0.44)	(-0.621)
p2			-253.5***
			(-95.47)
lrp2			49.65***
			(-17.51)
ocratiop2			-1.154
			(-4.181)
Constant	2,008***	2,375***	271.7**
	(-352.5)	(-289.9)	(-114.6)

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table C. Returned variable coefficients of model 1, model 2 and model 3

With p1 being the gross price ratio, lr the log of the range, lrp1 the interaction term between lr and p1, x the charging infrastructure per 1M residents, evsharepp the share of EVs in the total vehicle fleet in the previous period, lben the log of the financial benefits (subsidies + tax exemptions), ocratio the ratio of kilometers/EUR of EVs over the kilometers/EUR for ICE vehicles, ocratiop1 the interaction term between p1 and ocratio and p2 the price ratio with financial benefits already included in the EV price.