

# Masterproef

The impact of electric vehicles on travel behaviour, Formulate and estimate choice models for use of electric vehicles

Promotor : dr. ir. Ansar-UI-Haque YASAR

Abbas Golmohammadi Proefschrift ingediend tot het behalen van de graad van master in de mobiliteitswetenschappen



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# FACULTEIT BEDRIJFSECONOMISCHE WETENSCHAPPEN



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# FACULTY OF TRANSPORTATION AND TRAFFIC SCIENCE

Master of Transportation and traffic science

# Master thesis

# The impact of electric vehicles on travel behavior, Formulate and estimate choice models for use of electric vehicles

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Golmohammadi Abbas

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## Abbreviations

ANOVA:	Analyses of Variance
CD:	Charge Depleting
CS:	Charge Sustaining
EV:	Electric Vehicle
FCV:	Full Cell Vehicle
HDV:	Heavy Duty Vehicle
HEV:	Hybrid Electric Vehicle
IC:	Internal Combustion
IEA:	International Energy Agency
ITS:	Intelligent Transportation System
LDV:	Light Duty Vehicles
OECD:	Organization for Economic Co-operation and Development
PHEV:	Plug in Hybrid Electric Vehicle
PM:	Particulate Matter
SOC:	State of Charge
SWOT:	Strengthen, Weakness, Opportunity, Treat
VOC:	Volatile Organic Compound
WEC:	World Energy Council
SCADA:	Supervisory Control and Data Acquisition

#### Summary

This master thesis was aimed to study the feasibility and adoptability of electric vehicles. It is managed to find out advantages and disadvantages of them and conclude how handy they are? How they can be adapted to Flanders community as a case study? It is tried by this work to give an explanation and identification of different types of EVs and a perspective of Flanders community daily driving pattern, in order to find out how feasible these types of vehicles can be to this community. For these matters and also to be able to answer the study's questions, two different methodologies were applied. The first one was SWOT analysis and the second was statistical survey. In general this study is divided in 5 chapters which come as follow.

First chapter deals with introduction, which explains the current problems of our transportations sector and their causes, globally. Briefly this chapter acts as brain storm to the readers. It is concluded from this introduction that climate and environmental changes are the complicated puzzles of our societies which grate part of them are due to conventional transportation and fuel consumption. Therefore it is discussed in this chapter that seeking alternatives for current transportation is an obligation.

Second chapter reviews scientific literature and related works. In this chapter some existing works and studies of different authors and researchers on electric vehicles have been reviewed. By these works electric vehicles have been investigated from different aspects. For the sake of this thesis some of these works discussed about and also tried to find out which factors and characteristics of Electric Vehicles motivate consumers to consider using it and how can it impact their travel behaviours? It is identified from different authors and researchers works that important factors which can have great impact on electric vehicle usage and driving behaviour of vehicle users are, purchase price, maintenance cost, technical characteristics, driving range, charging time, acceleration performance, maximum speed, environmental friendliness, infrastructure and Psychological aspects.

Third chapter of this work dedicates to identification of electric vehicles, as important alternatives to our current transportation challenges. Now a day's most of the

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researchers and car manufacturers focused on them and try to make them feasible and adoptable to society. In this chapter it has tried to give a clear verification of different types of them and discuss the three main categories which are; Plug in hybrid electric vehicle (PHEV), hybrid electric vehicle (HEV) and pour electric vehicles (EV) in details. The major factors of this types which differentiate them from each other also explained about.

Fourth chapter is covered up by SWOT analyse. It is a structured planning method used to evaluate the Strengths, Weaknesses, Opportunities, and Threats involved in a project or in a business. A SWOT analyse can be carried out for a product, place, industry or person. It involves specifying the objective of the business venture or project and identifying the internal and external factors that are favourable and unfavourable to achieving that objective. In this chapter by use of this methodology it has been tried to analyse those parameters that related to advantages and disadvantages of electric vehicles.

Fifth chapter is survey analyse. By this section the questionnaire which had been lunched on line analysed. This analyse was done by R statistical programming software and SPSS. The items that have been highlighted by this analyse are, Currently Travel and driving pattern of responders, How EVs fits current travel behaviour, Regression and ANOVA analyses and finally what are the responder's attitude about electric vehicles.

Sixth chapter which is the last one goes over general conclusion and also some recommendation to future work.

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#### **1.1 Introduction**

Transportation sector although, faces dilemmas and challenges of its dependency to fossil fuels but presents and operates almost in every aspect of human activities. The use of fossil fuel brings large environmental costs, since it is responsible for contributing massively to the greenhouse effect. It is believed that this greenhouse effect damages human health, plants and animals and upsets sensitive ecosystem balances. Increase in transportation demand due to economic growth will open several challenges to the transportation sector. It is estimated by United Nations[1], that world population from 7.2 billion in 2013 is going to increase by almost 1 billion within the next twelve years and will grow to 8.1 billion in 2025 and in 2050 it is going to be 9.6 billion. According to the World Energy Council's (WEC) report for 2011, on Global Transport Scenario<sup>[2]</sup>, after four decades about more than twothird of world population will live in cities as compared to current amount that is half of it. As it is mentioned above that transportation sector depends mainly on fossil fuel. In Global Transport Scenario's report[2], it is mentioned that in 2010 this sector consumed about 2.2 billion tons of oil globally which constitutes about 19% of global energy supplies. Figure 1 shows that in 2010, as a source of energy for transportation sector, oil was used 96% while the rest was from natural gas, bio fuels, and electricity. Global Transport Scenario's report[2], also states that out of 87 million barrels per day around 51 million barrels was used by transport sector, which is around 60%. Figure 1 shows that 76%, of this energy goes to road transportation which has always dominated the transport energy consumption. This figure also indicates that light duty vehicles (LDV) and heavy duty vehicles (HDV) together consuming almost 70% of transport energy consumption. WEC believes that between 1990 and 2006, global transport energy usage grew at an average of about 1.8% a year for OECD<sup>\*</sup> countries and about 2.8% for non-OECD countries. It is predicted by the U.S. Energy Information Administration[3], that by 2040 world energy consumption will increase by 56%. Transportation sector will be a major factor for high shares in the increased demand of

<sup>&</sup>lt;sup>\*</sup> Twenty countries originally signed the Convention on the Organisation for Economic Co-operation and Development on 14 December 1960.

energy. It is also stated that energy demand by transportation sector will increase by an average of 1.1 % per year for those coming years in the future.



FIGURE1. Transport energy consumption by source and by mode for 2010 (total ~2200 Mtoe), [2]



FIGURE2. Global transport final energy uses by mode (Mtoe), [2]

By discussing about such huge amount of fuel consumption this question should be asked, whether all of the fuel that is consumed by transportation sector is used in an efficient way and converted to the energy that we expected. Of course based on thermodynamics laws all fuel which consumed by vehicles are converted to energy, but not in an efficient way. What is fossil fuel vehicle efficiency then? Let estimate that, as David JC MacKay[4], argued an internal combustion vehicle (IC) or fossil fuel vehicle which drives at 100 km uses about 80 kWh of energy which approximately is equal to 10 kWh/L fuel and for 100 km driving almost 8L fuel is needed. Where does this energy go? Depending on properties of the vehicle, the energy in a typical fossil fuel vehicle goes to four main destinations which are: 1) Speeding up the car by accelerating then slowing it down by using the brakes. 2) Air resistance. 3) Rolling resistance. 4) Heat, 75% of the energy that produced by fuel converted to heat and thrown away because the energy conversion chain is inefficient.

It strongly proves that efficiency of fuel which consumed by internal combustion vehicles are very low. Despite this fact, it will not be exaggerated if we say, almost all motorized transport vehicles relied on combustion of fossil fuel, which produces energy and makes them able to move. Now it might be asked what the combustion is and how does it produces pollution? Michael Biarnes[5], in his written text about combustion explained it as a chemical reaction of hydrogen and carbon that exists in the fossil fuel with oxygen in the air to produce heat, water vapor  $(H_2O)$  and carbon dioxide  $(CO_2)$ . These products are not harmful to human health but indirectly can have major effects. In fact CO<sub>2</sub> is the main principal gas responsible for greenhouse effect. This environmental phenomenon by trapping solar energy increases the average temperature of the earth, changes the global climate and causes natural disasters. The more energy consumed for transportation, the more CO<sub>2</sub> emitted. This fuel combustion produces a number of other byproducts that more directly damaging human health than water vapor and CO<sub>2</sub>. Roger Gorham[6], divided the possible origins of these byproducts in three groups. First, that part of existed Carbon which during combustion doesn't do a completed chemical reaction with oxygen, because of complex reasons, and produces either carbon monoxide (CO) or condenses to form solid carbonaceous particles (soot). Second, hydrocarbons which neither evaporated nor combusted completely, they released as gaseous hydrocarbons and called volatile organic compounds (VOCs). Third, other components of fuel such as sulphur, lead, nitrogen, zinc and magnesium, those are involved in combustion process and converting to oxides of sulphur  $(SO_x)$ , oxides of nitrogen  $(NO_x)$ , sulphate  $(SO_3)$ , aerosols and ash that are harmful to life species. Either those byproducts damage human health directly or react in the atmosphere and produce secondary transport pollutants such as sulphuric acid, sulphates and

ozone, which are also harmful. The sort and amount of those secondary pollutants strongly depend on local atmospheric and climate conditions. Climate and atmosphere, together with urban pattern, population densities and traffic densities, influence the portion of population that exposed to primary and secondary pollutants.

According to these studies about fossil fuel vehicles and their impact on environment and human health it is proven that transportation sector is one of the major cause of environmental hazards and economic damages, therefore to solve these problems we can think of some strategies such as; transportation reduction, increase in public transport as an alternative, changes in fuel characteristics by innovative techniques or introducing alternative energy pathways. In International Transport Forum of 2010[7], it has been suggested that lowering CO<sub>2</sub> emissions by controlling the volume of transport is almost impossible because of constant increasing demand of private vehicles. Some studies also reveal that public transport has some disadvantages as well. Some of these disadvantages are directly related to the operation of public transport companies and some of them are related to the local and the regional level of administrative bodies. Another issue as said by Gabriela[8], is that people are not willing to switch from privet car using to public transports. For such reasons the substitution of conventional gasoline and diesel fuel has been subject of discussion for the last decades, Rolima[9].

In a book about Electric Vehicles (EV) benefits and barriers by Seref Soylu[10], it has been strongly argued that due to high efficiency EVs are seen as the cars of the future (see figure 3), producing no local pollution, no noises and can be used for power regulation by the grid operator. However, electric vehicles still have critical issues which need to be solved. The three main challenges of them are limited driving range, long charging time and high cost. These three main challenges are all related to the battery package of the car. The battery package should contain enough energy in order to have a certain driving range and it should also have a sufficient power capability for the accelerations and decelerations.



FIGURE3. ICs are very inefficient energy converters as compared to electric motors EVs, [10]

In his book Seref[10], has clarified that EVs as an alternative to ICs are more environmental friendly and less pollutants, which can be called green transport. EVs have different technological barriers and structural limitations such as price, battery capacity, charging time to charge the battery completely, charging infrastructures, distance that an EV can travel, engine power, speed limitation, size of the car, number of passengers seats and so on, which make their functionalities to be differed from IC vehicles. These foundational differences have high impacts on travel behavior of EV users. The goal of this study is to find out, how EVs can be adopted and managed by car users, based on their daily driving patterns? How users will adopt their travel behavior? Taylor[11], believes that, behavior change stands out as a critical factor to face the challenges of reducing energy consumption and emissions, because improvements in technology by themselves will not be enough and therefore it is essential to educate people not only to choose more efficient vehicles but also to change the way they use them at optimized level to their daily driving patterns. Driving patterns and travel behaviors are partially related to characteristics, psychological aspects, life styles and living atmospheres of car users and partially related to the potential, ability and feasibility of vehicles which in our case are EVs.

#### **1.2 Problem Statement**

Due to current environmental problems caused by conventional vehicles, the global aim is to diminish greenhouse gas emissions. In order to do so, conventional vehicles should be replaced by alternatives such as EVs. The international energy agency (IEA)[12], has developed an improved scenario to reduce CO<sub>2</sub> emissions and oil dependency by introducing low emission vehicles, such as plug-in hybrid electric vehicles (PHEVs), battery electric vehicles (BEVs), and fuel cell vehicles (FCVs). In this scenario, 27 million PHEVs and BEVs are expected to be sold by 2020 and over one billion by 2050. However, the launch of EV is still in its initial and hesitant stages and the challenges to manage their usage are still there to be solved. For that reason, to formulate the EV using, it is of great interest to find out which factors are important in daily driving behaviors of car users. A review study by Curtis[13], on travel behavior which purposed to summarize current knowledge about the factors which influence individual travel behavior argued that those factors are varied but can be divided into two broad groups: 1) The impact of urban form on travel behavior and, 2) Socio-demographic and lifestyle that influence travel behavior. The most important socio-demographic variables which influence travel behavior are age, household composition, income, gender and car ownership. The challenges that this particular work is facing now are; to analyze those benefits and barriers of EVs either as positive or negative to society and to find out the daily travel behavior of vehicle users in order to manage the feasibility of EVs.

#### 1.3 Study Questions

In section 1.2 it is mentioned that an alternative for current source of energy for transportation is necessary. This alternative can be electric vehicle, but these kinds of vehicles are still in their initial stage. Therefore discussing their advantages and disadvantages will foresee the future of transportation. Another issue is to learn about daily travel patterns to be able to argue how feasible those EVs are. To shed some light to the subject this study has divided into two parts and is going to answer these questions which are:

"What are the important elements which have impact on electric vehicles use based on SWOT analyses?"

"How can EV be adopted by Flemish community as an example?"

## **Chapter 2: Literature Review**

#### 2.1 Related Works

Previous chapter dealt with some present and future challenges of transportation sector. It argued that a substitute for fossil fuel vehicle is necessary. It was certified that, EV should be that substitute because most of transportation decision-makers and transportation researchers unanimously believe that EV has enough potential to solve major part of transportation challenges. But as it is mentioned, EVs are facing some barriers which partially related to their mechanical and technological characteristics and partially to social demography, driving pattern and attitude of car users toward them. This chapter is going to deal with those issues that have impact on EV usage and based on them later on a SWOT analysis will be described for major issues which are considered as barrier in EV adoption. These issues have been discussed in recent research efforts in details almost all over the world. Now to find out which factors and characteristics of EVs motivate consumers to consider using them and how their travel behaviours will be changed by electric vehicle adoption a literature review is presented below which discuss different characteristics of EV and their impact on the penetration of EV into the market.

#### 2.2 Purchase Price

In 2012 European commission [14], lunched a survey among six European countries to examine the attitude of European car users toward electric vehicles. The survey results showed that EV's price was a big issue to 56% of responders.

Another survey which conducted by Sanya Carley[15], in US cities indicated that more than 50% of responders believed the sticker price of a plug-in electric vehicle to be one of those major barriers to their purchasing decision. A study by Yong Zhang and his colleagues[16], in China shows that 46.2% of respondents choose an EV that cost them no more than 150,000 Chines Yuan (CNY) which is almost equal to18000 €.

In a master thesis by Eva-Maria Emsenhuber[17], the results of a survey which was conducted in 2012 by Euro tax Glass<sup>†</sup> has been discussed about which comes as follow. As she said, survey results revealed that 36% of Austrian respondents considered EV's purchase price as a crucial factor to their purchasing decision. Furthermore, 38% said, they would like

<sup>&</sup>lt;sup>†</sup> (Europe's leading provider of information, data, publications and services for all types of vehicles)

to purchase an EV, if it is not expensive. Regardless to high or low purchase price about 12% said they are not interested in EV at all.

#### **2.3 Maintenance Costs**

In part 2.2 of this chapter, it is said that EV's price plays an important role in purchasing decision of individual car users. Almost half of individuals prefer a cheaper EV. But it has to be noticed that vehicle price is only initial cost and if we are interested to compare the economic aspect of an EV to IC then maintenance cost as an important factor has to be considered too. According to Greene[18], consumers take the maintenance cost as an important factor to the vehicle using. But due to battery's durability which represents the major cost component of EV maintenance cost is more critical. Greene[18], states that currently durability of an EV's battery is up to six years while due to constant development of new battery technologies, it will possibly be more than ten years in future. Biere[19], believes the mechanical wear of EV is low and its maintenance costs can become less important if battery must not replace. A survey which conducted by Canadian Automobile Association[20], showed to 19% of the respondents maintenance and service costs of a vehicle is even more important than its safety.

#### **2.4 Technical Characteristics**

When EV is not operating on engine or generator and only have short battery life then its technical characteristics such as, driving range, charging time, acceleration performance and maximum speed might be different from IC. Same as the economic issues which have impact on purchase decision of individuals these technical issues addition to that have impact on their daily driving behaviour too. In order to complete the driving tour using an EV as a transport mode, the impact of these technical parameters on driving behaviour should be considered.

#### 2.4.1 Driving Range

The maximum driving range of most recently manufactured EVs with a full charged battery, as it is mentioned by Emsenhuber[17], is almost 160 km. Ireland's Sustainable Energy Authority (SEAI)[21], also claims that the range of Battery only Electric Vehicle's (BEV) is between 60 to 160 km. This low driving range is mainly due to low energy density and short life of battery. The batteries capability of storing electrical energy is low. A research by Deloitte[22], argues that driving range of most recently produced EVs doesn't satisfy the consumer's expectations. He said, in order to consider purchasing an EV more than 60% of respondents expect a driving range of at least 160 km. However, the results of some previous surveys on person's daily driving distance which have been cited in a work by Franke[23], indicate that 61% of Europeans drive less than 100 km per day. In US this individuals average driving is 61km per day and in Germany it is almost 62 km. later on his discussion he gave other results that are opposite to these average driven ranges. He said average acceptable range to purchase an EV by German residents is 353km. For EU in general it is 308 km and in US it is much higher and is 473km. Despite of peoples demand for longer driving range the low driving range of EV should not be an obstacle for daily driving distances.

#### 2.4.2 Charging Time and infrastructures

Since the IC vehicles refuelled conventionally at the gas stations the time spending except on traffic jam situation is not a big issue, while for EVs it is. Vehicle drivers wouldn't be willing to accept long time charging or refuelling process. According to Segal[24], almost six hours charging time of an EV would discourage consumers to purchasing it. According to him, the charging time of an EV is going to be an even more important factor than its driving range.

By looking back to Deloitte's survey [25], it can be noticed that consumers aren't satisfied by EV's technical characteristics, majority of them responded that they expected an EV's battery to be recharged within two hours or even less. Long charging time such as six or even eight hours is only acceptable by a small part of them. Since long charging time is a fact by current EV batteries, therefore EV users facing another challenge which is where to overcome this challenge, a sophisticated and fast charging infrastructure is proposed on public places like office buildings, supermarkets, parking lots etc. In the following we will discuss about which types of charging technologies currently exist.

According to a scientific paper by Ramteen Sioshansi[26], three major charging technologies currently are available. Level one charging that uses a standard wall outlet and provides electricity connection of 110V and 15A. For typical EV, with battery capacity between 16 and 25 kWh, using such a connection will take 12 to 18 h to charge completely. Level two charging provides 220V and between 15A to 30A, electricity connection. Then

for EVs with battery capacity between 16 and 25 kWh it will take almost 6 to 9 h to be charged. Level three, which called Direct Current (DC), is fast charging and provides high voltage from 400 to 500V and by almost 30 minutes of time it can fully charge a typical EV battery. Since level three requires special equipment, due to its safety and economic matter is not expected to be deployed in any standard residential location.

This brief explanation of charging levels indicates that some other related challenges of charging facilities are number, type and optimized locations of charging stations. In the paper by Ramteen Sioshansia[26], a simulation optimization model that determines where to install charging stations in order to maximize their use by EV users has been discussed in the following. His modelling approach consists of three steps. The first was EV's flow determination between the sub regions. Therefore to determine it, demographic data on EV adoption probability by vehicle owners who are living in each sub region was used. The second step was determination of expected number of EVs that successfully charge at a candidate location, as a function of number of chargers built, by developing a simulation model. The final step was to determine the location and size of charging stations by use of a linear integer programming (IP) model. His case study was the city of Columbus at the central Ohio region and its surrounding metropolitan area. It covers about 6000 km<sup>2</sup> and in 2010 had 1.7 million inhabitants and 1.1 million light duty vehicles. They examine the case by this assumption that EVs consist 1% of the light duty vehicle fleet. The result of his work which is illustrated in figure4 shows the number of expected EVs that based on his simulation model of public charging infrastructures cannot complete their daily tours. This study shows that about 96% of vehicle users drive by a range less than modelled EV with 117 km assumed range. It means only 4% of EV users wouldn't complete their tours without midday recharging. He argues that public chargers reduce the number of EVs that cannot complete their tours by up to 16%. For him between 80% and 96% of those EVs that cannot finish their tours drive to locations that are not modelled and thus would not have access to the public chargers. He said if only consider those EVs that drive to locations which are modelled in the IP, then 99 to 100% of them would be able to complete their daily tours.



FIGURE4. Expected numbers of EVs that cannot complete their tours, [26]

#### 2.4.3 Acceleration Performance

Although there is not any proof of change in consumer's attitudes, if the high acceleration performance of EVs can be seen as a possibility to improve its global image, but a work by Potoglou and his colleagues[27], stats that vehicle users especially males highly value acceleration performance and maximum speed of the vehicles. In another survey about vehicle purchasing choice by Burge[28], the importance of high acceleration performance as a purchasing decision factor, has been confirmed. His survey results showed, although the size, maximum speed and fuel price were of smaller importance for households with low and high income but both were willing to pay a price for a vehicle with high acceleration performance as conventional vehicles, these findings can be considered to be in favour of EVs.

#### 2.4.4 Maximum Speed

Grünig[29], states that, maximum speed of a purely battery EV can reach to172 km/h on average. Then compared to currently IC's driving speed, EV's maximum driving speed dose not significantly makes any difference but due to overheating, without any sophisticated cooling systems they cannot maintain this maximum speed for a long time.

According to Dagsvik's[30], survey which conducted in Norway, the vehicle's maximum speed for some respondents wasn't so important but male respondents younger than 30 years of age and older than 50 years of age found this technical characteristic more important than other respondents.

#### 2.5 Environmental Friendliness

In previous chapter it was explained that EVs due to their energy efficiency are considered to show great promise for reduction of greenhouse gas emissions and a cleaner environment. It means that some power plants which producing the electricity may emit tailpipe pollutants therefore the environmental friendliness of EVs depends on the type of electricity generators. The electricity derived from nuclear, wind or solar powered plants is environmental friendly. According to Danish Energy Agency[31], the Danish wind turbines produce excess amount of power than demand which can make it possible that EVs exploit the excess of wind power in the future.

It has to be noticed that by transport sector greenhouse gas emission is not considered as the only environmental pollutant, noise emissions can be another as well. In this case due to their low noise level, EVs have an advantage over conventional vehicles. Therefore the massive use of EVs, especially in larger cities, would be advantageous for both drivers and residents. However it might have an impact on safety of vulnerable road users. As vulnerable road users such as pedestrians and cyclists might not be able to hear EVs approaching which can cause any road accident.

#### 2.6 Psychological Aspects on EV Driving Behaviours

Davis and his colleagues[32], discussed the Technology Acceptance Model which derived from the Theory of Planned Behaviour. They argued in order to understand Technology Acceptance Theory the Theory of Planned Behaviour has to be elaborated first. The Theory of Planned Behaviour is an extended model of Theory of Reasoned Action by Ajzen and Fishbein[33],. It consists of "Attitude towards the Act of Behaviour", "Subjective Norm" and "Perceived Behavioural Control". The "Behavioural Intention" and "Actual Behaviour" partially influenced by these two attributes. The "Attitude towards the Act of Behaviour" means the belief of a person that certain behaviour will lead to certain outcomes,

whereas the factor "Subjective Norm" indicates the belief that a certain person having the opinion that one should or should not perform certain behaviour. It further explained by Schiffman[34], he stated that "Perceived Behavioural Control" indicates whether or not persons are able to act according to their actual intentions.

The major assumption which Theory of Planned Behaviour reveals is that, both intention and behaviour are correlated with the natural personality of a person and the external or social influence and control. It was based on the Theory of Reasoned Action and the Theory of Planned Behaviour that in order to be able to predict person's behavioural intentions in relation to technological innovations Davis[35], proposed his Technology Acceptance Model.

From this general literature review it can be concluded that both social and technological factors play role on adoptability and feasibility of EVs side by side. Vehicle users are very careful with vehicle prices and costs. They prefer to have one which is cheaper in price and its maintenance cost doesn't disturb household budget. Except to some who are living on fantasy life, this economic point of view has strong psychological attitude towards vehicle consumption and they all have privet reason for. As it is explained in above mentioned psychology explanation, attitude changes intention and consequently intention changes behaviour, therefor the EV purchasing decision as an intention and later on EV consumption as a driving behaviour will be dominated by this economic point of view. In this research work, we are only interested in the purchasing and maintenance cost as a user's perspective, although manufacturers have some other perspective which is not included in our scope. Technical aspects are also other factors which dealt with in this literature review. Consumers prefer a vehicle with bigger driving range, however their daily driving range is even less than EVs driving rang. Maximum driving speed and acceleration to some "meals and youth" are important but to others are acceptable. These parameters can also be justified by vehicle user's psychological behaviours. There is a clear contradiction between these factors by both sides, what the Vehicles offer and what the consumers expect.

## **Chapter 3: Type of electric vehicles**

#### **3.1 Type of Electric Vehicles (EV)**

An electric vehicle is a sort of automobile that in order to powering the wheels uses electrical energy stored in battery or another energy storage device. This vehicle has been described by Erwing and Sarigöllu [36], as an innovative vehicle. European Parliament [37], defined it as; *"It has the highest engine efficiency of existing propulsion systems and zero tailpipe emissions"*. Anderson[38], states that EV is less emission producer, conserves more energy than fossil fuel vehicle and addition to that is more cost saving.

Whereas the concept of EV commonly used for any battery electric vehicle but based on their research on EVs technology, Larminie and Lowry[39], distinguished six different categories of them which are: a) Battery Electric Vehicle, b) Hybrid Electric Vehicle, c) Vehicles supplied by power lines, d) Vehicles using replaceable fuel, e) Vehicles using solar energy from radiation and , f) Vehicles storing energy by alternative means.

From those categories mainly the battery electric vehicle (BEV) is at the focus of this work and by the next chapters that type is going to be analysed and discussed about. But before of that in order to have a general and clear perspective of them, by this chapter the three main types which at most are at the attention of transportation sectors have been discussed about. This coming explanation clarifies their impact on daily driving behavior of car users if are going to be used.

These three types are: Hybrid Electric Vehicles (HEV), the Plug-in Hybrid Electric Vehicles (PHEV) and the Battery Electric Vehicles (BEV). There is also another one which is called fuel cell electric vehicle or hydrogen fuel cell vehicle, but it is not at scope of this study. Every one of these vehicles has some advantages and disadvantages.

#### 3.1.1 Hybrid Electric Vehicle (HEV)

In a book by Larminie, and Lowry[39], the Hybrid Electric Vehicle (HEV) described as a type of vehicle which is between internal combustion engine vehicle and battery electric vehicle. It can be called as a transitional type from an IC vehicle to the EV vehicle. Houyu and Guirong[40], also described them based on their technological characteristics and said they have long engine operating time, a less motor pollution, with over 10% of increased thermal efficiency and over 30% of improved exhaust gas emission and the lower noise.

From those technological characteristics it can be seen that HEV operates and covers the same distance as IC, but in case of energy consumption and consequently pollution production are different. They operate based on both engine drive and direct electric motor drive systems. The engine and the electric motor compose the mix dynamic system together to force the vehicle to travel. This type of system operation causes less noxious gas production out of vehicle's fuel consumption and due to that less waste gas discharges. Currently the fuel consumption of a passenger HEV is about 3L/100km. In this vehicle engine's power is smaller than generally the same rank internal combustion engine vehicle. Besides, it does not need a ground charging facility.

Comparing to BEV in HEV available IC engine generates power together with electric motor and after filling it up by fuel can travel about 500 to 1000 kilometers. HEV recharges its battery as a supplement electrical energy therefore does not need to look like BEV which needs a constructed ground charge facility. When hybrid electric vehicle decelerates and takes brake the drive motor transforms into the generator and changes the braking energy into the electrical energy and causing the deceleration and the braking energy to be recycled. It is helpful to know what the HEV major technical units are:

#### ✤ Engine

HEV may use the four stroke regulation internal combustion engine, two stroke internal combustion engines, the rotary engine, the gas turbine and Sterling engine and so on.

#### ✤ Motor

HEV may use the shunt electrical machine, the AC induction electrical machine, permanent magnetism electrical machine and the switched resistance electrical machine and so on. Now, the shunt electrical machine is seldom used while the induction electrical machine and permanent magnetism electrical machine are used widely. The switch magnetic resistance electrical machine application is also used and the special motor as HEV the drive motor is used.

✤ Battery

HEV may use different batteries, fuel cell, energy storage and super capacitor.

#### 3.1.1.1 Types of HEV

Because the HEV's power might provide by different type of mechanical combination, therefore based on its composition and structure it varies in different types. This HEV mainly divided into three types: series (SHEV), parallel (PHEV) and the combined type (PSHEV) according to the energy synthesis's form.

#### **3.1.1.2 Series Hybrid Electric Vehicle**

The series power as it is explained by Heejey Kang[41], includes engine, generator and motor. In this category as it is illustrated in figure 5, the wheels are getting their power from electric motor which it also gets its power either from battery or generator that is driven by an engine. Therefore the engine is not directly coupled to the wheels but to the generator. This generator converts the mechanical energy of engine to electric energy. This energy splits to recharge the battery or drives the motor which is connected to transmission. When the vehicle needs more power to drive then the motor draws power from battery and engine. The benefit of this series HEV is that engine is able to operate in a constant efficient speed when continuously converting energy to charge the battery or drive the vehicle. But because it has to go through a double power converting "from mechanical energy of engine to electrical energy of motor then from electrical energy of motor to mechanical energy to the wheels" it has inherent efficiency losing.



FIGURE5. Series Hybrid Electric Vehicle structure, [5]

#### **3.1.1.3 Parallel Hybrid Electric Vehicle (PHEV)**

The Parallel Hybrid Electric Vehicle has two set of driving systems, the engine drive and the electric drive, as shown in figure 6 both already may drive and may also actuate the vehicle. In this vehicle engine works in a highly effective situation and causes fuel efficiency to be quiet high and emission much low. In this type of vehicle because the driving system may choose the parts with the small power, therefore it is mainly used in the small cars.



FIGURE6. Parallel hybrid electric vehicles structure, [5]

For the parallel engine and the motor by the mechanical energy superimposition's way drive vehicle, the engine and the motor both may drive together or individually. The motor may be used as the motor or the generator, also called the electrically operated power

set. With the independent generator, the engine may directly transmit the power to the wheel through the transmission system actuation and supply the electrically operated generator electricity to battery.

#### 3.1.1.4 Combined Hybrid Electric Vehicle

As it is illustrated in figure7 due to its structural composition, the major characteristic of the combined hybrid electric dynamic system is that in order to reduce the possible loss of energy when the vehicle starts and travels at the low speed its engine may shut down completely.



FIGURE7. Hybrid electric vehicles structure, [5]

#### **3.1.2 The Plug-in Hybrid Electric Vehicles (PHEV)**

Plug-in Hybrid Electric Vehicle is a type of vehicle that can use fuel and electricity, independently or even not, but both fuel and electricity have to be recharged by external sources. This type can be seen as an intermediate technology between BEV and HEV. It can be considered as either a BEV supplemented with an internal combustion engine in order to increase the driving range or as a conventional HEV where the all-electric range is extended as a result of larger battery packs that can be recharged from the grid. The PHEV has been defined by Nemry and his colleagues[42], as any hybrid electric vehicle which contains at least a battery storage system of 4 kWh or more that used to power the motion of vehicle and recharged from an external source of electricity and has ability to drive at least 10 miles (16 Km) in all electric mode and consumes no gasoline. A plug-in hybrid electric vehicle

can be designed with the same types of technological architecture as current hybrid vehicles, namely series-hybrid, parallel-hybrid, or combined series-parallel hybrid which are mentioned above, look at figure 8.



FIGURE8. Simplified representation of HEV/PHEV configuration (blue: series; red: parallel) [7]

#### **3.1.3 Battery Electric Vehicle (BEV)**

A Battery Electric Vehicle is a type of electric vehicle that doesn't use an internal combustion engine. It is all electric, which means it is totally depends on battery. It has to plug in to the power grid to charge the battery. So the battery is used as only resource to power an electric motor, which in his turn drives the vehicle. Due to electricity consumption BEV can drives and operates without any emissions. It has also no noise except the noise that comes from the fires and can operate in complete silence. Due to the characteristic of an electric engine, the car won't need gear box most of the time. Most new BEVs also make use of regenerative braking, where the lost energy from braking can be restored in the battery.

It is true that battery electric vehicle produces no emission when is operating, but to over view 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 than the electric vehicle can offer a large reduction of environmental impact than the others.

# **Chapter 4: SWOT Analysis**

SWOT analysis is a structured planning method which used to evaluate and analyse Strengths, Weaknesses, Opportunities, and Threats involved in a project or in a business venture. It can be carried out for a product, place and industry to identify internal and external factors that are favourable and unfavourable to achieving that objective. This method enables to identify the positive and negative influencing factors of companies which are inside and outside of their organizations. Besides that it can be used in areas such as community health and development and education to improve their guiding principles. The key role of SWOT analysis is to help develop a full awareness of all factors that may affect strategic planning and decision making. In this chapter the goal of applying this method is to find out those factors which internally or externally have impact on EV's feasibilities and consumptions. Let's begin with first parameter of SOWT methodology which is strengths.

#### 4.1 Strengths

#### 4.1.1 Less Emission in General

As it is mentioned in chapter1, more than 60% of oil consumed globally, about 51 million barrels per day, goes to transportation sector. Figure1 shows, road transport accounts for about 76% of transportation energy consumption. The light duty vehicles (LDVs), including light trucks, light commercial vehicles and minibuses accounted for about 52%, while trucks, including medium and heavy duty, accounted for 17%. The remaining share of this energy consumption goes to full sized buses, 4% and two or three wheelers, 3%. Air and marine each accounted for about 10% of total transport energy consumption, while the railways accounted for only 3%. Let's take 76% of fuel consumption which is up to 38.76 million barrels of oil per day for road transport as our basic calculation. A standard crude oil barrel is almost 159 litres. By used of following basic model which mentioned in a book by Mackay[4], the emission of this amount of oil can be calculated.

"1 liter of diesel weighs 835 gram, Diesel consists 86.2% of carbon, or 720 gram of carbon per litre diesel. In order to combust this carbon to  $CO_2$ , 1920 gram of oxygen is needed. Then the sum will be 720 + 1920 = 2640 gram of  $CO_2$ /litre diesel".

The amount of fuel which is consumed by road transportation sector per day in the whole world is almost equal to  $38.76 \times 159 = 6,162,840,000$  litres. Then the amount of CO<sub>2</sub> which will be released by this amount of fuel consumption is  $6,162,840,000 \times 2640 = 16.3$  million ton CO<sub>2</sub>/ day. By this result we can assume if 1% of road transport vehicles switch to EV then it will be 163,000 ton CO<sub>2</sub> reductions per road transport every day. This argument proves that one of the strength aspects of EV is CO<sub>2</sub> reduction and environmental friendliness. We can calculate this amount of CO<sub>2</sub> producing for Belgian community too. According to EU transport report for 2011[43], in Belgium about 8.9 ktoe, (kilo tonne), petrol and diesel had been consumed in only road transportation sector. By converting this kiloton amount to litre it shows that 8.9 kiloton is almost equal to 10.7 billion litre of fuel for whole the year which in average is 2.9 million litres per day. The emission of this amount had been 28.24 million ton of CO<sub>2</sub> for whole the year and 77400 ton per day. Again by switching 1% of transportation vehicles to EV it could be 282400 ton reduction of CO<sub>2</sub> for whole the year (2011) which is equal to 770 ton/day. This result can be adopted as the yearly indicator for CO<sub>2</sub> reduction.

#### **4.1.2 Oil Independency**

According to world energy agency[44], the world demand for oil in 2012 was 89.84 million barrels per day, which as it is mentioned above 38.76 million barrel of it goes to road transportation. Again assume that 1% of IC switch to EV then it will be 387600 barrel reduction of oil consumption per day.

#### 4.1.3 Cost Efficiency

In order to estimate the cost efficiency of energy per unit of fuel which is also called the calorific value or energy density, it is interesting to estimate this sort of quantity by a bit of lateral thinking. Vehicle fuels, either diesel or petrol, are hydrocarbons. This hydrocarbon, with its calorific value conveniently written on the side which is roughly 8 kWh per kg, can also be found on our breakfast table, "Look at the label on a pack of butter or margarine". The calorific value is 3000 kJ per 100 g, or about 8 kWh per kg. To turn fuel of 8 kWh per kg, (energy per unit mass) into energy per unit volume, we need to know the density of the fuel. Well what is the density of butter? We know that butter just floats on water but fuel spills, so fuel density must be a little less than water's which is 1 kg per litre. As it is also mentioned in section 4.1.1, one litre fuel is equal to 835 gram, and then if we consider a density of 0.835 kg per litre it obtains a calorific value of 8 kWh per kg  $\times$  0.835 kg per litre. This brief explanation clarified whole the idea. But to be more accurate rather than fully perpetuate an inaccurate estimate, the actual value which is 10 kWh per litre of fuel that used by MackKay[4], is going to be adopted.

Here this work is interested to find out how much fuel as energy is consumed in road transportation sector in Flemish community per year and how financially it might be different with its equivalent electricity. In 2012 in this community about 169.6 Peta-joules, PJ (10<sup>15</sup> joules) energy was consumed by road transportation sectors [45].

The unit of energy which used as everyday electricity is known as kilowatt-hour (kWh) and one kWh is equivalent to  $3.6 \times 10^6$  J, therefore by converting the amount of energy consumption to electricity then we will come to the  $(169.6 \times 10^{15}) / (3.6 \times 10^6) = 47 \times 10^9$  kWh. Now we are interested to find out the fuel equivalent of this amount of energy. As it is mentioned above energy of petrol is 10 kWh per litre, it means in 2012 in Flamish community equivalent 4.7 billion litre fuel had been consumed to produce the demanded energy by road transportation. In section 4.1.1 it is said that fuel consumption for whole the Belgium in 2011 was 10.7 billion, then somebody might say half of it will be share of Flamish community, presumably it might be true but we tried to be as accurate as possible.

Up to here we have the fuel consumption which is  $4.7 \times 10^9$  L and its equivalent electricity which is  $47 \times 10^9$  kWh. Now we want to compare them financially. The question is, can just simply multiply their price and say the differences? Of course not, because of two reasons it might not be correct, 1) The price of diesel and petrol aren't the same and 2) Efficiency of fuel and electricity aren't at equal level. In chapter one it is already discussed about that Seref Soylu[10], in his book about EVs benefits and barriers said that fuel efficiency is 30% when for electricity it is 80%. Table1 gives the amount of private vehicles and type of fuels that in 2012 used in Flanders community as it is illustrates all this energy which had been consumed didn't come from the same energy sources and even didn't use by the same transport modes. In here we are dealing with road transport, therefore the shear of petrol and diesel users by road transport modes were 36.35% and 62.64% consequently. The other 1.01% consumption belongs to the rest of fuel types.

Fuel type	Year 2012	
petrol	1.180.597	
diesel	2.034.548	
LPG	18.770	
Electricity	340	
Hybrid*	7.308	
Gas	135	
mixing lubrication	6	
Diesel + Gas	4	
Electricity + LPG	0	
Bio-ethanol	79	
Petrol + LPG	1	
Petrol + Gas	26	
Not clear	6.213	
Total	3.248.027	

TABLE1. Fuel type used and number of cars individually in Flanders, Belgium in 2012, [45]

It is calculated that Flanders fuel consumption was  $4.7 \times 10^9$  L, from this amount the share of petrol and diesel with 36.35% and 62.64% of consumption would be  $(1.6 \times 10^9)$  litre petrol and  $(2.97 \times 10^9)$  litre diesel. The price of petrol and diesel per litre in 2012 in Belgium in average were 1,760 and 1,550 consequently [46]. Then as it is given in table2 the paid price for that was 7.3 billion in total which is paid by individual consumers. Now what it would be the price if it was electricity? First we have to calculate the electricity equivalent to that amount of fuel based on their efficiencies than calculate the price of it.

$$\frac{(Fuel efficency)}{(Electric efficency)} \times (Amount of equivalent electricity to fuel)$$
(1)

By use of this model it will be equal to  $(30/80) \times (47 \times 10^{9})$  kWh =  $17.6 \times 10^{9}$  kWh. The price of electricity in 2012 was 0.22 Euro/ kWh. Then for that amount of electricity if it was used instead of fuel would be 38.7 million  $\in$ . This price calculation shows how different the general price of fuel comparing to electricity would be, table 2.

Fuel consumed for road transportation in 2012(Flanders Belgium), Billion litre	Price of consumed fuel, Billion Euro	Equivalent of electricity price if was used, Euro/ million
Petrol 1.6	Petrol 2.8	Price of electricity in 2012
Diesel 2.97	Diesel 4.6	0.22 /kWh
Total 4.57	Total 7.4	Total 38.7

#### TABLE2. Comparison of electricity to fuel in road transportation

#### 4.1.4 Low Rate of Noise

The noise and vibration of the automobile depends on the engine and the driving condition. Compare to engine vehicles, EV has much fewer vibration sources, no burning procedure, no mechanical motions, only has noises from air compressor, cooling fan and transmission mechanism. Thus its noise level is much lower than engine vehicles. While reducing noise pollution is desirable, but quiet vehicles could negatively affect pedestrian safety because of sound cues reduction compared to louder internal combustion engines, see part 4.2.4 of weaknesses.

#### 4.2 Weaknesses

#### **4.2.1 Power Production Pressure**

If anybody thinks about such huge amount of energy consumption by transportation sector which mainly comes from fossil fuels he or she initially might think that replacing IC by EV will be a great pressure to power production sector because that needed amount of energy have to be produced by electricity power sites. But researchers have different ideas Luk Knapen and his colleagues[47], by studying the power demand for EVs in Flanders believe that pressure will not be so considerable. It can also be foreseen by compering efficiencies of both vehicles which are 80% to 30% for EVs and IC consequently. It means by less electricity consumption the equal amount of energy which produced by fossil fuel can be obtained. A study by London Royal Academy of Engineering in 2010[48], said that an EV uses almost around 0.2 kWh/km in normal city trip. Table1 said that in 2012 in Flanders around 3.23 million private fossil fuel vehicles were commuting and according to survey results in chapter five of this work, the average daily driving distance of them is
almost 40 km/day then every vehicle to be able to complete its daily tour based on royal academy report needs 8 kWh energy/day. This amount for whole Flanders will be 9.4billion kWh/year. It is also said that in 2012 electricity production in Belgium were 84.2billion kWh[49]. This amount was produced by different sources such as; Fossil fuel 38.4%, Hydro 0.6%, Nuclear 59.3% and Renewable 1.7%. These figures say that Belgium still relays on nuclear and fossil fuel to generate power. Thus compering 84.2 billion kWh productions to 9.4 billion kWh extra demands, then 11.16% extra electricity power is needed to switch 100% of fossil fuel vehicles to EV which might not be a big issue because the vehicles are going to be replaced gradually not at once. But what going to be challenges are: 1) If this extra demanded energy is going to be produced by use of fossil fuel, and 2) Charging period is not going to be regulated and everybody tries to charge his or her vehicle at pick hours of day then it will put more pressures on electricity grids.

## 4.2.2 High Costs of the Battery and Its Life Cycle

As it is said by Kwo Young[50], the two major battery technologies that currently used in EVs are nickel metal hydride (NiMH) and lithium ion (Li-ion). Currently almost all available HEVs in market use NiMH batteries due to its mature technology. But because of potential of obtaining higher specific energy and energy density, the adoption of Li-ion batteries expected to grow fast in EVs industry particularly in PHEVs and BEVs. It should be noted that there are several types of Li-ion batteries based on their different chemical technologies. According to Anderson[38], the cost of Li-ion battery includes material cost such as anode/cathode materials, manufacturing, marketing and transportation cost. Material cost includes almost 75% of the total battery pack cost while manufacturing and other costs represent around 5% and 20% respectively. As it is mentioned by Clean Technica website texts[51], in 2009 the price of Li-ion battery was in range of 700-1000 \$/kWh or even higher. In 2012 this price decreased to 650 \$/kWh and estimated to be 400 \$/kWh in 2020. Now to calculate the cost of battery, let's go to our EV sample which has explained as, Ford Focus full Electric vehicle, by range of 76 miles (120 km), Charge rate 6.6 kW, charging time about 4 hours and Battery capacity of 23 kWh. If we take the currently price of battery which is 650 \$/kWh (472.45€) then the price of our example vehicle battery will be 23 kWh × 472.45 kWh= 10.866 €/ 23kWh. As you can see this price is quite high. Another issue about EV battery is its cycle life.

As Han and his colleagues explained[52], there are two major criteria for the cycle life of a battery. One is a cycle life that represents the battery life in terms of the achievable cycle count, and the other is a storage life that estimates the retainable duration without considering the cycling of the battery. Since the purpose of EV charging control is to reduce the charging cost or to attain the additional revenues by actively cycling the battery, cycle life is the key criterion that should be considered. Let's go back to our EV example vehicle, in 2013 in US it was sold for 35000\$. This price is almost equal to 25300€. Now if we try to adopt it to Flanders community in Belgium then what will be the overall cost of it? Well the increasing rate of diesel price for this community is 0.227€ per year in average. This increasing rate is due to different political and economic situations which are not at concern of this work then to be more realistic we take 10% increasing rate in account for our calculation. If we assume that cycle life of this vehicle is 15 years and battery cycle life "depends on manufactured battery" can also be the same cycle life as vehicle or half of it. If that car is used for 25 Km driving distance per day in average and its fuel consumption is 1.25L fuel per day than it should be 456.25 L fuel consumption per year. Diesel fuel cost in Belgium in 2013 in average was 1.4650€ /L. The whole cost for 1 year consumption would be 668 €, then by considering 0.1 as increasing rate per year the possible consumption fuel for whole vehicle cycle life which is 15 years, by following mathematic model can be obtained.

$$FV_{annuity} = \frac{(1+r)^{n}-1}{r} \times (payment \ amount)$$
(2)

Where r = interest rate, n = number of periods. The simplest way to understand the above formula is to cognitively split the right side of the equation into two parts, the payment amount and the ratio of compounding over basic interest. The ratio of compounding is composed of the aforementioned effective interest rate over the basic (nominal) interest rate. This provides a ratio that increases the payment amount in terms of present value. Let go back again to our example vehicle, it is said that by a full battery of 23 kWh it can complete a range of 120 km which is 5.22 km per l kWh electricity power. Now we can calculate the electricity consumption cost for the cycle life of it same as what we did for fuel consumption. Again we assume an increasing rate of 0.1 for power price and 25 km daily driving distance. Based on electricity price which in 2013, in average was 0.227 per kWh of the yearly electricity consumption cost for 25 km driving distance per day for this vehicle should be  $402 \in$ . We take this amount as basic year and calculate it for 15 years in the future, table 3.

Price of VE	Fuel Consumption in one year for 25 km travel per day	Electricity consumption in one year for 25km travel per day	Price of diesel consumption in 15 years in future by 10% price increasing	Price of electricity consumption in 15 years in future by 10% price increasing
25300€	456.25 L	1748 kWh	21237€	12774€
	-		PV +FV	PV+FV
			46537	38074

TABLE3. Comparing the lifecycle cost of EV to IC

This costing calculation shows that without concerning other external costs of vehicle such as taxes, maintenance and so on, by only taking account the purchase price and fuel or electricity consumption in whole vehicle cycle life the electricity is more efficient but if life cycle of battery is half of the vehicle than it makes different. It shows that cost can be 38074+10866=48940.

## 4.2.3 Limited Range

It is mentioned by Shiau Ching-Shin[53], that technological advantage of PHEVs stems from its capability of driving on different energy modes and resulting in different state of charge (SOC) levels. These Two basic modes are;

1- In the Charge Depleting operating mode (CD), the vehicle is powered only or almost only by the energy stored in the battery, and the battery's SOC gradually decreases up to a minimum level which depends on the battery size. The vehicle thus mostly behaves as an electric car which particularly suits to urban driving. This mode can actually operate in two ways, a) under the "CD blended mode" that IC engine is turned on, b) Under the "CD all electric' mode" that IC engine is turned off.

2- During the Charge Sustaining mode (CS), the SOC over a driving profile may increase and decrease but will in average remain at its initial level. The battery's SOC is maintained within an operating range and can be recharged through regenerative braking, from IC engine. In this case, PHEVs behaves as conventional HEVs. This brief explanation says that PHEV still relays on engine and fuel consumption. This limited capacity of battery doesn't allow zero emission targets.

Since EVs do not come with engines or generators and only have a short battery life, they provide more limited driving ranges than conventional vehicles.

Nathaniel. S. Pearre and colleagues[54], used one full year of driving data from 484 instrumented gasoline vehicles in the US to analyse daily driving patterns and from those infer the range requirements of EVs. As it is illustrated in figure 9 to be able to interpret it a crosshair, "the cross and circle target" has been included near the lower left hand corner. On the Range axis the crosshair is aligned with 125 miles or 201 km and on the Days Requiring Adaptation axis the crosshair is aligned with 2 days. If this crosshair aligned on the axes in this way then it falls on the 0.25 isobar line. This may be interpreted as follows, If electric vehicles have driving range of 125 miles or 201 km and the owners of these vehicles are willing to adapt their travel behaviour no more than two days per year (switching vehicles or charging during the day) then that vehicle would be compatible with the current driving patterns of 25% of fossil fuel vehicle drivers. Put it on another way, 25% of the monitored vehicles travelled no more than 125 miles or 201 km per day except on two or fewer days per year.



FIGURE9. Driving success surface, the fraction of the 363 vehicle fleet (numbers on lines) which would be suitable for an EV with the shown vehicle range (x axis) on all but a given number of days requiring adaptation (y-axis),[40]

## 4.2.4 Safety Risks

In the case of noise and safety a study by Michael S. Wogalter[55], shows that 70% of interviewees believed that the lack of noise of an electric car would be a potential danger for pedestrians. A sizeable number, 86% agreed that sounds emitted from a moving vehicle made them more aware of its location and direction. In addition, most participants 73% said that when crossing a street they have used vehicle sound as a cue that a vehicle is approaching.

## **4.3 Opportunities**

## **4.3.1 Legal Regulations for Low Emissions**

Particulate matter (PM) is a complex mixture consisting of small solid and liquid fragments, fragments with solid cores and liquid exteriors. These fragments consist of various materials such as metal, soot, soil, dust, or a combination of them. The two most regulated classes of particulates are PM<sub>10</sub> and PM<sub>2.5</sub>. The numbers 10 and 2.5 refer to the size of the particles which are measured on micrometre ( $\mu$ m) unites. The level of PM<sub>10</sub> or PM<sub>2,5</sub> in the atmosphere is measured as the quantity of PM<sub>10</sub> or PM<sub>2,5</sub> particles in micrograms per cubic meter,  $\mu g / m^3$ . PM is created as a direct result of burning fuels such as oil, gasoline or wood. However, windblown dust as well as chemical reactions between Sulphur Dioxide (SO<sub>2</sub>), Nitrogen Oxides (NOx) and other substances such as Ammonia can indirectly contribute to atmospheric levels of PM. It is strongly discussed by Environmental Protection Agency[56], that PM<sub>10</sub> has been linked to serious cardiopulmonary diseases, acute respiratory infection, trachea, bronchus and lung cancers. In response to increased concerns about the detrimental health effects of air pollution the EU[57], has issued a series of Clean Air Directives which introduced EU-wide limits on ambient PM<sub>10</sub>. This regulation which is on practice science first January 2010 says that the amount of PMs in a polluted situation has to be limited to a yearly average of 20  $\mu$ g /m<sup>3</sup> and daily average (24-hour) of 50  $\mu g$  /m<sup>3</sup>. It is already mentioned that EVs have great capacity to reduce fossil fuel consumption (look at section 4.1.1 of this chapter), than it can be concluded as a high opportunity to support the EU air quality regulation.

## 4.3.2 New Business Models and Manufacturers

It is explained by Allcock[58], that International Energy Agency's (IEA) has developed an improve scenario to reduce  $CO_2$  emissions and oil dependence by introducing low emission vehicles such as PHEVs, BEVs, and fuel cell vehicles (FCVs). In this scenario 27 million PHEVs and BEVs are expected to be sold by 2020 and over one billion by 2050. This should be looked at as a new manufacturing opportunity by international vehicle manufactures.

## **4.3.3 Public Funding and Investments**

EVs are available and used in the market primarily due to public authority intervention. Another important step on the path from ICs to EVs concerns battery power infrastructural requirements. Widespread and convenient refuelling facilities are needed to ensure the reliability of EVs. According to this idea, potential customers would not be willing to buy EVs without the proper infrastructure of energy tanking facilities. However, suppliers, such as energy companies or automotive manufacturers, avoid investing in the establishment of EV related infrastructure without sufficient sales volume. Than start-up funding initiated by the government could potentially resolve this dilemma.

## 4.3.4 Capabilities of Connected Vehicle System

As the transportation sector continues to see exponential growth on its highways, it is becoming clearly evident that connected vehicle technologies will be needed in order to monitor and resolve issues such as traffic congestion and automobile accidents in real time. As Figueiredo[59], illustrated the Intelligent Transportation System ITS, essentially the ultimate goal of such innovative technologies is to take the human error out of driving and create an intelligent network of smart cars with constant communication with their surrounding infrastructures. The benefits of ITS technologies can be in areas such as efficiency, safety and cost. In fact, connected vehicle technologies have the potential to significantly reduce vehicle accidents, total travel time and the average stop time in traffic. This ITS can also focus on one specific technology known as connected vehicle technology, in which EVs will be able to communicate in real time with the fast charging infrastructure. With conventional EV charging schemes, it is assumed that electricity prices are constant throughout the day and due to that EVs simply can start charging whenever they are. Karnama[60], argued that several studies have shown if such charging schemes, is not rely on ITS technologies to monitor the charging process or on real time charging schemes, than it will end to morning and evening peak demands. Another study by Waraich[61], showed that ITS must be integrated into the charging process through smart charging in order to reduce these peak demands which are dynamic with respect to both time and location.

In such a charging scheme, there are several ITS technologies that allow grid enabled vehicles, or connected vehicles, to interact with the electrical grid in real time. Waraich [62], by his work said, there are numerous benefits of smart charging including real time communication with utilities for monitoring the electrical grid loading and real time pricing based on times of peak and off peak demands. Another study by Glanzer[63], demonstrated that smart charging strategies have tremendous capabilities in monitoring and reducing peak demands and in maintaining balance throughout the electrical grid. By integrating intelligent energy management into EVs, the electric utility companies will also be able to improve their Supervisory Control and Data Acquisition (SCADA) system. Connected vehicle technologies have the potential of essentially transforming the current electrical grid into an intelligent network of constant communication between vehicles and infrastructure. In fact, this may eventually allow them to create a network in which the utilities can monitor and control electrical equipment and influence demand in real time. For example the EVs would be routed to an optimum charging sham that would aim to minimize both the impact on the electrical grid and the charging time for the EVs. Fernandez[64], said the electrical network is more likely to withstand charging demand without causing over capacity and blackouts.

In addition to optimizing the EV charging process through dynamic pricing and real electric load time balancing, connected vehicle technologies can also be implemented to provide the EVs with real time traffic conditions. By using microscopic simulation in a study by Yongchang[65], he demonstrated the benefits of a connected vehicle technology, also known as vehicle infrastructure integration, combined with artificial intelligence algorithms to monitor the real time traffic conditions of the roadway network. Another follow up study by the same authors[66], revealed superior performance for a vehicle infrastructure integration based on line travel time prediction system. In such a system these connected vehicles would be notified in real time of any incidents that may have resulted in

blocked lanes of traffic jams. These studies revealed that predictive traffic data, such as those that can be generated by vehicle infrastructure integration, can be successfully utilized by the energy management system in a PHEV for improving energy efficiency. EVs with vehicle infrastructure integration or other connected vehicle technologies would be able to optimize total travel time to the charging station while avoiding traffic jams in the network as well as total charging time by avoiding long queues at any specific charging station.

## 4.4 Threats

In the study by Simone Steinhilber and colleagues[67], understanding the barriers to electric vehicles have been discussed. According to them the introduction and penetration of EVs is confronted by several barriers that inhibit a larger market penetration under current conditions. Several shortcomings of the technology which presented in this study exemplify the immature status of developing technology that has not achieved commercialisation yet. Some other barriers are, a fragmented infrastructure, missing standards and regulations and scepticism of consumers towards an emerging technology. These barriers which are coming in fellow considered as threats to EV's future.

## 4.4.1 EV Contradiction to Travel Time Budget (BREVER- law)

In 1972 Szalai and his colleges[68], found an average personal travel time budget of 1h13min per day, or 444h per year. Later on in his thesis Hupkes (1977) formulates it as BREVER-law, based on the time budget survey of Szalai. The law of conservation of travel time and trips (in Dutch: Behoud van Reistijd en VERplaatsingen). This travel time budget has been proven by different studies that it is stable over space and time and can be used for Projecting future levels of mobility and transport mode. Therefore covering greater distances within the same travel time budget requires that travellers shift to faster modes of transport and this tendency to choose the fastest manner to make a trip has not led to a reduction of time spent on travel, but to an increase in kilometres. This brief argument initially shows that considering BREVER-law as the fix travel time budget then adopting EV will be a threat to future pattern of spatial travel distance of transport users. But those different survey results and the one that is done by this work indicate that average driving distance in different places are between 40 to 60 km/day and mostly inside the cities (look at survey result at chapter 5), then it can be concluded that EVs will not violate BREVER-law and

time travel budgets of daily trips inside the cities. It can be a treat for those car users which driving longer distance and face the battery charging as a challenge to their travel time budget.

## 4.4.2 Urban Planning and Road Traffic Regulations

One of the major issues that emerged from the research findings was the possibility of publicly accessible charging infrastructure creating new challenges for urban planners. This was highlighted by most of the interviewees in both Germany and the UK. There is no clear regulation as to where public EV charging spots may be installed. There are unclear regulations regarding parking on spaces equipped with a charging spot. If local authorities decide to proceed with the roll out of charging infrastructure, including reserved parking spaces, in order to promote use of EVs, then this may raise new problems. If EV is not immediately present in the anticipated large numbers, this can lead to frustration among drivers of conventional cars that see free parking lots but are not allowed to use them, especially in inner city areas which often suffer from a shortage of parking spaces. Must a space remain unused if not occupied by an EV? If so what signage is required to designate the restriction? What codes control this and who will be enforce?

## 4.4.3 Different Opinions on Emission Issue

Steinhilber and his colleagues[69], by their research indicate that opinions on the issue of emissions are different, although very different interests are involved. Non-government organisations (NGO) and environmental groups criticised the current EU regulation for considering EVs to be zero-emissions vehicles and forgiving super-credits to a vehicle which has  $CO_2$  emissions of less than 50 g/km. While the NGOs and environmental groups acknowledge that the automotive industry has no influence on the electricity mix which determines the emission of an EV, they fear that considering EVs to be zero-emissions will not provide an incentive to car makers to develop more energy efficient EVs.

It is already explained at the beginning of this chapter that swot analyse is designed to have a general overview of organization and system to find out which factors internally or externally effecting that system either in positive or in negative ways. So far this analyse ended to a 2x2 matrix. When the matrix is ready it is the time to find strategies to maximize the strengths and opportunities and minimize the weakness and treats. As it is illustrated in table 4 most of those factors that play roll at our EVs adaptability have been discussed about and even by used of some mathematic methods tried to be proven. This table4 is the matrix result of our SWOT analyse.

Strength	Weakness
Less emission in general	Power production pressure
Oil independency	High costs of the battery and its life cycle
Cost efficient	Limited range
Low rate of noise	Safety risks
Opportunity	Treat
Legal regulations for low emissions	EV contradiction to Travel time budget (BREVER- law)
New business models and manufacturers	Urban planning and road traffic regulations
Public funding and investments	Different opinions on emission issue
Capabilities of connected vehicle system	

### **TABLE4.** General conclusion of SWOT analyse

Finding strategies in order to mitigate or minimize the treats and weakness of EV's are other issues and it is very soon to discuss about them. Those are the future challenges of EVs. But as premature strategies the environmental friendliness and lower maintenance costs as the strongest items of EV can be used as motivation to convince the individuals to purchase it. Battery technology improvement and its cost reduction also can be an opportunity to car manufactures in order to improve its capabilities. By this battery improvement those weakness items such as limited range and high cost of EV can be switched to a positive way.

## **Chapter 5: Survey Results**

In previous chapters it was tried to certify that transportation sector deals with some challenges and to overcome those challenges an alternative for IC is necessary. Farther on it was said that EV should be that alternative therefor its benefits and barriers have been discussed about and it has considered as one with potential to solve some of currently transportation challenges. In this chapter the feasibility and adoptability of EV to Flemish community as a case study is going to be dealt with. For that matter a questionnaire was launched on line and so far 79 people responded to it which might not be so much but as a statistical sample can be a window to the real world of this community and leads to farther studies. Also to have an accurate results about this community statistical parameters we have tried to compare our results by statistical analyse which has done based on conducted survey by OVG[70], from September 2011 to September 2012.

## 5.1 Demographical characteristic of responders

First of all we must say that statistical analyses and modelling have been done by used of R statistical programming language and SPSS statistical software. The general statistical results of demographical analyses show that, 62% of responders are male and 38% are female, 67.1% married or are in a sort of relationship. Farther on age group results which illustrated in figure10 reveals that the highest category belongs to group 51 to 60 with 29.1% and the lowest one belongs to 18 to 25 with 6.3%. Results for number of children per household say that 41.8% don't have any child and 29% have one child and 25.3% have two children and the rest which are 3.8% reported to have more than two children. Education level analyse shows that 21% of responders have high school level of education and 25%, 30% and 22.8% have bachelor, master and Ph.D respectively. There are also 57% employed or self-employed people, 11% unemployed and the rest which are 23% either are student, house keeper or retired. Income statistical results clarify that 35.4% of responders have monthly income from 1500 to 2500 and the other 24% and 21% belong to income groups which are from 2500 to 3500 and 3500 to 4500 respectively.



FIGURE10. Age group frequencies

## 5.2 Currently Travel and Driving Pattern of Responders

As private household vehicles, 40.5% of responders have only one car at home, 31.6% have two or more cars and the rest don't have any. By OVG survey results it is 51.76% who have one car and 26.05% who have two or even more. In general, 59.5% of those who have car use it 1 to 3 times per day, 18% of them use it 3 to 5 times per day and 17.7% not using any private car at all. It is concluded from this demographic explanations that this people are attached to car either it is because of family status which makes them to use it, e.g. to get the children to school or shopping, or they need it for their work matter. Later on in this chapter this demographic result will be used for regression model analyses.

The way that they using their car from home to work is also relevant to this study, the result of this analyse shows that about 58.8% of responders drive directly from home to work but 19% go to train or bus stations and take a bus or train for the rest of their trip. Almost 29.2% combine their journey to work with other transport modes such as bicycle or walking. By OVG, the home to work tripe as a self-driver is 70.28% and by any other modes is 29.72%. We are also interested to know how fare does them driving per day. Table 5 shows that results of it. It says that Majority of car users 58% use their car to drive in a range of 0 to 60 km per day. From those responders it is almost 6% that driving more than 90 km per day.

Daily driving distance /km	Frequency	Percent	Cumulative Percent
0-30	37	46.8	46.8
31-60	21	26.6	73.4
61-90	15	19.0	92.4
90 and more	6	7.6	100,00
Total	79	100,00	

TABLE5. The daily driving distance/km

The part that this study is interested in is the percent of those car users which are driving more than 90 km per day because it is almost over riding the EV's limitation range later on by this chapter it will be discussed about in more details.

Fuel consumption which is discussed about in the previous sections is also one of those factors which motivate transportation sector decision makers to find an alternative for IC vehicles. The survey results table 6 shows that fuel consumption is quiet high in Flanders community it says 65.7% consume more than 50 litre fuel per month and 34.2% use 100 litre or even more than that.

Fuel consumption/month	Frequency	Percent	Cumulative percent
0-50	35	44.3	44.9
51-100	17	21.5	66.7
101-150	13	16.5	83.3
151-200	8	10.1	93.6
More than 200	5	6.3	100.00
Missing	1	1.3	
Total	79	100.00	

TABLE6. Amount of fuel consumption per month

Another important factor which had mentioned in that questionnaire was to indicate which one of this five driving activities such as: 1) driving to work, 2) driving to take children to school, 3) driving for education reason, 4) driving for shopping and 5) driving for social and recreational matters per day are your most priority daily driving activity. The result shows that for 55.7% of responders driving to work is the first priority. But OVG home based work activity survey result is even greater than that and is 70.28 %. Taking the children to school is the second priority of almost 30% of them when the shopping is 35.7% and 39.3% as the second and the third respectively. Social and recreational trip is randomly

important to some people and is almost the last priority of daily driving. It might be questioned why is it so important to know degree level or priority of respondents daily activities. It is important because EV adaptation to daily driving activity requests some regulations due to its range limitation and battery charging duration. For those who are unemployed, pension, student or not working so far from home and using their vehicle for short trips have opportunity to charge it at home even several times during the day. But who are using it to drive to work either has to charge it fully at home or "if there is any charging facilities" at their work places. This second group are more careful because they don't like to jeopardise their work situation. Is that why when it is asked which type of EV do they prefer to have and where do they prefer to charge it, 56.7% said they like to have HEV due to its performance which is almost same as IC and 60% said they like to charge it at home. As it is revelled by this survey, using vehicle to go to work is important daily activity of 55.7% of responders and they will not compromise it with any other daily activities. Therefore if EV looks for opportunity to be able to replace IC it has to bring satisfaction to people with daily work trip. Those how use their vehicles to go to work actually do it as a daily habit and it is sort of obligation to them.

## 5.3 How EVs Fits to Current Travel Behaviour

The total daily distance travel in kilometre based on survey results is given in table 7. It is clear that current average daily distance travel of responders is 40.74 km per day it is interesting that OVG declared it to be 41.46 km / day in average. This average is less than half of our example EV's range (ford focus) which is120km per a full battery. This average of daily distance driving might be low but frequency distribution or better to say range of it for this work survey is quiet high, which is from 1 to 168 km per day. It says that there are some vehicle users who driving more than our EV's range limitation which is 120km per a fully charged battery. This work is interested to target this group and know its proportion. This group might need more facility assist and more driving behaviour change.

In the histogram of daily travel pattern or daily driving distance, Figure 11, we can see that skewness of curve is positive which is +1.539. It means distribution of values (which in this case are our responder's daily distance driving/km) at the right tail is longer and the mass of distribution concentrated on the left side of the figure.

Statistical parameters	Statistical values	Std. Errors
Mean	40.74	4.63
Median	26.00	
Variance	1542.82	
Std. Deviation	39.28	
Minimum	1.00	
Maximum	168.00	
Range	167.00	
Skewness	1.539	.283

TABLE7. Statistical description of total Km of car driving per day

It says although there are relatively few high values but most of the reported values are under range of 0 to 120 km. In general it is concluded that only 7 % of car drivers will drive more than120 kilometre per day which is more than our EV rang and if they switch to EV they will have problem in completing their daily driving tour and activities. If we consider half rang of EV which is 60 km per a full battery than still 76.4% of our responders distance driving range is covered by it. In general it is strong positive result for EV because it covers almost 90% of car user's driving distances and daily activities during the week days.



FIGURE11. The histogram and distribution curve of daily driven distance /km

It is clear that this is a statistical sample of daily distance driving for Flanders community as our statistical population. But what would it look like if it was possible to survey whole the community. We know it is almost impossible due to its time and finance consumption but statisticians try to be as close and accurate as possible. Therefore one of the major applications of statistic is to estimate population parameters from sample statistics then for that reason, in here we have tried to estimate the daily distance driving of whole the community. Let's take average driving distance per day as our point estimate. Point estimates are usually supplemented by interval estimates called confidence intervals in statistic. In order to get closer result to real population mean the confidence interval has been calculated by sample repeating of 1000 and 10000 times. It has done by Bootstrap statistical method. It might be necessary to have some words about this statistical method to make it clear for readers of this text. It is a statistical method which estimates properties of a population estimator. If we say that our sampling is one estimator which is going to estimate some statistical parameters of population such as mean, variance and so on, than bootstrap can help us to investigate this sampling and brings us closer to those real population statistical parameters. In the case where a set of observations or a sample from an independent and identically distributed population is extracted than this sample can be used to construct a number of equal sized randomly resampled of the observed dataset, for more information have a look at work by Efron and Tibshirani[71]. In this text bootstrap used to estimate the mean of distance travelled per day by vehicle users in our study area. As you can see it is point estimating which has to be based on confidence interval. If we take mean as the population parameter than confidence intervals for a given population parameter  $\theta$  are sample based range  $[\theta_1 < \theta < \theta_2]$ . Of course this range is with respect to all possible samples, each sample giving rise to a confidence interval which thus depends on the chance mechanism involved in drawing the samples. The two mostly used levels of confidence are 95% and 99%. In here for this discussion the level 95% is applied.

The results show that by 95% confidence the mean of population will be between  $[32.26 < \theta < 49.76]$  and  $[32.26 < \theta < 50.06]$  for 1000 and 10000 repetitions respectively, table 8. This probable mean is still lower than our vehicle driving range.

			Bootstrap <sup>a</sup>				
					95% Confide	ence Interval	
		Statistic	Bias	Std. Error	Lower	Upper	
Ν	Valid	72	0	0	72	72	
	Missing	0	0	0	0	0	
Mean		40.7361	1311	4.5980	32.2657	49.7635	
Std. Deviation	n	39.27871	48705	4.58152	29.49765	47.58874	
Variance		1542.817	-17.055	353.188	870.119	2264.689	
Skewness		1.539	025	.268	1.048	2.093	
Std. Error of	Skewness	.283					
Range		167.00					
Minimum		1.00					
Maximum		168.00					
a. Unless	otherwise noted, boots	strap results are based of	on 1000 bootstrap	samples			
				Boo	otstrap <sup>a</sup>		
					95% Confide	ence Interval	
		Statistic	Bias	Std. Error	Lower	Upper	
Ν	Valid	72	0	0	72	72	
	Missing	0	0	0	0	0	
Mean		40.7361	.0110	4.5920	32.2639	50.0552	
Std. Deviation	n	39.27871	54872	4.51698	29.64707	47.25967	
Variance		1542.817	-22.404	348.442	878.948	2233.476	
Skewness		1.539	035	.278	.999	2.086	
Std. Error of	Skewness	.283					
Range		167.00					
Minimum		1.00					
Maximum		168.00					

## TABLE8. 95% confidence interval of population mean by 1000 and 10000 possible sampling repetitions

a. Unless otherwise noted, bootstrap results are based on 10000 bootstrap samples

## 5.3.1 Hypothesis Testing

To test how the driving pattern of the population is going to be we test it by statistical model which is calculated by use of R statistical software. Let's repeat that our EV range is 120, than by considering this range limitation driving more than 80 km will be stressful to drivers. For this reason we choose null hypothesis as 80 km and more.

$$H_0: \mu \ge 80 \& H_1: \mu < 80$$
 (3)

This is the formula for how to calculate it.

$$Z = \frac{\overline{x} - \mu}{\sigma / \sqrt{n}} \tag{4}$$

When Z = standardization,  $\overline{x}$  = sample mean,  $\sigma$  = standard deviation of sample and n = sample size

The result reveals that z value is equal to -8.883961 and in  $\alpha$ =0.05 level its value will be 1.644854, p-value is 1 which is also at alpha =0.05 level. By this result we can conclude that p-value is far bigger than 0.05 and z-value is very low than significant level, therefore we **reject null hypothesis** with 95% statistical significance and can say that population mean will not be 80 km or more.

## **5.3.2 Weekend Driving Pattern**

Now the question is what about the weekend's activities and driving distances? How can EV be fitted to these activities? For this matter in that questioner it was a question about car users driving distance per weekend. The survey result of this question is illustrated in table 10.

			Bootstrap <sup>a</sup>				
					95% Confid	ence Interval	
		Statistic	Bias	Std. Error	Lower	Upper	
Ν	Valid	54	0	0	54	54	
	Missing	25	0	0	25	25	
Mean		101.3519	1430	11.5872	79.9885	125.3610	
Std. Deviation		83.40878	-2.29623	13.21740	61.01918	108.41743	
Variance		6957.025	-203.253	2225.384	3723.340	11754.339	
Skewness		1.551	318	.645	.116	2.227	
Std. Error of Skewness		.325					
Range		440.00					
Minimum		10.00					
Maximum		450.00					

TABLE9. Total driving km per weekend

a. Unless otherwise noted, bootstrap results are based on 1000 bootstrap samples

The Statistic survey of weekend driving activities in table 9 says that average driving range in weekend is 101.35 km, by minimum of 10 km and maximum of 450 km. From the table 10 it can be concluded that 35.2% of weekend car drivers pass the range of EV. The figure12 shows that around 64.8% of car driving distance can be covered by use of an EV. One important point for weekend driving is that these activities are done in two separate days (Saturday and Sunday) and this statistical figures are asked for whole the weekend, therefore it can be argued that more than 95% driving range of these weekend activities can be fully covered by EV's driving range, if their driving plan are good managed and the place that they are going has access to charging facilities.

Values	Frequency	Percent	Valid Percent	Cumulative Percent
10.00	3	5.6	5.6	5.6
15.00	1	1.9	1.9	7.4
20.00	1	1.9	1.9	9.3
22.00	1	1.9	1.9	11.1
24.00	1	1.9	1.9	13.0
25.00	1	1.9	1.9	14.8
28.00	1	1.9	1.9	16.7
30.00	3	5.6	5.6	22.2
33.00	2	3.7	3.7	25.9
35.00	1	1.9	1.9	27.8
40.00	2	3.7	3.7	31.5
42.00	1	1.9	1.9	33.3
44.00	2	3.7	3.7	37.0
50.00	2	3.7	3.7	40.7
55.00	1	1.9	1.9	42.6
58.00	1	1.9	1.9	44.4
66.00	1	1.9	1.9	46.3
67.00	1	1.9	1.9	48.1
78.00	1	1.9	1.9	50.0
86.00	1	1.9	1.9	51.9
100.00	6	11.1	11.1	63.0
120.00	1	1.9	1.9	64.8
129.00	1	1.9	1.9	66.7
149.00	1	1.9	1.9	68.5
150.00	2	3.7	3.7	72.2
156.00	1	1.9	1.9	74.1
160.00	1	1.9	1.9	75.9
165.00	1	1.9	1.9	77.8
170.00	2	3.7	3.7	81.5
180.00	2	3.7	3.7	85.2
189.00	1	1.9	1.9	87.0
200.00	3	5.6	5.6	92.6
205.00	1	1.9	1.9	94.4
225.00	1	1.9	1.9	96.3
250.00	1	1.9	1.9	98.1
450.00	1	1.9	1.9	100.0
Total	54	100.0	100.0	

TABLE10. Frequency of total driving km/weekend

a. Unless otherwise noted, bootstrap results are based on 1000 bootstrap samples



FIGURE12. The histogram and distribution curve of weekend driven distance /km

## 5.3.3 Regression Model and ANOVA

In order to find out the importance of those factors which might have strong impact on EV use and driver behaviour change in our study area (Flanders community) the regression model is applied. The model is represented on a multi-linear regression model which is:

$$X_{i} = \beta_{0} + \beta_{1}X_{1} + \beta_{2}X_{2} + \beta_{3}X_{3} + \dots + \beta_{n}X_{n} + \varepsilon$$
(5)

Where:

$$\begin{split} X_i &= \text{Dependent variable (daily driven distance /km),} \\ \beta_o &= \text{intercept,} \\ \beta_1, \beta_2, \beta_3, \beta_n &= \text{parameters/coefficients of the explanatory variables,} \\ X_1, X_2, X_3, X_n &= \text{are the explanatory variables,} \\ \epsilon &= \text{error term,} \\ n &= \text{number of explanatory variables.} \end{split}$$

Using a 5% level of significance (95% confidence level) at the P-value, we will reject the null hypothesis (Ho) if P-value < 0.05. Rejection of null hypothesis implies that the results are statistically significant and that the daily driven distance /km somehow is influenced by the variables.

```
Call:
lm(formula = Driving.per.day ~ Gender + Age.group + Family.status +
Number.of.children + Education.level + Employment.status + Income +
Number.of.cars.per.household)
Residuals:
  Min 1Q Median 3Q
                                  Max
-55.031 -23.074 -3.114 13.773 108.440
Coefficients:
                            Estimate Std.Error t value Pr(>|t|)
                            62.79671 33.61409 1.868 0.0664 .
(Intercept)
                            22.17391 10.22263 2.169 0.0339 *
Gender
                            -4.63234 3.35881
0.53793 6.00746
                                       3.35881 -1.379 0.1727
Age.group
Family.status
                                                0.090 0.9289
Number.of.children
                                     5.01546 -0.927 0.3576
                            -4.64761
Number.or.energy
Education.level
Employment.status
                            0.09364
                                       4.25364
                                                0.022
                                                         0.9825
                                     2.96196 -2.260
                                                         0.0273 *
                            -6.69300
                                     4.04385 1.213 0.2
5.07271 -0.596 0.5535
                            4.90495
Income
Number.of.cars.per.household -3.02221
Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1
Residual standard error: 37.18 on 63 degrees of freedom
(7 observations deleted due to missingness)
Multiple R-squared: 0.2049, Adjusted R-squared: 0.1039
F-statistic: 2.029 on 8 and 63 DF, p-value: 0.05704
```

TABLE11	Regression	model	summary
---------	------------	-------	---------

			Adjusted R	
Model	R	R Square	Square	Std. Error of the Estimate
1	.453 <sup>a</sup>	.205	.104	37.18187

a. Predictors: (Constant), Number.of.cars.per.household, Number.of.children, Income,

Employment.status, Education.level, Family.status, Gender, Age.group

TABLE12	<b>ANOVA</b>

Model <sup>a</sup>		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	22443.026	8	2805.378	2.029	.057 <sup>b</sup>
	Residual	87096.961	63	1382.491		
	Total	109539.986	71			

a. Dependent Variable: 'distance daily driven by car'

b. Predictors: (Constant), Number.of.cars.per.household, Number.of.children, Income, Employment.status, Education.level, Family.status, Gender, Age.group

Interpretation of model says that from all the explanatory variables gender and employment statute are statistically significant and the next age group, income and number of children also showing second degree of importance on our dependent variable which is daily driven distance /km. From the model it can be concluded that slops of explanatory variables ( $X_1$ ,  $X_2$ ,  $X_3$ ,  $X_n$ ) or better to say coefficients are positive and negative it means that those explanatory variables are in a linear relationship (although very weak for some) with dependent variable either in a positive or negative direction. The model summary table says that correlation coefficient is **R=0.453** which is not strong correlation because some of explanatory parameters such as family status and level of education are not correlated perfectly. **R**<sup>2</sup>= **0.205** which means 20.5% predicted variability of daily driven distance /km can be explained by all those explanatory parameters together. The standard errors of the estimation are also the different between predicted values by model and observed values.

Table 12 is interpretation of ANOVA. The first column shows the sources of variation, the second column shows the degrees of freedom, the third shows the sums of squares, the fourth shows the mean squares, the fifth shows the F ratio, and the last shows the probability value. Note that the mean squares are always the sums of squares divided by degrees of freedom. Result shows not strong statistical significant because the P value is 0.057 which is > .05 and the proportion of the regression mean square with 8 degree of freedom to residual mean square of observed values with 63 degree of freedom is 2.029 which is not equal to 1 there for the means are not equal and the general linearity is not strong.

## 5.4 Responder's Attitude about Electric Vehicles

It is clarified by this survey analyse in this section that 93% and 68.8% consequently for week days and weekend driving range are covered by EV's driving range. It means that switching to EV can be helpful to most of the responders. The big issue is if EV can be useful than what are the important parameters which make them hesitating to switch IC to EV? In below comes some explanation of survey results to clarify this question.

As it is mentioned in section 2.6 of chapter two the major assumption of the Theory of Planned Behaviour is that both intention and behaviour are correlated with the natural personality of a person, the external or social influence and control (Ajzen, 2005). Based on the Theory of Reasoned Action and the Theory of Planned Behaviour, Davis proposed the Technology Acceptance Model in 1985, in order to be able to predict behavioural intentions in relation to technological innovations. To find out the social influence of EVs it has asked in that questionnaire how familiar are the responder with it. From the results it is cleared that 21.5% of responders get to know it by publicities and magazines articles, 41.8% don't know anything about it at all and 24% either has personal experience as having one or knowing somebody how owns one, Figure 13.



FIGURE13. The bar graph of familiarity whit EV

This result shows that most of the responders almost 60% are anyhow familiar with EV, but to switch to it they need attitude changing as their psychology motivation. For that reason environment and human health at risk by air pollution can help to change the attitude.

The survey result shows that from responders 58.4% will be satisfied if there is any solution to pollution challenging by IC vehicles, Table 13. These results prove that motivation for behaviour change (switching from IC to EV) is strong. Now the question is if they really want to put it on action or not because it is just at motivation level for now.

Do you know that IC is air polluters?	Frequency	Percent	Cumulative Percent
Yes, I like alternative for it	45	58.4	58.4
Yes, but don't care	24	31.2	89.6
no, I don't know	8	10	100
Total	77	100	

TABLE13. Attitudes about air pollution by IC cars

Before giving any information about EVs it is asked if they like to have an EV because they are very clean to environment and to our health. It is interesting that 30.3% want to have an EV as their main car and 46.1% want it as their second car. It is also asked that these EV are expensive to buy but less expensive to use, do you still like to have one? This time 48.8% answered yes and 51.2% no. This concludes that EV price is an important matter to responders. In this phase we were interested to know which type of EVs do drivers prefer to have. It is asked if you want to have and EV, which type of it do you prefer to have Figure 14?



FIGURE14. The bar graph of responders EVs type choosing

The result of this question shows that 56.7% prefer to have a hybrid EV, this argument strongly clarifies that people are worried about EVs battery charging facilities and infrastructures. 60% of this responders says if they have an EV they prefer to charge it at home than power station. It is already said that people will not jeopardize their daily work tripe, is that way they prefer to charge it at home than put themselves at risk and go to power station and spend long time for battery charging. The last question of this survey was, in general by any chance if EV is not fit to your daily travel pattern than how would you like to drive it?

EV travel behaviour of responders	Frequency	Percent	Cumulative
			Percent
As the second car to short distances	35	64.8	64.8
Going to train station and taking the train	12	22.2	87.0
Going to bus station and taking the bus	3	5.6	92.6
Going to park and raid place	1	1.9	94.4
Going to a place for another car pooling	3	5.6	100
Total	54	100	

 TABLE14. Assumptions of travel behaviours of EV users

The result shows that 64.8% like to have it as the second car for short distances in daily life. In the other hand 35.2% want to have it as the partial transport mode for daily travel, for example to go to train and bus station, park and raid place or carpooling agreement place and take another transport mode to get to work, table 14.

## **Chapter 6: Conclusion and recommendations**

It is already mentioned in problem statement that the global aim is to diminish greenhouse gas emissions. Great amount of this emission is produced by transportation which consumes 2.200 million ton of oil. This is the reason why conventional vehicles are supposed to be replaced by electric vehicles as an alternative. It is argued by SWOT analyses that EVs have a great potential and ability to reduce greenhouse gasses. It is also said that EVs are more cost efficient compering to ICs. The matrix that resulted by SWOT analyses in chapter four revels that EV will bring some opportunities such as new business, new vehicle model manufacturing and IT innovation systems and so on. Generally from that SWOT analyses we can conclude that EVs have great positive and stronger factors which can be used as remedy to mitigate most of our transport problems. But we have to consider that some of these factors are confusing. For example it is argued that the cost efficient is the strongest point of an EV, but the investment price (initial car price) of EV is higher than IC. The EV's mechanical structure is not as complicated as IC's therefore it makes their maintaining cost much lower. Low rate of noise is also bilateral parameter, it can be a positive point if considered as a lower noise pollution or negative if put the life of other weak road users such as pedestrians and cyclists in danger. It is said that limited range is a weakness point of EV but it is clarified by this survey that majority of responders daily driving distances can be covered by an EV. Limited range can be a weakness point of EV but it can be regulated by car users. If the places where the car user drive in is supplied by infrastructures and charging facilities this problem can be easily fixed.

In addition to that SWOT analyses this study was interested to find out how these EVs can be feasible to Flanders as a case study. By the chapter five of this study it was tried to find answers to this question. It can be concluded from those statistical analyses that EV range is not limitation to daily driving distance of car users in this community, but the problem is how to manage the charging time of it and where to put the charging facilities to be optimized at most? The results show that average daily driving distance in this community is 40 km per day which is even less than EV middle driving range per a fully charged battery.

Despite of EVs feasibility, the results of survey show that people are not willing to switch to EV easily even by this knowledge that their daily activities will be completely covered by it. The conclusion is that people still are under psychological pressure. They are worried about their work travel. Their information about EVs is not enough and there is lack of facilities and infrastructures to support EVs.

By this study it is clarified that very intensive economic study and investigation still is needed to be done, (Cost and benefits analyses of EV).

The people have to be informed and convinced about EVs and their benefits to society.

It has to be studied in details how to organize and optimize charging facilities that are at the access to anybody, (Where those charging stations have to be located).

A professional psychological study is recommended to search car users attitude toward EV using in details, (It is clarified by responders of this study survey that there is an anxiety about EV's driving range among them).

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# Appendix

## **Electric vehicles**

Dear responder

I am Golmohammadi Abbas, a master student of traffic and transportation science at Hasselt University, Belgium. In order to gain my master degree, I have been working on a research project entitled," impacts of electric vehicles on travel behavior". It is evident that fossil fuel vehicles are harmful to environment and human health due to pollutant emission. Therefor to have a clean and healthy transportation one alternative is electric vehicles. This type of vehicles are very clean and environment friendly, but are not popular and in massive production. There are still some questions about them such as price, battery capacity, charging facilities, comfort, use ability and so on. Clean environment for a healthy life is one of the important requisite for human being. You might have same questions about electric vehicles too, there for to do this project and answer your questions, I invite you to participate in this scientific survey. This survey has been divided in two parts first part is without any information about the electric vehicles and the second part is based on your answer to the first part and with background information about electric vehicles. Pleas indicate if your answers is more than one choice!



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## **Electric vehicles**

1-Gender

1.

Male Female

## 2- Age group (in year) 018-25 026-30 031-40

○20-30 ○31-40 ○41-50 ○51-60 ○61-70 ○Over 70

### з.

### **3-Family status**

⊖Single ⊖In a relationship ⊖Married

4.

### 4- How many child or children do you have?

no child
 one child
 Two children
 three children
 four children
 More than four

.

## 5- What is the highest Education – degree and the level of school you have completed?\*

ONo school completed High school or similar Bachelor or similar Master or similar

⊖Ph.D. or similar

#### 6.

### 6-Employment status, are you currently...?

Cemployed Self-employed Unemployed A student A housekeeper Retired Unable to work

7.

### 7- Income - your monthly household income "Net Monthly Income"?

○500 - 1500
 ○1501 - 2500
 ○2501 - 3500
 ○3501 - 4500
 Omore than 4500

8- How many cars do you have in your household?	
⊖Not any	
01	
<b>○2</b>	
<b>○3</b>	

9.

9- How often do you use car on a normal working day ?

Not using at all 1 to 3 3 to 5 5 and more

OMore than 3

10.

11- When you drive from home to work by your car,

Ob you combine the trip with other purposes (shopping, bring children to school, pick-up carpool partner ...?
Ob you go to bus station, train station, agreed carpool place or park and ride and park your car than

© to work by those transport modes? Ob you drive straight to the work destination?

#### 12.

12-How far do you drive by your car per day total distances for all daily trips?

(0 - 30) km (31 - 60) km (61 - 90) km (90 and more) km

#### 13.

13- How much fuel in average does your car consume per month?

○(0 - 50) litre
○(51 - 100) litre
○(101 - 150) litre
○(151 - 200
○More than

#### 14.

14 -Which one of this activities is your daily activities that you are doing by your car? Please just

answer the distance per kilometre of the activity that you are driving for. If you don't do some of activities just leave the space empty?

After breakfast ,

Get my child or children to school, it is km far from my home.	
Going to buy newspaper from shop which iskm far from my home.	
Going directly to work which is	
Going to train station by my car which iskm far from my home than go to work by train.	
Going to bus station by my car which is	
Going to park and ride place which iskm from my home than take another car to work.	
Going to a agreed place which iskm from my home than going by my colleagues to work as	
At lunch time going for lunch from my work place by my car which is far from my work place.	
After work, going shopping which iskm far from my work place.	
After work going, for sport or entertainment place which iskm far from my work place.	
After work or after reaching home, going to visit my friends and relatives which are	

_
 _

15-If you using car for weekend activities how much km per weekend do you drive?

Saturday and Sunday.....km

### 16- How are you familiar with electric cars?

⊖you own an electric car

- Oyou have driven an electric car
- Oyou have read in newspaper or magazine articles about electric vehicles
- Oyou know someone who owns an electric car
- O someone told you her/his experiences with an electric car
- Oyou don't know anything about electric car at all

### 17.

17- Do you know that car emissions are one of the major air pollutants due to fuels used which release dangerous gases, including carbon dioxide (CO2), nitrogen dioxide (NO2), and sulfur (S) compounds that are hazardous to environment and human health?

○Yes, I know and I will be satisfied if there is an alternative for it ○Yes, I know but I have to use my car and I don't care ○No, I don't know anything about these things

### 18.

18- Electric vehicles show very low pollutants emissions because they don't use much fuel and are working on electricity, so do you like to have electric car instead of fuel car.

○Yes ○Yes ,but I will use it as my alternative car (second car) ○No

#### 19.

19- Electric vehicles are more expensive than fuel cars(combustion cars) to buy( almost 30% to 50%) more , but their use and maintenance are cost effective, because they need little fuel (almost1 litre
per 100 km) also electricity that they use, is cheaper to petrol or diesel. Therefor I prefer to have one in future?

⊖Yes ⊖No

## 20.

20- If you want to have an electric vehicle in future which type do you prefer more to have? (To answer this question, go to information box)

The battery electric vehicle
The plug-in hybrid electric vehicle and
The hybrid electric vehicle

21.

Before answering rest of the questions, Pleas read this informationes about electric vehicles for your own information.

## Information Box

Why one should buy an electric or hybrid vehicle (EV)?

EV's are cheaper to operate with low maintenance and up to 70% lower fuel cost, but are 30% to 50% more expensive than combustion cars.

EV's are very suitable for stop-start urban driving with good acceleration and lower top speed. They are smoother and more quite than conventional vehicles. Tail pipe emissions are lower or zero emissions (specifically for a battery EV)and making air cleaner and healthier in the cities. There are three types of electric vehicle: 1- the battery electric vehicle, 2- the plug-in electric vehicle and 3- the hybrid electric vehicle.

1-The high energy battery is the key technology of developing the battery electric vehicle. At present, the electric vehicle has a heavy battery, a big volume and a short driving range. It also needs a large area to build facilities for testing and charging. Battery EVs have ranges of up to 120km for now: vehicles can receive full charge within some hours at charging points or at home.

Advantages of battery EV:

Zero emissions. Cheap to run, (electricity is cheaper than oil). Very quit. Very useful in the city.

Disadvantages of battery EV:

A high capital cost. Small in size. A limited rang and speed. Slow recharge rate.

2- Plug-in Hybrid Electric Vehicles (PHEV) refer to vehicles that can use, independently or not, fuel and electricity, both of them rechargeable from external sources. PHEVs can be seen as an intermediate technology between battery EVs and hybrid EVs. It can indeed be considered as either a BEV supplemented with an internal combustion engine (ICE) to increase the driving range, or as a conventional HEV where the all-electric range is extended as a result of larger battery packs that can be recharged from the grid.

Advantages of plug-in hybrid electric vehicle:

Significant reduction in fuel consumption. Reduction of the in-use emissions. Very cheap to run. The electric motor provides quiet operation and rapid acceleration.

Disadvantages of plug-in hybrid electric vehicle:

High capital cost. Some types have very limited range. Because of the battery weight its size is small.

3- Hybrid electric vehicle (HEV) is a vehicle type between the internal combustion engine vehicle and the electric vehicle. It is a transitional type from an internal combustion engine vehicle to the electric vehicle. The hybrid electric vehicle displays the long engine operating time, the strong power, a free pollution of the motor, and the low noise, with over 10% of increased thermal efficiency and over 30% of improved exhaust gas emission. For this type of vehicle you don't need to charge the buttery because combustion and battery are working together, when you drive the engine is working and by generator electricity is producing, this electricity is saved in battery. Even if the car stopped the battery is still charging. For this type of car you only need some fuel but very less than combustion cars.

Advantages of hybrid electric vehicle:

It is significantly improves the efficiency of the fuel consumption and reduces running costs. It reduces the emissions. It is good for long distances and goes in same speed as fuel cars.

Disadvantages of hybrid electric vehicle:

Higher capital cost because of battery technology.

22.

21- For a pure battery elctric vehicle you need some time to charg it (from 4 to 8 hours), imagine that you have one electric vehicle where do you like to charge its buttery?

○At home during night when you sleep.
○At power station .
○At work if there is power facilities.

23.

22- Imagine that your company or the place that you are working for, prepares free electric charging facilities(I mean the company or employer pay the price of charging) And according to short rang of electric vehicle is it manageable to you to use electric car for your whole round trip, home to work -work to home do you prefer to use electric car or fuel car?

⊖Electric car ⊖Fuel car

## 24.

23- Imagin that you have an electric car but you are working far a way and using car during a day more than the range that a battry electric allowed you which kind of activities do you prefer to use it for?

OAs the second car for short distances such as bring my children to school and take them back home,

- doing shopping, going to sport place ans so on .
- OGoing to train station by electric vehicles than go to work by train.
- OGoing to bus station by electric vehicles than go to work by bus.

OGoing to park and raid place by electric vehicle than take another car to work.

OGoing to a pland place by electric vehicle than going by my colleagues to work as a car shearing plane.

I do appreciate your participation on this survey

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