

FACULTY OF BUSINESS ECONOMICS

Masterproef

Development of an agent-based model for electric vehicle penetration of the European fleet over the next decennium

Promotor : Prof.dr.ir Tom BELLEMANS

Wim Vanderheyden

Master Thesis nominated to obtain the degree of Master of Management , specialization Management Information Systems



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Master of Management: Management Information Systems



Supervisor : De heer Luc KNAPEN dr. Ansar-UI-Haque YASAR



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Preface

This master thesis forms the concluding piece of the Master of management – Management Information Systems course at the Hasselt University.

I would not be able to finish this master thesis with the help and support of many people. I like to make use of this moment to thank those people who helped writing this master thesis.

First off all, I would like to thank my promotor, Prof.dr.ir Tom Bellemans, and my copromotors, Dr. Ansar Yasar and Mr. Luk Knapen for their constructive critique and great encouragement. Without their input, it would be impossible to finish this thesis.

I would also like to thank my parents and my brother. Thanks to their continuous support, I had the opportunity to finish my bachelor and master courses successfully.

I wish you a lot of pleasure reading this master thesis.

Wim Vanderheyden

Hechtel, mei 2012



Summary

This master thesis is a research with the purpose to develop an agent-based model for the electric vehicle penetration of the European fleet over the next decennium.

Nowadays, we are living in a world where the emphasis is put on the health of our planet. Different manufacturers and producers are using this trend to develop a wide array of "green products". These products are less harmful for the environment. Among these ecofriendly products, the hybrid and electric vehicles play a large role. The purchase of these kinds of vehicles is often encouraged by the government.

Not everybody will buy such a vehicle with the purpose of being green or to help the environment. Many people would buy these cars because of financial reasons. These financial reasons could include the steep rise of the gasoline prices. The technology around these cars is furthermore getting more and more reliable. This translates into a higher battery range. The vehicles also pass the ISO safety rules, so the general safety of the cars is not an issue anymore.

Technically speaking, we can state that a hybrid or electric vehicle can be perfectly used by a lot of people. But the purpose of this master thesis is to get an idea of what the perception of the consumer regarding the hybrid or electric vehicle is and which factors play an important role in the decision which car to buy. This will be shaped into an agent-based model which can be used to predict the hybrid and electric vehicle penetration rate in the overall fleet.

The research question of this master thesis is formulated as follows:

"What are the main agent behavioral characteristics in an agent-based model to predict the hybrid and pure electric vehicles market penetration rate in the European fleet over the next decennium?" To be able to give an answer to this research question, it is necessary to conduct a study of the relevant literature. After this study, a practical research will be presented in this master thesis.

Literature study

The chapter involving the literature study consists of 3 sections.

The first section will describe the background of the hybrid and electric vehicles. There are a lot of authors who have investigated the penetration of these vehicles on the road. The first paper is one from Nemry and Brons from 2010. They state that the electric drive vehicles are currently emerging in the market and are seen as a promising option towards a less carbon intensive road transport. A second study is one conducted by Pike Research in 2011. They have calculated some figures regarding the penetration rate of (Plug in) electric vehicles. A third paper is the important paper written by Margaret J. Eppstein. This paper from 2010 describes an agent-based model to study the market penetration of plug-in hybrid electric vehicles in the United States. This thesis will play a very important role in this master thesis.

The second section of the literature study is dedicated to the different types of electric vehicles. In this section, the 3 main types of electric vehicles will be discussed. This are respectively the battery electric vehicle (BEV), the hybrid electric vehicle (HEV) and the plug-in hybrid electric vehicle (PHEV)

The third section describes the agent-based modeling technique. This is a powerful simulation modeling technique that has been used in a number of applications in the past few years. This technique was also applied to real-world business problems. This thesis is written with an eye on this technique.

Practical research

The literature study is followed by the practical research of this master thesis. In this research, we will try to give an answer to the research question. We will try to find how an agent-based model to predict the hybrid and electric vehicle penetration rate of the European fleet over the next decennium will look like.

The first part of the practical research consists of a comparison between the results and conclusions in the Eppstein paper and the results of a survey I conducted personally. This survey asks the respondents what they find important in the decision making to purchase a hybrid or electric vehicle. These answers of the respondents will be compared with the results in the Eppstein paper. This comparison will be built on 5 important factors:

- Gasoline prices
- Battery range
- Purchase price (and rebates)
- Social and media influences
- Consumer values regarding financial vs non-financial concerns

After this comparison, we know if there are a lot of differences between the European respondents in my survey and the respondents from the United States in the Eppstein paper.

In the second part of the practical research, the agent based model will be described according to the results of the comparison between the Eppstein paper and the personal survey. After the characteristics of the agents, a set of rules will be defined how to model the agents. The factors taken into account are the following ones:

- The time resolution
- The Sensitivity to the cost
- The social network
- The population and size of the agent
- The range anxiety

After the suggestions about these factors, we will make a suggestion about the effective decision model that can be used to decide which kind of vehicle the agents will purchase.

This master thesis will be terminated with an appropriate conclusion and some suggestions for future work.



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Chapter 1: Introduction

1.1 Problem definition

Nowadays, we are living in a world where the emphasis is put on the health of our planet. Nobody can escape this trend to "be green". That is why everybody is convinced that they have to buy products which are less harmful for the environment. Different manufacturers and producers have developed a wide array of "green products". This array spreads out from eco-friendly dishwashing detergent to produce your own green electricity at home.

The hybrid and electric vehicles are also represented in those eco-friendly products. In some countries, the choice by the consumer to buy such a vehicle is even encourage by the government. This is done under the form of lower taxes and in some cases different kinds of premiums. There are also a lot of companies who offer their employees cars with a certain limit on the CO_2 emission to give the company some kind of a green image.

But not everybody would buy this kind of vehicles with the purpose of being green or to help the environment of the planet. There are a lot of persons who would buy these cars because of financial reasons. The steep rise of the gasoline prices plays a major role in this case. You will read further in the text that the gasoline price have increased with almost 80% in Belgium over the past 10 years. It is not to expect that these gasoline prices will decrease in the near future considering the economical circumstances. Another factor that plays a role in the adaptation of the hybrid and electric vehicles is the fact that the technology around these products is getting more and more reliable. The range of the cars is getting larger and larger which means that the cars are getting more and more efficient. The hybrid and electric vehicles nowadays also pass the ISO safety rules. These kind of vehicles are generally heavier than similar vehicles with an internal combustion engine because of the heavy battery. If a car is heavier, the car is safer for the passenger when they suffer a heavy collision.

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1.2 Research question

Technically speaking, we can state that a hybrid or electric vehicle can be perfectly used by a lot of people. But the purpose of this master thesis is to get an idea of what the perception of the consumer regarding the hybrid or electric vehicle is. It is important to know what the consumer takes into account when he or she has to make the decision which car to buy. This will be shaped into an agent-based model which can be used to predict the hybrid and electric vehicle penetration rate in the overall vehicle fleet.

This brings us to the following research question:

"What are the main agent behavioral characteristics in an agent-based model to predict the hybrid and pure electric vehicles market penetration rate in the European fleet over the next decennium?"

1.3 Subquestions

This research question will be answered with the use of some subquestions:

- What are the important factors in the agent-based model?
- How do the European respondents value those factors?
- Are the opinions of the European respondents similar to the opinions of respondents from the USA?

Chapter 2: Literature review

2.1 Background

In the literature, there are a lot of authors who have investigated the penetration of the electric or hybrid vehicles on the road. In this section, I will discuss some of the papers which are written around this subject.

The first authors which I will discuss are Nemry and Brons. In their paper from 2010, they have investigated the market penetration scenarios of electric drive vehicles. They see that the electric drive vehicles are currently emerging in the market and are seen as a promising option towards a less carbon intensive road transport.

Their report presents a prospective analysis in relation with 2 of the current main bottlenecks for the diffusion of the electric vehicles. These bottlenecks are the performance and the cost of the batteries, and the access to charging infrastructures. The analysis develops scenarios for the future market for electric cars based on projections of these factors. It also provides indicative estimations of the impacts on the energy consumption and the CO2 emissions at an EU level.

In the paper, a modeling approach was developed, which makes it possible to assess the future market penetration of the electric vehicles and to evaluate the effects of some key factors determining electro mobility, including battery costs and performance and access to the grid for recharging. This approach offers the possibility to assess the effects of policies such as infrastructure investment and incentives to car consumers. So this approach is in a sense mainly demand driven. The possible constraints from the electricity grid and from the power generation sector are not considered. Also are the effects of a growing electricity demand and possible charging profiles not addressed in this paper.

In this paper from Nemry and Brons, the main conclusions drawn from the analysis are the following ones:

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- The deployment of the pure electric cars is expected to remain very limited at least until 2020. This is due to a barrier to a large scale market development of electric cars, namely the access to charging infrastructures at home, in working and urban public places. The authors conclude that a faster market penetration would be achieved in the case of PHEVs as soon as they are commercialized. A voluntary development of the standards and charging infrastructure would contribute to a doubling of the market penetration of the Electric and PHEVs by 2030 compared with what would happen under a much more limited development.
- The upfront costs for the electric-driven vehicles are much higher than conventional car costs due to the battery costs. Different business models currently tested would help spreading these costs over the life of the car and this will help improving the attractiveness of those cars. But the electric-driven vehicles are also less cost effective on a lifetime perspective than their conventional counterparts. The progress in the battery performance and costs are possible and this would largely improve both the cost performance and the autonomy range. This would represent the second driver for the future success of the electric-driven vehicles market, and in particular for the pure electric cars. The scenarios which are considered suggest however that the full benefits of these progress on batteries would manifest the most in the case where charging infrastructure deploy.
- At the EU level, the impact on the fuel and electricity consumption by the road passenger transport would be negligible until 2020-2025. The effects would become significant later and the magnitude of the fuel savings could be in a range of 6 to 20 % by 2030 compared with a reference scenario where electro mobility doesn't develop.
- This would also result in a reduction of the CO2 emissions from road passenger transport by 4 to 12% compared to the reference scenario. The situation at the country level would be largely influenced by the power generation mix (Nemry and Brons, 2010).

Also Pike Research has calculated some figures regarding the penetration rate of (Plug in) electric vehicles (PEV). These results were published in September 2011. It forecasts that the annual sales of the plug-in electric vehicles will reach almost 360000 vehicles by 2017 in the USA. This will represent a compound annual growth rate of 43% between 2011 and

2017. To understand where the vehicles will likely be sold, the Research group has created a forecast model using a variety of inputs including the population and demographic trends, the affinity towards electric vehicles, and automakers' intended availability of vehicles.

It appears that the most populous states will see the highest sales volumes, with California, New York and Florida leading the way. But when we take a look at the percentage of total vehicles sales, the smaller states will lead. Then Hawaii, Oregon, Washington, DC and Delaware are going to be the top states for the plug-in electric vehicles penetration. Pike thinks that California, New York and Florida will post cumulative PEV vehicle sales in the year 2011 until 2017 of 366099, 146242 and 101530 units respectively. This represents 5.4%, 3.7% and 2.8% penetration respectively.

The top state will be Hawaii with PEVs representing 6.3 % of the total light-duty vehicle sales in 2017. This is a surprising result because this state has typically the highest gas prices in the nation. The second highest penetration rate will be situated in California (5.4%). This state is followed by Oregon (5.4%), Washington, DC (4.6%) and Delaware (4.5%). (Pike Research, 2011)

Another important author which investigated the hybrid and electric vehicles is Margaret J. Eppstein. Her paper from 2010 describes an agent-based model to study the market penetration of plug-in hybrid electric vehicles in the United States. The concept of agent-based modeling is explained further in the text.

In this paper, a spatially explicit agent-based vehicle consumer choice model is developed to explore the sensitivities and nonlinear interactions between various potential influences on plug-in hybrid vehicle (PHEV) market penetration. The model accounts for the spatial and the social effects (these include the threshold effects, homophily and conformity) and also the media influences. By use of preliminary simulations, Eppstein demonstrates how such a model could be used to identify nonlinear interactions among potential leverage point, inform policies affecting the PHEV market penetration, and help to identify future data collection necessary to more accurately model the system.

The sensitivity of the model is examined by means of different factors. These factors are the following:

- Gasoline prices
- Ability of agents to consider fuel costs
- PHEV purchase price and rebates
- PHEV all-electric battery range
- Consumer values regarding financial vs. non-financial concerns in vehicle purchase
- Agent comfort thresholds with the PHEV technology
- Social and media influences on PHEV market penetration

The simulation in the paper indicates that the PHEV market penetration could be enhanced significantly by providing consumers with ready estimates of the expected lifetime fuel costs which are associated with the different vehicles. Also the simulations make clear that an increase in the gasoline price could nonlinearly magnify the impact on the fleet efficiency. The simulations also point out that a potential synergy from a gasoline tax with proceeds is used to fund the research into longer-range lower-cost PHEV batteries. (Eppstein, 2010)

In the table below, you can read the different conclusions and recommendations for the important factors. This table also comes from the Eppstein paper from 2010.

Potential leverage points	Examples of potential	Examples of potential
	vehicle manufacturer and	governmental influences
	dealer influences	
Purchase price of PHEV	Keep sticker price as low as	Rebates or tax credits to
	possible to stimulate sales	PHEV purchasers, state sales
	and get PHEVs into the	tax rates sensitive to fuel
	market; try to lower PHEV	efficiency; tax breaks or
	sticker prices when rebates	other manufacturer
	are retired	incentives to keep PHEV
		sticker prices low
Gasoline price	NA	Gasoline tax; keep electricity
		costs low relative to gasoline
		price
Battery range of PHEV	Prioritize research and	Tax breaks or other
	development of long-range	manufacturer and research

	affordable PHEV batteries	incentives battery
		improvements
Ability of vehicle consumers	Provide easy-to-use fuel cost	Require vehicle
to accurately assess fuel	estimators on websites and	manufacturers to include
costs for GVs, HEVs, and	on kiosks in dealerships;	average estimated lifetime
PHEVs	include bounds on 5-year	costs on the sticker; provide
	fuel cost estimates on	easy-to-use fuel cost
	sticker, based on typical	estimators on websites; use
	driving patterns and high and	PSAs to educate consumers
	low EIA gasoline cost	on the magnitude of PHEV
	projections	fuel savings
Comfort level of vehicle	Provide strong PHEV battery	Use PSAs to educate
consumers in adopting the	warranties; provide for PHEV	consumers; provide rebates
new PHEV technology	battery trade-ins; provide	or tax breaks for PHEVs and
	PHEV battery leasing	household electric service
	options; repurpose used	upgrades needed for
	PHEV batteries	recharging; install municipal
		recharging stations
Relative weight that	Use PHEV advertisements to	Use PSAs to educate
consumers place on rational	raise consumer awareness of	consumers on environmental
financial vs. other reasons to	environmental benefits;	and energy security
save gasoline	focus initial PHEV	concerns; keep
	distributions and marketing	environmental issues visible
	on more environmentally	through press conferences,
	minded regions	policy discussions, etc.

Table 1: Recommendations and conclusions Eppstein 2010

2.2 Types of Electric Cars

Nowadays, most cars are driven by a "classic" combustion engine. This engine runs mainly on petrol or diesel. There is a small share of the cars which run on LPG (Liquefied Petroleum Gas). Next to those "classic" cars, there are alternatives which are driven by an electric technology. We can distinguish 3 main alternatives which are relevant for my work, namely the Battery Electric Vehicle (BEV), the Hybrid Electric Vehicle (HEV) and the Plug-in Hybrid Electric Vehicle (PHEV). These 3 types will be explained in this topic.

2.2.1 Battery Electric Vehicle (BEV)

A battery Electric Vehicle is a type of electric vehicle that doesn't use an internal combustion engine. They are all electric, which means that they are totally dependent on plugging in to the power grid to charge the batteries. So the batteries are used to power an electric motor, which in his turn drives the vehicle. This makes it possible that the BEV can drive and operate without any emissions. They can also operate in complete silence, except the noise that comes from the tires. The exact technological working of the vehicle is beyond the scope of this work.

Due to the characteristics of an electric engine, the car won't need a gear box most of the time. Most new BEV also make use of "regenerative braking", where the lost energy (friction) from braking can be restored in the batteries.

It is true that the battery electric vehicles produce no emissions when they are used. But to overview the wide scale environmental benefits, one also has to take the source of the electricity into account. If this electricity is generated by renewable energy, the electric cars can offer a large reduced environmental impact than the other vehicle technologies. But the investigation concerning where the energy comes from to produces the cars is a discussion beyond the scope of this thesis.

The main advantages of a battery electric vehicle are the following:

- They produce zero emissions when they operate
- They are cheap to run, because it doesn't cost much to recharge the batteries
- They are very quiet when they operate
- They are very useful in the city

But the battery electric vehicles also some disadvantages:

- They have a high capital cost
- They are generally small in size
- They come with a limited range and speed
- They have a slow recharge rate

An example of a battery electric vehicle is the Nissan Leaf.

The next section will contain the illustration of the Hybrid Electric Vehicle.

2.2.2 Hybrid Electric Vehicle (HEV)

The hybrid electric vehicles are driven by 2 (or more) sources of energy. They are powered by a combination of electricity and either petrol or diesel. The electricity has the function of an intermediate energy storage medium and so the overall efficiency of the vehicle will be improved. So the hybrid electric vehicle doesn't need to be plugged in to recharge the battery. The result is that the amount of fuel needed will decrease, which in his turn lowers the emissions and the overall fuel cost.

As with the BEV's, the most part of the HEV's make use of the "regenerative braking" technology, where the energy from braking is restored into the batteries.

One can divide the hybrid electric vehicles into 2 groups, namely the parallel HEV on the one hand and the serial HEV on the other hand. In case of the parallel HEV's, the electrical engine is coupled to the combustion engine, and they can both drive the wheels. An example of such a HEV is the Honda Insight. In case of the serial HEV's, the wheels are exclusively driven by the electrical engine, which in turn gets its energy from a battery driven by the combustion engine. A Van Hool bus is an example of a serial HEV. When a manufacturer combines the parallel and the serial technology, we speak about combined or power-split HEV. An example of such a vehicle is the Toyota Prius. Just like in the case of the battery electric vehicle, the exact technological working of a hybrid electric vehicle is beyond the scope of this work. These are the main advantages of the hybrid technology:

- It significantly improves the efficiency of the fuel consumption and it reduces the running costs
- It reduces the in-use carbon dioxide and other emissions which are harmful, particularly in the urban driving conditions

Unfortunately, there are also a few downsides:

- There is a significantly higher capital cost because of the additional components and the current expensive battery technology
- The higher production and disposal emissions than the other conventional vehicles have to be taken into account

The third type, namely the Plug-in hybrid electric vehicle, will be illustrated in the next section.

2.2.3 Plug-in Hybrid Electric Vehicle (PHEV)

The plug-in hybrid electric vehicle can be labeled as a middle course between the battery electric vehicle and a hybrid electric vehicle. They work similar like a conventional hybrid electric vehicle in the sense that they can use the petrol or diesel engine as well as the stored electricity from the electric motor. But the PHEV have much larger batteries than the conventional HEV and they can also be charged from the main electricity network when the car is not used. Because of this, the range of the electric motor can be maximized. The most PHEV's also make use of the "regenerative braking" technology to restore the lost energy from braking back into the batteries.

The PHEV's can be divided into 2 key types. The first type can use their petrol or diesel engine to run indefinitely because this engine provides necessary energy for the motion. The second type is in fact a BEV with a small onboard generator with the purpose to extent the range of the vehicle.

These are the main advantages of a plug-in hybrid electric vehicle:

• Significant improvements in fuel consumption

- Reduction of the in-use emissions. They can potentially be zero
- They are very cheap to run
- The electro motor provides quiet operation and rapid acceleration

There are also some disadvantages with concerning the PHEV's:

- They have a high capital cost
- Some types have a very limited range
- Because the additional weight of the battery packs, PHEV's tend to be smaller vehicles

2.3 Agent-based modeling

In my research, I will make use of an agent-based model. This section will contain more information about this modeling technique. Agent-based modeling is a powerful simulation modeling technique that has been used in a number of applications in the past few years. Also this technique was applied to real-world business problems.

In an agent-based modeling (ABM), the system is modeled as a collection of autonomous decision-making entities. These entities are commonly known as agents. Every agent individually assesses his specific situation and then this agent makes decisions on the basis of a set of rules. The agents may execute various behaviors appropriate for the kind of systems they represent. This can be for example producing, consuming or selling. The repetitive competitive interactions which exist between the different agents are also a feature of agent-based modeling. The technique then relies on the power of computers to explore the dynamics out of the reach of the pure mathematical methods.

At the simplest level, an agent-based model only consists of a system of agents and the relationships which exist between them. But even a simple agent-based model can exhibit some complex behavior patterns. It also provides valuable information about the dynamics of the real-world system that it imitates. Agents may also be capable of evolving. This allows unanticipated behavior to emerge. Those sophisticated agent-based models sometimes incorporate neural networks, evolutionary algorithms or other learning techniques to allow realistic learning and adaptation.

Bonabea states that the benefits of Agent-based modeling over other modeling techniques can be captured in 3 statements:

- Agent-based modeling captures emergent phenomena
- Agent-based modeling provides a natural description of a system
- Agent based modeling is flexible

He also states that it is clear that the ability of an agent-based model to deal with the emergent phenomena is what drives the other benefits. The 3 benefits will be explained briefly on the following page.

2.3.1 Agent-based modeling captures the emergent phenomena

The emergent phenomena are a consequence from the interactions between the individual entities. By definition, the entities can't be reduced to the parts of the system: the whole is more than the sum of its parts because of the interactions between the parts. An emergent phenomenon can have properties that are decoupled from the properties of the part. Think of this example: A traffic jam results from the behavior of and interactions between the individual drivers. But this traffic jam may be moving in the direction opposite to that of the cars that cause it. This is a characteristic of emergent phenomena that makes them difficult to predict and to understand. They can be counterintuitive. Agent-based modeling is by its nature the approach to model these emergent phenomena. This modeling approach models and simulates the behavior of the system's constituent units, which are the agents, and their interactions. It captures the emergence from the bottom up when one runs the simulation.

So one may want to make use of agent-based modeling when there is a potential for emergent phenomena. This is the case when

- The individual behavior is nonlinear and this behavior can be characterized by if-then rules, thresholds or nonlinear coupling.
- The individual behavior exhibits memory, path-dependence and hysteresis or temporal correlations, including learning and adaptation.
- The interactions between the agents are heterogeneous and they can generate network effects.
- If averages will not work. Aggregate differential equations tend to smooth out fluctuations. This is not the case with agent-based modeling, which is important because under certain conditions.

2.3.2 Agent-based modeling provides a natural description of a system

Agent-based modeling is in many cases the most natural for describing and simulating a system which is composed of behavioral entities. It is a fact that agent-based modeling has the ability to make the model seem closer to reality. For example, in a supermarket, it is more natural to describe how shoppers move than to solve this with equations that govern the dynamics of the density of the shoppers. Because the density equations result from the behavior of the shoppers, the Agent-based modeling approach will also make it possible for the user to study aggregate properties.

To summarize, one can use agent-based modeling when describing the system from the perspective of the activities of the units is more natural. This is the case when

- The behavior of the different individuals can't be clearly defined through aggregate transition rates
- The individual behavior is complex. In principle, one can do everything by means of equations. But the complexity of the differential equations increases exponentially when the complexity of the behavior increases until the point that it is not feasible anymore.
- The activities are a more natural way of describing the system than the processes.
- The calibration and the validation of the model by means of expert judgment is a crucial factor. Agent-based modeling is often the most appropriate way when one tries to describe what is actually happening in the real world. With agent-based modeling, the experts can easily connect to the model and they can have a feeling of ownership.
- Stochasticity applies to the agents' behavior. When using agent-based modeling, the sources of randomness are applied to the right places as opposed to a noise term added more or less arbitrarily to an aggregate equation.

2.3.3 Agent-based modeling is flexible

The flexibility of agent-based modeling can be seen along multiple dimensions. It is for example possible for one to add more agents to an agent-based model. This type of model also provides a natural framework for the tuning of the complexity of the agents: the degree of rationality, the behavior, the ability to learn and evolve, and the rules of interactions.

A second dimension of the flexibility is the ability to change the levels of description and aggregation. It is easy to play with aggregate agents, subgroups of agents and single agents, which have different levels of description coexisting in a given model.

It is possible for someone to use agent-based modeling when the appropriate level of description or the level of complexity is not known ahead of time and finding it requires some thinking. (Eric Bonabeau, 2002)



Chapter 3: Practical research

3.1 Comparison personal survey vs. Eppstein paper

As mentioned in the previous chapter, there are a lot of authors which have written about the penetration rate of the hybrid and electric vehicles. In this chapter, papers from Nemry and Brons and from Pike Research have been discussed. Also a very important paper from Margaret J. Eppstein has been explored. This last paper will be used during the research in this paper. This will be explained from the next paragraph on.

The scope of this thesis is to develop some kind of agent-based model to predict the electric vehicle penetration of the European fleet over the next decennium. In the paper which is written by Eppstein in 2010, the author uses an agent-based model to study the market penetration of plug-in hybrid electric vehicles in the United States. This model is built on opinions of respondents on some factors via a survey that Eppstein conducted. So we can state that this paper is a good benchmark to compare the results in the United States with results from Europe. The purpose of my research is to conduct a survey and then compare the results of this survey with the conclusions in the Eppstein paper.

The survey which I have conducted has been filled in by 68 respondents. In the next figure on the next page, the age of the respondents has been summarized.



Figure 1: Age group of the respondents

It is clear that the most respondents come from the age group 18 – 21 and 22 – 30, with respectively 24% and 34%. But there are also quit enough respondents from the higher age categories in order that the survey is somewhat representative. Still, we have to bear in mind that there are more young people among the respondents when we are interpreting the results.

In the next figure, some characteristics of the respondents have been summarized.



Figure 2: Characteristics of the respondents

The respondents had the opportunity to fill in more than one characteristic. Most respondents label themselves as students, car enthusiast, suburb/rural commuter and environmentalist/ green enthusiast.

The paper from Eppstein uses a number of factors to examine the sensitivity of the model. These factors have been mentioned previously in the text. In this thesis, the following factors will be used to compare the opinions of the respondents in my survey with the conclusions in the Eppstein paper:

- Gasoline prices
- Battery range
- Purchase price (and rebates)
- Social and media influences
- Consumer values regarding financial vs non-financial concerns

This research will start on the next page, with the study of the gasoline prices.

3.1.1 Gasoline prices

The first factor which I am going to discuss is the gasoline price. This is without a doubt a very important factor, because everybody is concerned about the current trend of the gasoline prices. The prices keep rising, which is a problem for a lot of households and companies. To give an indication, the next table describes the rise of the gasoline prices in Belgium¹:

	Fuel	Diesel	LPG
2002	1,009 Euro	0,765 Euro	0,473 Euro
2007	1,402 Euro	1,094 Euro	0,515 Euro
2011	1.605 Euro	1,441 Euro	0,661 Euro
2012	1,760 Euro	1,550 Euro	0,791 Euro

Table 2: Gasoline prices in 2002, 2007, 2011 and 2012

You can see that the gasoline prices have met a large increase. For example, the prices for fuel, diesel and LPG have increased with respectively 74%, 102% and 67%. It doesn't need an explanation that many households and companies are affected by this.

The CBO (Congressional Budget Office of the United States) has investigated the effect of the gasoline prices on the general driving behavior. This study dates from 2008. This CBO study illustrates the kinds of effect that the increase in gasoline prices have had on consumers. It also suggests the kind of consumer effects that could be expected from different policies which seek to discourage the gasoline consumption. In the long run, this will also limit the associated carbon dioxide emissions. The study is based on a 4 year collection of data about motorists' behavior from the metropolitan freeways in California between 2003 and 2006. The study uses statewide average gasoline prices and wages over that period.

The study states that the first way drivers can reduce the transportation costs is to drive less. This can be achieved my means of public transportation, alternative modes of transportations (for example a bike), carpooling, consolidation trips or telecommuting to

¹ The prices are in Euro/liter. VAT included. The prices for 2002, 2007 and 2011 are the average year prices. The price for 2012 is the current price when I typed this text (8/3/2012)

work. The drivers can also make shorter trips and substitute the more-distant shopping locations by shopping locations closer in the neighborhood. In the long run, one might move closer to work or choose a job that is closer to home.

The possibility that a motorist will make one of the changes presented in the previous paragraph, will mainly depend on the price of the gasoline. It will also depend on other factors which determine how attractive driving is or will be compared with the alternatives. For example, someone who routinely faces heavy traffic jams and/or high parking fees, the benefit for this individual to switch to public transportation can be quite large. On the contrary, motorists who were willing to accept these costs without switching therefore place a relatively high value on driving. In general, work commuters are more likely to switch to public transported by the OVG 4.2 analyses in Flanders. (IMOB, 2010)

In the study, the investigators say that recent empirical research suggests that the total driving, or the vehicle miles traveled (VMT), is not very responsive to the price of gasoline. In 2008, a 10 percent increase in the price of gasoline was estimated to reduce the VMT by as little as 0.2 percent to 0.3 percent in the short run and by 1.1 percent to 1.5 percent eventually in the long run. I think that, given that the gasoline prices are roughly 25 percent higher in 2012 compared to 2008, that the vehicle miles traveled will reduce more than 1.5 percent if the gasoline price would rise 10 percent right now.

Some of the response in vehicle miles traveled comes from motorist who decides to switch to commuter rail. It is obvious that an increase in the gasoline prices raises the relative cost of the driving in comparison with the rail transit. But also the opposite is true. Voith gives an illustration of the price sensitivity of the demand for rail transit. He states that a 10 percent increase in the transit fares is estimated to reduce ridership by about 5 percent in the short run and by about 10 percent in the long run (Voith, 1997). A research from Washbrook has proven that a change in the cost of driving is the most important factor the motorists consider when they want to decide whether they continue driving or if they are going to switch to some other modes of transportation (Washbrook et al., 2006). The CBO findings state, however, that a large escalation in the gasoline prices only slightly cause a shift from the automobiles to the public transportation, at least in the short run.

I have to mention that de analysis in this study of the CBO is based on traffic volume (which refers to the total vehicles per day) on metropolitan highways, rather than on total vehicle miles traveled. But it is reasonable to accept that these measures are correlated. They state in the study that recent research indicates that VMT is relatively insensitive to the gasoline prices. The higher prices of the latest years should not be expected to cause large changes in the traffic volume on the freeway. The CBO also states in their study that if the prices of gasoline increase, drivers must readily limit their lowest value trips. For example, if they value their weekend trips generally less important than their weekday trips, the weekend traffic volumes should also be more responsive to the changing gasoline prices in those places where a transit rail service is available, particularly on weekdays. The reason for this is that the rail service is a better substitute for weeked y driving to work than that is for weekend driving and this because of 3 reasons:

- The transit service is often less frequent.
- Some destinations may be less well served by the public transportation. For example sports fields or places of worship.
- Trips are more likely to involve hauling purchased items or recreational gear.

Now is it time to look at the results of the CBO study. The CBO's analysis shows that the average weekday traffic volumes on some freeways have declined slightly in response to higher gasoline prices. That response was detected on routes which were adjacent to commuter rail systems. The weekly average gasoline prices appear to have had a little effect on the traffic volume at other freeway locations or on weekend. Also worth mentioning, is the fact that in the California data which the CBO analyzed, the higher prices of gasoline also are associated with a slightly greater ridership on the transit rail systems.

The data contains the daily traffic counts for a dozen different freeway locations in the metropolitan areas of California. The data covers the period from early 2003 until the end of 2006. It covers 4 primary metropolitan areas (Sacramento, The San Francisco Bay Area, Los Angeles and Orange County and San Diego County). The CBO has collected the data at representative freeway locations adjacent to the commuter rail system in that specific region and at the other locations in the region where rail transit was not available.

Results will be discussed using the next figure:

Estimated Effect of a 20 Percent Increase in Gasoline Price on Relative Traffic Volume

(Percen	t)		
		Weekends	Weekdays
Average All Sa Statistic	e Effect, Impled Routes al Significance	0.12 Not significant	-0.40 1.4 percent*
No Rail Option Statistical Significance		0 Not significant	0 Not significant
Parallel Rail Statistical Significance		0.20 Not significant	-0.69 0.04 percent* *
Source:	Congressional Bu Freeway Performa https://pems.ee	dget Office based on ance Measurement P cs.berkeley.edu.	a data from the Project,
Notes:	<pre>Notes: * = significant at <5 percent; ** = significant at <1 percent.</pre>		
A 9 \$	20 percent increa asoline costs \$2.50 3.00.	se would be 50 cents) per gallon or 60 ce	s per gallon if nts if the price is

Figure 3: Estimated effect of a 20 percent increase in gasoline price

When we take a look at figure 1, we can see that on average, over all locations, the price of gasoline in a given week had a negligible effect on the volume of weekend traffic. But on weekdays, higher gasoline prices had a small but statistically significant effect. To be more specific, a 20 percent increase in the price of gasoline would reduce the weekday freeway traffic by an average of 0.4 percent. This effect would entirely take place in the response at rail-accessible freeway locations, which is shown in the last 2 rows of the table. At those places, a 20 percent price increase would reduce the weekday traffic by an average of 0.60 percent. This result is strongly statistically significant, although we only talk about 730 fewer vehicles out of on average of 106,000 vehicles per weekday at those locations. The gasoline

prices didn't affect the weekend traffic volume at any of the locations, nor did those prices affect weekday traffic at those places where rail commuting was not an option.

Results personal survey

In my survey, there is a question if the rise of the fuel prices is an incentive for the respondents to buy an Electric of Hybrid car. The next figure summarizes the result of this question.



Figure 4: Rise of fuel price incentive to buy Electric/Hybrid car

As you can read from the figure, 13% of the respondents are strongly agreed with this statement. 49% of the respondents agreed and 24% is somewhat agree. Only 15 % is not agreed with this statement. So we can say that the gasoline price is an important incentive for someone to buy an Electric or Hybrid car.

Results Eppstein paper

The CBO study which I discussed dates from 2008 where they have used data from 2003 until 2006. I think it is reasonable to assume that, with the current fuel prices, a increase in the gasoline prices of 20 percent would have a bigger effect on the relative traffic volume.
It is commonly known that it is fair to state that these gasoline prices will keep rising. This will affect households and companies, and they will have no choice other than to search for other alternatives. These alternatives can be public transport, railway transportation or maybe riding your bike. Another important alternative is an electric vehicle, because such a vehicle will seriously cut the gasoline cost of driving.

In the paper written by Eppstein, they examine the sensitivity of the penetration due to the fuel prices. The increases in gasoline prices could nonlinearly magnify the impact on the fleet efficiency. The paper immediately states that as the gasoline prices increase, the fuel saving with PHEV and electric vehicles will be greater. The paper uses an agent attribute G, which indicates how much weight the agent places on heuristically perceived benefits related to saving gasoline that are independent of rationally estimated financial benefits.

The paper states that if gasoline prices stay relatively low or agents do not account for fuel costs when assessing the vehicle financial costs, the overall fuel efficiency of the fleet remains under 33 mpg, implying most of the agents own the gasoline vehicle (GV). Only when all buyers estimate fuel costs and when gasoline prices are high does the sticker price of the PHEV vehicle have much impact on its market penetration.

Also Eppstein concludes that Long range PHEV purchased use less gasoline than shorterrange PHEV, and therefore contribute to a higher fuel efficiency of the model fleet.

The result of the model used in the Eppstein paper shows that rational financial concerns were always the deciding factor in electing to buy a GV, HEV or PHEV. When gasoline prices are high, many agents with R=1 (R is the level of rationality, this is how the agent estimates the projected fuel costs) realize it is cheaper in the long term to purchase the PHEV and the overall fuel efficiency of the fleet can increase significantly. Not surprisingly, a higher median G both increases the overall fleet efficiency and reduces the sensitivity of the results to gasoline prices, because more agents make their vehicle-purchasing decisions based on heuristically estimated benefits that favor more fuel-efficient vehicles , regardless of actual savings in fuel costs. An increase In mean initial G increases PHEV market share by cutting into the market share of both GVs and (to a lesser degree) HEVs.

The model indicates that, as long as the purchase price premium for PHEV remains high, PHEV market penetration is not likely to increase significantly unless gasoline prices rise, which argues for a gasoline tax to at least set a floor on gas prices.

Because increasing the importance that consumers place on non-financial reasons to reduce gasoline reduces the sensitivity of the market to gasoline prices.

Assuming there are sufficient potential early adopters , this model results indicate that providing consumers with readily accessible estimates of lifetime vehicle fuel costs could be very important for promoting PHEV market penetration . As vehicle consumers learn to consider the actual financial benefits of fuel savings , increasing gasoline prices could nonlinearly magnify PHEV market penetration and resulting increases in fleet efficiency.

Comparison results personal survey vs. results Eppstein paper

In my survey, most of the respondents say the rise of the fuel is definitely an incentive to buy an electric car. In Eppstein, they say that due to the increasing concerns regarding nonfinancial reasons, the sensitivity to the gasoline prices reduces. So this is a difference.

This difference can be explained as that the Eppstein paper is from respondents in the USA, and my respondents all live in Europe, where the gasoline prices are very high. In Belgium, the gasoline prices are approximately 1.65 euro per liter. This is about 2.1 dollar per liter. The actual gasoline price in the USA is about 1.1 dollar per liter.

My opinion is, that if the price of the gasoline in the USA would be as high as in Belgium or Europe, then the people in the USA would also consider the gasoline price as a bigger incentive to buy a PHEV or electric vehicle. This is also a bit confirmed in the Eppstein Paper. When the price of the gasoline is high, many respondents with R = 1 would see that it is cheaper to buy a PHEV or electric vehicle in the long run.

But Eppstein also states that the gasoline price has nonetheless an important role considering the market penetration. This statement is similar to the results in my survey.

3.1.2 Battery range

Another factor which is important and also discussed in Eppstein's paper is the battery range. In this section I will try to explain more about the battery range without going to deep into the technical details. But I will begin with an explanation of the "range anxiety", which is a term that is inevitable connected to the battery range.

Range anxiety

The term "range anxiety" refers to the fear that a vehicle has insufficient range to reach its destination with the consequents that it would strand the vehicle's occupants. In general, this term can refer to all vehicles, but it most applies to the range of electric vehicles. The concern that those electric vehicles may become stranded due to an inadequate battery performance or a to small battery range, has led to the development of public charging networks. To give a response to this, the electric vehicle manufacturers have tried to limit the concerns through increased battery capacities in order to extend the vehicle's range. One important cause of range anxiety is the lack of information. Therefore, a good navigation system which contains knowledge of the battery capacity and the remaining distance can minimize the fear. There is also always the possibility to minimize this fear before buying an electric vehicle.

In a paper of 2009, Vasilash states that when we get used to something, like a technological development, people get to the point where they think that it is normal. He gives the example of the cell phone. The author has been familiar with the desktop phones with rotary dials. At one moment, the pushbutton phone was introduced. After that the portable telephone was introduced. He strengths his arguments by stating: "how many of the people under 20 nowadays have never heard of the concept of the payphone in a booth?" Nowadays, everybody is carrying a phone around and that is just normal. We even become annoyed if the signal is bad or the call is dropped, even if we call someone who is 10000km away. (Vasilash et al, 2009)

Motor companies nowadays have set the idea regarding reducing the need for petroleumpowered cars. They are trying to make the switch to electric vehicles. Vasilash has interviewed Goodman (vice president of Automotive Alliances, Better Place), who explained that there are really 2 things that need to be addressed in this transition to electric vehicles. These 2 things are the consumer and the technology.

Regarding the consumer issues, Goodman quotes the range anxiety. He describes this as: "What if I go in an electric vehicle, will I be able to get to where I'm going and back without having to perform scientific calculations?" He states that there is a price, because as much as someone loves the world, there is only so much that that person will do to be green. If it works within someone's budget, OK. Otherwise, tough luck. He also says that one has to pay attention to other certain characteristics of the car, like the performance, the comfort, the ability to take five people, etc. (Vasilash et al., 2009)

This paper also says that there is, to borrow an appropriate metaphor from another mode of transportation, a third rail. This rail is the car companies. Goodman states that in the past, the OEMs thought that they were responsible to be the providers of everything, except for the gasoline itself. By large, that's still the case. Better Place, the company where Goodman works, thinks that there is a Better way. It has established itself as an Electric-Car Grid Operator. To be clear, this is not a vehicle manufacturer. It works with OEMs. So it has, for example established an alliance with Renault-Nissan. Simply put, it has the objective to build an electrical charging infrastructure that can address the range anxiety. The OEM solution to this, Goodman says, is either a big battery or putting a generator in the car, which still requires fuel. Instead, the solution of Better Place is not only establishing a charging station, where people can plug in, but places where there would be some battery switching stations, which are capable of swapping out a battery in five minutes. (Vasilash et al,. 2009)

To conclude, Goodman wants to make clear, in effect, that the transportation monoculture must end. There must be participation by OEMs, governments, utility companies and other interested parties. In effect, these intentions must be similar to the coalitions that had to exist to get the cars on the road in the first place.

Regenerative braking

Another way to improve the battery range of an electric vehicle, which makes the range anxiety of the people drop, is regenerative braking. This is an energy recovering mechanism which slows the vehicle down by converting its kinetic energy into another form of energy, which can be either used immediately or stored until needed. This is in contrast with conventional braking systems. With those systems, the excess kinetic energy is converted to heat by friction and is therefore wasted. I will explain the concept of regenerative braking further with the aid of a paper by Ye, Bai and Coa from 2007.

The authors state in their paper that regenerative braking is an effective way to extend the driving range of a battery electric vehicle. The concerns about energy efficiency, energy diversification and environment protection, are ever increasing. Therefore, the development of the electric vehicle has taken an accelerated pace. What is difficult is that the driving range of an electric vehicle is not cost effective. Based on energy recovery for the traditional automobile, regenerative braking for an electric vehicle has attracted considerable interest during the last 25 to 30 years. Using regenerative braking is an efficient approach to extend the driving range of the electric vehicle without any additional cost. At the same moment, the concept of regenerative braking plays an important role in energy saving. There have been many efforts with the aim of developing models of the regenerative braking system and improving the brake performance. (Ye et al, 2007)

The authors come to the conclusion that regenerative braking can minimize the wear of the brake pad and reduce the maintenance costs significantly. They also state that the driving range can be improved by up to 18 % by regenerative braking. The comparison of the predicted and experimental results showed good agreement, which validated the feasibility and effectiveness of regenerative braking for the battery electric vehicle. They also say that this system can be applied for the hybrid electric vehicle and the fuel cell electric vehicle also. (Ye et al, 2007)

Results personal survey

In my survey, there is a question which asks about an acceptable battery range for the vehicle. You can see the results on the next figure on the next page.



Figure 5: Acceptable battery range

The figure makes clear that 3% of the respondents answers that a range between 0 and 100 km is acceptable. 21 % want a car which lasts between 101 and 200 km with a charge. 30% claims that they want to ride between 201 and 300 km with a charge. 27% want a car which rides between 301 and 400 km. 19 % want to ride at least 401 km with one charged battery. So it is obvious that the opinions are a bit divided concerning this question. But to satisfy most of the respondents, I think a range of 400 km would be acceptable.

Another question asked about the importance of the range of travel on a charge. The results of this question are summarized in the next figure on the next page.



Figure 6: Importance range of travel on a charge

78 % of the people say that the range of travel is a very important attribute for them. Only 17% stated this as medium important and only 5 % do not pay attention to the range of travel on a charge.

There was also a question which asked about the fact if someone would like to pay for faster charging. The next figure gives an overview of these results



Figure 7: Willingness to pay for faster charging

The conclusion is that people are not willing to pay nothing or not much for this. 82 % of the respondent said they would like to pay between 0 and 500 Euro for this. 43 % of the respondents explicitly stated they don't want to pay extra for this service.

Another investigation was if someone would have the opportunity to charge their car at home or at work. The next 2 figures summarize the results of these 2 questions.



Figure 8: Opportunity to charge car at home



Figure 9: Opportunity to charge car at work

53% said they could charge their car on a daily pattern at home. 31% said this was possible every few days. The results are a bit more negative when considering the question if someone could charge their car at work. Only 15% states they would be able to do this every day at work, and only 29% said it was possible every few days.

I also asked about the fact if someone is comfortable at leaving their car in public during the charging of the battery. The next figure summarizes the results regarding this question.



Figure 10: Comfortable to leave car in public

It is clear that 65% of the investigated people stated they were comfortable with this and that leaving their car at a charging point is not a problem. I think this is reasonable because it is in my opinion a bit the same as parking your car somewhere. 35% of the respondents were not comfortable to leave their car.

Results Eppstein paper

The paper which is written by Eppstein concludes that there will be a large increase in the resulting fleet efficiency as the battery range of the PHEV increases. This has 2 reasons. First, when the range of the PHEV battery increases, the projected lifetime fuel costs drop for more agents. Therefore more agents who consider rational estimates of fuel savings purchase PHEVs, resulting in more PHEVs in the fleet. Second, the longer-range PHEVs

purchased use less gasoline than shorter-range PHEVs, and this therefore contributes to a higher fuel efficiency of the model fleet.

Comparison results personal survey vs. results Eppstein paper

The conclusion regarding the battery range of the Electric/Hybrid vehicles are similar in my survey and the paper of Eppstein. Both studies come to the conclusion that the battery range is a very important factor in the decision making model. Both the respondents in the USA and in Europe desire a high battery range. Also they both state that the battery range is very important in the decision to buy a certain car.

When we are talking about the battery range, there is one thought that is worth mentioning. From my experience, I think that the respondents and the people in general are expecting a battery range which is unnecessary high. They want to have an electric or hybrid car with a range which is too high when this range is compared with what they actually need.

I will make this statement more clearly using some data which is collected by the survey. In the next figure, you will find the commute distances of the respondents in my survey.



Figure 11: Average commute distance

In the graph above, one can see that more than 85% of my respondents have a commute distance which is less than 60 km. It is true that those respondents will use their car also for

other things than to commute. So we have to take this into account. But I think it is a reasonable assumption that those respondents with a commute distance less than 60 km will not drive more than 100 km a day.

If we compare this distance with the acceptable battery range, we can see that this range is well above the distance that the respondents need to drive every day. From the graph that summarizes the results of the acceptable battery range, you can see that 97% of the respondents desire a battery range of at least 100 km. and 76% of the investigated people even would like a battery range that is over 200 km. So it is clear that most of the people like a battery range that is well over their daily needs. I think it is important to make the people aware of the fact that their acceptable battery range is too high. This would have a positive effect on the penetration rate of the Hybrid or Electric vehicles.

3.1.3 Purchase price (and rebates)

The purchase price is on of the most important factors to deal with when one is considering buying an electric vehicle. The actual purchase price of such a vehicle is the first thing which the potential buyers are confronted with. So for many potential buyers, it is very frightening when they see an electric vehicle with a relatively high price.

A recent study conducted by Pike research, confirms that many potential buyers will hold off on purchases of electric vehicles during 2012 due to the premium price of the vehicles. They say that Nissan had raised the price of the 2012 Leaf. The 2012 Chevrolet Volt will cost 1000 dollars less. But the downside is that this car comes without several features which were previously standard but are now options. (Pike Research, 2011)

The research has managed to extract an optimal price for a plug-in electric vehicle. Based on the data from the Pike Research annual Electric vehicle consumer survey, the optimal price for such a vehicle to engage the consumers is 23750 dollar. With the 2012 Toyota Prius PHEV (32 000 dollar), the Honda Fit BEV (36625 dollar) and the Ford Focus EV (39995 dollar) which cost more than 30000 dollar before federal incentives, the consumers hoping for an affordable EV have been left wanting.

So those relatively high selling prices are a constraint for the market for plug-in electric vehicles in 2012. Research director John Gartner says that the vehicles on sale in 2012 will still benefit from recent cost reductions in the batteries, because the batteries in those vehicles were ordered before 2012. Any flexibility in the reduction of the vehicle price will, according to him, not occur until 2013 or 2014 at the earliest. Nevertheless, Gartner believes that the global market for plug-in electric vehicles will grow to more than a quarter million vehicles in 2012 in the USA. This will be a number sufficient to put an end to the speculation "Are the electric vehicles for real" that has surrounded the market for years. (Pike Research, 2011)

The Pike Research also gives a number of industry predictions for 2012. These include the following:

• The car-sharing services will expand the market for the electric and the hybrid vehicles.

- The battery production will outstrip the vehicle production.
- The Asia-Pacific region will become the early leader in the vehicle to grid (V2G) systems.
- The third-party electric vehicle charging companies will dominate the public charging sales.
- Employers will start to purchase electric vehicle chargers in large numbers.
- The electric vehicles will begin to function as home appliances. (Pike Research, 2011)

Results personal survey

In my survey, I asked the people what they think would be an acceptable price range for an electric of hybrid vehicle. The answers of the respondents are shown in the next figure.



Figure 12: Acceptable price range of electric/hybrid vehicle

The results show that 32% of the respondents are willing to pay to a limit of 15000 for an electric or hybrid vehicle. 50 % of the respondents think a price between 15001 and 25000 euro is acceptable. The other respondents, 18% of the total, think a price between 25001 and 35000 euro is reasonable. Nobody of the people in my survey accept a price above 35000 Euro.

Another question tried to find something out about the importance of the purchase price for the respondents. The results to this question are summarized in the figure on the next page.



Figure 13: Importance of the price range

From the results of the survey, it appears that 73% of the people find the purchase price of the electric or hybrid vehicle very important. The rest of the respondents, 27% of the total, think the purchase price is medium important. No one thinks that the purchase price is not important. I don't think this is a surprising result.

Results Eppstein paper

The Eppstein paper states 2 general conclusions regarding the purchase price of the PHEV and the influence on the market penetration.

Firstly, the model of Eppstein indicates that, as long as the purchase price premium for PHEVs remains high, the PHEV market penetration is not likely to increase significantly unless the gasoline prices rise. This conclusion confirms the fact that the purchase price and the gasoline prices are interlinked. It is for example possible that a lower gasoline price will compensate a higher premium price for the PHEV.

A second conclusion made by Eppstein is the fact that the model results indicate that temporary rebates on the PHEV purchase are not likely to significantly impact the PHEV market penetration. Eppstein also states that incentives such as those purchase price rebates and gas taxes will have little effect on the PHEV market penetration if consumer confidence thresholds have not been met. It is thus critical to gain a clearer understanding of consumer willingness to consider PHEVs before large investments are made in these other areas.

Comparison results personal survey vs. results Eppstein paper

As mentioned in the text, the purchase price is a very important factor in the decision to buy an electric or hybrid vehicle according to the respondents of the survey. Almost three quarters of the respondents think that the price factor is very important. The Eppstein paper states that the purchase price plays an important role in the penetration rate of the electric of hybrid vehicles. If this factor stays high, Eppstein states that , in combination with the same gas prices, the penetration rate is not likely to increase significantly. So the important role of the purchase price in the Eppstein paper is obvious. So it is justified to state that the results of my survey and the Eppstein paper are similar.

3.1.4 Social and media influences

Another important factor in the process in of buying an electric vehicle is the social or media influence. This is a consequence of the fact that today's customer can be heard loud and clear. The customer can share its opinion about a certain product everywhere, including review websites, blogs, Youtube videos, Tweets, Facebook updates and other social media outlets. Companies have to pay attention to this, because social media is changing the way customers do business. It is effectively influencing the entire buying process. If those companies don't pay attention, they risk losing customers to the competition who used to be small and powerless. So the most obvious way that the social media has changed the consumer behavior, is by giving the customer a bigger voice than they have ever had before.

According to a study by the Euro RSCG, 31.5 % of U.S social media users state that they feel empowered to do things they have always wanted to do and 20% have lashed out against brands and companies online. So the customers feel empowered to say something they have always wanted to mention, but they have never had the opportunity to do so. Customers feel more safe and anonymous by the social media. This has a consequence that they feel more confident in expressing their true feelings about the brands they interact with and the products they buy.(straczynski, 2009)

And all of this has an effect. A study performed by OTX Research reveals that about 2/3 of the customers use the information they find through social media to influence their buying decisions. Moreover, 67% of the customers are likely to pass this information to others, and over 60% of the customers trust the information they find through social media more than traditional advertisements. So it is clear that customers are using social media outlets to research companies before doing business with them. If you are a company, and the social media is filled with a lot of negative information about your brand, you are probably losing a lot of customers (OTX Research, 2008)

A study by Axsen and Kurani shows that the social and media influences also have an influence on the purchasing decision of an (Plug-in) electric vehicle. They have obtained the following insights:

- The interpersonal influence, as it occurs via the social interactions, plays an important role in participants' assessment of electric vehicle technology.
- Social proximity provides a usefully broad basis for the mapping of the social network of a car buyer, and this at least for the observation of the interpersonal influence relating to the formation of perceptions of (plug-in) electric vehicles.
- The social interactions between the primary participants and an alter are more likely to influence the trial participant's assessment if the societal aspects of the PHEV are addressed, the alter has relatively more alternative fuel expertise or the participant and alter are very close socially. (Axsen and Kurani, 2011)

Results personal survey

In one question, I asked the respondents about the importance of a so called "cool factor". It indicates if someone finds it important of they look cool in an electric vehicle. The results are shown in the next figure.





The figure shows that he results of this question are somewhat divided. Most of the respondents , 48%, find this attribute medium important. 28% don't think it this cool factor is important. 24% think it is very important if another person finds it cool to drive an electric or hybrid vehicle.

Another question investigated the fact if the respondents think it is important what other people think about their car. The answers are summarized in the figure on the next page.



Figure 15: Important what other people think about the car

The figure states that 33 % of the respondents disagree with this statement, and 30 percent even strongly disagree. So 63% of the respondents don't find it important what other people think about the vehicle you drive. 23% are not disagree and not agree. 14 % think it is important what other people think. So also here the opinions are a bit divided, but overall, the investigated people are not concerned about the fact what someone thinks about the car they drive.

Results Eppstein paper

Concerning the social and media influences on the agents, Eppstein makes use of an attribute called G. To discuss the social and media influences in this paper, it is necessary that we have a good understanding of this G value. This will be discussed from the next paragraph on.

Different surveys indicate that many customers are willing to pay a price premium for a more fuel efficient vehicle and that the non-financial reasons related to the environment, energy and attraction to the new technology can play a large role in the willingness of the consumer to buy a HEV, EV or PHEV. Eppstein has modeled this through an agent attribute G. This G indicates how much weight the agent places on the heuristically perceived benefits related to saving gasoline that are independent of rationally estimated financial benefits. In the model of Eppstein, the only agent attributes that can change during a simulation, are the heuristic weight G and the current vehicle ownership.

The only agent attributes that can change during the simulation are a) the heuristic weight G, which can change dynamically due to social and media influences and b) current vehicle ownership. In step 1 of the simulation, we allow the agents value for the heuristic weight G to be increased or decreased due to media and/or social influences. This is done by the intensity of the media coverage. All agents are exposed to the same daily media coverage. However, the average annual change in media cover ΔM leading up to the day each agent considers buying a car differs. Based on the assumption that changes in media coverage can influence attitudes over time, each agent's value for G is adjusted based on the agent's personal susceptibility (S_M) to media influence as follows:

$G = G + \Delta M X S_M$

This is the expression for the update of the media coverage.

Each agent also has a social network which is made of other agents of similar age, salary and residential location. Each year the agent assesses whether its heuristic weight G is above or below the median of the G values of those in its social network. If above (or below), one "friend" is selected at random (to simulate stochastic social influences) from the half of the agent's social network that is also above (or below) this median, and the agent will adopt its friend's value of G if it is higher (or lower) than the agent's own current value. This update is motivated by the social science theories of "homophily" and "conformity". These theories state that people tend to associate with others who are similar and desire to have one's attitudes and behaviors conform to others in one's social network. Over time, the media influences will tend to increase or decrease the median of the G values of the entire agent population as a whole, while social influences cause a slight bimodality in the evolving distribution of G. It also have to be mentioned that some individuals are more susceptible to social and media influences than others and most people switch attitudes or behaviors infrequently. If we take a look at the effect of the G value on the market penetration, Eppstein states that a higher median G both increases the overall fleet efficiency and it reduces the sensitivity of the results to gasoline prices. This is because more agents make their vehicle-purchase decision based on heuristically estimated benefits that favor more fuel-efficient vehicles, regardless of the actual savings in fuel costs. The paper also shows that a increase in the mean initial G value increases PHEV market share by cutting into the market share of both GVs and HEVs.

Comparison results personal survey vs. results Eppstein paper

It appears from my survey, that the social and media influences play a limited role in the decision to buy an hybrid or electric vehicle. The opinions of the cool factor are divided and this cool factor is not very important. Also 63 % of the respondents don't find it important what other people think about their car. So we can draw the conclusion that the social and media influences don't have an important influence when the consumers are thinking about buying an hybrid or electric vehicle.

In the Eppstein paper, the social and media influences are modeled by means of the G value. It appears that in this paper, a higher G value has a large influence on the market penetration of the hybrid and electric vehicles.

So we can conclude that there is a difference in the results between my personal survey and the results from the paper that is written by Eppstein.

3.1.5 Consumer values regarding financial vs. non-financial concerns

It is important to know the reasons why one would buy an electric vehicle. In this topic, we will take a look at the consumer values regarding the financial and non financial concerns. This will be investigated by giving an overview of the motives to purchase an electric or hybrid vehicle, based on a paper by Ozaki and Sevastyanova from 2009.

This paper tries to answer the question: "What makes consumers adopt energy-sustainable innovations?" In the study, the authors mention a brief review of the empirical research on the actual hybrid vehicle purchase motives of individual consumers. The motivational constructs attached to the adoption of hybrid vehicles fall into 5 groups, which will be discussed next.

The first group is related to the financial benefits and the other policy-related advantages. It appears that the consumers consider the financial benefits, like the fact to improve the fuelefficiency and the money saving on petrol. They also replace larger and more expensive cars with smaller and lower-cost hybrid cars in order to reduce the overall costs. The results reveal that the choice to purchase a hybrid car is a response to an increase in petrol prices and government incentives. It is also seen as a way to reduce the energy consumption and to improve the energy security.

The second group relates to a particular symbolic meaning attached to the hybrid cars: environmentalism. This is the group of consumers which is concerned about the environment. They show high levels of environmental awareness and they take action to reduce their ecological footprint. Some consumers even explicitly express and communicate their concerns for the environment. It is a reflection of their "greenness". Some consumers want to be seen to be driving an explicitly green car, because people like the image of greenness conveyed by the hybrid or electric vehicle. For example, some purchasers pay little attention to the fuel consumption of the vehicle, their purchase decision is based only on environmental awareness.

The third group is concerned with the matching with the norms of the community. It is a fact that green consumers tend to be clustered geographically forming so called green communities. This develops an ideology that hybrid car ownership is a reflection of sharing the community's values and norms.

For the fourth group, the paper shows that new technology is intrinsically attractive to some. These consumers have positive attitudes to innovations and are likely to adopt these new technologies.

The fifth group of consumers is concerned with achieving independence from oil producers through reduced petrol consumption.

These 5 different motives are all equally important elements in the light of the individual decision-making. This shows that the hybrid or electric adoption is more complicated than the cost-benefit or financial reward model. The decision making cannot be explained using only economic factors. The following table presents 23 motivational constructs which are identified in the empirical research of the paper.

Motivational constructs identified in the literature.

- Opportunity to pay less for fuel
- Other government incentives
- Free access to town centre
- Free parking
- Tax payback (*US specific)
- Permission to drive in the carpool lane (*US specific)
- Unaffected by fuel price fluctuations
- Awareness of climate change and global warning
- Decreasing natural resources consumption
- Preservation of the environment
- Reduction in pollution level
- Mitigation of personal ecological footprint.

- Being a trendsetter of proenvironmental technologies
- Being part of socially responsible activities
- Being considerate to others
- Attracted to new technologies
- Being a pioneer in the technological sphere
- Educating others about a new type of vehicle
- Sharing technological knowledge
- Enjoying the benefits of the innovation
- · Doing the right thing
- Sharing a common ideology within the community
- Independence of oil producers

Figure 16: Motivational constructs

Results personal survey

In my survey, I have some questions which aim at the non-financial concerns of the respondents regarding the electric or hybrid vehicles.

The first attribute is the cargo or storage capacity. The figure on the next page summarizes the importance of this attribute according to the respondents.



Figure 17: Importance of the cargo/storage capacity

From the results, it is clear that the opinions regarding this attribute are a bit divided. 56% of the people say it is medium important. 28% think that the storage capacity is very important. The rest of the investigated people, 16% don't find the cargo of the car important.

Another attribute which is present in the questionnaire, is the crash rating. In the next figure, you can find the answers of the respondents regarding the importance of the crash rating.



Figure 18: Importance of the crash rating

The results indicate that 45% of the respondents pay medium attention to the crash rating of the car. Also 45% think the crash rating is very important. Only 10 % don't look at the crash rating. In my opinion, this is a somewhat surprising result.

The third attribute regarding the non-financial concerns, is the general safety of the electric or hybrid vehicle. The next figure gives a summary of the answers of the respondents regarding this attribute.



Figure 19: Importance of the general safety

This is for the respondents an important attribute. 35% of the respondents find it medium important, and 65% find it very important. This means that nobody of the respondents find the general safety not important.

The next factor is the low emission of the car. The figure on the next page gives an overview of the results regarding this attribute.



Figure 20: Importance of the low emission

From the results, one can see that only 12% of the people don't find this attribute important. Respectively 43 and 45 % of the respondents find this medium and very important. So the factor is important in the eyes of the investigated respondents.

I also asked if someone would be interested in buying an electric or hybrid vehicle for the environmental reasons. The answers of the respondents are shown in the next figure.





As one can see from the figure, the answers to this question are much divided. 8 % of the respondents strongly disagree with this statement. 16% strongly agree with it. In between, the opinions are more divided. Respectively 26%, 26% and 24% of the respondents disagree, nor disagree/nor agree and agree.

Results Eppstein paper

Eppstein mentions in her paper that most consumers elect to purchase HEVs for nonfinancial reasons, rather than on detailed rational financial analyses of the expected lifetime costs. These non-financial reasons related to the environment, energy and the attraction to next technology can play a large role in the consumer willingness to purchase an HEV. The paper also states that an increase in the consumer appreciation of the non-financial reasons to minimize the gasoline usage could also have a significantly positive influence on the PHEV market penetration. This public opinion can be influenced through the media. Increasing the importance that consumers place on the non-financial reasons to reduce the gasoline reduces the sensitivity of the market to gasoline prices. This approach could help temper the need for high gas taxes and rebates and it is believed to be a cost-effective strategy that policy-makers should pursue. So the paper written by Eppstein states that a cost-effective way to influence the PHEV market penetration is by influencing the consumers to place more weight on the non-financial considerations that encourage lower gasoline consumption when making a vehicle purchase.

Comparison results personal survey vs. results Eppstein paper

In the survey which I conducted, the non-financial concerns are rated with a high importance by the respondents. Also, the Eppstein paper highlights that the non-financial concerns play an important role in the decision to buy a PHEV. So we can state that the results of my survey and the results in the Eppstein paper concerning the non-financial concerns are similar.

3.2 Description personal model

In this section, I will describe an agent based model which can be used to forecast the penetration rate of electric and hybrid vehicles. Moreover, this section will describe how the agent has to be specified. It will also give an indication about the behavior of the agent.

It is necessary to start with some characteristics of the agents. These are some general assumptions which apply to all agents:

- The agents in the model are potential buyers of electric or hybrid vehicles who communicate with each other. They interact and they share information with each other.
- The agents have the opportunity to help each other
- The agents should have similar social-economic-demographic profiles
- Because of the fact that the agents interact with each other, the behavior of the agent can be influenced by another agents. This is also possible via the social network of the agents
- The agents have the opportunity to get feedback from other agents.

After the characteristics, I will now define a set of rules how to model the agents, holding in mind how the agents will behave. The result will be an advice made under some assumptions of how to build such an agent.

3.2.1 The time resolution

The time resolution is an important factor in the process of buying a car. I think this factor is twofold. On the one hand it means the time that it takes to choose which car to buy. It is obvious that a potential buyer wants to test several cars. It is rare that one buys the first car they test. It is reasonable to accept that a buyer will test at least 3 different cars and that they would like to think it over after the testing. It is a reasonable assumption to put to average time to choose a car at 3 weeks. On the other hand, the time resolution stands for the time between the purchasing of a car. It is normal that some agents will do 10 years with one car and others only 3 years. In my opinion, I put this average time between the purchasing of a car on 5 years. Hence, the time resolution will be one day or one week.

3.2.2 Sensitivity to the cost

The cost of the electric or hybrid vehicle contains 2 things: the initial cost of the purchase and the marginal km cost. For the initial purchase cost, I have looked at the purchase price of the Toyota Prius. This car is a good benchmark and it was also used in the paper written by Eppstein. In may 2012, this cars starts at a cost of 28 959,99 Euro. If I take a look back at the survey which I have conducted, this price is high compared with what the respondents are willing to pay for it. More than 80% of the respondents think that the acceptable price of the car is below 25000 euro. The second part of the cost is the marginal km cost. In the case of a hybrid electric vehicle, this is a combination of the fuel cost per km and the electric cost per km. When the car is electric, only the electric cost per km has to be taken into account.

The marginal cost per km in case of an electric vehicle can be calculated by multiplying the electricity needed per km to charge the battery times the unity price of 1 kilowatt-hour (for instance 0.2 kWh per km X 0.17 euro/kWh = 0.034 Euro/km).

In case of an hybrid vehicle, one has to sum up the cost per km of the all electric range and the cost of the remaining kilometers driven on fuel. The marginal cost per km can be calculated like the following example. Let us state the following assumptions:

- The all electric range of the hybrid vehicle equals 60 km
- The average agent drives 80 km per day
- The electric usage equals 0.2 Kilowatt-hours per km
- The fuel price equals 1.5 Euro/liter
- The cost of 1 kilowatt-hour equals 0.17 Euro
- The needed fuel equals 6 liter/100 km

Than the marginal cost per km can be expressed as follows:

[60 km X 0.2 Kilowatt-hours /km X 0.17 Euro/kWh + 20 km X 6 liter/100 km X 1.5 euro/liter]/80 km = 0.048 Euro per Km

3.2.3 The social network

As previously mentioned in this section, the agents interact with each other and they create some kind of social network around them. So it is obvious that the agents are influenced by the behavior of the other agent in the network. It is for some agents even possible that they experience some kind of peer pressure. In that case, agents will change their behavior in order to conform to the group norms. When we relate this phenomenon to the topic of this thesis, the agents can be influenced by the group and pressured to buy an electric or hybrid vehicle.

In is possible to link the peer pressure in the social network with the so called "cool factor" which I have used in my personal survey. There was a question regarding the importance of the cool factor for a respondent. 48% of the respondents think this factor is medium important. 28 % find this factor not important and 24 % of the people have the opinion that the cool factor is a very important factor. So the results are a bit divided.

The peer pressure can also be linked with another question in the survey. The survey asked the respondent if it is important what other people think about their car. The survey reveals that 63% of the respondents don't find it important what other people think about their car. In my survey, the investigated people are not much concerned about the fact what someone thinks about the car they drive.

It is possible to model the effect of the social network in a similar way as Eppstein did in her paper. She used the G value which was updated via the media and/or social media influences. In my model, the distribution found for the cool-factor and the peer-pressure can be used to sample a value for the agent's personal susceptibility like the one that is used for the G value updates.

3.2.4 Population and size of the agent

The content of this factor is to see if there are some trends and generalizations in the population, and if one can draw some conclusions for a part of the population. There is also the question if it is possible to take a sub-population from the entire population and run the model for this sub-population. In the next table, there is an example using the respondents from my survey. In this example, the sub-population is composed by means of the age of

the respondents. Then it is possible to see if there are trends inside an age group regarding some factors. This is done by checking the results of people from a certain age group on some factors. I will check the results regarding the acceptable purchase price and the acceptable battery range.

Age group	Acceptable price range	Acceptable battery range
Under 18	No respondents under 18	No respondents under 18
18 – 21 (17 respondents)	0 - 15000 → 41%	0 - 100 → 6%
	15001 - 25000 → 47%	101 - 200 → 12%
	25001 - 35000 → 41%	201 - 300 → 41%
		301 - 400 → 29%
		Over 400 → 12%
22 - 30 (24 respondents)	0 - 15000 → 38%	0 - 100 → 0%
	15001 - 25000 → 45%	101 - 200 → 21%
	25001 - 35000 → 17%	201 - 300 → 30%
		301 - 400 → 25%
		Over 400 → 24%
31 – 40 (5 respondents)	0 - 15000 → 20%	0 - 100 → 0%
	15001 - 25000 → 40%	101 - 200 → 20%
	25001 - 35000 → 40%	201 - 300 → 20%
		301 - 400 → 20%
		Over 400 → 40%
41 - 50 (9 respondents)	0 - 15000 → 25%	0 - 100 → 0%
	15001 - 25000 → 63%	101 - 200 → 12%
	25001 - 35000 → 12%	201 - 300 → 25%
		301 - 400 → 38%
		Over 400 → 25%
51 - 60 (8 respondents)	0 - 15000 → 25%	0 - 100 → 12%
	15001 - 25000 → 63%	101 - 200 → 25%
	25001 - 35000 → 12%	201 - 300 → 12%
		301 - 400 → 38%
		Over 400 → 13%

61 – 70 (5 respondents)	0 - 15000 → 0%	0 - 100 → 0%
	15001 - 25000 → 60%	101 - 200 → 40%
	25001 - 35000 → 40%	201 - 300 → 40%
		301 - 400 → 20%
		Over $400 \rightarrow 0\%$
71 – 80 (1 respondent)	0 - 15000 → 100%	0 - 100 → 0%
	15001 - 25000 → 0%	101 - 200 → 100%
	25001 - 35000 → 0%	201 - 300 → 0%
		301 - 400 → 0%
		Over $400 \rightarrow 0\%$
Over 80	No respondents over 80	No respondents over 80

Table 3: Example subpopulation respondents

This is one way of dividing the population into sub-populations. In this example, the age was used. It is also possible to make use of attributes like the net income or the commute distance. It is also an option to divide the agent into so called agent classes. One possibility to divide them is like the example, namely the age. In that way we can make agent classes like students or seniors.

In case of this example, where the sub-population is made according to the age categories, a particular density function per relevant age group can be used to sample the agent characteristics. If for instance an agent is 26 years old, there is a probability of 45% that the acceptable price range is situated between 15001 and 25000 euro and the probability that the acceptable battery range is between 201 and 300 mounts to 30%. So the table which is presented here identifies the age-category probability densities of the acceptable price range.

It has to be noted that the 4 oldest age categories used here have a small amount of respondents. In order to have enough respondents in 1 age category, there is an option to combine the last 4 age categories into 1 category called "age 50 +".

3.2.5 Range anxiety

As mentioned previously in this thesis, the term range anxiety refers to the fear that a vehicle has insufficient range to reach its destination with the consequents that it would

strand the vehicle's occupants. The term expresses the fear of the drivers that the electric or hybrid electric vehicle will have an insufficient range to reach the destination of the journey. Obviously, the drivers of a hybrid electric vehicle have less fear that the drivers of the pure electric vehicle. This is because the pure electric vehicle has range that is less than the range of the hybrid electric vehicle.

The range anxiety is linked with the battery range of the hybrid or electric vehicle. As previously mentioned in the text, the respondents expect a battery range that is larger than a battery range which they actually need. This is a conclusion based on the comparison between the acceptable battery range and the average commute distance. So the range anxiety of the agents is in many cases not needed. It is thus necessary that the perception of the agent changes, so they see that they don't have to expect such a high battery range. This can be done via information spreaded out by the government or the car manufactures.

A possibility to limit the range anxiety, it is a possibility for the agents to buy a hybrid or electric vehicle as a secondary car. In that way they can use a regular car with an internal combustion engine to drive long distances, for instance to go on a holiday. For shorter distances, the agents can make use of a hybrid or electric vehicle. In the survey, 79% of the respondents have a secondary mode of transport. 1 respondent has a hybrid electric vehicle. The survey also asked if the respondents would be interested to buy a hybrid or electric vehicle if it were to by the secondary car. 31% of the respondents disagree with this statement, and 18 % of the respondents even strongly disagree. 27% of the investigated people are not disagree or not agree. Only 22% of the respondents would be interested to buy a hybrid or electric vehicle if it were to be the secondary car. So the conclusion is that the opinions are divided, but we can state that overall the respondents are not very interested in buying such a vehicle as a secondary car.

To model the agent regarding the range anxiety, I suggest making use of a range/commute Distance ratio. This is a suggestion when there is no car-swapping within a household is possible. Say that the probability that the range anxiety allows the BEV purchase is a linear function of D/R where D is the daily commuting distance and R the advertized range of the BEV, so that

• $Prob(BEV) = 1 \text{ if } 0 \le D/R \le A$

- Prob(BEV) = (D/R A)(B-A) if $A \le D/R < B$
- Prob(BEV) = 0 if $B < D/R \le 1.0$

With for example A = 0.50 and B = 0.75. This probability then can be used while sampling p0 (a number between 0 and 1) from a uniform distribution. If $p0 \le Prob(BEV;D/R)$ then the purchase of a BEV will be considered by the agent.

3.2.6 The decision model

After the suggestions about the time resolution, cost sensitivity, social network, the population and the range anxiety, it is necessary to make a suggestion about the effective decision model which can be used in to decide which kind of vehicle the agents will purchase. A suggested model that can be used is the multinomial logit model. This is a regression model which generalizes logistic regression by allowing more than two discrete Let us state that the consumer has to option to choose between a (plug-in) hybrid electric vehicle, a battery electric vehicle and a vehicle with an internal combustion engine. With the help of the survey, it is possible to obtain values for different continuous variables like age, income, ... This can be fit in the following model:

A . age + B . income + ... => [Pphev, Pbev, Pice].

With this model, one can obtain the probabilities of the agent to choose for a (Plug-in) hybrid electric vehicle, a battery electric vehicle or a vehicle with an internal combustion engine.

Chapter 4: Conclusion and future work

This master thesis had the purpose to find an answer to the question about what the main agent behavioral characteristics in an agent-based model to predict the hybrid and pure electric vehicle market penetration rate in the European fleet over the next decennium are. I have tried to find this answer via a comparison between the Eppstein study from the United States and a personal study in Europe.

The Eppstein paper uses an agent-based model to study the market penetration of plug-in hybrid electric vehicles in the United States. The conclusions and results of this paper have been compared with the results of a survey which I personally conducted. Moreover, the results where compared on the base of 5 different factors, namely the gasoline prices, the battery range, the purchase price, the social and media influences and the consumer values regarding financial vs. non-financial concerns. It appears that there is only a difference between the results of the Eppstein paper and the results from m personal survey regarding the social and media influences.

Furthermore, I gave advice how the agents of the agent-based model can look like. This description is based on several assumptions regarding the time resolution, the sensitivity to the cost, the social network, the population and size of the agent and the range anxiety. These assumptions have been woven into a decision model.

To end this thesis, it is necessary to share some ideas for the future work that can be done regarding this topic. The first thing that can be done is using a model that contains agents which are described by the rules in this thesis. That is a way how the ideas described in this thesis can be used in practice. Another idea is to conduct my personal survey again in order to have more respondents in the different age groups. As you have noticed, there were a lot of respondents from the age groups 18 until 30. The results can be somewhat different if the number of respondents in the different age groups is more equally divided.
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Appendix

Personal survey

Mijn naam is Wim Vanderheyden en ik zit momenteel in mijn masterjaar Management -Management Information Systems aan de faculteit Bedrijfseconomische Wetenschappen van de Uhasselt.

In het kader van mijn thesisonderzoek, waarin ik de penetratiegraad van elektrische voertuigen voor de komende 10 jaar in Europa tracht te voorspellen, heb ik deze enquête opgesteld.

Uiteraard worden de resultaten van deze enquête uitsluitend voor dit onderzoek gebruikt en zijn ze anoniem.

Ik wil u graag bij voorbaat danken voor de tijd die u vrijmaakt om deze enquête in te vullen.

My name is Wim Vanderheyden and currently I am enrolled in my masteryear Management -Management Information Systems at the faculty Economics at the Uhasselt.

For the research topic in my master thesis, where I will try to predict the penetrationratio of electric vehicles in Europe over the next decennium, I have put together this questionnaire.

The results of this questionnaire will only be used for my research and they are anonymous.

I would like to thank you for your time.

Groetjes/Regards Wim

Please select all the profiles that best describe you:

- Environmentalist/Green Enthusiast
- Car Enthusiast
- Senior Citizen
- C Student
- City/urban Commuter
- Suburb/Rural Commuter
- Car Pooler/Ride Sharer
- C Other

2.

Please specify your age group: *

O Under age 18 O Age 18 - 21 O Age 22 - 30 O Age 31 - 40 O Age 41 - 50 O Age 51 - 60 O Age 61 - 70 O Age 71 - 80 O Age over 80

3.

Describe the make and model of your current primary mode of transportation? (This is the vehicle you use most of the time) *

- Gas/Diesel or other fuel vehicle
- C Electric vehicle
- Hybrid

- Motorcycle
- Bicycle or another human powered vehicle
- Public Transportation

What is your current secondary mode of transportation? (This would be another vehicle you or another family member uses some of the time) *

0	Gas/diesel or other fuel vehicle
0	Electric vehicle
0	Hybrid
0	Motorcycle
0	No secondary mode of transportation

5.

If you are a commuter, what is your round trip commute distance? *

```
O
    0-15 km
O
    16 - 30 km
0
    31 - 45 km
\circ
    46 - 60 km
O
    61 - 75 km
0
    76 - 90 km
O
    91 - 105 km
0
    more than 105 km
```

6.

How many kilometers do you typically put on your primary and secondary vehicles each year? $\ensuremath{^*}$

O - 7500 km

- C 7501 15000 km
- C 15001 22000 km

C 22001 – 30000 km

O 30001 - 40000 km

More than 40000 km

7.

Specify your annually net income. *

0	0 – 5000 Euro
0	5001 - 10000 Euro
0	10001- 15000 Euro
0	15001 - 20000 Euro
0	20001 - 25000 Euro
0	250001 - 30000 Euro
Ō.	More than 30000 Euro

8.

How would you rate your knowledge and interest about Electric/ Hybrid Vehicles? (Low, Medium or High)

Knowledge	Low O	0	High C
Interest	0	0	0
9.			

What price range would be acceptable for you to buy an electric/hybrid vehicle? *

○ 0 - 15000 Euro

C 15001 - 25000 Euro

C 25001 - 35000 Euro

C 35000 - 45000 Euro

• More than 45000 Euro

If the price range is ok, what is the likelihood that you would purchase one in the following timeframe? (Low, Medium or High)

0 - 1 Year	Low	0	High O
1 - 3 Years	0	0	0
3 - 5 Years	0	0	0
More than 5 years	0	0	0
11.			

If you would buy one, what would your estimated usage of this Electric/Hybrid vehicle be (1, 2, 3, 4, 5, 6 or 7 days a week):

Commute	1 O	0	0	0	7 O	0	0
Errands	0	0	0	0	0	0	0
Trips	0	0	0	0	0	0	0
Fun	0	0	0	0	0	0	0
Other	0	0	0	0	0	0	0

12.

Please rate the attributes you feel would be most important to you in owning an Electric/Hybrid vehicle (Not important, medium important, Very important)

Range of travel on a charge	Not important	0	Very important
Purchase price	0	0	0
Recharging time	0	0	0
Battery life	0	0	0
Reliability	0	0	0

Low maintenance	0	0	0
Storage or cargo capacity	0	0	0
Cost of ownership	c	0	0
Crash rating	0	0	0
General safety	0	0	0
Low pollution	0	0	0
Cool factor	0	0	0

13.

How often would you be able to charge your Electric/Hybrid Vehicle at home? st

0	Daily
0	every few days
0	other

14.

How often would you be able to charge your Electric/Hybrid Vehicle at work? *

0	Daily
0	Every few days
0	Other

15.

What is important to you regarding service access? (Not important, medium important, very important)

Having an accessible authorized service center?	Not important	0	Very important
Accessibility to an online or telephone technical service representative?	C	0	0
Service representatives who make house calls?	0	0	0

What range between battery charging would be acceptable for you? *

0	0 – 100 km
0	101 – 200 km
0	201 – 300 km
0	301 - 400 km
0	Over 400 km

17.

If there is a public charge place available, would you be comfortable leaving your car here?

0	P _{Yes}	
0	No	
18.	.8.	

How many times a year do you take your car to the garage for a service? *



19.

Can you charge a car at home via a regular wallplug? *

• Yes • No

If you could get acces to a faster charging infrastructure (The charging time would be half of the normal charging time), would you be willing to pay for it? *

0	Νο
0	Yes, but I would pay max 0 - 500 Euro/Year
0	Yes, but I would pay max 500 - 1000 Euro/ Year
0	Yes, but I would pay max 1000 - 1500 Euro/ Year
Q	Yes, and I would pay more than 1500 Euro/Year
21.	

Please indicate how the following statements apply to you. (1 = Strongly disagree, 2= Disagree, 3 = Not disagree, not agree, 4 = Agree, 5 = Strongly agree)

	1	2	3	4	5
I expect to buy an Electric/Hybrid vehicle within the next 10 years.	0	0	0	0	0
I am prepared to pay more for an Electric/Hybrid vehicle as for a regular vehicle	0	0	0	0	0
If there comes an Electric/Hybrid vehicle to the market which is as expensive as a regular car with an action radius of 200 Km and a recharge time of 6 hours, I would be interested to buy this car.	0	0	0	0	C
If there comes an Electric/Hybrid vehicle to the market which is as expensive as a regular car with an action radius of 500	C	C	0	0	C

Km and a recharge time of 6 hours, I would be interested to buy this car.					
If there comes an Electric/Hybrid vehicle to the market which is as expensive as a regular car with an action radius of 500 Km and a recharge time of 12 hours, I would be interested to buy this car.	0	0	0	0	0
The rise of the fuel prices is an incentive for me to buy an Electric/Hybrid car.	C	0	C	С	0
I would only be interested in buying an Electric/hybrid vehicle if it were to be my secondary car.	C	C	C	С	0
I find it important what other people think about my car.	C	0	C	C	0
I would be interested in buying an Electric/Hybrid vehicle for environmental reasons.	C	C	0	C	0
I would be interested in buying an Electric/Hybrid vehicle if a low maintenance is guaranteed.	C	0	C	C	0

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Vanderheyden, Wim

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